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(31) **2014329**	(32) **11.09.2020**	(33) **GB**
(31) **2014330**	(32) **11.09.2020**	(33) **GB**
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(43) Date of A Publication **18.05.2022**

(56) Documents Cited:
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(58) Field of Search:
As for published application 2601035 A viz:
INT CL **B41M, B42D**
Other: **WPI, EPODOC, Patent Fulltext**
updated as appropriate

Additional Fields
INT CL **G07D**
Other: **None**

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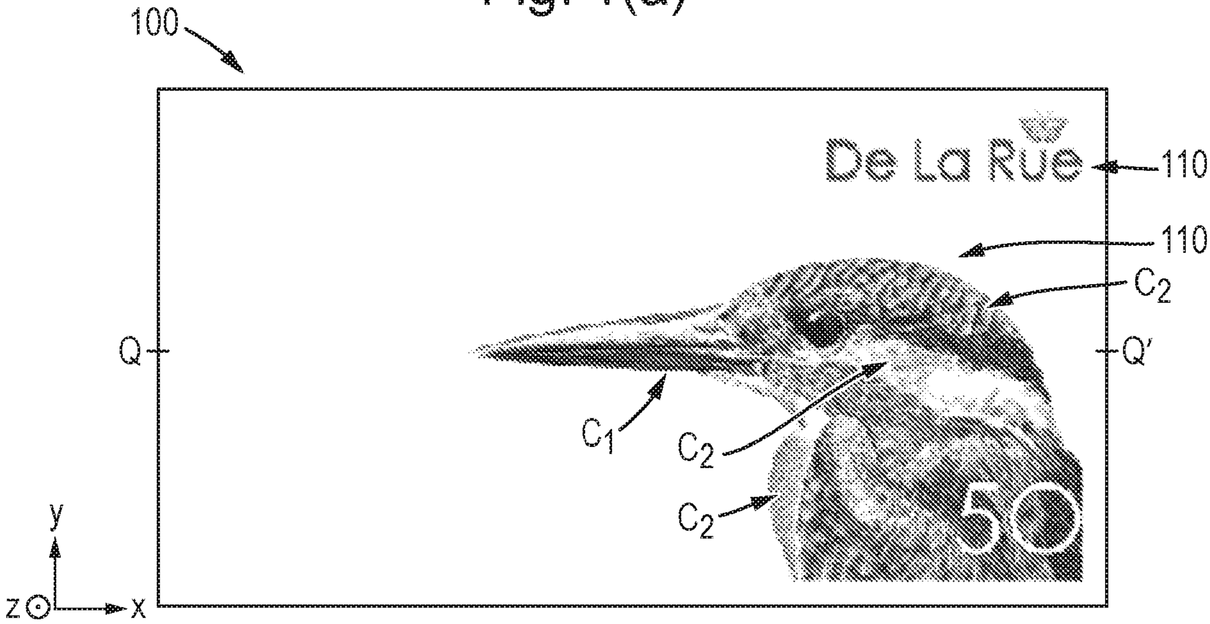
Fig. 1(a)



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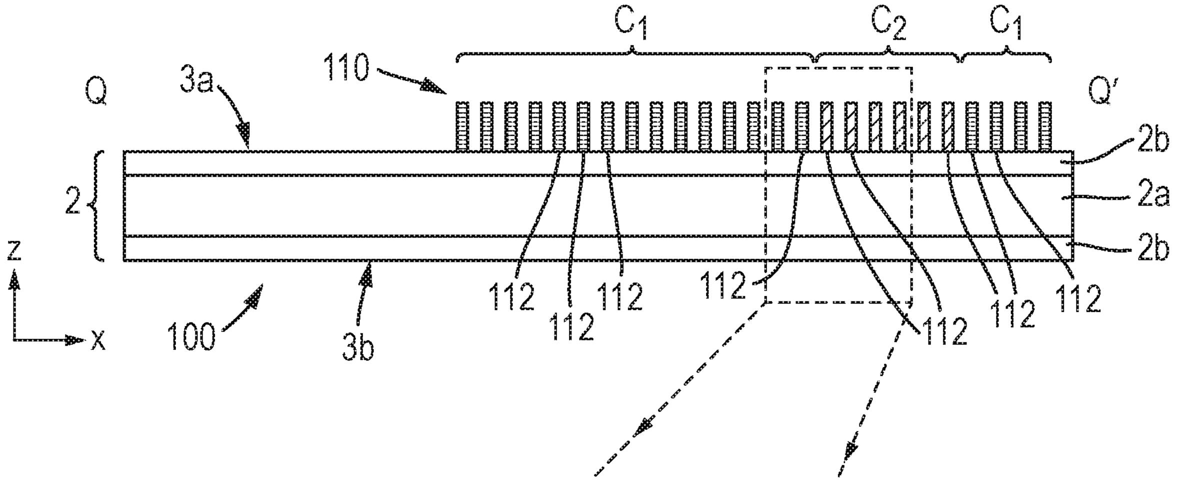
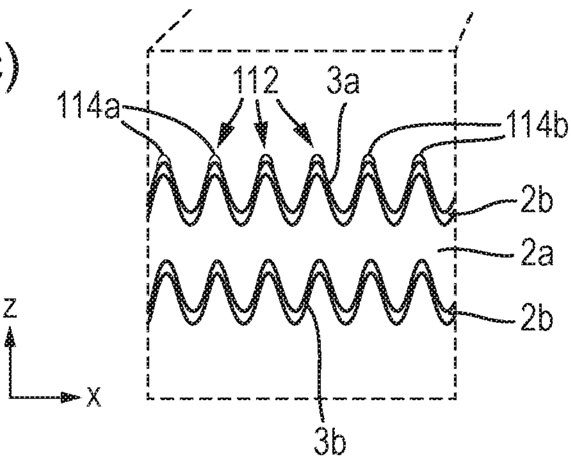


Fig. 1(c)



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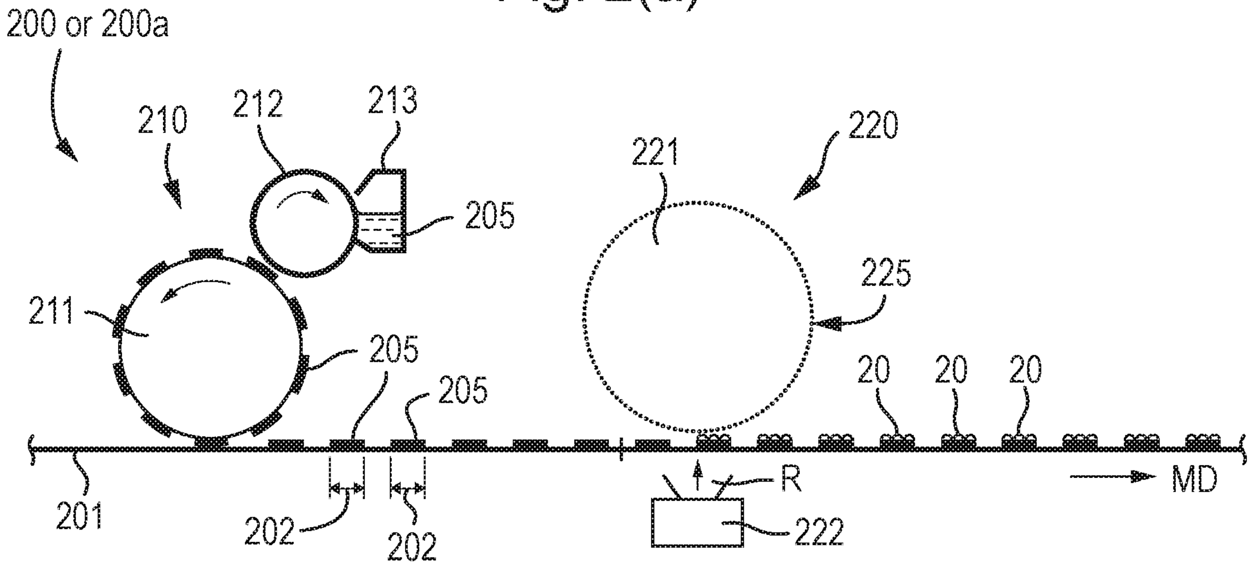

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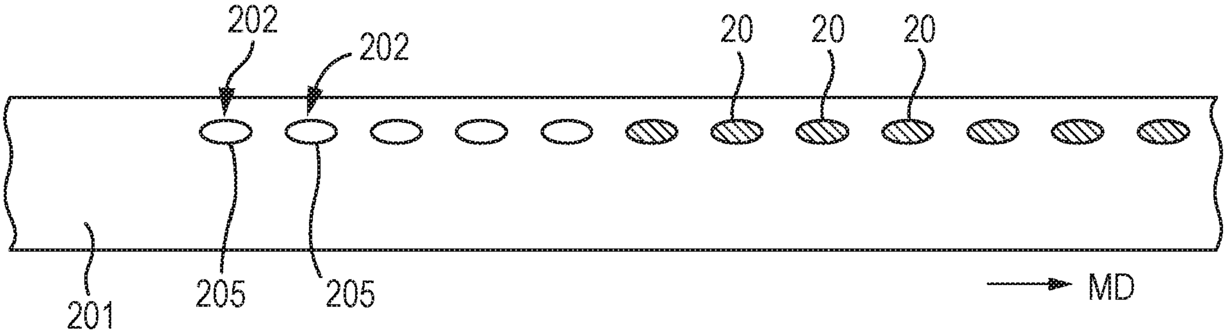

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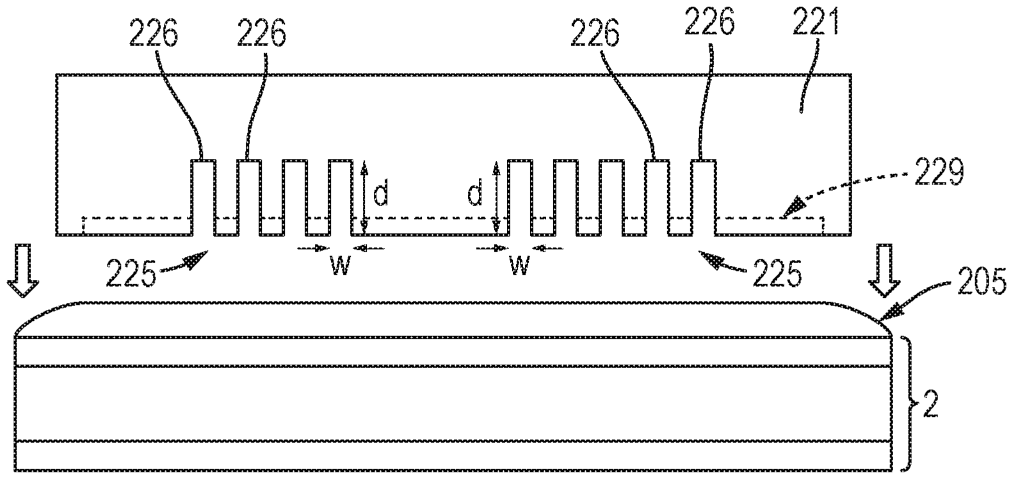
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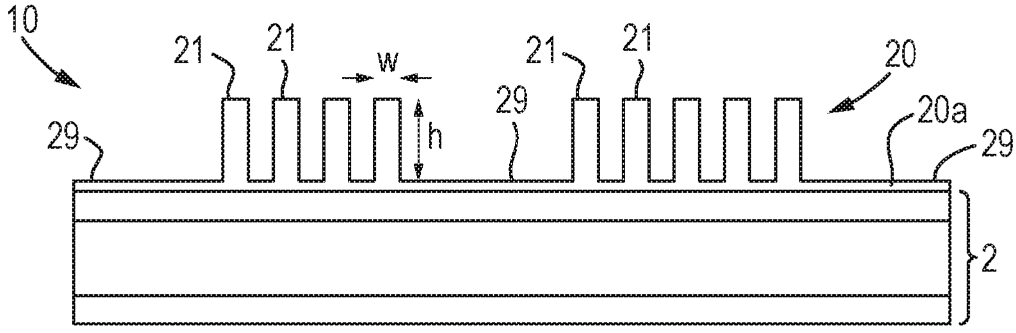
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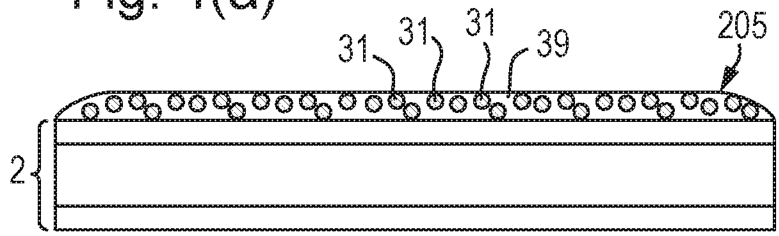

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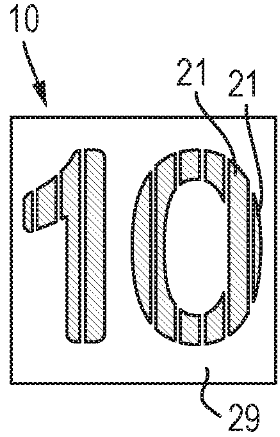

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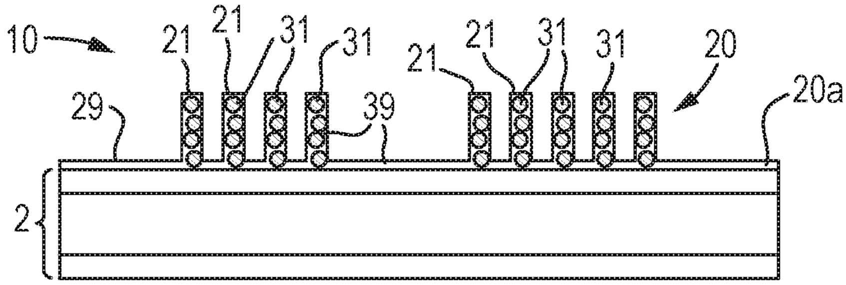

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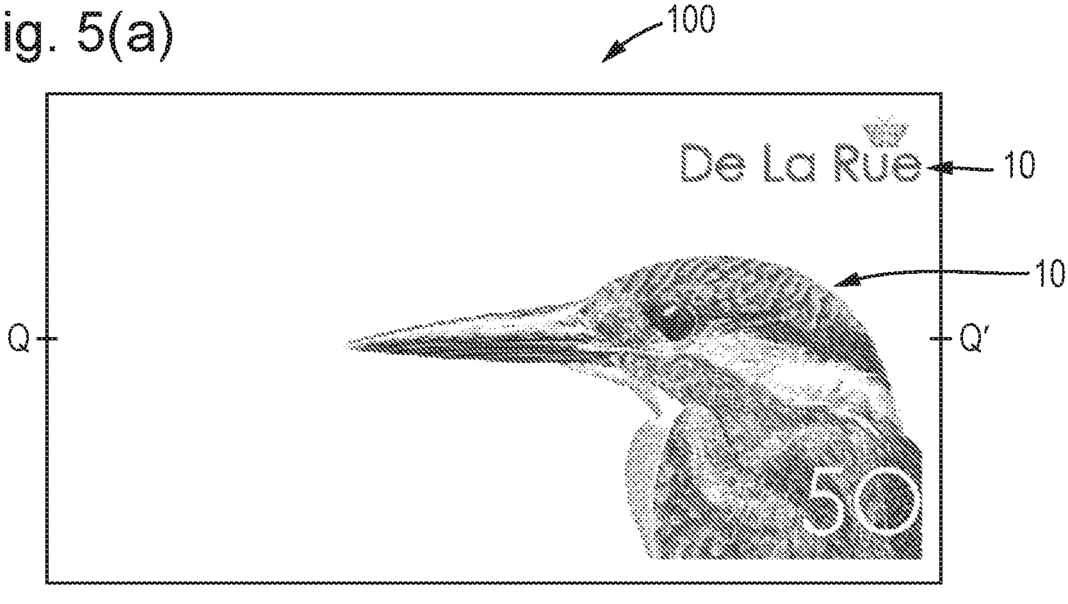

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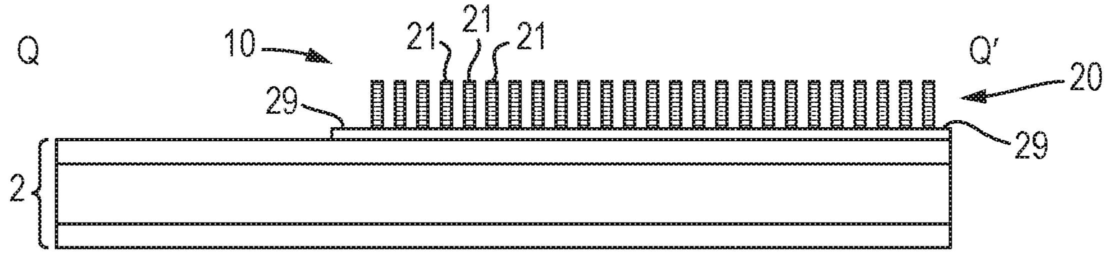

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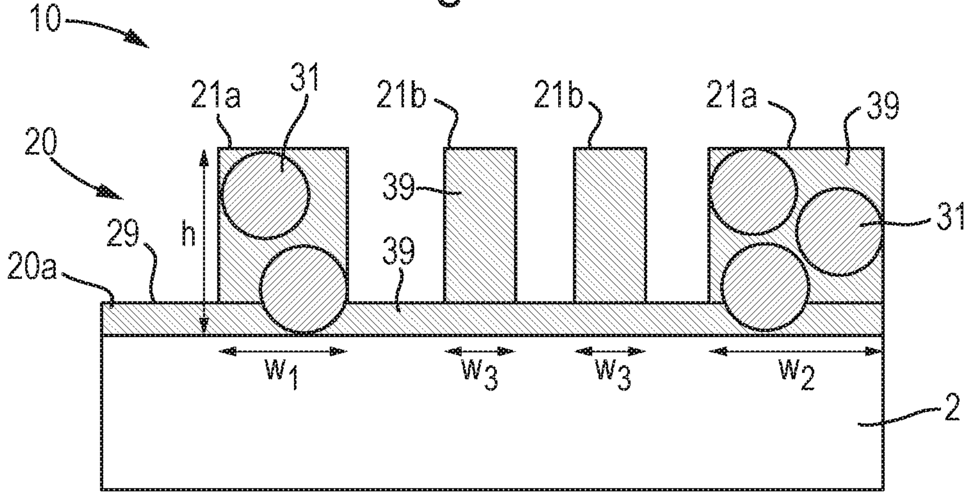

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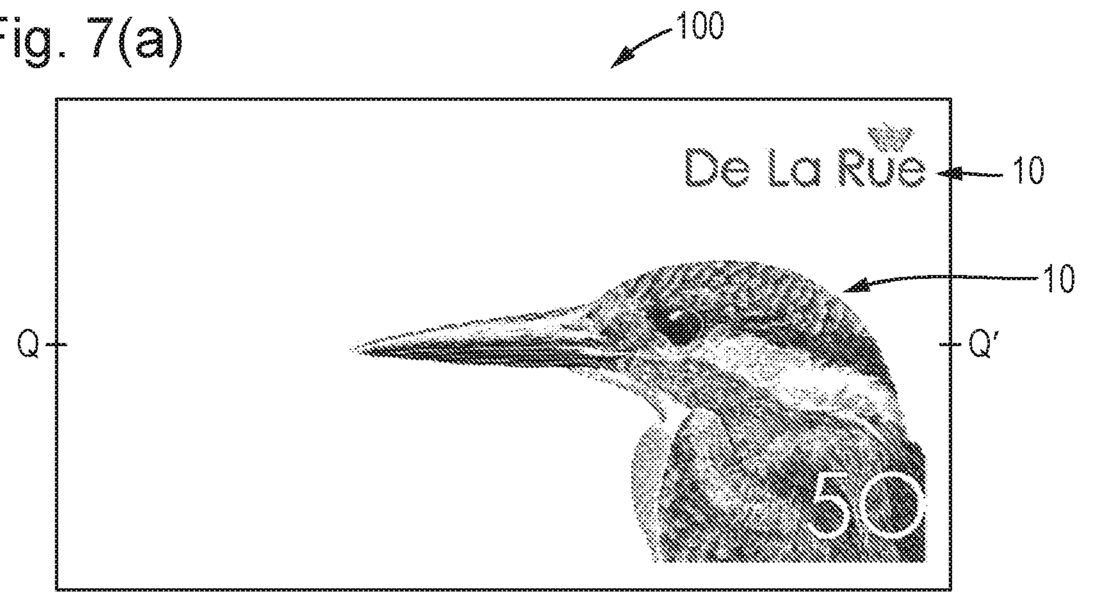

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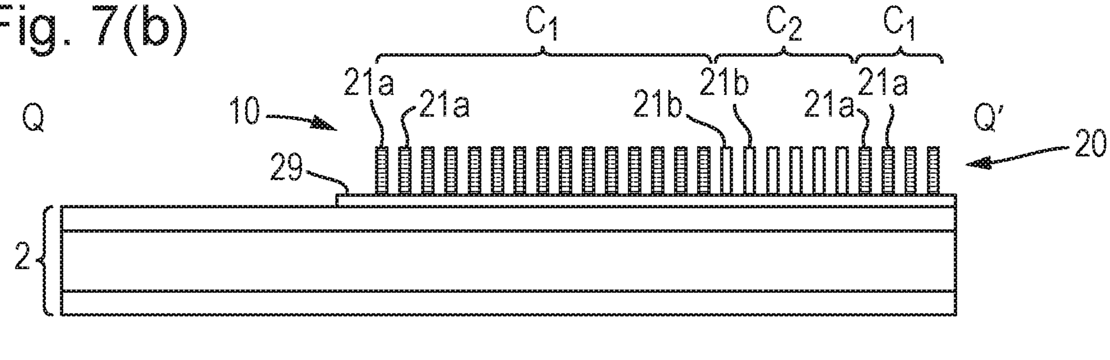

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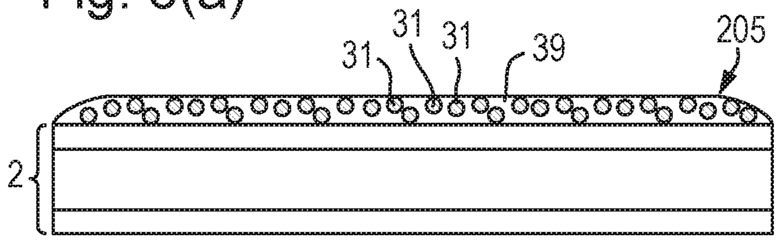

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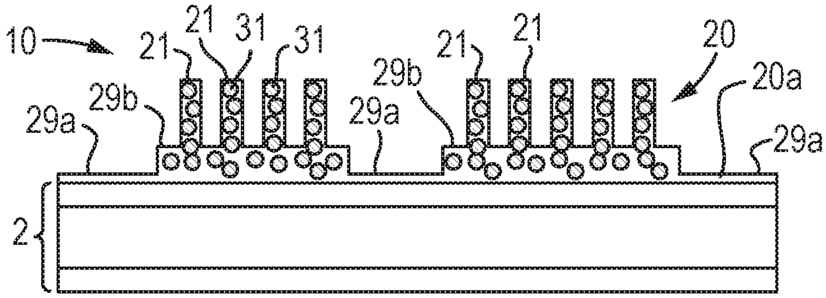

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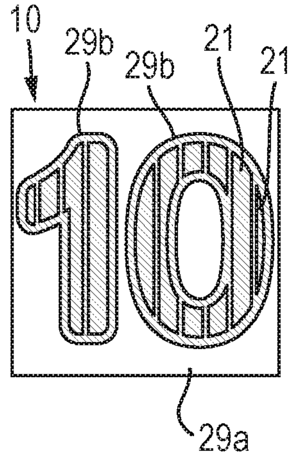

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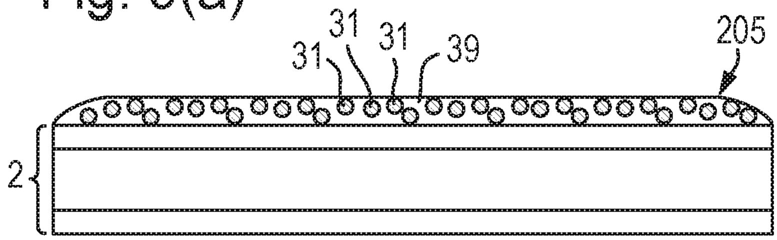

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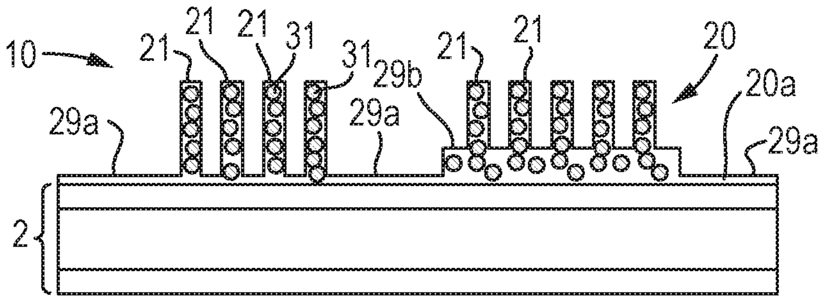

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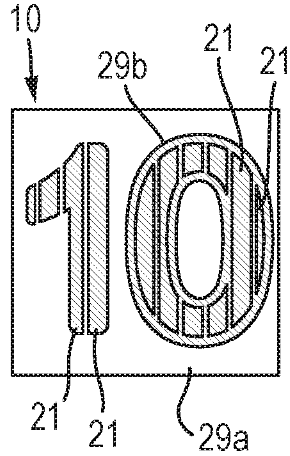

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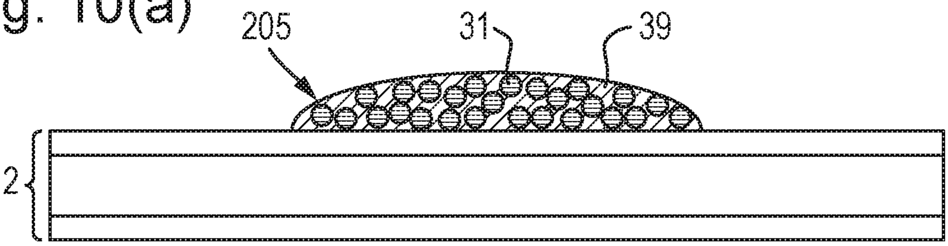

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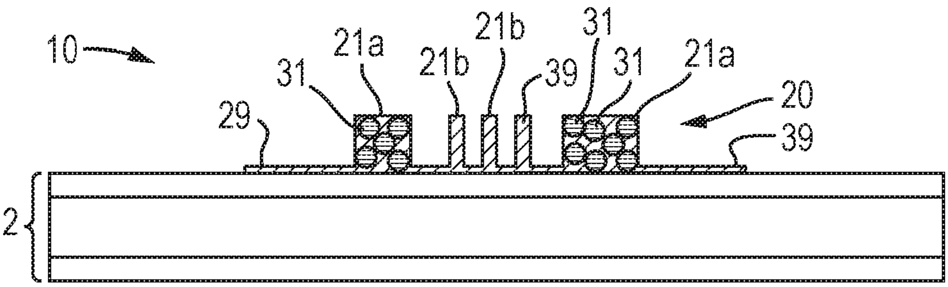

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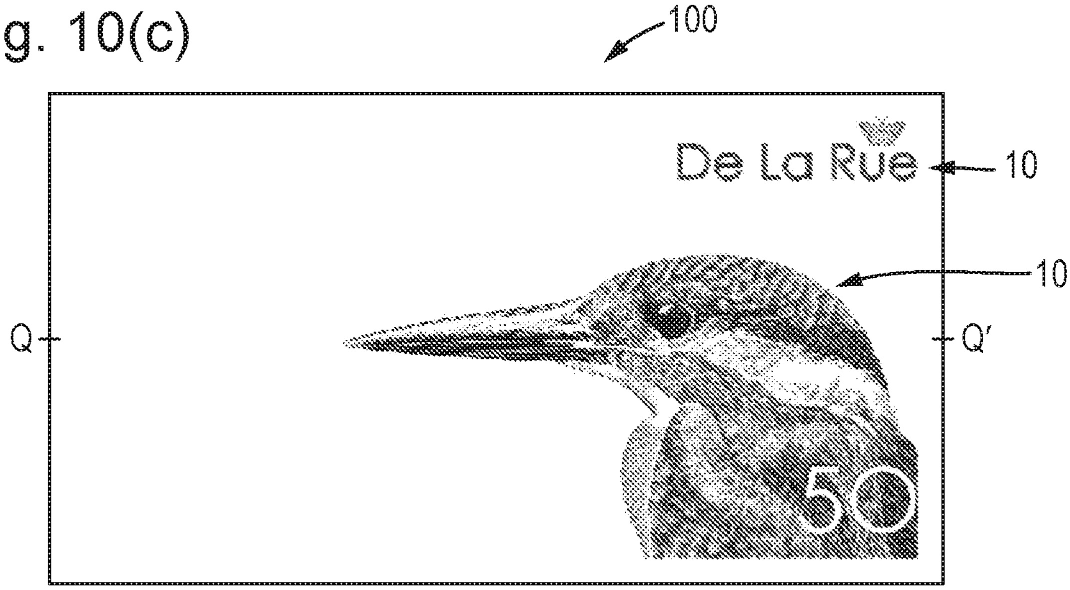

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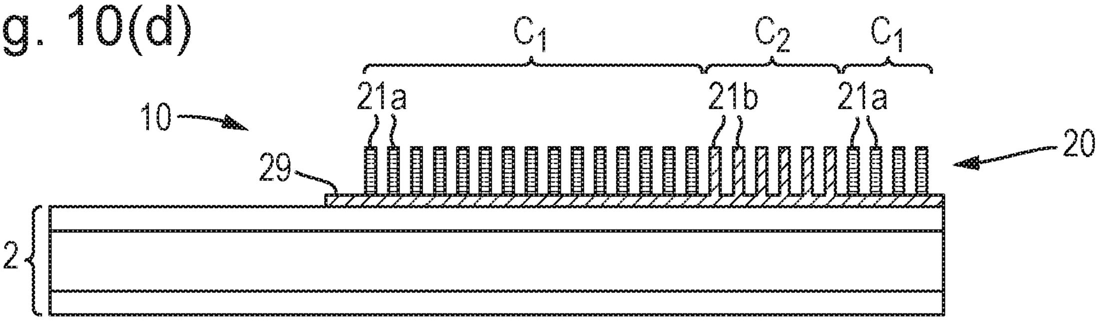

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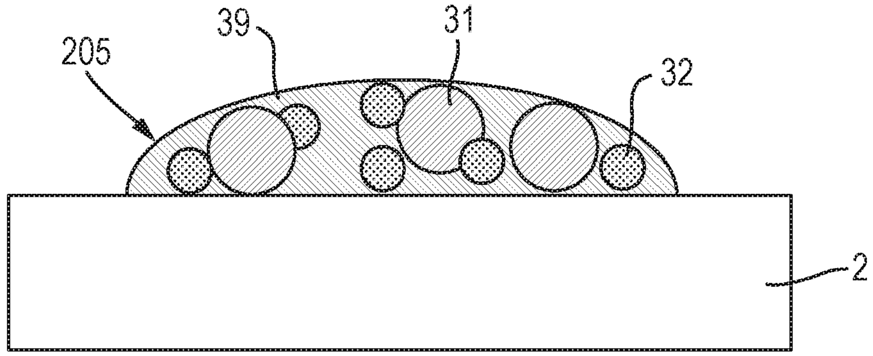

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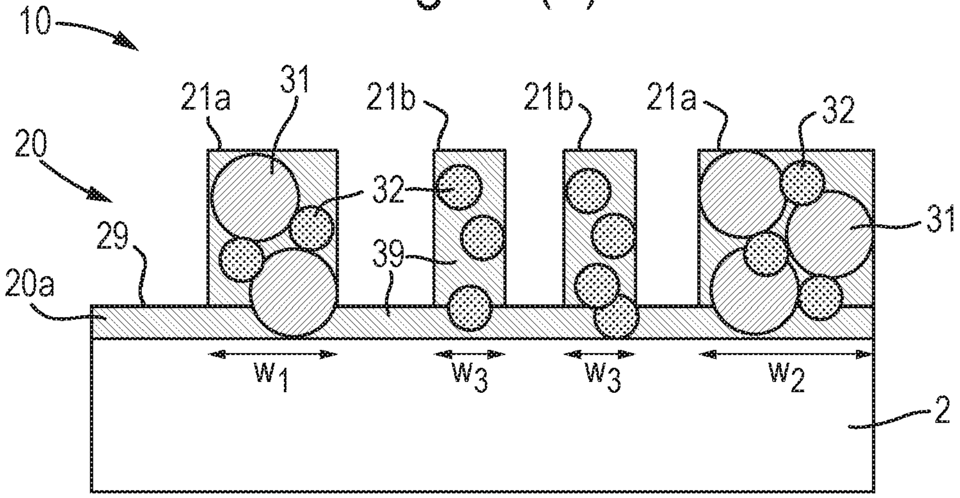

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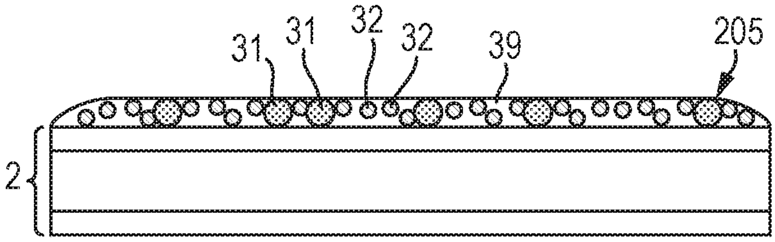

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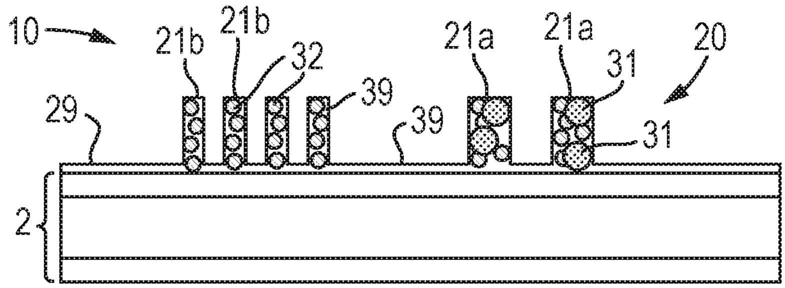

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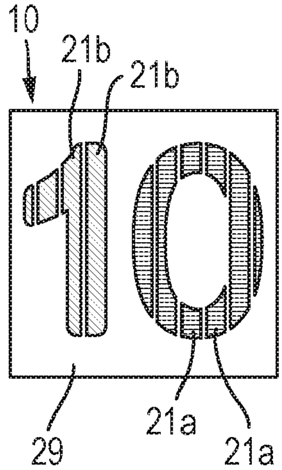

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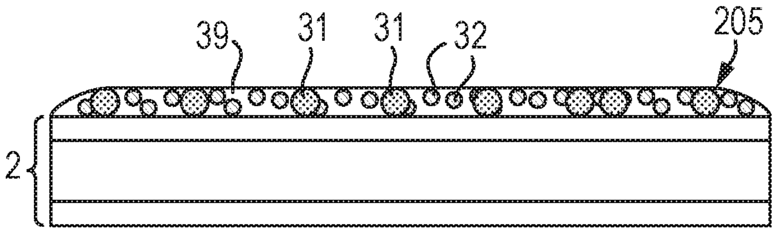

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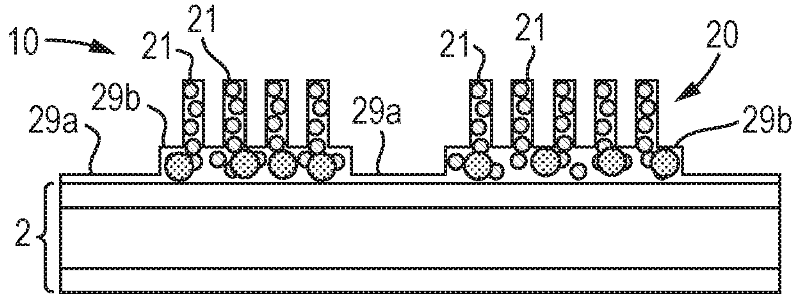

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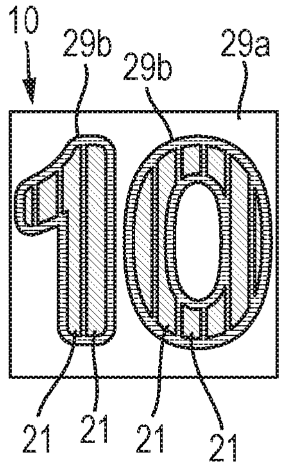

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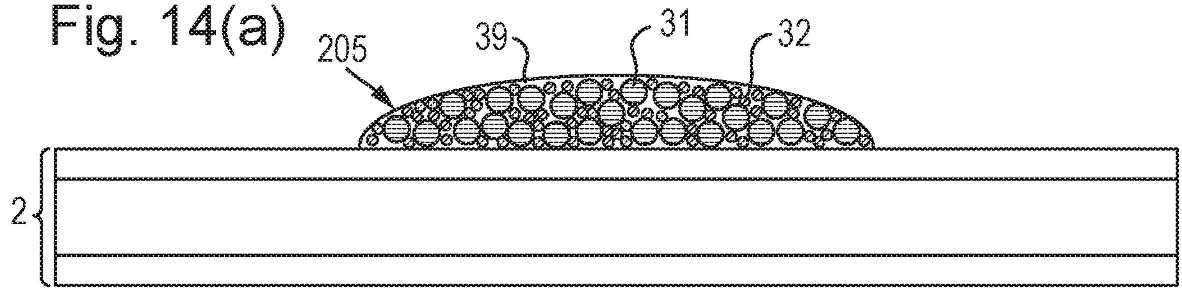

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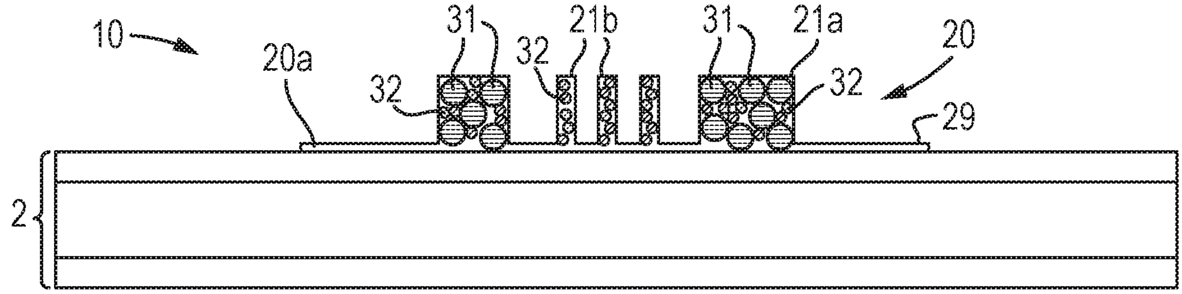

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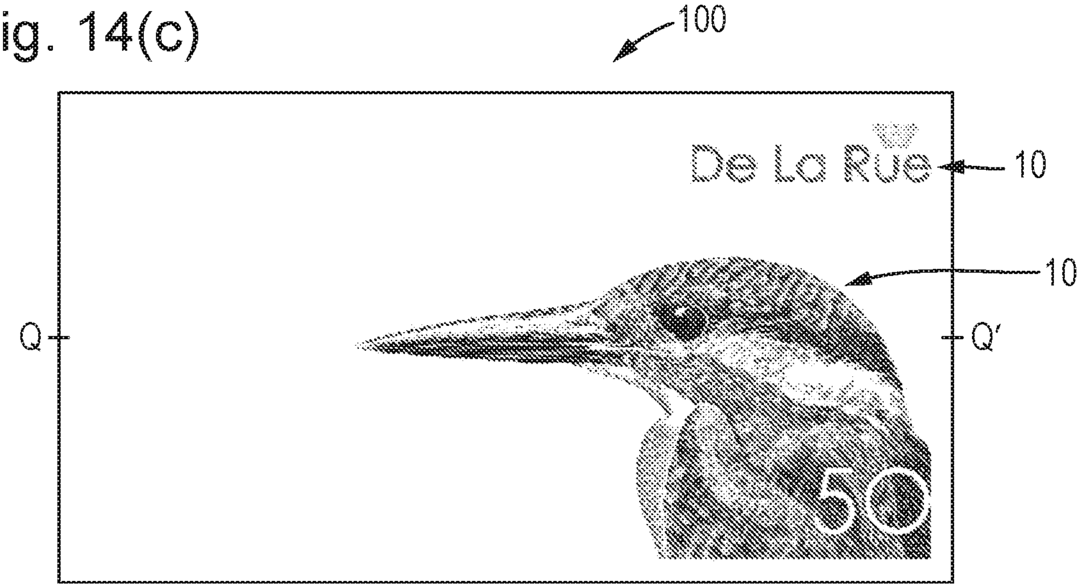

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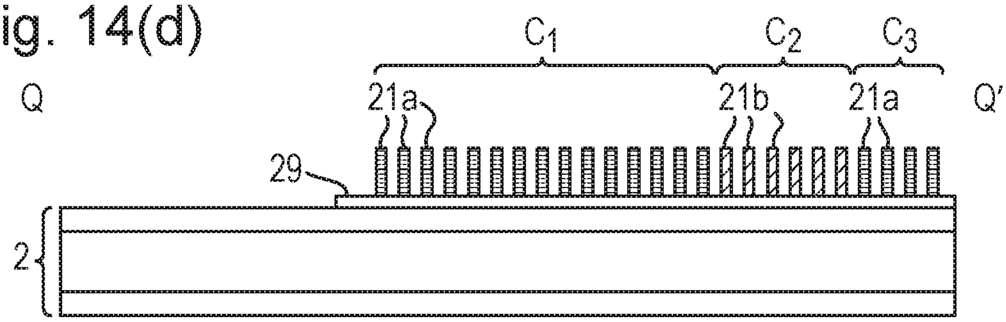

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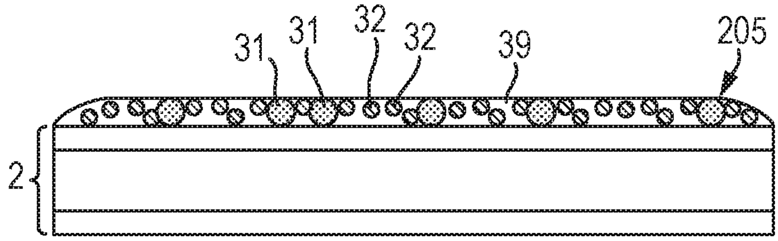

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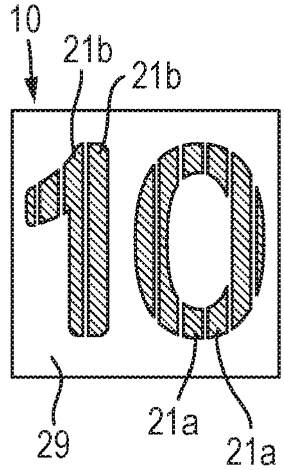

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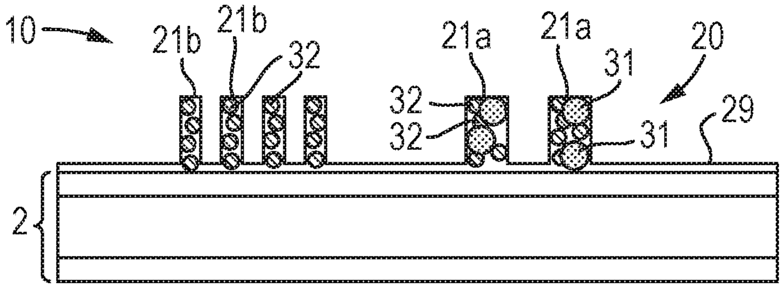

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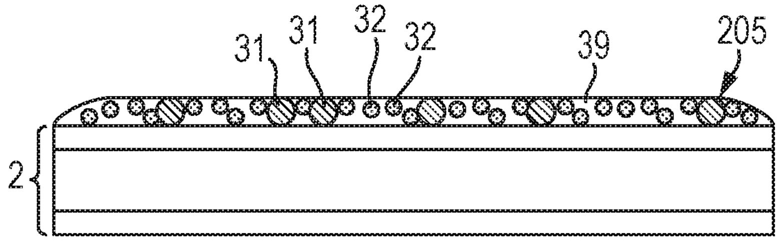

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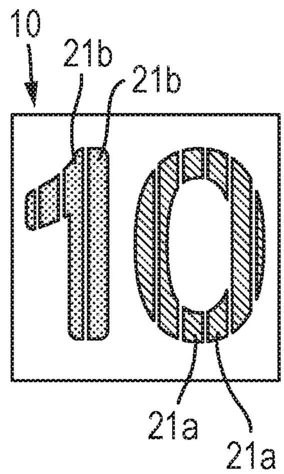

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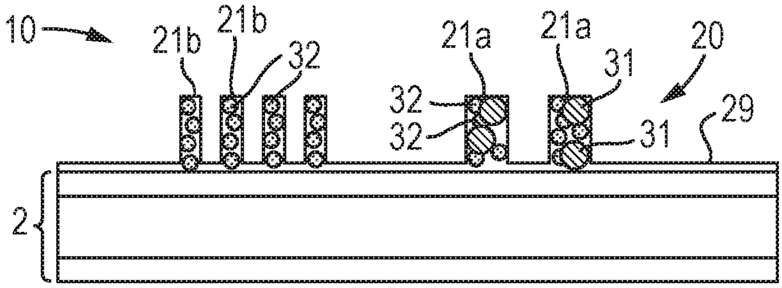

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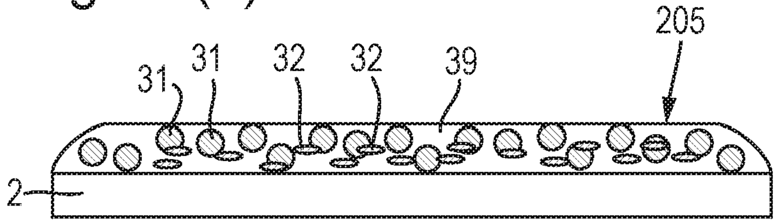

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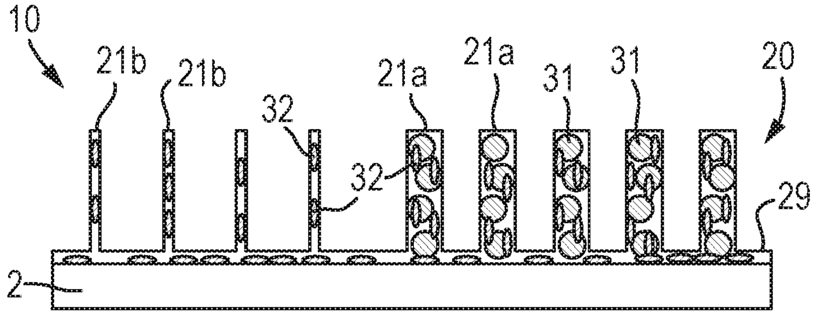

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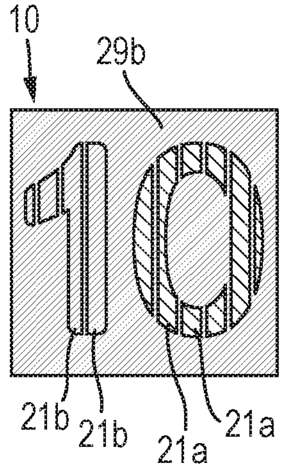

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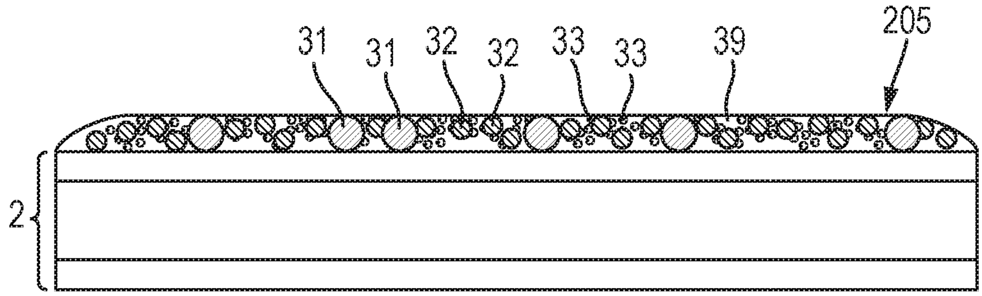

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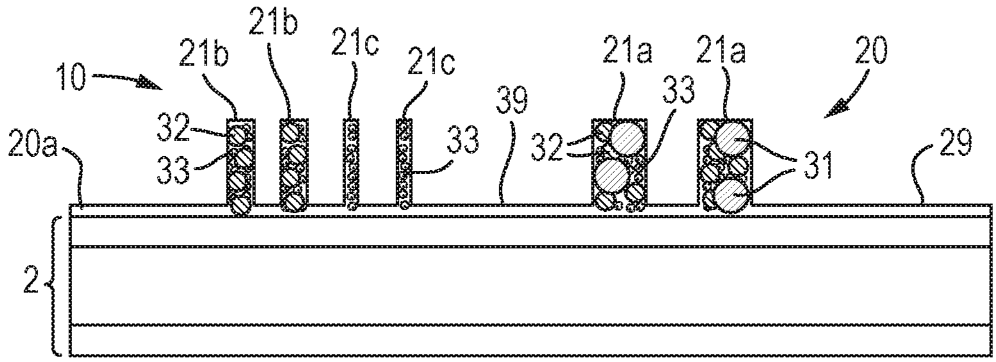

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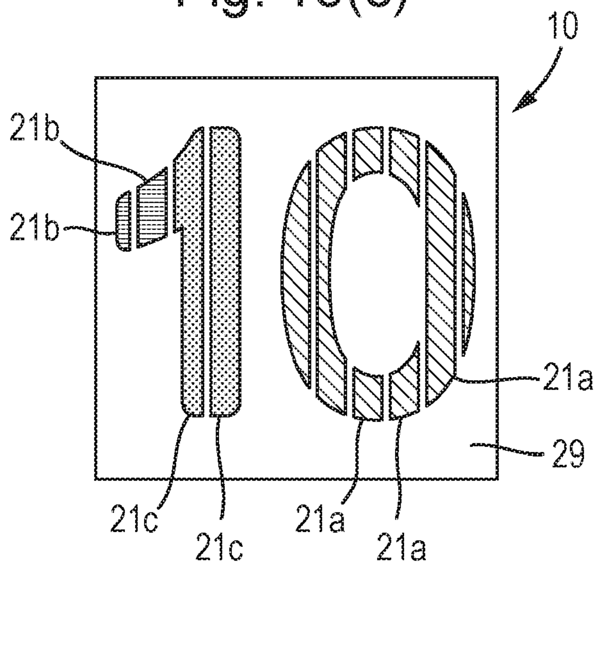

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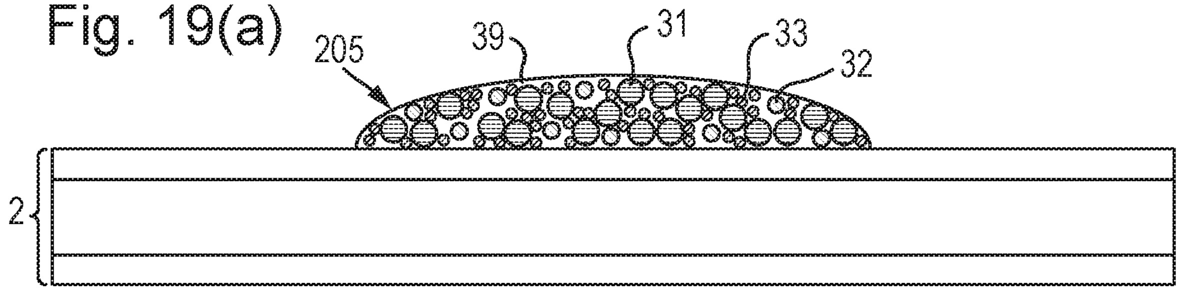
Fig. 19(a)



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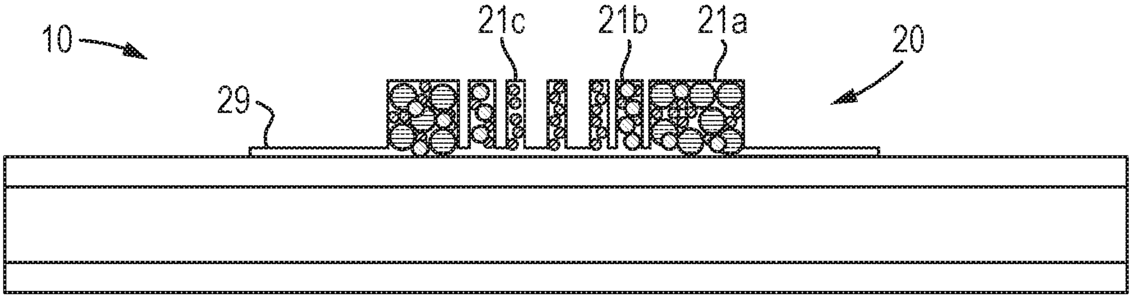

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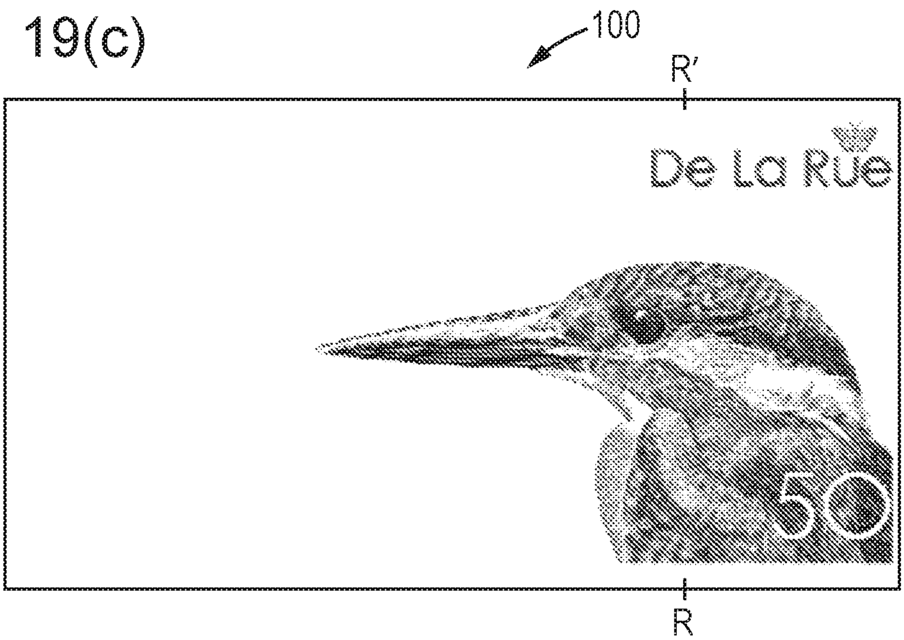

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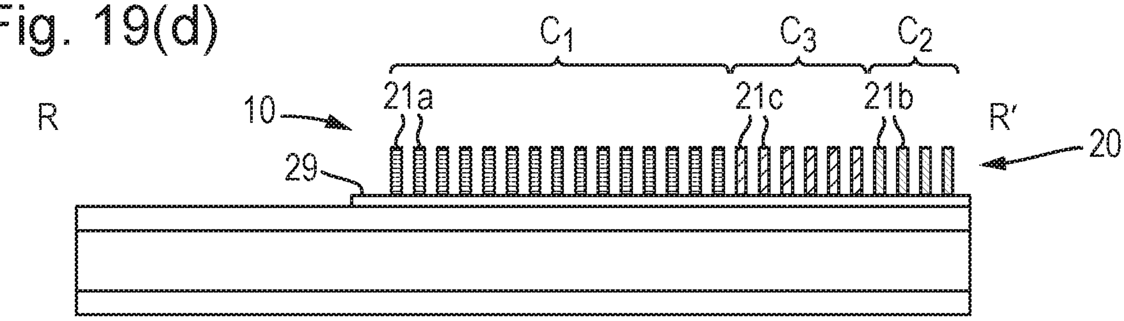

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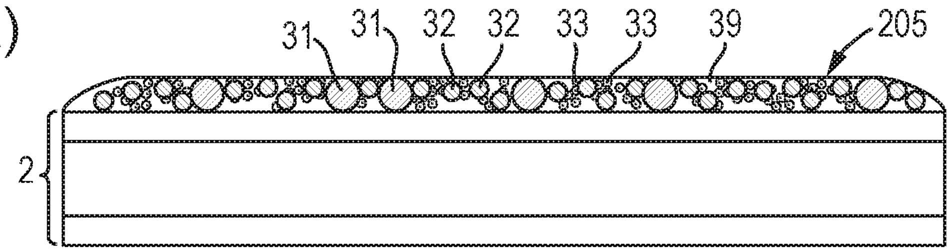

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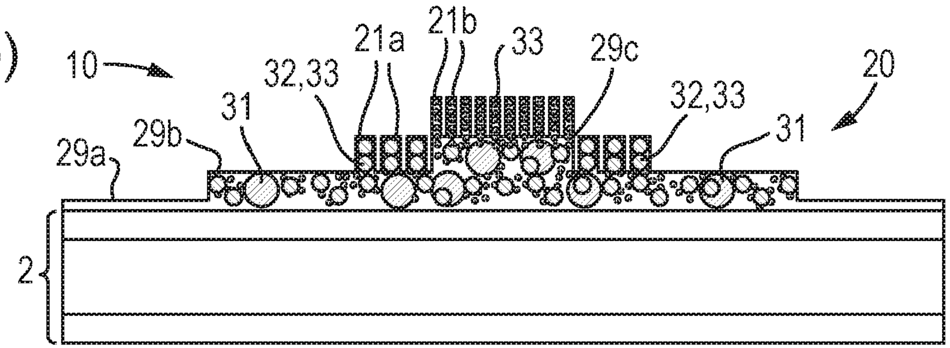

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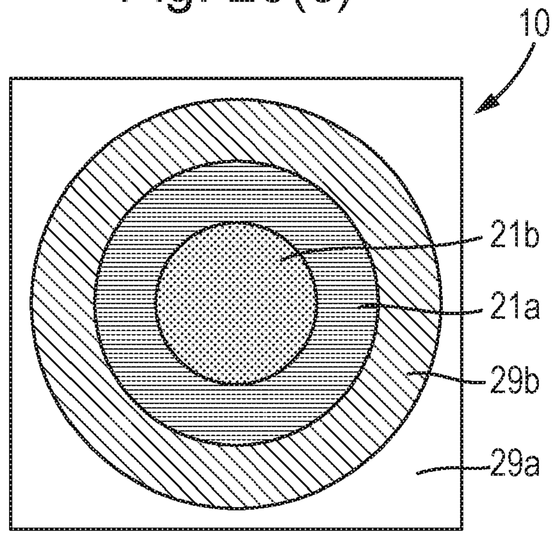

Fig. 21

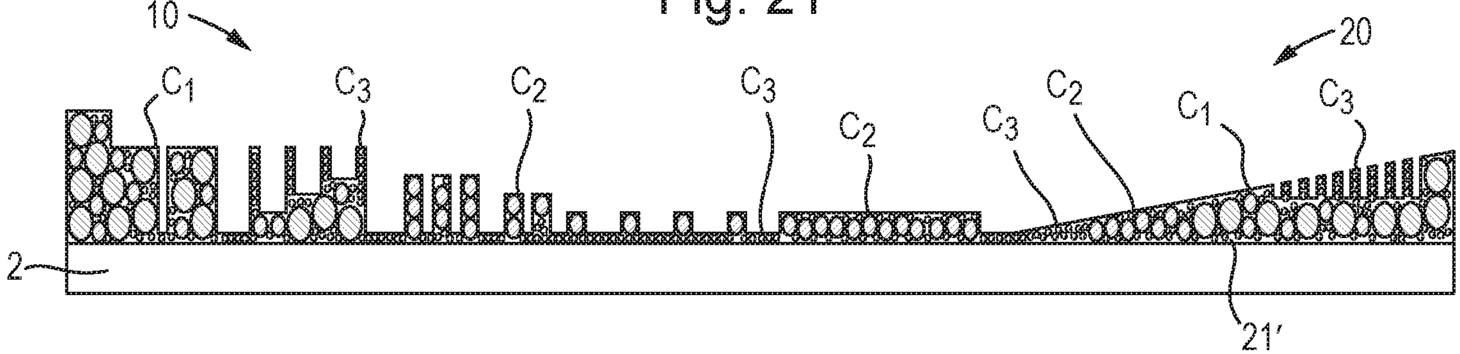

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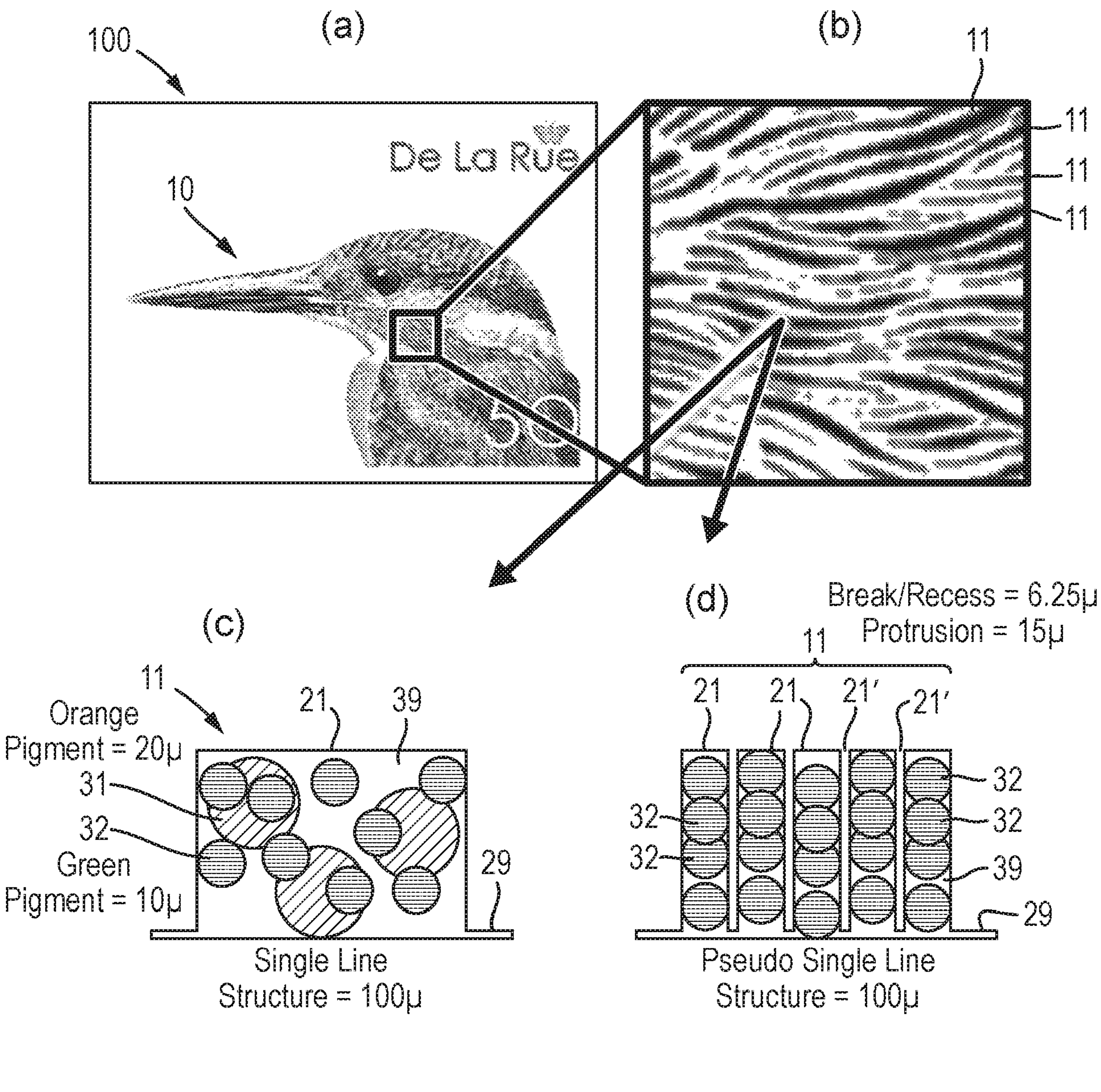
Fig. 22(a)



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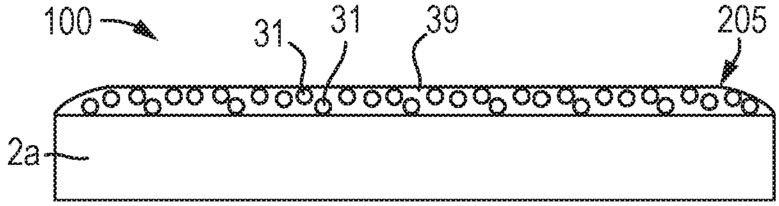

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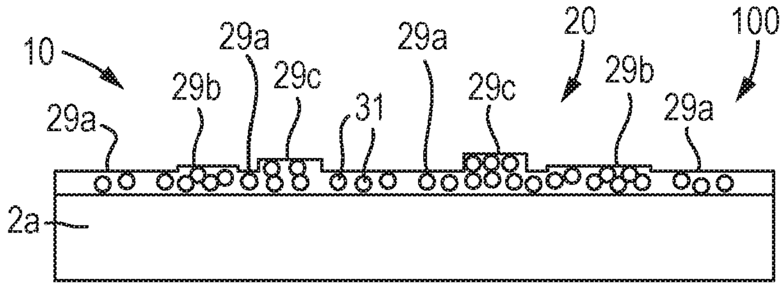

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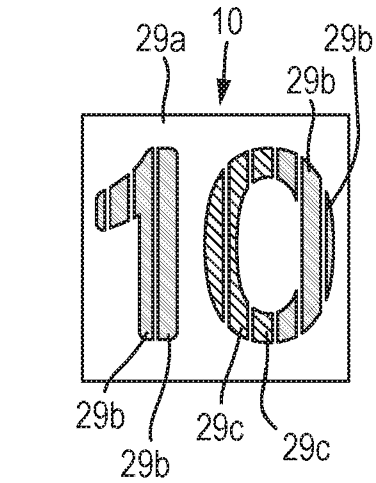

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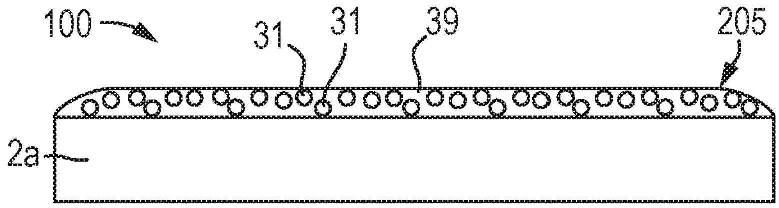

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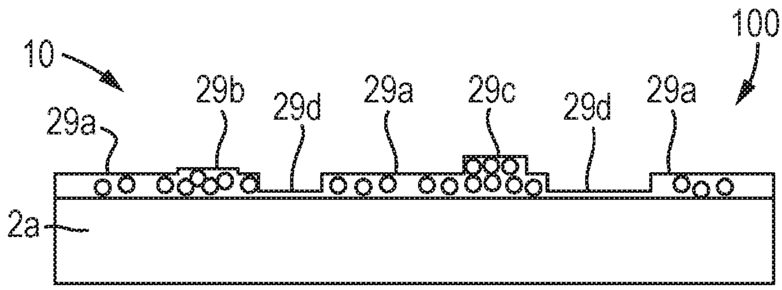

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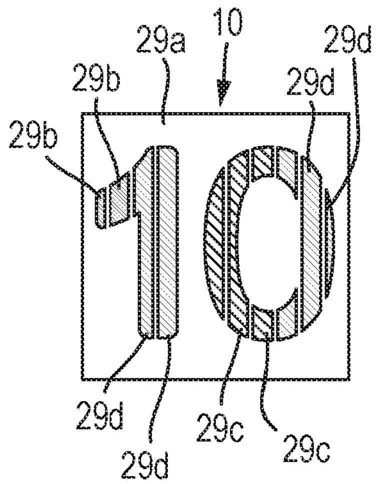

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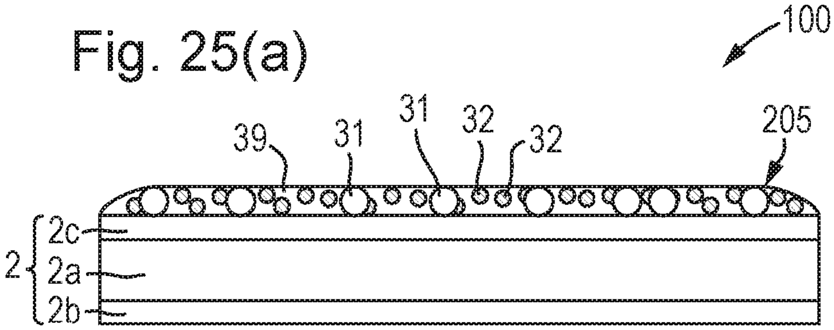

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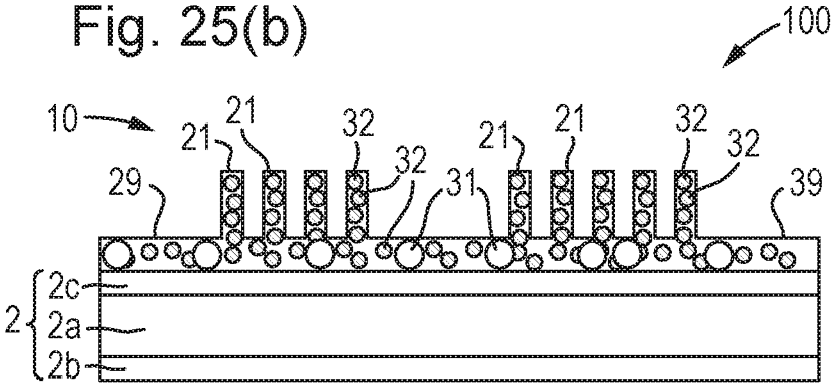

Fig. 25(c)

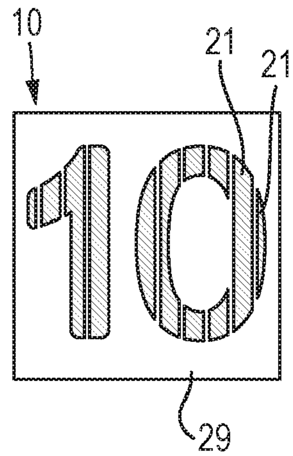

Fig. 26(a)

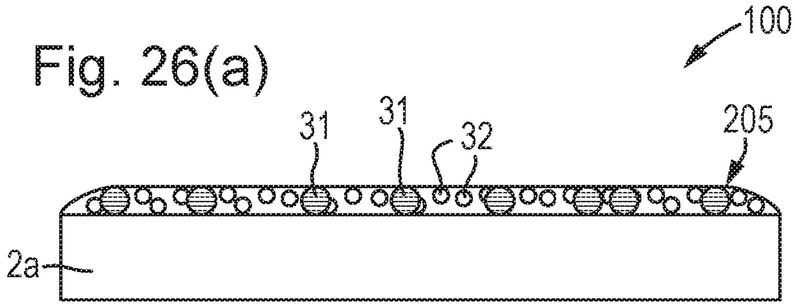

Fig. 26(b)

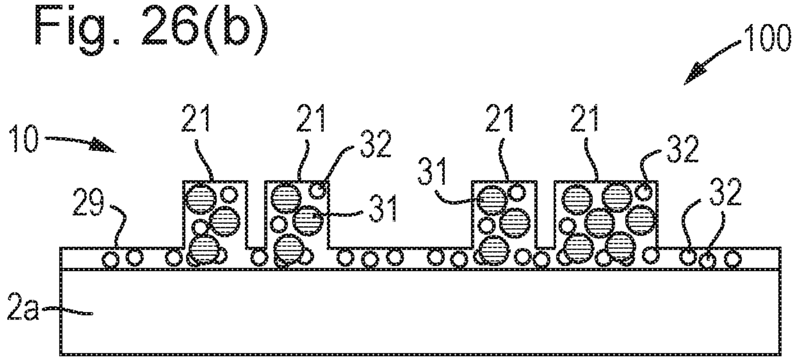

Fig. 26(c)

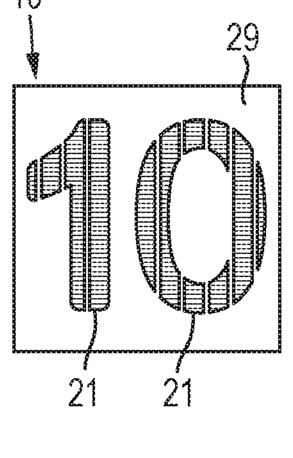

Fig. 27(a)

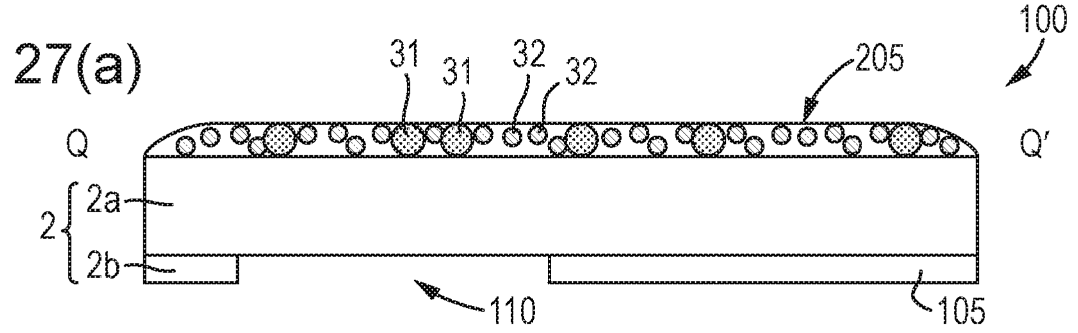

Fig. 27(b)

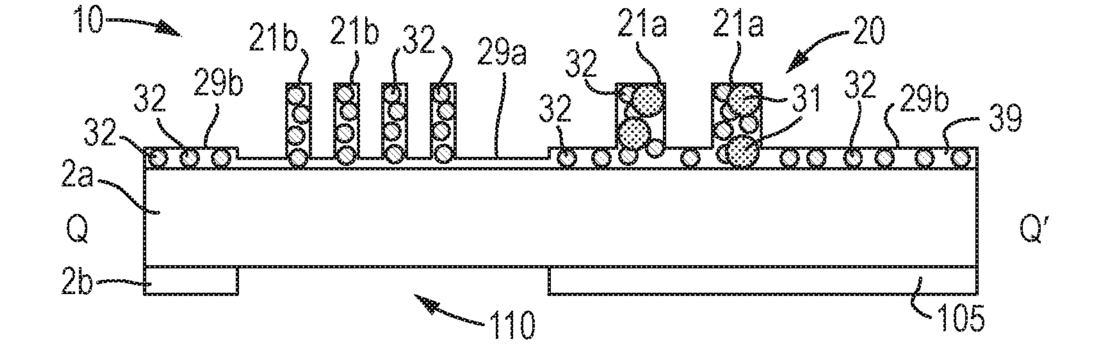

Fig. 27(c)

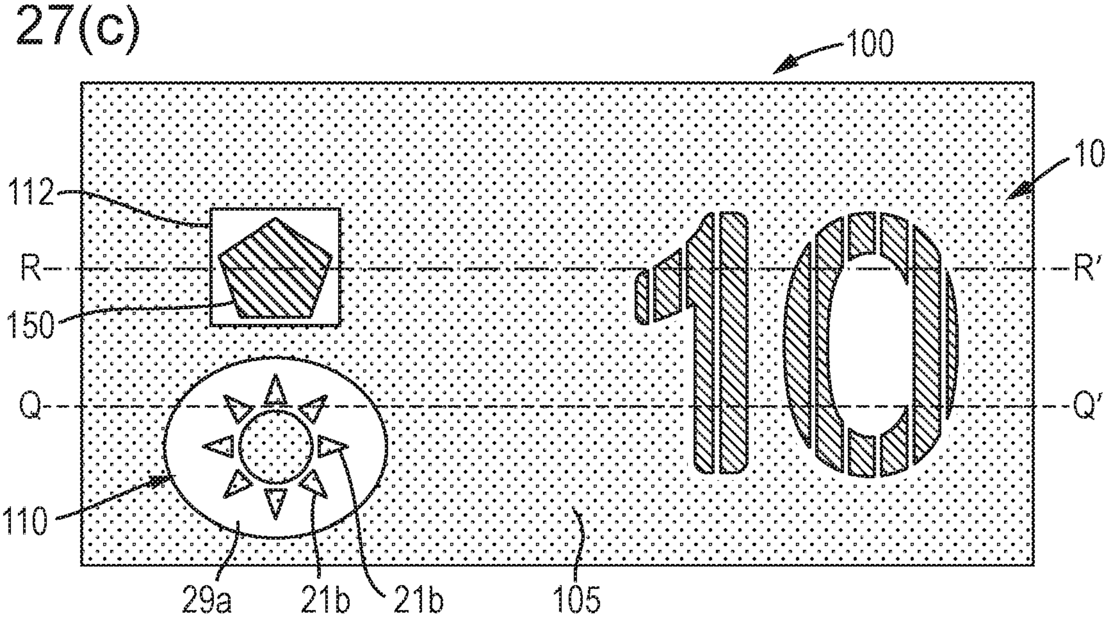

Fig. 27(d)

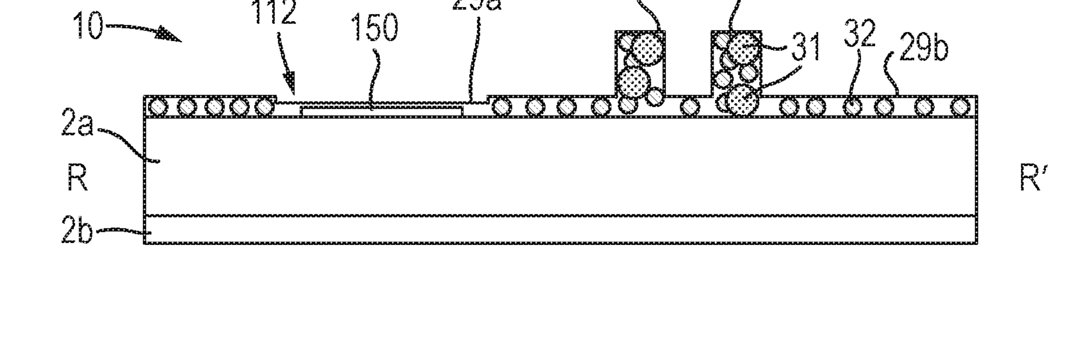

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Fig. 28(a)

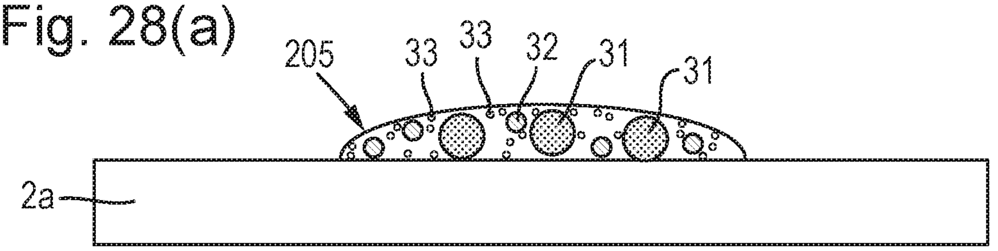


Fig. 28(b)

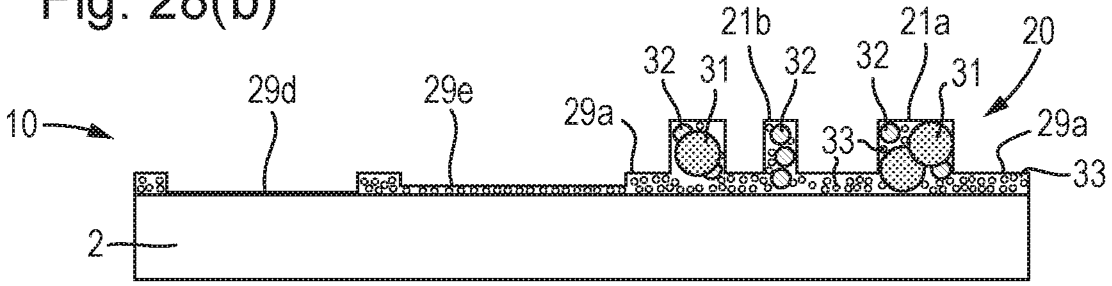
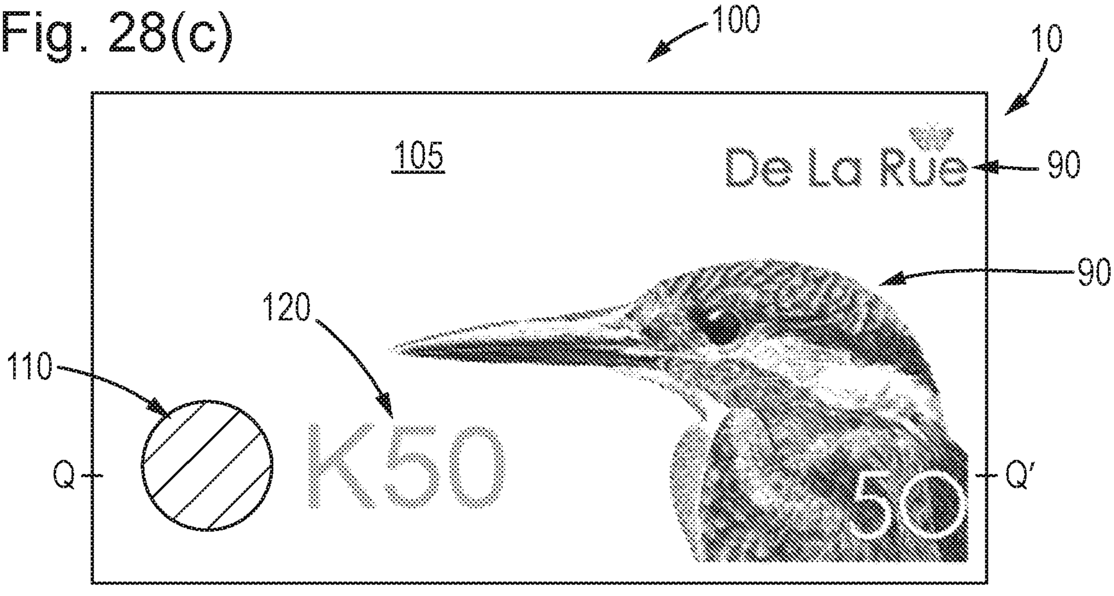


Fig. 28(c)



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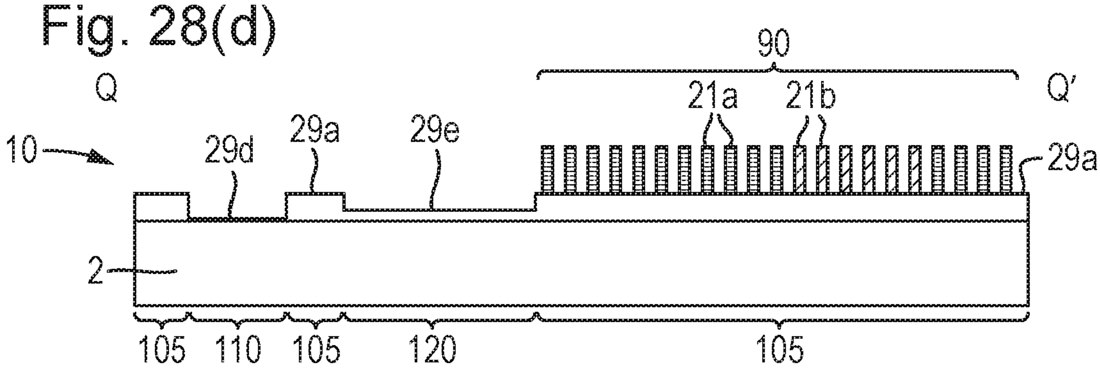

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Fig. 29(a)

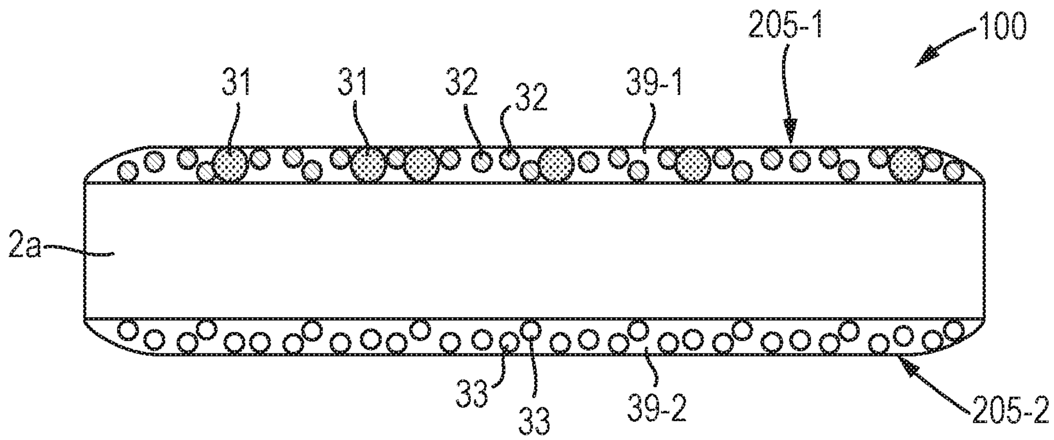

Fig. 29(b)

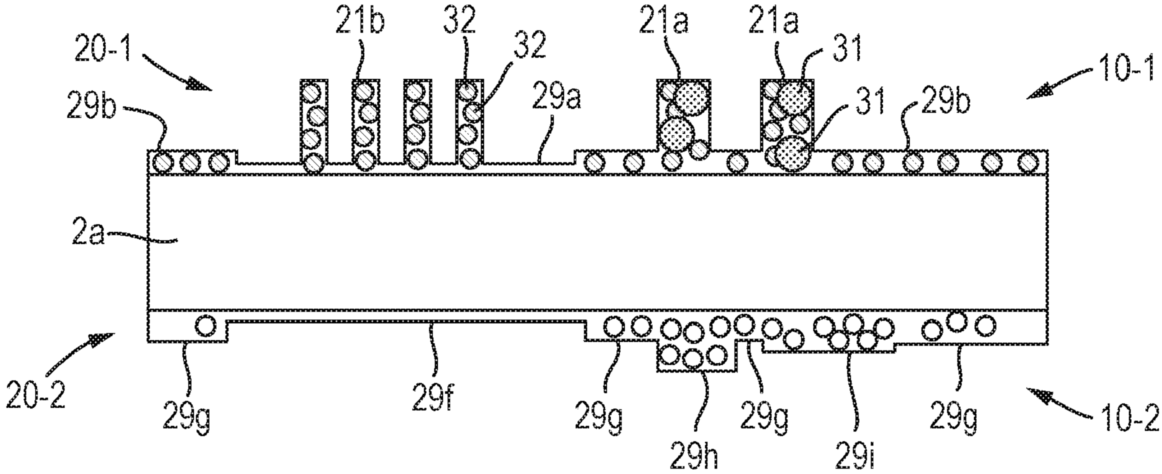

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Fig. 30(a)

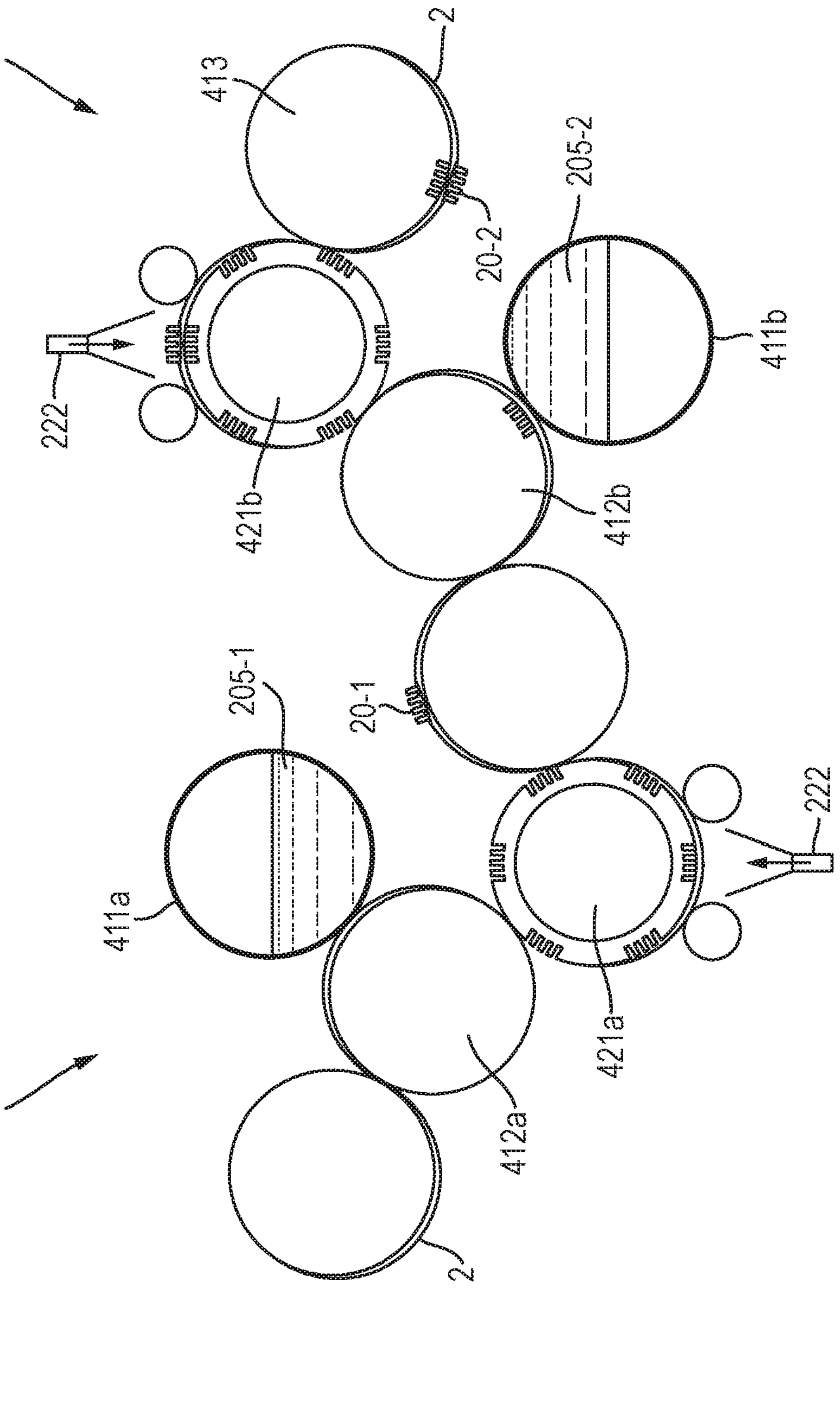

Fig. 30(b)

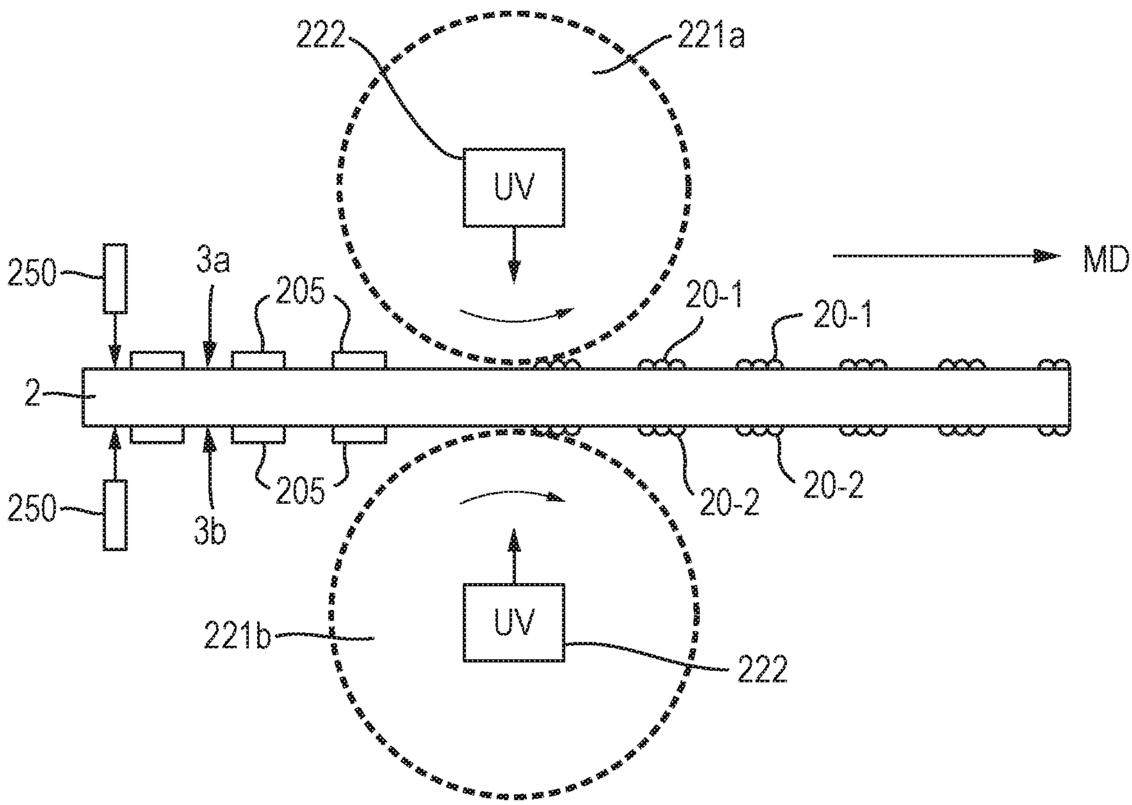

Fig. 30(c)

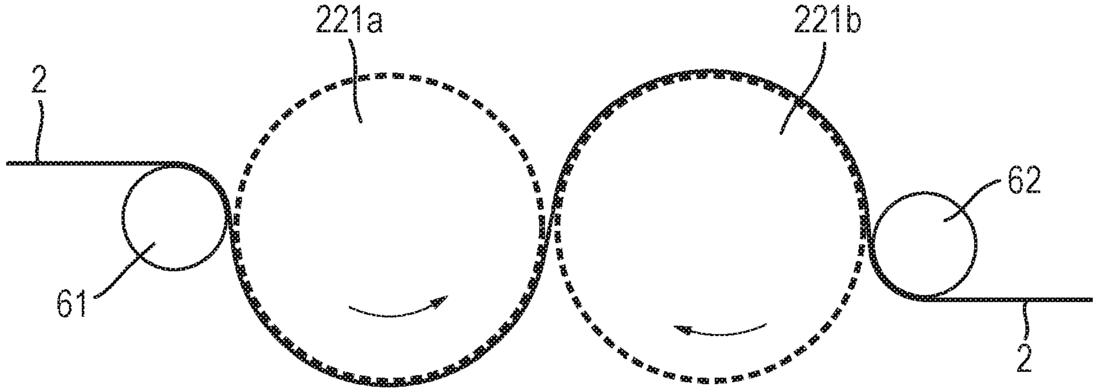

Fig. 31(a)

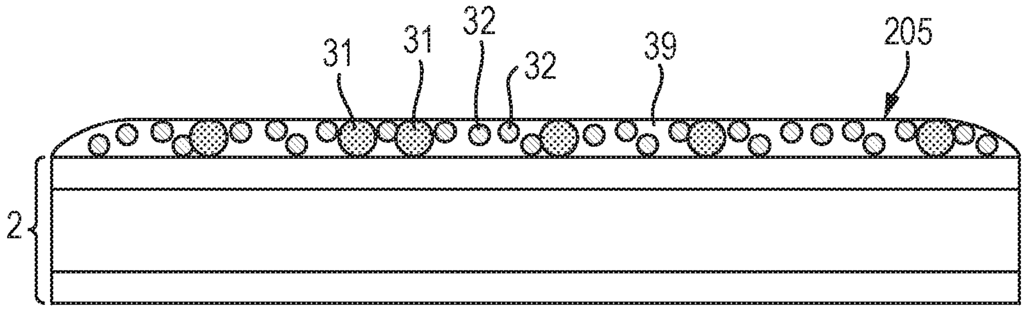

Fig. 31(b)

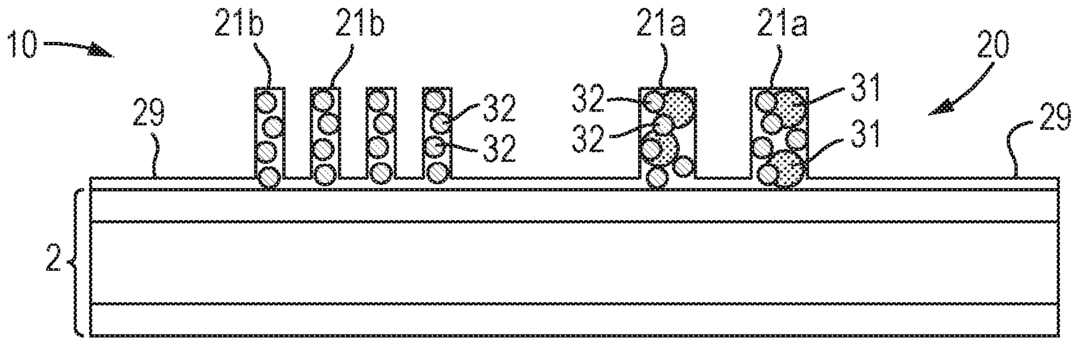

Fig. 31(c)

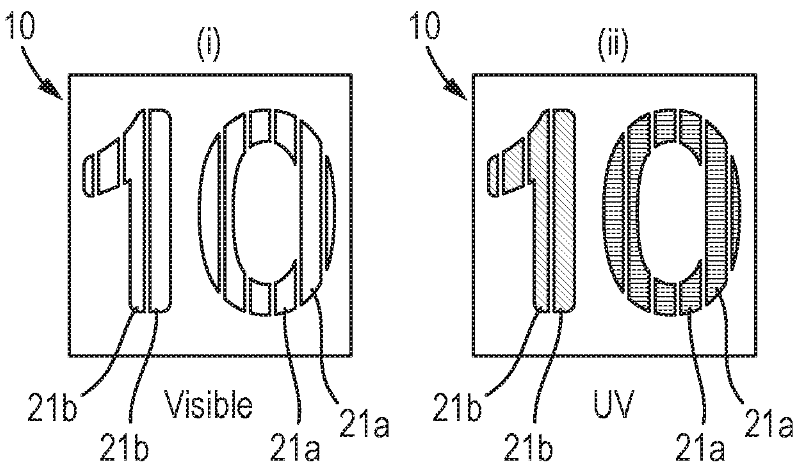

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Fig. 32(a)

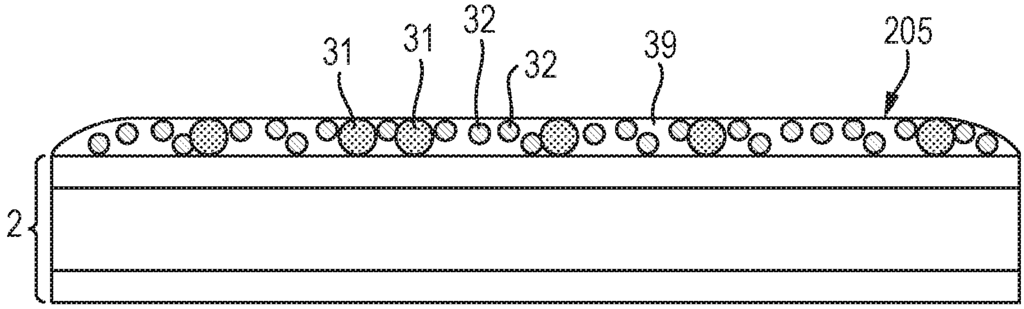

Fig. 32(b)

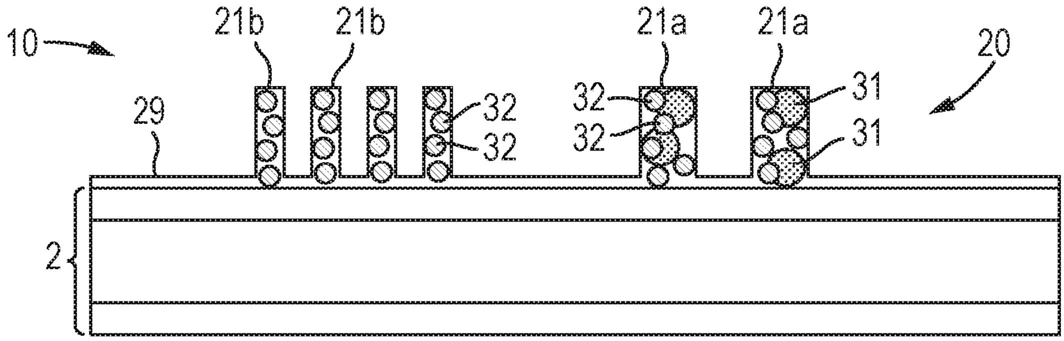

Fig. 32(c)

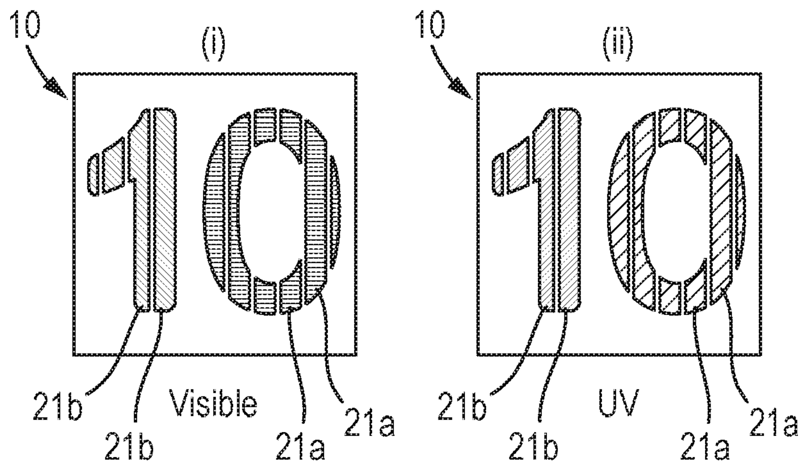

Fig. 33(a)

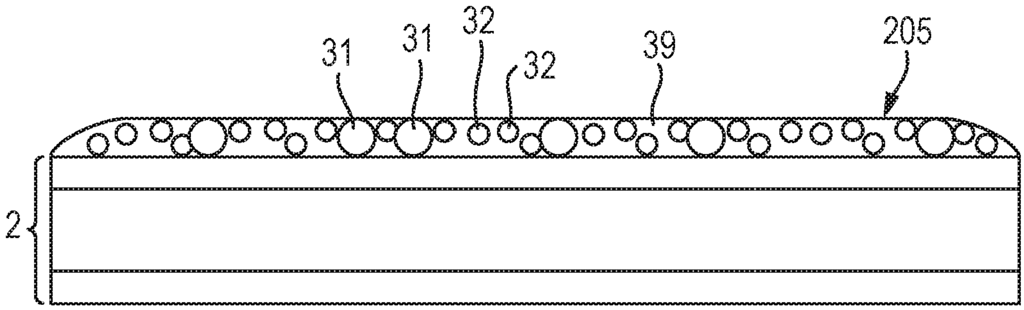

Fig. 33(b)

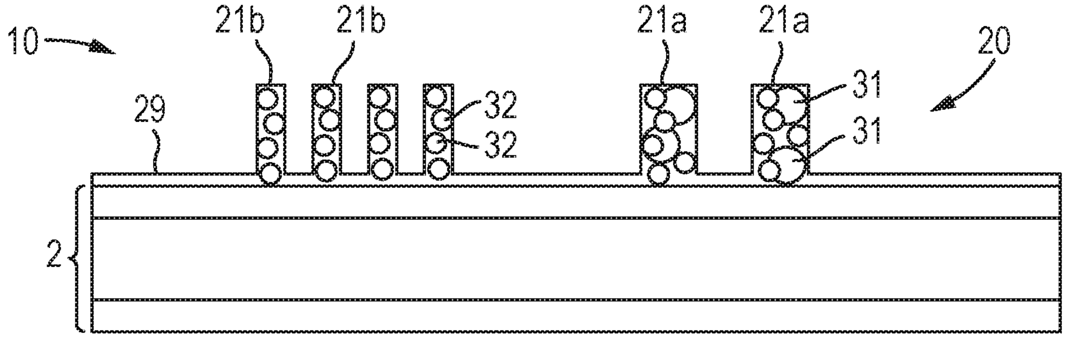

Fig. 33(c)

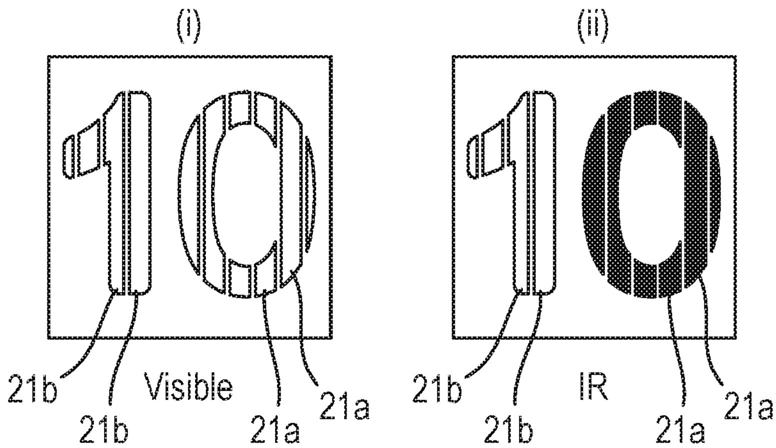

Fig. 34(a)

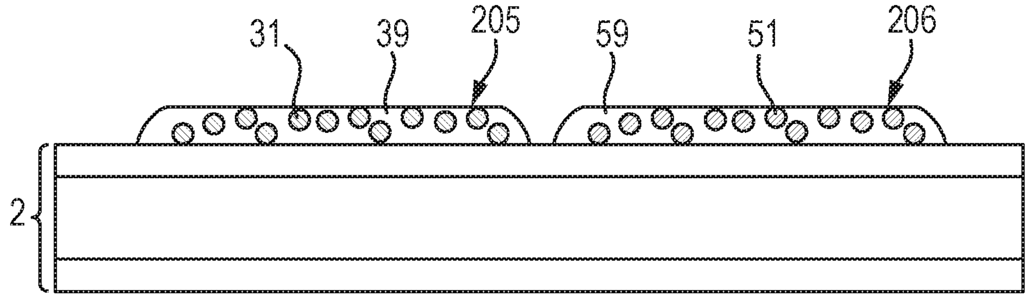

Fig. 34(b)

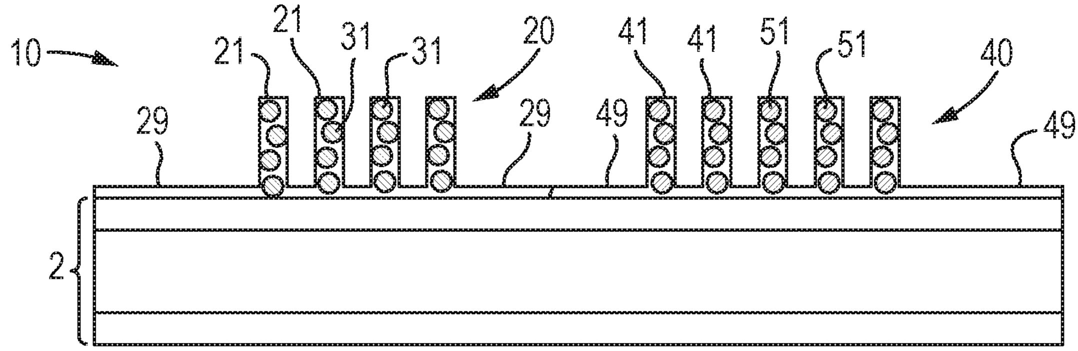

Fig. 34(c)

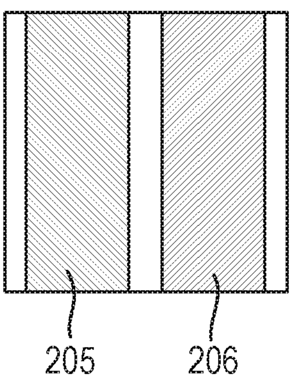

Fig. 34(d)

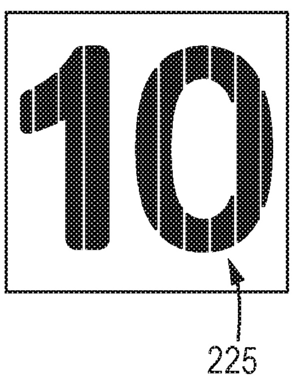

Fig. 34(e)

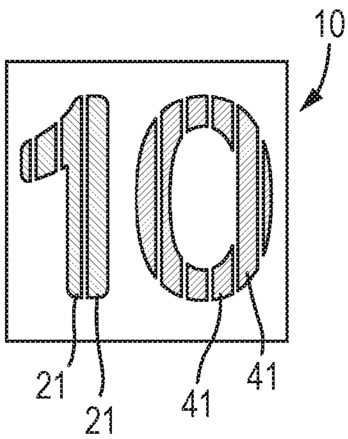

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Fig. 35(a)

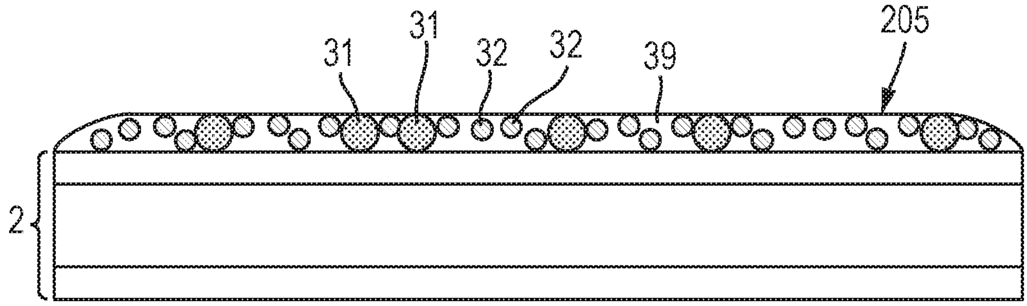

Fig. 35(b)

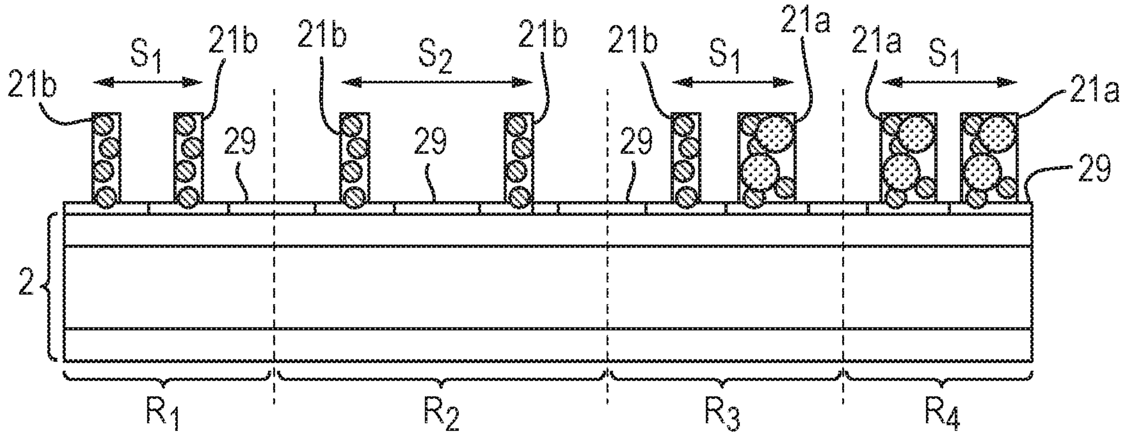

Fig. 35(c)

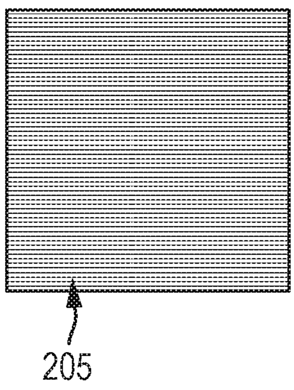

Fig. 35(d)

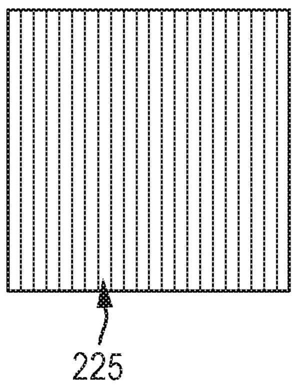

Fig. 35(e)

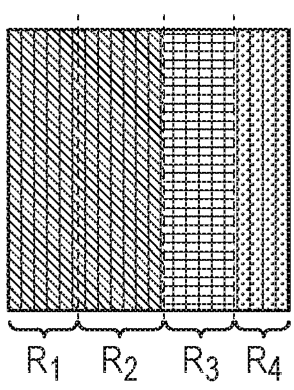

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Fig. 36

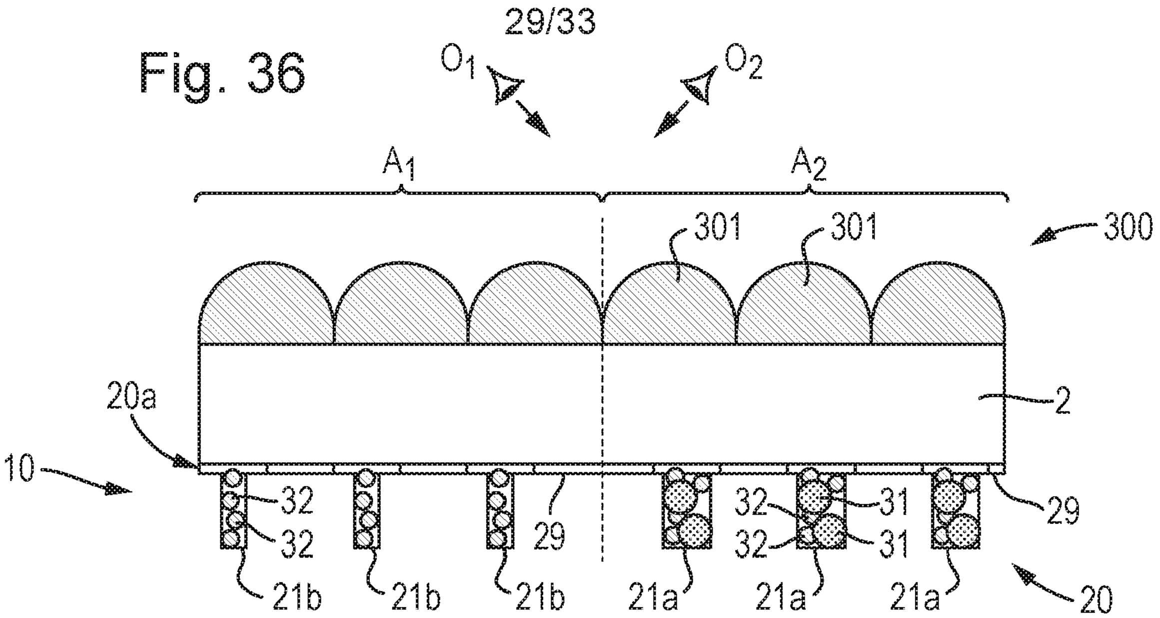

Fig. 37(a)

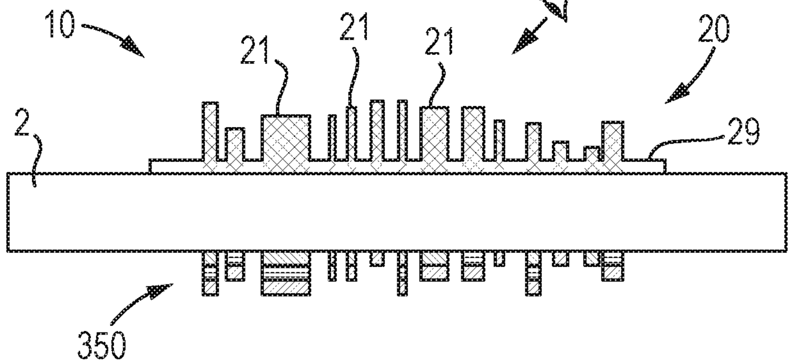

Fig. 37(b)

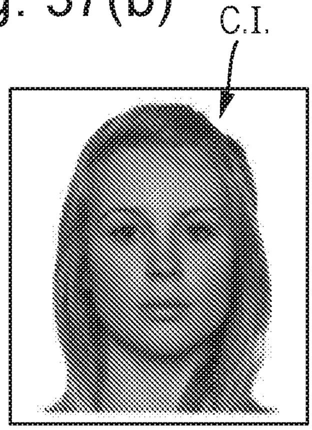

Fig. 37(c)

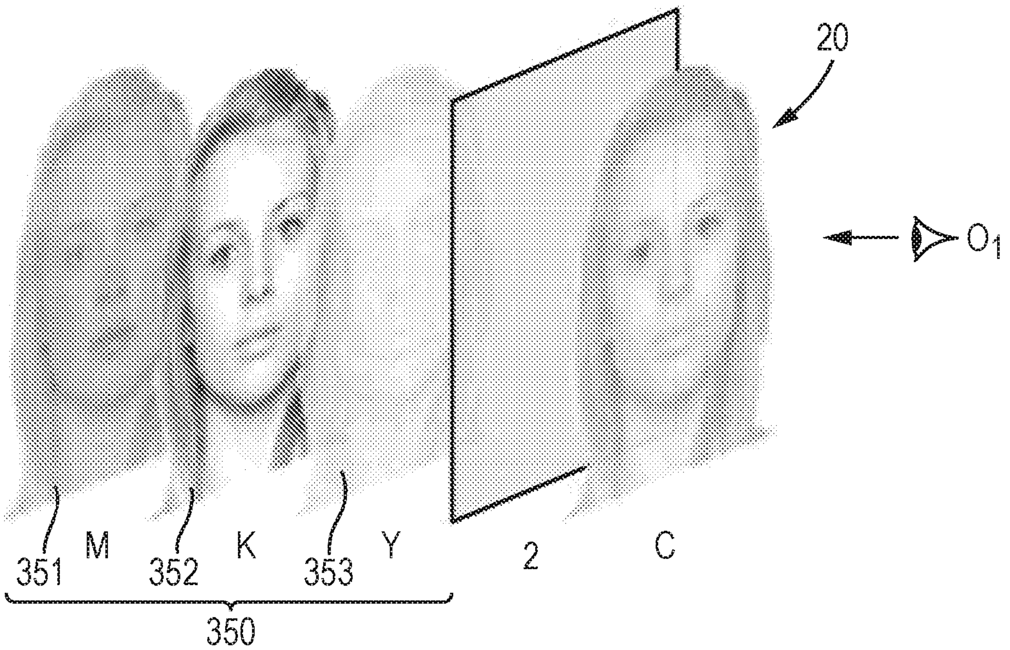

Fig. 38(a)

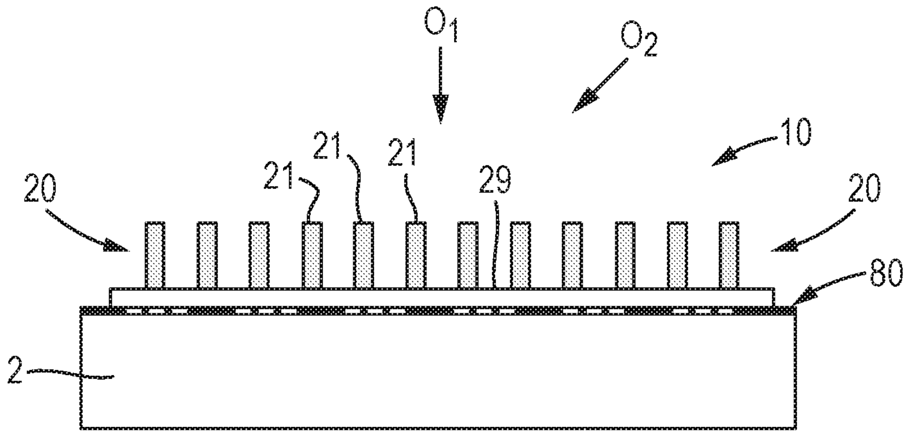

Fig. 38(b)

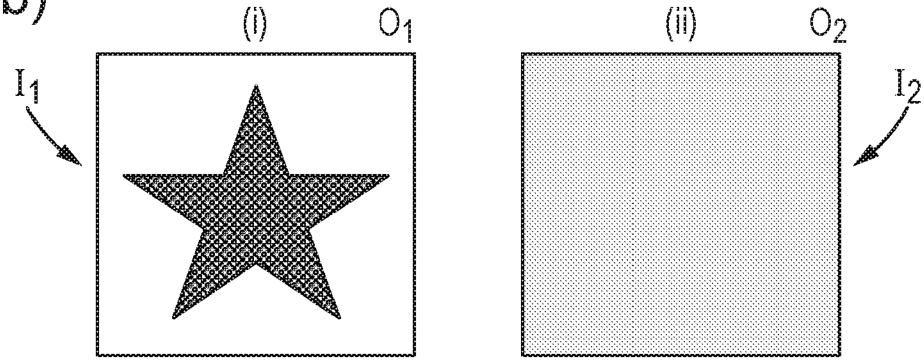

Fig. 39(a)

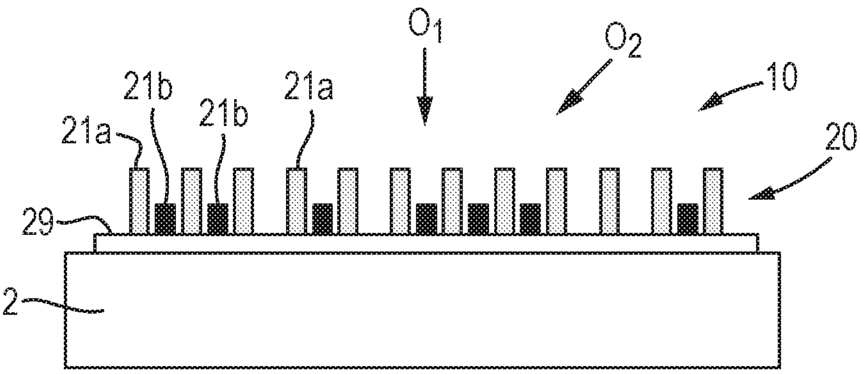

Fig. 39(b)

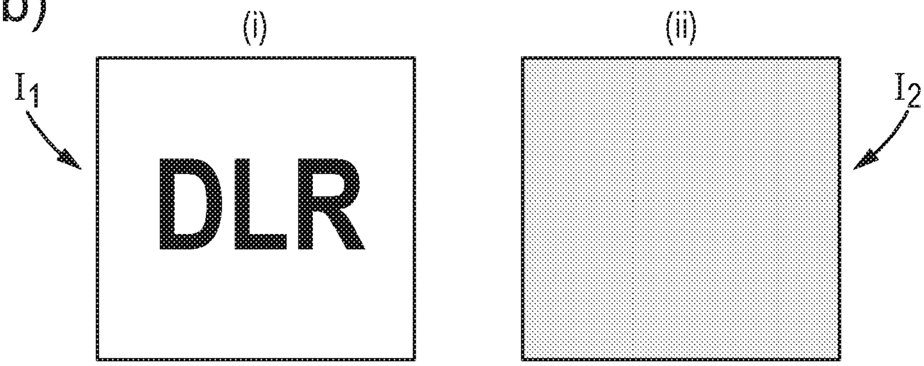

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Fig. 40(a)

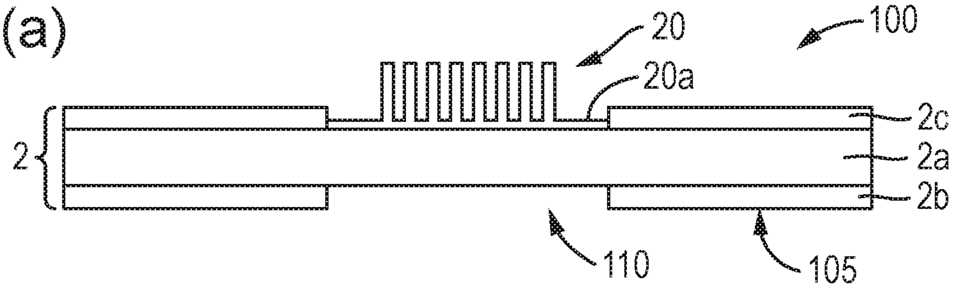

Fig. 40(b)

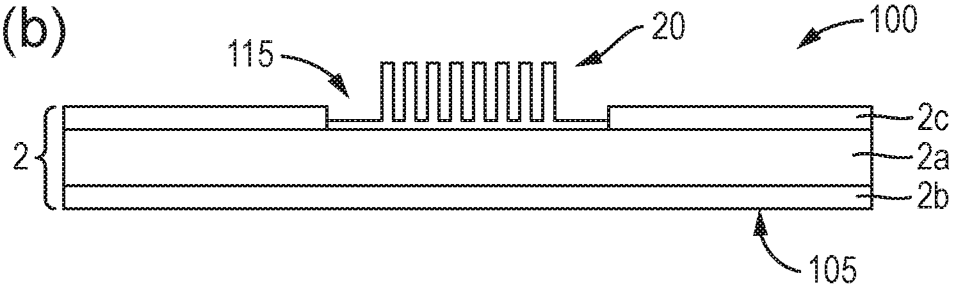

Fig. 40(c)

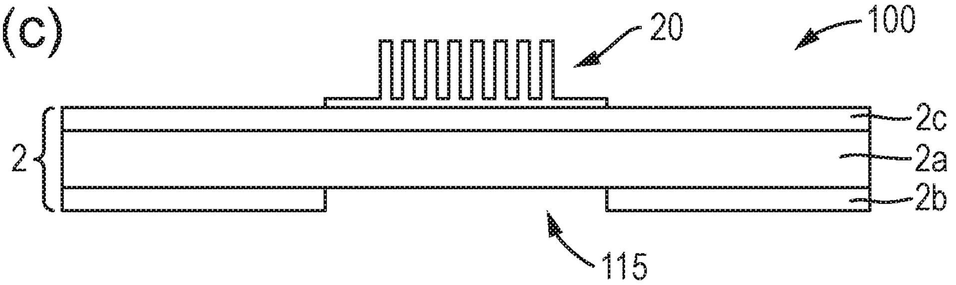

Fig. 40(d)

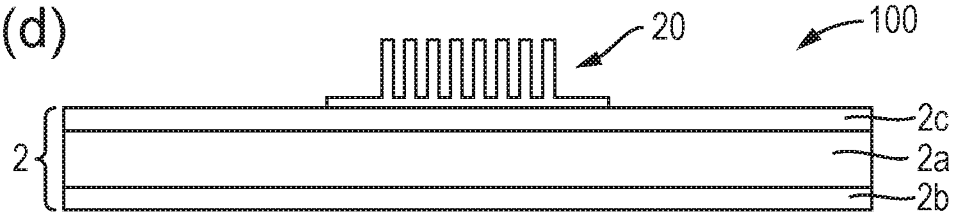

Fig. 40(e)

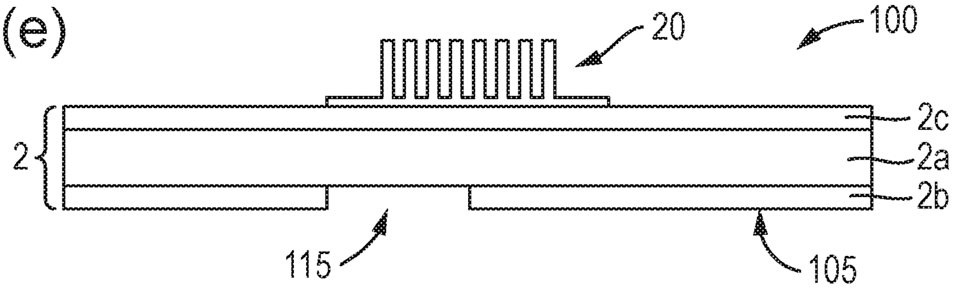

Fig. 40(f)

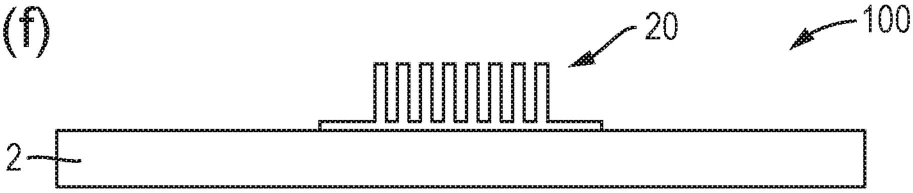

Fig. 40(g)

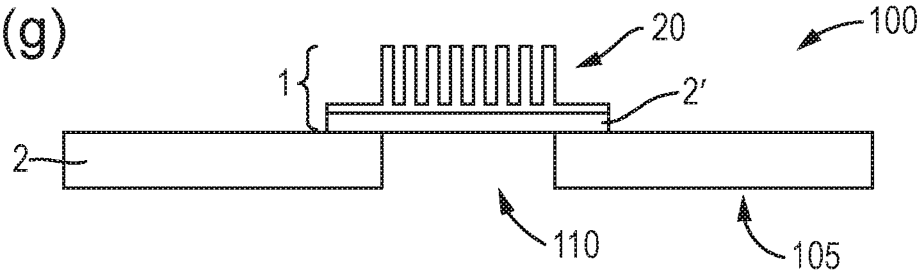

Fig. 40(h)

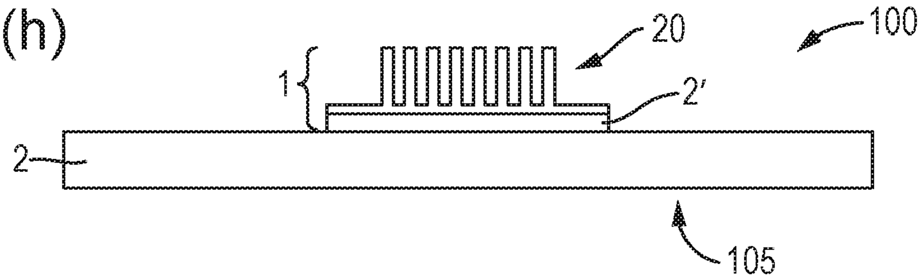

Fig. 41

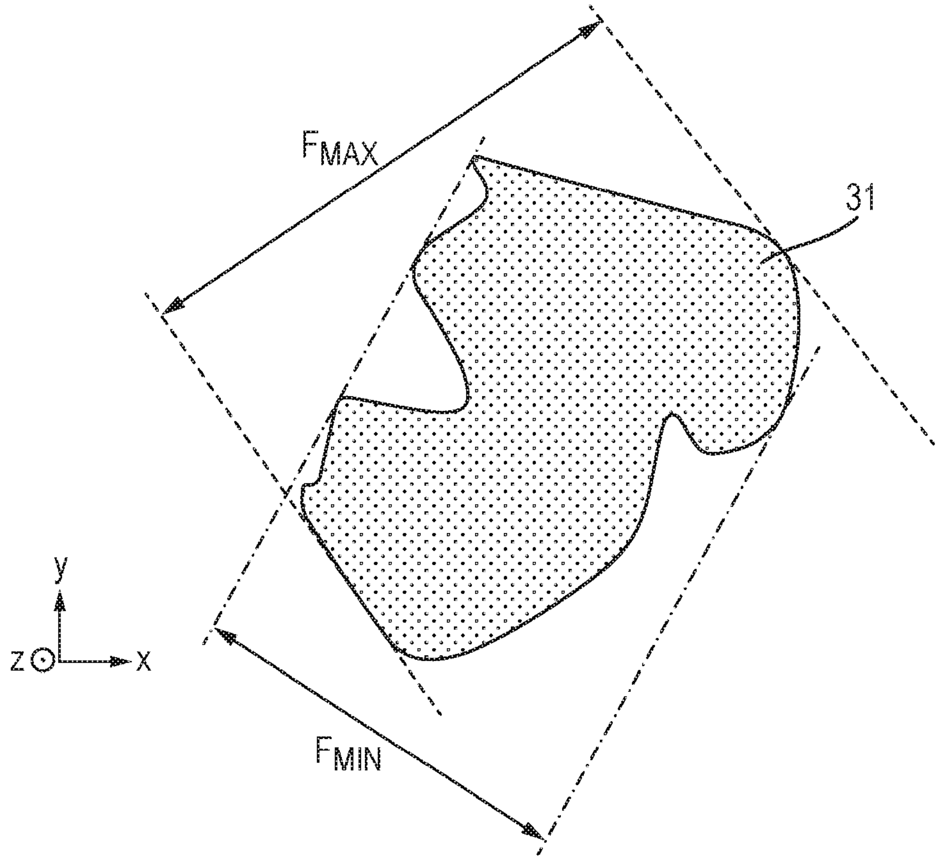

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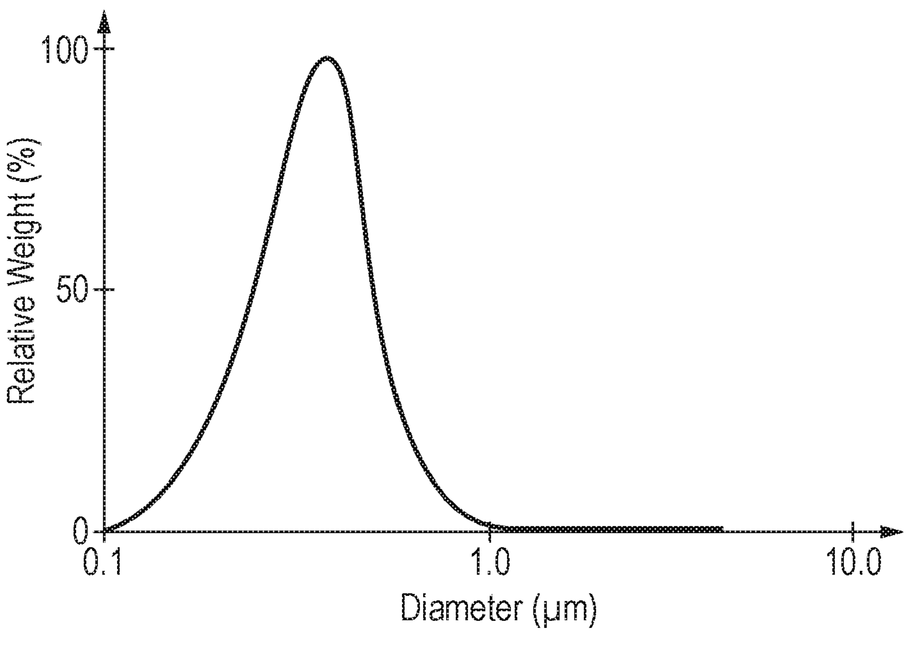
Fig. 42



SECURITY DEVICES AND METHODS OF MANUFACTURE THEREOF

CROSS-REFERENCE TO RELATED APPLICATIONS

The entire content of each of the six international patent applications filed on 10 September 2021 in the name of De La Rue International Limited and claiming priority from the following British patent applications (each filed on 11 September 2020) is hereby incorporated by reference: GB2014325.1, GB2014326.9, GB2014327.7, GB2014328.5, GB2014329.3, GB2014330.1 and GB2014331.9.

FIELD OF THE INVENTION

This invention relates to security devices such as may be used as a mark of authenticity associated with an object of value, such as a security document including banknotes, passports, certificates, licences and the like. Methods for manufacturing security devices are also disclosed.

BACKGROUND TO THE INVENTION

Objects of value, and particularly documents of value such as banknotes, cheques, passports, identification documents, certificates and licences, are frequently the target of counterfeiters and persons wishing to make fraudulent copies thereof and/or changes to any data contained therein. Typically such objects are provided with a number of visible security devices for checking the authenticity of the object. Examples include features based on one or more patterns such as microtext, fine line patterns, latent images, venetian blind devices, lenticular devices, moiré interference devices and moiré magnification devices, each of which generates a secure visual effect. Other known security devices include holograms, watermarks, embossings, perforations and the use of colour-shifting or luminescent / fluorescent inks. Common to all such devices is that the visual effect exhibited by the device is extremely difficult, or impossible, to copy using available reproduction techniques such as photocopying. Security devices exhibiting non-visible effects such as magnetic materials may also be employed.

One class of security device which is widely used on banknotes and other documents is the intaglio print. For instance, many banknotes in circulation carry an image, such as a portrait or an architectural drawing, applied by intaglio printing. Typically all or part of the image is formed of an array of image elements, such as fine lines or dots, which can be individually discerned under close inspection and/or magnification. The intaglio printing technique not only ensures high resolution and accurate reproduction of the image (which prevents the production of passable counterfeit by readily available commercial printing techniques), but can also be used to impart tactility to the image. This significantly increases the security level, since would-be counterfeiters may have access to highly accurate printing systems which can reproduce the visual appearance of an intaglio print, but not its three-dimensional quality and hence its haptics (feel). On the other hand, due to the nature of intaglio printing, it is difficult to produce images of more than one colour, at least in a fully controllable manner. In addition, the tactility is limited to the amount of ink that can be transferred to the substrate and the amount of thermal/pressure deformation that substrate can endure/retain. Polymer banknotes have less thermal stability and cannot be embossed as much as paper, resulting in a lower intaglio profile.

Separately, in other classes of security device, it is known that casting of curable materials (e.g. UV resins) can produce highly tactile effects. However, due to the nature of casting a single resin, the resulting feature will be is either colourless or of a single colour. For increased security it would be better to have multicolour tactility, or other detectable variations between different parts of the feature.

SUMMARY OF THE INVENTION

In accordance with the present invention, a security device is provided, comprising:

a surface relief structure formed of a cured material, the cured material comprising a binder and dispersed therein at least a first pigment having a first detection characteristic, the surface relief structure defining a plurality of protrusions which vary in height and/or width across the surface relief structure and a base layer integral with and linking the bases of the protrusions, wherein the surface relief structure is configured such that part(s) thereof have dimensions sufficient to accommodate a first concentration of the first pigment and other part(s) have dimensions too small to accommodate the first concentration of the first pigment, and preferably too small to accommodate substantially any of the first pigment, whereby the detection characteristics of the cured material vary across the surface relief structure in accordance with the dimensions thereof.

Also provided is a method of manufacturing a security device, comprising:

providing a casting tool having a relief structure defined in a surface thereof;

applying a curable material to a substrate or to the relief structure of the casting tool;

bringing the substrate and the casting tool together, to thereby form (shape) the curable material in accordance with the relief structure and curing the curable material such that a surface relief structure formed of the cured material is retained on the substrate;

wherein the curable material comprises a binder and homogenously dispersed therein at least a first pigment having a first detection characteristic; and

the forming of the curable material causes the first pigment to become non-homogenously dispersed in the cured material whereby the detection characteristics of the cured material vary across the surface relief structure in accordance with the dimensions thereof.

Embodiments of the present invention therefore envisage the use of a casting resin that has at least one pigment in it with a size which will enable it to fit in some parts of the cast structure but not others. The curable material (e.g. resin) is uniform/homogeneous when applied to the substrate or casting tool (e.g. by printing) and then the structure of the embossing controls the final placement of the pigment within the cured material. The first pigment will have a first detection characteristic (and optionally other detection characteristics also) which may for instance be an optical detection characteristic such as a visible colour – other examples will be given below. Since the concentration of the first pigment accommodated by the surface relief structure is different in different parts of the surface relief structure (i.e. the first pigment is non-homogeneously dispersed in the cured material across the surface relief structure), so is the apparent colour (or other detection characteristic) of those respective parts. The respective parts will typically be laterally offset from one another and non-overlapping but they may be intermingled with one another on a small scale, e.g. interlaced.

In particularly preferred examples, some parts of the surface relief structure will not be able to accommodate any of the first pigment (since its average size and/or shape does not fit within the dimensions of those parts). If, for instance, the curable material does not comprise any other pigments, then these parts of the surface relief structure will then exhibit only the properties of the binder itself (which may for instance be colourless). Other parts of the surface relief structure will, meanwhile, be able to accommodate the first pigment and hence will exhibit its properties (in combination with those of the binder). In this way the surface relief structure varies in the properties exhibited by the cured material forming different parts thereof, despite having been formed from a single curable material. Thus, security devices which are multi-coloured or otherwise vary in their detection properties can be formed in a precise, controllable manner.

As noted above, the curable material could comprise only the first pigment (or a mixture of first pigments of substantially the same size and shape, which will have the same placement in the final structure – this could be needed to achieve a particular mixed colour, for instance). However, in particularly preferred embodiments, the curable/cured material further comprises a second pigment having a second detection characteristic, different from the first, wherein the first and second pigments have different average sizes and/or shapes from one another, the surface relief structure preferably being further configured such that part(s) thereof have dimensions sufficient to accommodate a second concentration of the second pigment and other part(s) have dimensions too small to accommodate the second concentration of the second pigment, most preferably being too small to accommodate substantially any of the second pigment.

Thus, in an enhancement, different pigments (e.g. of different colours) could be dispersed homogeneously in the resin – the different pigments have different sizes/dimensions/shapes that when cast fill the embossing casting structures in different areas depending on specific structures/placement. For instance, if the first pigment has a greater average size than the second pigment, the first pigment will be excluded (or present only at a reduced concentration) in certain parts of the structure which are too small to accommodate it, whereas the second pigment may be present throughout the structure. In this case, some parts of the structure would exhibit the properties of the second pigment only (in combination with those of the binder) whereas other parts would exhibit a mixture of the properties of the first and second pigments (in combination with those of the binder). Hence, for instance, two different visible colours can be displayed by different parts of the structure. Considerations for scenarios in which either of the pigments has a particle shape which deviates significantly from spherical are discussed below.

Optionally, the structure may be further configured to control the placement of the second pigment also. For instance, further parts of the structure may be configured so that the second pigment cannot be accommodated. In this case it would be possible for the structure to exhibit at least three detectably different parts – those with the first and second pigments present; those with only the second pigment present; and those with neither pigment present.

It will be appreciated that the curable material could be equipped with any number of further pigments having different detection characteristics and different average sizes and/or shapes. The greater the number of different pigments included, the more complex the security devices that can be achieved and hence the greater the security level. Hence, in general terms, preferably two or more pigments with different detection characteristics (e.g. colours) and different dimensions or shapes are provided.

The surface relief structure can be of any form as required to form the desired security device. In preferred cases, the structure may include one or more protrusions (i.e. portions of greater height than their surroundings), corresponding to recesses in the casting tool. For instance the protrusions could be arranged to form raised elements of an image, a tactile structure, optical elements such as lenses, mirrors or prisms, or any combination thereof. (Typically, if optical elements, are formed the design may be such as to exclude certain pigments from the protrusions forming the optical elements since the pigments may scatter light to such a degree that the cured material would not be sufficiently clear to achieve the desired optical effect). Preferably, the surface relief structure defines a plurality of protrusions which vary in height, width and/or length across the surface relief structure. “Height” means the dimension of the protrusion along the direction normal to the substrate (including any base layer present – i.e. the local thickness of the cured material), while “width” means its smallest dimension in the plane of the substrate and “length” means its longest dimension in the plane of the substrate. This variation may be between protrusions (i.e. one protrusion has a different height, width and/or length from another) or individual protrusions can exhibit varying height, width and/or length if desired. Both types of variation can be employed together in some cases.

Generally it is the height and width which are used to control how much of a specific pigment can be accommodated within a certain protrusion, if any (since the length will be definition be greater than the width). For instance, if a protrusion has a width at its base (or, correspondingly, a recess on the casting tool has a width at its open end) which is smaller than the average size of the pigment, then very little if any of that pigment will be able to enter the protrusion. Similarly, if the protrusion has a height (or, correspondingly, a recess on the casting tool has a depth) which is less than the average size of the pigment, then very little if any of that pigment can be accommodated in the protrusion. However, the height and/or width of a protrusion may vary along the protrusion’s length in which case the amount of pigment that can be accommodated in the protrusion may also vary along its length such that the detection properties are different between one end of the protrusion and the other.

That said, beyond a certain height and/or width (large enough for the pigment to be accommodated comfortably), further increases in a protrusion’s dimensions will not affect the concentration of the pigment contained therein since it is already at its maximum. Nonetheless, under these conditions, varying the height of the protrusions will still result in a variation of the detection characteristics, due to the variation in the absolute amount of the pigment which the protrusion contains (i.e. the amount of pigment stacked on top of itself). In preferred embodiments this is made use of by arranging for at least some of the plurality of protrusions to vary in height, higher protrusions exhibiting a greater intensity (if any – it can be zero) of the first and/or second detection characteristic, preferably a greater optical density, than lower protrusions of the same width as a result of their containing a greater volume of the first and/or second pigments than the lower protrusions. Thus, the depth of the casting can control the colour density of final structure, while the width can remain constant.

Preferably, the plurality of protrusions vary in height and/or width, the concentration of the first pigment and/or the second pigment in each protrusion (if any – the concentration could be zero), and hence the detection characteristics of the cured material, depending on the height and/or width of the protrusion. As explained above, the variation could be within an individual protrusion and/or from one protrusion to another. In some preferred embodiments, the height, width and/or length will be constant across the individual protrusion. As noted above, assuming the protrusions have at least a minimum height which can accommodate the pigment(s), then the width of casting can be used to control colour hue – it controls the ratio of pigment mixing.

Some preferred implementations are where:

- the plurality of protrusions include one or more protrusions in which the concentration of the first pigment, and of the second pigment if provided, is substantially zero;
- the plurality of protrusions include one or more protrusions in which the first pigment is present and the concentration of the second pigment, if provided, is substantially zero (or vice versa); and/or
- the plurality of protrusions include one or more protrusions in which the first pigment and the second pigment are present.

It will be appreciated that any combination of the above arrangements could be deployed in order to arrive at a security device of the desired configuration. While the above implementations are described in terms of the finished protrusions, it will be understood that these are formed by providing corresponding recesses in the casting tool. The same applies to any preferred configurations of protrusions described below.

In a particularly preferred example, the plurality of protrusions include a first set of one or more protrusions each of which has a height and a width which are each greater than or equal to a first predetermined threshold, the first predetermined threshold being approximately equal to the average size of the first pigment, wherein the first predetermined threshold is preferably in the range 5 µm to 10 µm, still preferably about 5 µm. Here, “approximately equal to” encompasses up to 10% over the average size. Hence, the first set of protrusions will be able to accommodate the first pigment.

In another preferred example, the plurality of protrusions may include a second set of one or more protrusions each of which has a height and/or a width which is less than a first predetermined threshold, the first predetermined threshold being approximately equal to the average size of the first pigment, wherein the first predetermined threshold is preferably in the range 5 µm to 10 µm, still preferably about 5 µm. Hence the second set of protrusions will not accommodate the first pigment. If the first and second sets of protrusions are both provided, the two sets will therefore have different detection characteristics from one another (e.g. colour).

Where the curable/cured material further comprises a second pigment, preferably the height and width of each of the second set of one or more protrusions are each greater than or equal to a second predetermined threshold, the second predetermined threshold being approximately equal to the average size of the second pigment, wherein the second predetermined threshold is preferably in the range 0.1 µm to 4 µm, still preferably about 1 µm. This set of protrusions will therefore be able to accommodate the second pigment but not the first pigment, assuming that the second pigment has a smaller average size than the first pigment. In this scenario, the first set of protrusions (described above) will accommodate both the first and second pigments. It is also possible to provide a third set of one or more protrusions which are sized so as to be unable to accommodate the first and second pigments.

In each of the above situations, if the first or second pigment is non-spherical, it is the typically the average Feret minimum diameter (see below) which is used as the average size of the respective pigment, since if this is sufficiently small the pigment may still be accommodated by the protrusion in some orientations.

The protrusions can be configured at various different scales. For instance, if the protrusions are large enough to be individually visible to the naked eye, the result will be relatively low resolution but this may be desirable, e.g. to display sharp contrasts between different coloured protrusions. Alternatively, the protrusions could work in combination with one another at a smaller scale so as to collectively provide an area of the device with a certain mix of properties. In a specific preferred example, within a first region of the device, the plurality of protrusions are arranged according to a first repeating pattern, whereby the first region exhibits a first substantially uniform set of detection characteristics, and preferably within a second region of the device, the plurality of protrusions are arranged according to a second repeating pattern, different from the first, whereby the second region exhibits a second substantially uniform set of detection characteristics, different from that of the first region. The patterns may be periodic or aperiodic patterns. Preferably the patterns are arranged on a scale so small that the individual protrusions are not distinguishable to the naked eye. Changes between the displayed properties may be discrete (e.g. step-wise) or continuous (gradual). The latter can be achieved for instance by providing three or more such regions and arranging the detection characteristics to vary successively from one to the next.

Similarly, in some embodiments it is advantageous to provide one or more groups of protrusions which have lateral dimensions such that within one group the individual protrusions cannot be distinguished by the naked eye. In this way, the group of protrusions appears to the observer as a single element (e.g. an image element), but due to its sub-structure, the pigment(s) it contains can be controlled using the same principles as above. For instance, in some cases the security device may be configured to exhibit an image made up of image elements which are individually resolvable by the human eye, at least under low magnification – e.g. 50 µm or more in line width. The or each image element may be formed of a group of protrusions of smaller width as necessary to control pigment access to the protrusions. The protrusions forming the group are spaced from one another by narrow recesses which block the entry of certain pigment(s). The spacing between protrusions forming the group will be less (preferably substantially less, e.g. 10 times less) than the spacing between image elements of the image.

As mentioned above, individual protrusions could have a height and width which is constant – i.e. of substantially square or rectangular cross-section. In this case the detection characteristics of the cured material will also be substantially constant across the protrusion. However, it is also possible to provide individual protrusions with varying detection characteristics. In a preferred embodiment, the security device comprises at least one protrusion (which may form part of the plurality already mentioned) either: having a width and/or length which varies along the height of the protrusion, whereby the concentration of the first pigment and/or the second pigment varies along the height of the protrusion; and/or having a height which varies along the width and/or length of the protrusion, whereby the concentration of the first pigment and/or the second pigment varies along the width and/or length of the protrusion. For instance, structures are envisaged where the base is wide (accommodating multiple pigments), but the top is thin (accommodating only small pigments), such as protrusions with triangular, curved, sloped, domed or arcuate cross-sections. The height and/or width could additionally or alternatively vary along the length of a protrusion. All of these options allow for control of the colour (or other detection characteristic) within one protrusion.

In all of the above cases, it is preferable that the surface relief structure includes a base layer, the base layer having dimensions such that the concentration of the first pigment and/or the second pigment is substantially zero in the base layer, optionally wherein the base layer has dimensions such that the first pigment is present in the base layer and the concentration of the second pigment, if provided, is substantially zero in the base layer, or vice versa. By “substantially zero” concentration, we mean a concentration too low for the properties of the pigment to be detectable, e.g. by the naked eye. The pigment in question may or may not be completely absent from the base layer, since in practice there will be a range of particle sizes for any pigment and hence it is likely that some very small particles may be present in a very low concentration. However preferably the concentration is so low as not to be detectable. Typically the base layer will be integral with, and link the bases of, any protrusions present. Due to the dimensions of the base layer not accommodating at least one of the first and/or second pigments, there will typically be a contrast between the detection characteristics of the base layer and of some or all of the protrusions. For instance, the height of the base layer may be 1 μm or less, preferably 0.5 μm or less.

To form such a base layer, the casting tool and the substrate are brought together in a manner resulting in a base layer of the surface relief structure, the base layer having dimensions such that the concentration of the first pigment and/or the second pigment is substantially zero in the base layer, optionally wherein the base layer has dimensions such that the first pigment is present in the base layer and the concentration of the second pigment, if provided, is substantially zero in the base layer, or vice versa. This could be achieved by providing the casting tool with a cavity corresponding to the desired base layer, or simply by controlling the pressure between the casting tool and the substrate (or via a combination of the two approaches). It will be understood that there is typically no wiping/doctoring step removing curable material from between the recesses in the cast-cure process. In preferred examples, a ratio of the height of at least one protrusion to the height of the base layer joining the raised element to an adjacent protrusion is at least 10, preferably at least 20, and furthermore is preferably no greater than 400, preferably no greater than 200. In some embodiments, a ratio of the height of each protrusion to the height of the base layer is at least 10, preferably at least 20, and furthermore is preferably no greater than 400, preferably no greater than 200. This is especially the case where the protrusions are configured to form image elements, particularly of multi-tonal images.

The surface relief structure could be configured to form various different types of security device. In a first preferred example, the surface relief structure comprises a plurality of protrusions which vary in height and/or width across the surface relief structure, the plurality of protrusions defining a plurality of raised elements spaced from one another, the raised elements corresponding to elements of an image, whereby the size, spacing, shape, detection characteristic and/or intensity of the elements varies across the surface relief structure so as to exhibit a multi-tonal version of the image. For example, the structure may exhibit a macroscale screened image in which the elements are arranged on a regular or irregular grid. The raised elements could be line elements (straight or otherwise), dot elements or have any other lateral shape. The image could be a multi-tonal portrait, landscape or botanical or architectural drawing, for instance, as are typically seen on banknotes, passports and other security documents, large enough to be viewed by the naked eye. Such images are static and typically not optically variable (unless comprising an inherently optically variable pigment).

Additionally or alternatively the surface relief structure defines a tactile structure, preferably having at least two regions of different tactility. For instance, a multitonal image of the sort mentioned above will preferably also be tactile. However, it is also possible to form the security device of abstract patterns and the like which may or may not convey a visual meaning but are detectable by touch.

In still further embodiments, the surface relief structure may define microscale alphanumeric text, or a micro-graphic. For instance, individual protrusions may have lateral shapes in the form of letters, numbers or symbols or other graphics such as logos. These may be visible only under close inspection and/or magnification.

The disclosed security device could also be provided with one or more additional components which work in conjunction with the surface relief structure to generate a further optical effect, such as an optically variable effect. For instance, the additional component could be an optical element which at least partially overlaps the surface relief structure (on the same or opposite side of the substrate) so that the surface relief structure can be viewed via (or in combination with) the optical element. Optical elements such as one or more lenses, prisms, mirrors or caustic elements could be employed.

For instance, the surface relief structure could define an image array which, when viewed in combination with a corresponding array of image selection elements, preferably focussing elements, generates an optically variable effect. An optically variable effect is one in which the appearance of the device changes with viewing angle. For instance, the image array could be a set of interleaved image slices which when combined with a suitable array of image selection elements (such as lenses) displays different images at different viewing angles. This is typically referred to as a lenticular device, some examples of which are described in US-A-4892336, WO-A-2011/051669, WO-A-2011051670, WO-A-

2012/027779 and US-B-6856462. Alternatively, the image array could comprises an array of microimages, which has a different pitch and/or orientation from the array of image selection elements, resulting in magnification of the microimages due to the moiré effect, and apparent movement of the magnified images upon changing viewing angle. This is commonly referred to as a moiré magnifier, examples of which are described in EP-A-1695121, WO-A-94/27254, WO-A-2011/107782 and WO2011/107783.

As mentioned above, the detection characteristic provided by the pigment(s) which is caused to vary across the surface relief structure by the disclosed mechanism is, in many preferred cases, visible colour. However, this is not essential and the pigment(s) may additionally or alternatively exhibit different properties which are detectable (either by a human or by a suitable sensing device), which can be caused to vary across the device using the same approach. It should be noted that the detection characteristic may or may not be exhibited under all conditions by the pigment but may require a certain stimulus, such as particular illumination conditions or temperature. In general it is preferred that the detection characteristic(s) are any of:

an optical characteristic (i.e. anything detectable in the electro-magnetic spectrum whether visible or invisible), preferably visible colour, luminescent colour and/or wavelength-specific absorption or emission properties (e.g. a UV or IR response);

a magnetic characteristic;

an electrical characteristic, preferably conductivity or anti-static; and

a tactile characteristic.

Advantageously, the first and second detection characteristics are first and second optical characteristics, the first and second pigments preferably having at least one of:

different appearances from one another under white light illumination, preferably different visible colours or different optical variability (i.e. different viewing angle dependency);

different (visible or invisible) responses to illumination by a non-visible wavelength, preferably UV radiation;

different absorption of illumination at a non-visible wavelength, preferably IR radiation;

different (visible or invisible) responses to changes in stimuli such as temperature and/or illumination.

By “appearance” it is meant what is seen by the naked human eye. This might include a visible colour, or it might be the absence of colour (i.e. colourless). The appearance may also be changed by the intensity of a colour (i.e. the optical density) and/or the degree to which the substance scatters light. “Visible colours” include all chromacities which can be seen by the naked human eye. This includes achromatic hues such as black, grey, white, silver etc., as well as chromatics such as red, blue, yellow, green, brown etc. “Different” visible colours are those which clearly present a contrast to one another that is visible to the naked human eye even without a close inspection. The difference might be in terms of the colour’s hue or tone or both.

For example, in preferred embodiments, two colours will be considered substantially the same as one another if the Euclidean distance ΔE^*_{ab} between them in CIELAB colour space (i.e. the CIE 1976 L*a*b* colour space) is less than 3, more preferably less than 2.3. The value of ΔE^*_{ab} is measured using the formula

$$\Delta E^*_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

Where ΔL^*, Δa^* and Δb^* are the distance between the two colours along the L*, a* and b* axes respectively. Conversely, if ΔE^*_{ab} is greater than or equal to 3 (or, in more preferred embodiments, greater than or equal to 2.3), the two colours will be considered different. The colour difference ΔE^*_{ab} can be measured using any commercial spectrophotometer, such as those available from Hunterlab of Reston, Virginia, USA.

In a preferred example, the first and second pigments have substantially the same appearance as one another under white light illumination, preferably substantially the same visible colour, and different appearances from one another when illuminated by a non-visible wavelength, preferably UV radiation, preferably different visible colours. The ultra-violet spectrum typically comprises wavelengths from about 200nm to about 400nm. This implementation is particularly advantageous since the device may appear to exhibit a single colour under standard lighting conditions, but two or more colours when viewed under UV (or another selected wavelength). Most preferably, the first and second pigments each exhibit a change in appearance between white light illumination and illumination by a non-visible wavelength, preferably UV radiation. That is, both pigments undergo a change in appearance between the two lighting conditions such that the two colours seen under UV are both different from the single colour seen under standard white light.

In another preferred implementation, the first and second pigments have substantially the same appearance as one another when viewed in the visible spectrum, preferably substantially the same visible colour, and different appearances from one another when viewed at a non-visible wavelength, preferably an infra-red wavelength. This can be achieved for example via the use of pigments which absorb the non-visible wavelength to differing degrees. The presence of the two different pigments will be checked using a suitable camera or other sensor which can detect the non-visible wavelength.

Different effects can be achieved via different combinations of pigment sizes and corresponding detection characteristics. In many cases it will be preferred that the average size of the first pigment is larger than the average size of the second pigment, and optionally the first pigment exhibits a detection characteristic having a greater intensity per unit volume than that of the second pigment, preferably a greater colour density per unit volume. For instance, the larger pigment may be of a darker visible colour than the smaller pigment. This tends to be beneficial since the smaller pigment will often be present throughout the cast structure, or at least in the same parts that can accommodate the larger pigment, so by providing it with a lesser intensity detection characteristic, it will not overwhelm that of the larger pigment where both are present. Thus, pigment size is preferably decided by colour density – define lighter colours as smaller pigments, so the colour of wider casted structures (that have multiple pigments) is dominated by the denser/darker larger pigments. However, in some circumstances, the opposite arrangement may be preferable.

In some preferred examples, the first pigment and/or the second pigment, if provided, may comprise any of:

a pigment with a body colour which is visible to the naked eye under white light illumination;

a pigment which visibly or invisibly luminesces in response to a non-visible wavelength, preferably UV illumination;

a pigment which absorbs a non-visible wavelength, preferably IR illumination (e.g. an IR up-converter);

a photochromic or thermochromic pigment;

a metallic pigment;

an optically variable pigment (optionally magnetic), preferably comprising a thin-film interference pigment, a pearlescent pigment or a liquid crystal pigment;

a plasmonic pigment, preferably exhibiting a visible colour;

an electrically conductive pigment, preferably graphite, metal, metal alloy or carbon black;

an anti-static pigment (typically these are not ohmic conductors, but do transmit some static charge);

an opacifying pigment which is preferably white, off-white or grey under white light illumination, the opacifying pigment most preferably comprising titanium dioxide;

a magnetic or magnetisable pigment; and

a tactile pigment such as silica or another hard substance.

Of course, each pigment could also have any combination of the above properties.

The use of a pigment which is an opacifying pigment is a special case, in which the surface relief structure could be configured to form an opacifying layer of a document substrate. This provides significant benefits since, if desired, multiple features of the document can be produced in a single processing step. For instance, in preferred embodiments where the first pigment is an opacifying pigment and the surface relief structure is configured to form an opacifying layer of a security document, the surface relief structure may include any of:

- a part in which the cured material has substantially zero concentration of the first pigment (e.g. to thereby form a window or half-window region of the document – this would only be a sub-part of the structure);
- a part in which the cured material has a non-zero concentration of the first pigment and the structure has a first height (e.g. to thereby form a “base level” of opacity which might cover a large proportion of the document surface area); and
- a part in which the cured material has a non-zero concentration of the first pigment and the structure has a second height greater than the first height (e.g. forming one or more portions of increased opacity which may be used to form a pseudo-watermark type effect).

Of course, any number of different heights of the structure could be used, in order to obtain different opacity levels in different parts of the device. Part(s) of the structure having non-zero concentrations of the opacifying pigments can also be provided locally, within a window region of the document, to form an image or other design visible against the transparent/translucent background of the window, such as a cameo portrait.

Yet more complex features can be achieved where the cured material contains another pigment, with different detection properties from the opacifying pigment, e.g. a contrasting visible colour and/or fluorescence. The opacifying pigment could be the larger or smaller of the pigments. Preferably the cured material further comprises a second pigment of larger average size than the first pigment, the first and second pigment having different detection properties, and the surface relief structure further includes a part in which both the first and second pigments are present, preferably in the form of one or more protrusions. For instance, this could be used to form an image (e.g. mimicking an intaglio print, or a serial number) having the detection properties of the second pigment either against opacified surroundings or against transparent/translucent surroundings depending on the content of the base layer locally.

Hence in an example the surface relief structure can, if desired, be configured to perform a dual function – namely, to provide both an opacifying layer (as is typically found on documents with a polymer substrate) and a feature superimposed thereon. For instance, the opacifying pigment could be the smaller of the two pigments, provided alongside a larger pigment with a strong contrasting colour. The surface relief structure could be configured to include a thin base layer which extends over a substantial part of the substrate (possibly all-over, optionally excluding any window regions), of such dimensions that only the opacifying pigment can be accommodated therein and not the larger pigment. The structure may then also include one or more protrusions of sufficient dimension to accommodate the larger pigment also, arranged according to a desired design such as a screened image. The larger pigment will dominate the colour of the protrusions which will then appear as a contrasting design against a background formed by the opacifying base layer.

Alternatively or in addition, the opacifying pigment could be sized to fit in the protrusions but not in the base layer (at least in a region of the surface relief structure). For instance, this could be used to provide a base layer with substantially zero concentration of the opacifying pigment (so that it is preferably clear and colourless), carrying opacified protrusions, e.g. arranged to form a design. This could be used to mimic gravure printed designs in or around window regions of polymer documents. This implementation may or may not make use of a further coloured pigment.

Area(s) of the surface relief structure which exclude the opacifying pigment in this way can also be used to expose underlying features, such as a security element which may be provided in or on the document substrate, e.g. a security print or an optically variable device such as a diffractive element or a micro-optic device. The cured material can in this case act as a protective layer over the security element, which is visible (or otherwise detectable) through the part of the surface relief structure with substantially zero concentration of the opacifying pigment.

In preferred implementations, an opacifying base layer or protrusion of the sort just mentioned would have a brightness L* in CIE L*a*b* colour space of at least 70, preferably at least 80 and more preferably at least 90.

The size of the various pigments may be selected not only based on the desired outcome of the above casting process (and hence on the dimensions of the structure to be cast), but also on the technique by which the curable material is to be applied and/or taking into account the need for the pigments to be able to freely move in the uncured binder. It will be appreciated that each pigment will comprise particles having a range of sizes according to a size distribution curve. In preferred examples, the first pigment and/or the second pigment, if provided, has an average size between 0.001 μm and 500 μm, preferably between 0.05

µm and 150 µm, more preferably between 0.1 µm and 50 µm, most preferably between 1 µm and 10 µm. Usually the median (D50) value of a distribution is taken to be the average value of that distribution. Typically the curable material will be applied to the substrate or casting tool via a printing technique. Small pigment sizes will be suitable for application by many techniques, including inkjet printing and gravure printing, whereas larger pigment sizes may require specialised techniques such as screen printing.

The pigments could have various shapes but preferably the first pigment and/or the second pigment, if provided, has a non-platelet average shape, the largest dimension (e.g. measured as F_{MAX}) of an individual particle preferably being no greater than 150% of the smallest dimension (e.g. measured as F_{MIN}) of the same individual particle, on average. Platelet (or flake-like) pigment shapes are less advantageous when used with the presently disclosed technique since their out-of-plane dimension is much smaller than their in-plane dimensions, making it difficult to accurately control their placement. Pigments having shapes which are closer to spheroids are preferred since their ability to fit into a certain space will not depend significantly on their orientation.

Where the first and second pigments have particle shapes which are substantially spheroidal, their “size” corresponds to any diameter of the particle (the diameters should all be approximately the same for any one particle irrespective of direction across the particle), and hence the “average size” of a pigment can be taken to be the average of the range of diameters exhibited by the plurality of particles making up that pigment. However, where one or both of the first and second pigments have a particle shape which deviates significantly from spherical, a more complex analysis is required. In this case the first and second pigments will be considered to have different average sizes and/or shapes from one another if at least one of the average Feret maximum diameter (F_{MAX}) and the average Feret minimum diameter (F_{MIN}) differs between the two pigments. Preferably, the average Feret minimum diameter (F_{MIN}) will be different between the two pigments since in many cases it is this which can determine whether a particle will fit within a certain space or not. In particularly preferred cases, the pigment having the largest average Feret maximum diameter (F^1_{MAX}) has an average Feret minimum diameter (F^1_{MIN}) which is larger than the other pigment's average Feret maximum diameter (F^2_{MAX}). This removes any overlap between the dimensions of the two pigments' average particle dimensions and hence improves the ability of the process to separate the different pigments from one another in certain part(s) of the relief structure. Feret diameters are standard parameters frequently referenced in particle shape analysis and will be explained hereinafter.

In selecting the formulation of the curable material it may also be important to consider the end volume of each part of the structure to be cast, to ensure that there is sufficient space to accommodate the amount of each pigment which will be present. If the concentration of the first pigment in the homogenous, curable material is too high, then it may not be possible for all of the first pigment to fit into the parts of the structure designed to receive it, which will result in a poor quality end product. Likewise, if the concentration is too low, there may be insufficient pigment to fill the parts intended to receive it, again leading to an undesirable result. The correct concentration range can either be determined via appropriate calculations of the structure volume and space occupied by the pigments, or through testing.

The binder in which the pigment(s) are dispersed could be of any suitable type including an appropriate curing agent, which can be activated by corresponding curing energy (e.g. radiation such as UV) to cause chemical hardening of the material (typically cross-linking). The binder will advantageously be transparent or at least translucent, preferably optically clear, i.e. with very low optical scattering. In many preferred embodiments, the binder will be colourless to the naked eye under white light illumination so as not to affect any colour exhibited by the pigment(s). However, in other cases the binder may comprise a visibly coloured tint, preferably in the form of a dye (so as not to cause scattering). Advantageously any such tint would visibly contrast with the visible appearance of the first pigment, e.g. being of a different visible colour.

It is also important to consider the viscosity/rheology of the curable material, to allow for the free movement of the pigment(s) dispersed therein during casting. In preferred cases, at the point of bringing the substrate and the casting tool together, the curable material has a room temperature viscosity in the range 0.1 to mPa.s to 3000 mPa.s, preferably 0.1mPa.s to 1000 mPa.s, more preferably 1 mPa.s to 500 mPa.s. Desirably the viscosity is low, so as to better allow for the movement of pigment.

In many preferred implementations, the at least semi-transparent curable material is applied to the relief structure in the casting tool surface so as to substantially completely fill recesses of the relief structure and form a layer of the at least semi-transparent curable material over elevations of the relief structure. Substantially the whole body of curable material (including the parts inside the recesses and the layer over the elevations) will be cured and transferred onto the substrate, resulting in a single integral contiguous body of cured material (albeit of varying pigment concentration). In such implementations there is no wiping or doctoring step which would otherwise remove the curable material from the elevations.

However, in alternative examples, the curable material may be applied only to recesses of the relief structure of the casting tool, preferably through the use of a removal means such as a doctor blade, and the method further comprises, subsequent to applying the curable to the relief structure and before bringing the substrate and casting tool together, applying a further layer of the or another curable material to substantially the whole surface of the casting tool so as to improve the retention of the cured material on the substrate. In such examples, the further layer acts to improve the adhesion of the curable material – which are located only within the recesses of the casting tool relief structure – to the substrate. The dimensions of the recesses in the casting tool relief structure still determine whether any of the pigment(s) in the curable material can access the each recess and hence the detection properties of the resulting protrusions. As the further layer is applied to substantially the whole surface of the casting tool (i.e. over the filled recesses of the relief structure in the surface of the tool and the elevations between them), the resulting surface relief structure comprises an integral base layer as described above. The curable material forming the base layer could be the same as that used to fill the recesses or may be different if another detection property is to be exhibited by the base layer.

The present invention further provides a security article comprising a security device as described above, the security article preferably being a security thread, strip, insert, foil or patch.

Also provided is a security document comprising a security device or a security article, each as described above, the security document preferably comprising a banknote, a passport, an identification document, a driver's licence, a bank card, a cheque, a certificate, a stamp or a visa. Thus the security device can be formed directly on the security document, or on a security article which is later applied to or incorporated into such a document.

As mentioned above, the use of the disclosed technique to form an opacifying layer of a security document is particularly advantageous. Hence in preferred embodiments, the security document comprises a document substrate and the first pigment of the security device is an opacifying pigment, the surface relief structure is configured to form an opacifying layer of a security document. Preferably, the surface relief structure may include any of:

- a part in which the cured material has substantially zero concentration of the first pigment (e.g. to thereby form a window or half-window region of the document – this would only be a sub-part of the structure);

- a part in which the cured material has a non-zero concentration of the first pigment and the structure has a first height (e.g. to thereby form a “base level” of opacity which might cover a large proportion of the document surface area); and
- a part in which the cured material has a non-zero concentration of the first pigment and the structure has a second height greater than the first height (e.g. forming one or more portions of increased opacity which may be used to form a pseudo-watermark type effect).

In particularly preferred cases, the security document further comprises a security element (such as a printed feature or an optically variable device) disposed at the first surface of the document substrate, the security element preferably being partially or fully covered by the cured material of the security device. The surface relief structure can thus act as a protective layer for the security element. Most preferably, the security element is partially or fully covered by a part of the surface relief structure in which the cured material has substantially zero concentration of the first pigment, the part preferably being substantially transparent. In this way, the security element is not concealed by the opacifying pigment.

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BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1(a) and 1(b) show a comparative example of a security document in plan view and cross-section respectively, Figure 1(c) showing an enlarged detail of the cross-section of Figure 1(b);

Figure 2(a) schematically depicts exemplary apparatus suitable for forming a surface relief structure in embodiments of the invention, Figure 2(b) illustrating the formation of the surface relief structure in perspective view;

Figures 3(a) and 3(b) schematically show two manufacturing steps in an exemplary method of manufacturing a security device in accordance with embodiments of the invention;

Figure 4 shows a security device in accordance with an embodiment of the invention at different stages of manufacture: Figure 4(a) shows the curable material before casting; Figure 4(b) shows a cross-section through the security device after curing; and Figure 4(c) shows a plan view of the security device;

Figure 5 shows a security document having a security device in accordance with an embodiment of the invention: Figure 5(a) shows the security document in plan view and Figure 5(b) shows the security document in cross-section along the line Q-Q';

Figure 6 schematically shows a security device in accordance with an embodiment of the invention in cross section;

Figure 7 shows a security document having a security device in accordance with an embodiment of the invention: Figure 7(a) shows the security document in plan view and Figure 7(b) shows the security document in cross-section along the line Q-Q';

Figure 8 shows a security device in accordance with an embodiment of the invention at different stages of manufacture: Figure 8(a) shows the curable material before casting; Figure 8(b) shows a cross-section through the security device after curing; and Figure 8(c) shows a plan view of the security device;

Figure 9 shows a security device in accordance with an embodiment of the invention at different stages of manufacture: Figure 9(a) shows the curable material before casting; Figure 9(b) shows a cross-section through the security device after curing; and Figure 9(c) shows a plan view of the security device;

Figure 10 shows a security device in accordance with an embodiment of the invention at different stages of manufacture and a security document it may be provided on: Figure 10(a) shows the curable material before casting; Figure 10(b) shows a cross-section through the security device after curing; Figure 10(c) shows the security document in plan view and Figure 10(d) shows the security document in cross-section along the line Q-Q';

Figures 11(a) and 11(b) schematically show two manufacturing steps in an exemplary method of manufacturing a security device in accordance with embodiments of the invention;

Figure 12 shows a security device in accordance with an embodiment of the invention at different stages of manufacture: Figure 12(a) shows the curable material before casting; Figure 12(b) shows a cross-section through the security device after curing; and Figure 12(c) shows a plan view of the security device;

Figure 13 shows a security device in accordance with an embodiment of the invention at different stages of manufacture: Figure 13(a) shows the curable material before casting; Figure 13(b) shows a cross-section through the security device after curing; and Figure 13(c) shows a plan view of the security device;

Figure 14 shows a security device in accordance with an embodiment of the invention at different stages of manufacture and a security document it may be provided on: Figure 14(a) shows the curable material before casting; Figure 14(b) shows a cross-section through the security device after curing; Figure 14(c) shows the security document in plan view and Figure 14(d) shows the security document in cross-section along the line Q-Q';

Figure 15 shows a security device in accordance with an embodiment of the invention at different stages of manufacture: Figure 15(a) shows the curable material before casting; Figure 15(b) shows a cross-section through the security device after curing; and Figure 15(c) shows a plan view of the security device;

Figure 16 shows a security device in accordance with an embodiment of the invention at different stages of manufacture: Figure 16(a) shows the curable material before casting; Figure 16(b) shows a cross-section through the security device after curing; and Figure 16(c) shows a plan view of the security device;

Figure 17 shows a security device in accordance with an embodiment of the invention at different stages of manufacture: Figure 17(a) shows the curable material before casting; Figure 17(b) shows a cross-section through the security device after curing; and Figure 17(c) shows a plan view of the security device;

Figure 18 shows a security device in accordance with an embodiment of the invention at different stages of manufacture: Figure 18(a) shows the curable material before casting; Figure 18(b) shows a cross-section through the security device after curing; and Figure 18(c) shows a plan view of the security device;

Figure 19 shows a security device in accordance with an embodiment of the invention at different stages of manufacture and a security document it may be provided on: Figure 19(a) shows the curable material before casting; Figure 19(b) shows a cross-section through the security device after curing; Figure 19(c) shows the security document in plan view and Figure 19(d) shows the security document in cross-section along the line Q-Q';

Figure 20 shows a security device in accordance with an embodiment of the invention at different stages of manufacture: Figure 20(a) shows the curable material before casting; Figure 20(b) shows a cross-section through the security device after curing; and Figure 20(c) shows a plan view of the security device;

Figure 21 shows a security device in accordance with an embodiment of the invention, in cross-section;

Figure 22 shows a security device in accordance with an embodiment of the invention and a security document it may be provided on, with variations: Figure 22(a) shows the security document in plan view; Figure 22(b) shows an enlarged part of the security device; Figure 22(c) shows a cross-section through one of the image elements in a first variant; and Figure 22(d) shows a cross-section through one of the image elements in a second variant;

Figure 23 shows a security device in accordance with an embodiment of the invention at different stages of manufacture: Figure 23(a) shows the curable material before casting; Figure 23(b) shows a cross-section through the security device after curing; and Figure 23(c) shows a plan view of the security device;

Figure 24 shows a security device in accordance with an embodiment of the invention at different stages of manufacture: Figure 24(a) shows the curable material before casting; Figure 24(b) shows a cross-section through the security device after curing; and Figure 24(c) shows a plan view of the security device;

Figure 25 shows a security document having a security device in accordance with an embodiment of the invention at different stages of manufacture: Figure 25(a) shows the curable material before casting; Figure 25(b) shows a cross-section through the security device after curing; and Figure 25(c) shows a plan view of the security device;

Figure 26 shows a security device in accordance with an embodiment of the invention at different stages of manufacture: Figure 26(a) shows the curable material before casting; Figure 26(b) shows a cross-section through the security device after curing; and Figure 26(c) shows a plan view of the security device;

Figure 27 shows a security document having a security device in accordance with an embodiment of the invention at different stages of manufacture: Figure 27(a) shows the curable material before casting; Figure 27(b) shows a first cross-section through the security document after curing; Figure 27(c) shows a plan view of the security document; and Figure 27(d) shows a second cross-section through the security document after curing;

Figure 28 shows a security device in accordance with an embodiment of the invention at different stages of manufacture and a security document it may be provided on: Figure 28(a) shows the curable material before casting; Figure 28(b) shows a cross-section through the security device after curing; Figure 28(c) shows the security document in plan view and Figure 28(d) shows the security document in cross-section along the line Q-Q’;

Figure 29 shows a security device in accordance with an embodiment of the invention at different stages of manufacture: Figure 29(a) shows the curable material before casting; and Figure 29(b) shows a cross-section through the security device after curing;

Figures 30(a) to 30(c) schematically depict three further exemplary apparatus suitable for forming surface relief structures in embodiments of the invention;

Figure 31 shows a security device in accordance with an embodiment of the invention at different stages of manufacture: Figure 31(a) shows the curable material before casting; Figure 31(b) shows a cross-section through the security device after curing; and Figure 31(c) shows a plan view of the security device (i) under visible illumination, and (ii) under UV illumination;

Figure 32 shows a security device in accordance with an embodiment of the invention at different stages of manufacture: Figure 32(a) shows the curable material before casting; Figure 32(b) shows a cross-section through the security device after curing; and Figure 32(c) shows a plan view of the security device (i) under visible illumination, and (ii) under UV illumination;

Figure 33 shows a security device in accordance with an embodiment of the invention at different stages of manufacture: Figure 33(a) shows the curable material before casting; Figure 33(b) shows a cross-section through the security device after curing; and Figure 33(c) shows a plan view of the security device (i) at visible wavelengths, and (ii) at an IR wavelength;

Figure 34 shows a security device in accordance with an embodiment of the invention at different stages of manufacture: Figure 34(a) shows the curable material before casting; Figure 34(b) shows a cross-section through the security device after curing; Figure 34(c) shows a plan view of the curable material before casting; Figure 34(d) shows a plan view of the casting tool; and Figure 34(e) shows a plan view of the security device;

Figure 35 shows a security device in accordance with an embodiment of the invention at different stages of manufacture: Figure 35(a) shows the curable material before casting; Figure 35(b) shows a cross-section through the security device after curing; Figure 35(c) shows a plan view of the curable material before casting; Figure 35(d) shows a plan view of the casting tool; and Figure 35(e) shows a plan view of the security device;

Figure 36 shows a security device in accordance with an embodiment of the invention, in cross-section;

Figure 37 shows a security device in accordance with an embodiment of the invention: Figure 37(a) shows the security device in cross-section; Figure 37(b) shows a plan view of the security device; and Figure 37(c) shows a schematic exploded view of the security device;

Figures 38 and 39 depict two further embodiments of security devices in accordance with the invention, (a) in cross-section, and (b) in plan view from (i) a first viewing angle and (ii) a second viewing angle;

Figures 40(a) to 40(h) show security documents in accordance with embodiments of the invention, in cross section;

Figure 41 schematically depicts an exemplary pigment particle; and

Figure 42 shows a particle size distribution for an exemplary pigment.

DETAILED DESCRIPTION OF THE DRAWINGS

The following description will focus on security devices formed directly on document substrates ultimately used as the basis for security documents such as banknotes, passports, certificates, licences, ID cards and the like. In many cases the security device is depicted as being arranged on a non-window region of the document substrate. However, as will be explained with reference to Figure 40, this is not essential and the device could alternatively or additionally be located in (or extend over) a window or half-window region (or any mixture of such regions). Likewise, as will also be explained with reference to Figure 40 all embodiments of the security device could alternatively be formed on a separate substrate, as a security article, for later application to (or incorporation into) a security document.

For comparison, Figure 1 shows an example of a conventional security device in the form of an intaglio print 110 on a security document 100. Figure 1(a) shows the security document 100 in plan view and Figure 1(b) shows a schematic cross-section along the line Q-Q’. It should be noted that, for simplicity, Figure 1(b) does not show the embossed nature of the substrate which is caused by intaglio printing and will be present in practice. This is shown in the enlarged detail of Figure 1(c). In this example, the intaglio print is shown as being formed on a document substrate 2 formed of an inner core substrate 2a, which may be a polymer material such as BOPP, and outer opacifying layers 2b, such as white ink. This is a typical construction of a polymer banknote substrate. However, intaglio prints 110 can be formed on any document substrate, including paper substrates.

As shown in Figure 1(a), here the intaglio print 110 comprises a linework image of a kingfisher and a line of text reading “De La Rue” with a logo above it. The image of the kingfisher is multi-tonal, being made up of an array of image elements 112 in the form of spaced inked lines of varying size and shape, configured as necessary to convey the features of the image. The image is formed in two colours C_1 (e.g. dark green) and C_2 (e.g. orange). The intaglio process involves providing a printing plate into which is etched all the lines defining the desired image elements. A first ink 114a of colour C_1 and a second ink 114b of colour C_2 are applied to respective regions of the printing plate corresponding to the areas in which the two colours are required. The inks are forced into the etched lines and cleaned off the intervening surfaces of the plate using a wiper blade or similar. The printing plate is then applied to a substrate 2 against an impression roller at high pressure, forcing the substrate 2 into the etched lines, thereby causing embossing of the substrate. Upon separation, the inks 114a, 114b are transferred from the printing plate onto the tops of the raised elements of the now-embossed substrate 2. The raised elements and the inks carried thereon form the image elements 112 of the intaglio print 110. The embossed nature of the print 110 results in a tactile quality.

Whilst it is possible to form an intaglio print having more than one colour, as illustrated in Figure 1, the design options are limited. Due to the composition of intaglio inks (which are very thick and paste-like) and the method of ink application to the intaglio plate, placement of individual inks on the intaglio plate is very difficult. The high pressure required to push the thick ink paste into intaglio plate recesses prior to printing makes the process difficult to control and limits placement of individual inks to blocks (groups) of recesses rather than individual recesses. The ink will invariably spread when being pushed into recesses and merge with adjacent inks. The wiping effect of cleaning the non-recess areas of the plate as part of the intaglio process also contributes to merging. Due to these reasons, each area of colour either needs to be of sufficiently large size so that merged regions are a minor part of the whole printed region (to appear as a single colour to the viewer) or sufficiently separated from the other colours to minimise merging. As such, it is not possible to place different colours closely together or to arrange different colours at high resolution such as would be required to exhibit a full colour image, e.g. of photographic quality. The number of colours which can be exhibited in an image is also limited, since it is not possible to spatially combine inks in a controlled manner as is necessary to provide the full spectrum of colours via additive or subtractive colour mixing.

In contrast, security devices in accordance with embodiments of the present invention comprise a surface relief structure formed of a cured material. An example of a suitable cast-cure process for forming surface relief structures 20 suitable for use in the security devices disclosed herein will be described with reference to Figures 2(a) and (b) hereto, which show the structure 20 only schematically. The process is shown as applied to a support layer 201, comprising a transparent or translucent film, which may be a document substrate 2 or could be another substrate 2' which is later applied to the document substrate 2. Document substrates 2 used could be of any type, including fibrous substrates such as paper or non-fibrous substrates such as polymer (or a hybrid of both). In preferred examples, the document substrate comprises a core polymer substrate such as BOPP with at least one opacifying layer disposed on one or both surfaces of the core polymer substrate, optional gaps in one or more of the opacifiying layers forming window or half-window regions of the document substrate. For example the security document could be a polymer banknote. The opacifying layers are preferably of non-fibrous materials such as a coating of binder containing light-scatting pigments, preferably white, off-white or grey in colour (such as TiO_2).

Alternatively the surface relief structure 20 can be cast onto a substrate 2' such as a transparent polymer film, e.g. comprising PET, PE or PC, which may form the support layer of a security article such as a security thread, strip or patch. The surface relief structure could be cast onto the substrate 2' before or after substrate 2' is applied to (or incorporated into) a security document. Examples of how such an assembly may be formed will be provided below.

Figure 2(a) depicts the apparatus from a side view, and Figure 2(b) shows the support layer in a perspective view, the manufacturing apparatus itself being removed for clarity. A curable material 205 is first applied to the support layer 201 using an application module 210 which here comprises a patterned print cylinder 211 which is supplied with the curable material from a doctor chamber 213 via an intermediate roller 212. For example, the components shown could form part of a screen printing system. Other printing techniques such as lithographic, flexographic, offset or inkjet printing could also be used. Print processes such as these are preferred since the curable material 205 can then be laid down on the support 201 only in selected regions 202 thereof, the size, shape and location of which can be selected by control of the print process, e.g. through appropriate configuration of the pattern on cylinder 211. However, in other cases, an all over coating method could be used, e.g. if the surface relief structure is to be formed all over the support 201. The curable material 205 is applied to the support 201 in an uncured (or at least not fully cured) state and therefore may be fluid or a formable solid.

The support 201 is then conveyed to a casting module 220 which here comprises a casting tool 221 in the form of a cylinder carrying a surface relief 225 defining the shape of the surface relief structure which is to be cast into the curable material 205. As each region 202 of curable material 205 comes into contact with the cylinder 221, the curable material 205 fills a corresponding region of the relief structure, forming the surface of the curable material into the shape defined by the relief. The cylinder 221 may be configured such that the relief structure 225 is only provided at regions corresponding to shape and position of the first regions 202 of curable material 205.

Having been formed into the correct surface relief structure, the curable material 205 is cured by exposing it to appropriate curing energy such as radiation R from a source 222. This preferably takes place while the curable material is in contact with the surface relief 225 although if the material is already sufficiently viscous this could be performed after separation. In the example shown, the material is irradiated through the support layer 201 although the source 222 could alternatively be positioned above the support layer 201, e.g. inside cylinder 221 if the cylinder is formed from a suitable transparent material such as quartz. In an alternative embodiment, the curable material 205 could be applied directly onto casting tool 221 rather than on to the substrate 201. This could be done in an all-over or patternwise manner.

Figure 3 shows an example of the cast-cure process in more detail at the level of forming a single security device 10. Figure 3(a) shows the process step just before casting takes place, and Figure 3(b) shows the resulting cast structure. In Figure 3(a), the casting tool 221, with relief structure 225 in its surface is shown adjacent the layer of curable material 205 which has been applied to substrate 2. The composition of curable material 205 will be explained in more detail below. In this example, the relief structure 225 is generally flat (although may follow the curvature of a cylinder, as explained above) other than for a set of recesses 226. Each recess has a depth d and width w which in this case is constant across the individual recess also this is not essential as will be explained. The depth and/or width may also vary from recess to recess. Each recess will also have a length in the direction normal to the page, which can also be different from one recess to another. The depth and/or width of the recess may or may not vary along the length.

Once casting has taken place, as shown in Figure 3(b), the now-cured material 20a exhibits a surface relief structure 20 which mirrors the shape of the surface relief 225 carried by the casting tool 221. Thus, the surface relief structure 20 comprises a set of protrusions 21, i.e. portions of cured material of greater height than their surroundings, which correspond to the recesses 226. Each protrusion 21 has a height h determined by the depth d of the respective recess 226 and likewise a width w corresponding to that of the recess. Hence, the protrusions 21 too can have heights and/or widths (and lengths) which vary within an individual protrusion and/or from one protrusion to another. “Height” means the dimension of the protrusion along the direction normal to the substrate, while “width” means its smallest dimension in the plane of the substrate and “length” means its longest dimension in the plane of the substrate. Linking the protrusions 21 is a base layer 29 which is also considered part of the surface relief structure 20, being integral with the protrusions 21. The base layer 29 is a result of the casting process, formed in this case by the flat surface of casting tool 221 approaching the substrate 2. The height/thickness of the base layer 29 can be selected via control of the pressure applied between the casting tool 221 and the substrate 2 during casting. Alternatively or in addition, the relief structure 225 in the casting tool surface could include a cavity 229, shown in dotted lines in Figure 3(a), at the open ends of the protrusions to form a base layer 29 in a defined lateral area. The “height” of a protrusion is considered to include any base layer present – i.e. it is the local thickness of the cured material.

Typically, in embodiments in which the curable material is applied directly onto casting tool 221, the curable material is applied so as to substantially fill the trenches 121, as well as form a thin layer of curable material over substantially the whole of the surface of the casting tool 221 in the first region – i.e. over elevations of the relief on the casting tool, as well as the elevations. There is no wiping/doctoring step. Following the casting process, this thin layer of curable material forms the integral base layer of the surface relief structure. In alternative methods, the curable material 205 may be applied to the casting tool so as to be present only within the trenches 121, for example by using a doctor blade or other removal means to remove material from the tops of the elevations. In such examples, a tie-coat layer is then applied over substantially the whole surface of the die form 221, i.e. coating both the filled recessed areas of the trenches and the raised areas between them, and the tie coat layer ultimately forms the base layer of the surface relief structure. The curable material of the tie coat may or may not be of the same composition as the curable material 205 in the trenches. In particularly preferred embodiments, the tie coat composition may be selected so as to improve the adhesion between the curable material 205 and the support layer. The tie coat is applied by a tie coat application module. It is desirable for the tie coat to be applied in a continuous, homogenous manner at the micron level hence it is preferably applied in a metered way via a slot die and transfer roller combination. The tie coat may be partially cured before the casting tool and the substrate are brought into contact.

Figure 4 shows a first embodiment of the invention. Figures 4(a) and 4(b) show sequential steps in the manufacture of the security device 10, which is visible in cross-section in Figure 4(b) and in plan view in Figure 4(c). In Figure 4(a), the curable material 205 has been applied to a substrate 2 as previously explained. The curable material 205 comprises a first pigment 31 homogeneously dispersed in a binder 39, which is preferably transparent (clear) and may be visibly colourless or tinted (preferably with a dye, so as to maintain optical clarity). The first pigment 31 has at least a first detection characteristic, such as a visible colour. For example, the first pigment 31 may appear blue to the naked eye. In this case, assuming the binder 39 is colourless, the patch of curable material 205 applied to the substrate 2 will appear uniformly blue all over, at this stage.

After casting, as shown in Figure 4(b), the now-cured material 20a is in the form of a surface relief structure 20 which in this example comprises a plurality of protrusions 21 and a base layer 29 joining them. It will be seen that the first pigment 31 is no longer homogeneously dispersed throughout the cured material 20a. Rather, the first pigment 31 is only present in the protrusions 21 and not in the base layer 29. This is achieved by careful selection of the pigment size, size distribution and pigment shape, and through design of the surface relief. In particular, the protrusions 21 are sized so as to be able to able to accommodate particles of the first pigment 31, whereas the base layer 29 is sized to exclude them. For example, the first pigment may comprise particles having an average size (diameter) of 5 µm. Therefore the recesses in the surface relief on the casting tool used to form the surface relief must have a height and width sized to result in protrusions 21 which also have a height and width of at least 5 µm. The base layer 29, meanwhile, has a lower height which is less than 5 µm. For instance, the base layer 29 may have a height of 1 µm or less. As explained with reference to Figure 3, this may be achieved either through the design of the casting tool and/or control of the pressure between it and the substrate during casting. Hence, during casting, the first pigment is forced out of the regions of the curable material which form the base layer 29 and into the regions forming the protrusions 21, with the result that the cured material 20a no longer contains a homogenous dispersion of the first pigment 31.

This has a corresponding effect on the detection characteristics of the cured material, which are no longer uniform. Instead, the first detection characteristic (contributed by the first pigment 31) is only detectable from the protrusions 21 and not from the base layer 29. In the case where the binder 39 is colourless and the first pigment is blue, therefore, the protrusions 21 will now appear blue, against a colourless background formed by the base layer 29. This is shown in plan view in Figure 4(c).

The lateral arrangement of the surface relief structure can take any form as necessary to exhibit the desired effect (visual or otherwise). In this example, the protrusions are configured to form elements of an image, here the number “10”. Each digit “1” and “0” could be formed by a single contiguous protrusion or, as shown here, the image can be formed of an array of image elements such as lines or dots arranged on a regular or irregular grid, e.g. a screened image. This results in an appearance which closely mimics an intaglio print, but with much improved control over colour placement.

To illustrate this, Figure 5 shows a further embodiment of a security device 10 which is formed using the same principles as explained with reference to Figure 4 but a different surface relief structure 20. Again, the surface relief structure 20 comprises a plurality of protrusions 21 sized to accommodate a first pigment 31, which here is dark green. The surface relief structure also includes a base layer 29 which is too thin to accommodate the first pigment and hence appears colourless (assuming the binder is colourless). The protrusions are configured so as to form image elements of a detailed linework image, as shown in plan view in Figure 5(a). As in conventional screened images, the size, shape and/or spacing of the image elements can be varied across the device so as to give rise to the impression of different tones in different areas of the image, and hence shading, resulting in a multi-tonal image. The technique provided by the present invention also offers an additional way to control the appearance of the device, since increasing the height of a protrusion will enable a greater absolute volume of the first pigment to be accommodated therewithin. This will result in a corresponding increase in the intensity of the first detection characteristic. For example, two protrusions of the same width and both able to accommodate the first pigment will appear the same colour as one another if they are the same height. However if one is taller, it will contain more of the first pigment and therefore exhibit a more intense colour than the other. Similarly, if a protrusion has a height which varies along its width or length, its colour intensity will also vary along its width or length. In preferred examples, a ratio of the height of at least one protrusion to the height of the base layer joining the raised element to an adjacent protrusion is at least 10, preferably at least 20, and furthermore is preferably no greater than 400, preferably no greater than 200. In some embodiments, a ratio of the height of each protrusion to the height of the base layer is at least 10, preferably at least 20, and furthermore is preferably no greater than 400, preferably no greater than 200. This is especially the case where the protrusions are configured to form image elements, particularly of multi-tonal images.

As alluded to above, while in many preferred embodiments the binder 39 will be colourless, this is not essential and it could contain a tint or other detectable characteristic. If the binder carries a visible tint this is preferably achieved using a dye so as to avoid optical scattering. The colour of the visible tint preferably contrasts with any visible colour of the first pigment. This can be used to achieve a multi-coloured end result. For instance, if the binder carried a yellow tint in the above examples, the security device 10 of Figure 4 would appear as a green number "10" against a yellow background. Similarly, the complex image achieved in the Figure 5 embodiment would be against a yellow background (the colour of its protrusions would likely not be much altered since it is already dark green).

It should be noted that while, for simplicity, the placement of the first pigment 31 within the cured material 20a has been described in a binary sense (i.e. present or absent), in practice this may not be the case. Since any sample of pigment will contain a distribution of particle sizes and shapes, as described further with reference to Figure 42 below, there will inevitably be some pigment particles present which are much smaller than the average size (or of an atypical shape) and hence may be able to remain in parts of the structure which are not designed to accommodate the first pigment. However, the proportion of such particles will be relatively small and hence the concentration of the first pigment in those parts will be much smaller than the concentration in parts of the structure designed to accommodate the first pigment. Hence, it is more accurate to describe the cured material as having a concentration of the first pigment which varies from one part to another, even if it is non-zero throughout. Nonetheless, for conciseness, the embodiments below will be described as if each pigment had a single particle size and therefore its location could be fully controlled (as implied in the previous examples), but it should be remembered that this is often not the case in practice. As such, in all embodiments, parts of the surface relief structure described as excluding one or more pigments (or having "substantially zero concentration" of that pigment) may in fact contain some of that pigment in practice, at a lower concentration than in the other parts of the structure. Preferably the concentration of the pigment in question is so low as not to be detectable, at least by the human eye.

In the above examples, all of the protrusions 21 are able to accommodate the first pigment 31, having heights and widths at least as great as the average size of the first pigment 31. In such cases, all the protrusions 21 could, if desired, be of the same height and/or width as one another (although this is not essential). However, in further embodiments, protrusions of different height and/or width are provided so as to attain different detection characteristics in different ones. Figure 6 shows a schematic example of a security device 10 in accordance with another embodiment of the invention to illustrate this principle. Here, the curable material 205 comprises only a first pigment 31 in a binder 39, which in this case is a red pigment of average particle size 5 µm. In this case, the surface relief structure 20 comprises four protrusions of varying width. The two protrusions 21a have respective widths w_1, w_2, each of which is greater than or equal to 5 µm and thus they are able to accommodate the first pigment 31. The two protrusions 21b are each of width w_3 which is less than 5 µm and hence they are not able to accommodate the first pigment 31. The device is otherwise formed in the same manner as described above. The result is that the narrow protrusions 21b are colourless as no pigment can be accommodated, and the wide protrusions 21a appear red as the pigment can fit inside. This again assumes that the binder 39 is colourless, which is not essential.

Figures 7(a) and 7(b) show a more complex device 10 formed on the same principles, in plan view and cross-section respectively. Here, the protrusions 21a, 21b are configured to depict a complex multi-tonal image of the sort already described with reference to Figure 5. A first set of protrusions 21a are sufficiently large so as to accommodate the first pigment 31 and hence appear in a first colour C_1 (e.g. green). A second set of protrusions 21b are smaller and hence do not accommodate the first pigment 31, and hence have a different appearance, corresponding to that of the binder 39 which may be colourless or of a second colour C_2 (e.g. yellow). The base layer 29 also excludes the first pigment and thus provides a background in the same colour (if any) as the binder 39.

The embodiments of Figures 6 and 7 could be made using any of the processes described above, including those in which there is no wiping step on the casting tool. However, structures such as these also lend themselves well to the use of the variation mentioned above in which the curable material is applied to the recesses only and then removed from the elevations of the casting relief in wiping or doctoring step. When the curable material is applied to the casting tool, the larger recesses (which ultimately form protrusions 21a) will accept pigment 31 whilst the smaller recesses (which ultimately form protrusions 21b will not. Hence the pigment becomes non-homogenously dispersed into the recesses and ultimately protrusions with different detection properties can be formed from a single type of curable material 205. Removal of the remaining curable material then allows the base layer 29 to be formed of a different curable material if desired, applied as a tie coat in the aforementioned manner. The resulting combination of cured protrusions and tie coat forms the surface relief structure 20.

In the previous examples, the base layer 29 has been sized so as to exclude the first pigment 31 throughout. However this is not essential and some alternative arrangements will now be described with respect to Figures 8 and 9. Referring first to Figure 8, once again, the curable material 205 is laid down on substrate 2 in a homogeneous form, containing first pigment 31 dispersed in binder 39, as shown in Figure 8(a). After casting, as shown in Figure 8(b), the cured material 20a is in the form of a surface relief structure 20 having a plurality of protrusions

21 and a base layer 29 of which different parts 29a, 29b have different heights. In the immediate vicinity of the protrusions 21, the base layer 29b has a height sufficient to accommodate the first pigment 31. Outside those regions, the base layer 29a has a lesser height which is not able to accommodate the first pigment 31. This height variation can be achieved by providing the casting tool with a suitable cavity at least for forming the regions 29b of the base layer. The result, shown in plan view in Figure 8(c), is that both the protrusions 21 and their immediate surroundings carry the pigment 31, forming in this case an image of the number “10” formed of line elements corresponding to the protrusions 21 and a border region immediately surrounding them. For instance, if the first pigment is blue, the whole area of the digit “1” and of the digit “0” will appear blue. However, since the protrusions 21 are of greater height than the base layer 29b, the line elements will exhibit a more intense colour than will the border, since the protrusions contain a greater absolute volume of the first pigment (per unit lateral area) than does the base layer 29b. Outside the border region, there is a colourless background corresponding to thinner base layer area 29a (again, assuming the binder 39 is colourless).

In a variant, shown in Figure 9, the base layer region 29b of increased height could be present only adjacent some of the protrusions 21 and not others. For instance, here the base layer 29 has an increased height, able to accommodate the first pigment 31 around the protrusions 21 forming the digit “0” but not around those forming the digit “1”. The result, shown in Figure 9(c) is that the “1” appears formed of individual line elements against a colourless background with no border region, whereas the digit “0” has the same appearance as in the Figure 8 embodiment. The line elements forming both digits “1” and “0” will however have the same colour intensity as one another as they are the same height.

As mentioned, the binder 39 is typically colourless but this is not essential and in other cases may be provided with a visibly coloured tint, which preferably contrasts with the colour of the first pigment 31. Figure 10 shows an example in which this is made use of to form a multi-coloured image. The curable material 205 applied to the substrate 2, as shown in Figure 10(a), comprises a homogenous dispersion of a first pigment 31 in a binder 39 carrying a coloured tint. For instance, the first pigment 31 may be a green pigment of average size 5 μm and the binder 39 may be tinted by an orange dye. The curable material is cast into a structure similar to that described with respect to Figure 6, resulting in a security device of which a portion is shown schematically in Figure 10(b). The surface relief structure 20 comprises first protrusions 21a which are sufficient height and width so as to accommodate the first pigment 31, as well as second protrusions 21b which are of smaller height and/or width and cannot accommodate the first pigment 31. The base layer 29 is also sized to exclude the first pigment 31.

In the resulting device, the first protrusions therefore appear in a first colour C_1 determined by the combination of the first pigment 31 and the binder 39. If the first pigment 31 is of sufficient colour density it may overwhelm any contribution from the binder tint. For instance, in this case the first protrusions 21a may appear green. The second protrusions 21b do not contain the first pigment 31 and hence exhibit the colour of the binder 39 (second colour C_2), at a colour density dependent on the height of the protrusion 21b. As shown in Figure 10(c) the protrusions 21a, 21b can be configured to form image elements of a multitonal complex image. The image elements will be seen against a background formed by base layer 29 which will carry the colour of the binder tint. However, if the base layer is very thin, the colour density may be very low and hence in practice the background may appear substantially colourless.

The embodiments so far have made use of a single pigment type. However, more complex security devices can be achieved by providing the curable material 205 with two or more different pigments. Examples utilising this principle will now be described.

Figures 11(a) and 11(b) show sequential steps in an exemplary method of making a security device (Figure 11(b) also showing an example of a security device in accordance with the invention, in schematic cross-section).

In a first step, a curable material 205 such as a UV resin is applied to a substrate 2, e.g. by screen printing. The curable material comprises a binder 39 (suitable materials are given below) in which is homogenously dispersed at least two different pigment types 31, 32. This includes at least a first pigment 31 which has a first particle size and a first detection characteristic, such as a red pigment formed of 5 μm particles, and a second pigment 32 which has a second (different) particle size and a second (different) detection characteristic, such as a yellow pigment formed of 1 μm particles. Preferably, pigments are selected such that the smaller the pigment, the lighter the colour. Figure 11(a) shows the curable material 205 as initially applied to the substrate 2, its domed shape being caused by surface tension.

In the second step, a casting tool (not shown) is brought into contact with the curable material on the substrate to form it into a desired surface relief structure 20. The casting tool has an appropriate relief structure defined in its surface. Generally, the relief structure is configured such that its impression will cause the pigments to become non-homogenously dispersed in the curable material so that, once cured, the relief structure will have an detection characteristic (e.g. colour) which varies from one position to another. This can be achieved, for instance, by the relief structure defining a plurality of recesses which vary in height and/or depth. These will produce corresponding protrusions in the final surface relief structure. By varying the recess depth (hence protrusion height), a different thickness of cured material will be present in the final structure. The greater the thickness, the greater the optical density since the more pigment will be present in the protrusion. By varying the recess width (hence protrusion width), the ratio of first:second pigment, and hence the detection characteristic (e.g. colour) can be varied. This is because the wider recesses will be able to accommodate more of the large pigment than will the narrower recesses. In particularly preferred examples, the narrower recesses may be too narrow to accommodate any of the larger pigment. Hence as shown in Figure 11(b), in this example the two, narrow protrusions 21b in the centre of the device appear yellow since, having widths w_3 in the range 1 to 4 µm, they can only accept the yellow pigment. In contrast, the two outer protrusions 21a which have widths w_1, w_2 greater than 4 µm (e.g. 20 µm) can accept both pigment types and so appear orange/red.

The base layer 29 formed by the casting tool on the substrate is preferably made so thin that no pigments remain, having been pushed into the recesses. The base layer 29 therefore comprises the binder 39 only which is preferably colourless.

It should be noted that the same result can be achieved if the curable material 205 is applied to the surface of the casting tool rather than to the substrate.

As previously noted, whilst the examples have been described as allowing each pigment to be either present or absent in each part of the structure, in practice the situation may not be so binary. Rather the narrower portions of the structure may accommodate a low (but not zero) concentration of one or both pigments and the wider portions a higher concentration of one or both pigments. This will still provide a suitable contrast.

Further examples which make use of the same principle are shown in Figures 12, 13 and 14.

In the Figure 12 embodiment, the curable material 205 applied to substrate 2 (as shown in Figure 12(a)) comprises a homogenous dispersion of first and second pigments 31, 32 in a colourless binder 39. The first pigment 31 is a yellow pigment with average size 5 µm, whereas the second pigment 32 is a cyan pigment with average size 1 µm. The cast surface relief structure 20 (shown in Figure 12(b)) comprises first and second sets of protrusions 21a, 21b which vary in size from one another. The first set of protrusions 21a are each sufficiently tall and wide so as to accommodate the first pigment 31 (and by default the second pigment 32 since it is smaller). For instance, each one may have a height and width at least as great as the average size of the first pigment, e.g. 5 µm. The second set of protrusions 21b are sized so as to exclude the first pigment 31 but accommodate the second pigment 32. For instance, each one may have a height and width at least as great as the average size of the second pigment, e.g. 1 µm, but less than that of the first pigment, e.g. 5 µm. The base layer 29 is so thin as to exclude both the first and the second pigments. As a result, the first set of protrusions 21a exhibits a mixed colour resulting from the combination of the first and second pigments (e.g. green). The second set of protrusions 21b exhibits the colour of the second pigment 32 only, e.g. cyan. The base layer 29 is colourless. In plan view, as shown in Figure 12(c), the security device 10 displays an image of the number “10”, where the digit “1” is formed of cyan line elements corresponding to protrusions 21b and the digit “0” is formed of green line elements corresponding to protrusions 21a, against a colourless background.

The Figure 13 embodiment utilises the same curable material 205 as in the Figure 12 embodiment just described, but the surface relief structure described with respect to Figure 8, in which the height of the base layer 29 varies. Hence in the resulting security device, shown in cross section in Figure 13(b) and plan view in Figure 13(c), there are a plurality of protrusions 21 each sized so as to accept only the second pigment 32 and not the first pigment 31. The regions 29b of the base layer immediately adjacent the protrusions are of sufficient height so as to accommodate the first pigment 31 (and the second pigment, by default). The other areas 29a of the base layer are so thin as to exclude both pigments. The result, as seen in Figure 13(c), is an image of the number “10” formed of line elements corresponding to protrusions 21 which each appear blue – despite some yellow pigment being present under them, the additional volume of the blue pigment 31 due to the height of the protrusions outweighs the contribution from the yellow pigment 32 in these locations. The line elements are surrounded by a border region corresponding to the increased height portion of the base layer 29b, which appears green due to the mixing of the first and second pigments in this area. The two digits are surrounded by a colourless background corresponding to base layer area 29a.

Figure 14 shows a more complex security device 10 formed using the same principles as in Figure 12. Here the curable material 205 applied to the substrate 2 comprises a homogenous dispersion of a first dark green pigment 31 of average size 5 µm, and a second orange pigment 32 of average size 1 µm, in a colourless binder 39. The cast structure, of which a portion is shown schematically in Figure 14(b), includes first protrusions 21a which have a height and width greater than the average size of the first pigment 31 and thus can accommodate both pigments. Also present are second protrusions 21b which have a height and width less than the average size of the first pigment 31 but greater than that of the second pigment 32, such that they accommodate the second pigment 32 but not the first pigment 31. The base layer 29 is sized so as to exclude both pigments. The dark green colour of the first pigment 31 is more intense than the orange colour of the second pigment 32 and thus dominates the appearance of those parts of the structure where both pigments are present. As a result, the first protrusions 31 appear in a first colour C_1 (dark green) while the second protrusions 32 appear in a second colour C_2 (orange), against a colourless background. The protrusions are arranged to form elements of a complex multitonal image as shown in Figure 14(c) and previously described with respect to Figure 5.

In all of the above embodiments, the binder 39 could instead have a coloured tint in which case the colour in each part of the structure would be modified accordingly, displaying a mixed colour resulting from the combination of the binder and the pigment(s) present.

As has been mentioned, the detection characteristics achieved in the final product (e.g. colour) will depend on the interplay between those of the two pigments. For instance, a pigment having a strong colour will typically overwhelm a pigment having a weaker colour wherever the two are mixed in reasonable proportion. This will be illustrated with respect to Figures 14 and 15, in each of which the same surface relief structure 20 is cast but into two different curable materials. In the Figure 15 embodiment, the curable material 205 comprises first and second pigments 31, 32, where the first pigment 31 is larger than the second pigment 32 and of weaker colour density. For instance, the first pigment 31 may be a yellow pigment of average size 5 μm while the second pigment may be a dark grey pigment of average size 1 μm. The cast structure 20 includes first protrusions 21a able to accommodate both pigments 31, 32 as well as second protrusions 21b only able to accommodate the second pigment 32. However, since the dark grey colour of the second pigment 32 will overwhelm the yellow pigment 31, both sets of protrusions 21a, 21b will have substantially the same appearance in the finished product, as seen in Figure 15(c).

In contrast, Figure 16 illustrates the outcome where the colour/size relationship of the two pigments is reversed. Now, the first larger pigment 31 is dark grey, while the second smaller pigment 32 is yellow. The redistribution of the two pigments 31, 32 is the same as in Figure 15 (based on their sizes). This results in the darker first pigment being present only in first protrusions 21a and not in second protrusions 21b. Now the first protrusions 21a appear dark grey while the second protrusions 21b appear yellow, thereby achieving a more distinctly multi-coloured device as shown in Figure 16(c). Generally, therefore, arrangements of this sort in which the larger pigment is of the darker colour (or more intense detection characteristic, to generalise) is preferred. However, this is not always necessary (see Figure 13 for an example in which multiple colours would be achieved with a curable material of the same sort as described in Figure 15).

In the embodiments so far, it has been assumed that the first and second pigments 31, 32 each have particle shapes which are close to spherical. As such, the "average size" of each pigment can be considered to reference the diameter of the particles making up that pigment, which will be approximately the same in all dimensions. However, it is also possible to use pigments which have other shapes, which may deviate significantly from spherical. For instance, Figure 17 shows an embodiment in which the first particle 31 is approximately spheroidal while the second particle 32 has a platelet or needle-like shape, i.e. having at least one dimension which is significantly greater than the other one or two dimensions. For instance, the first pigment 31 may have an average diameter of 5 μm (in all three dimensions) while the second pigment may have a platelet shape with a maximum dimension (in the plate of the particle) which averages 4 μm (across the sample of particles present) and a minimum dimension (the particle "thickness") which averages 0.1 μm (across the sample of particles present). Figure 17(a) shows the curable material 205 comprising a homogenous mix of the first and second pigments 31, 32, prior to casting. Due to the small thickness dimension of the second pigment 32, after casting, the second pigment may remain present in base layer 29 as shown in Figure 17(b). The cast structure 20 includes first protrusions 21a able to accommodate both pigments 31, 32 as well as second protrusions 21b only able to accommodate the second pigment 32. The appearance of the device 10 is shown in Figure 17(c). In an example using a blue first pigment 31 and a red second pigment 32, the device displays red protrusions 21b forming the digit "1", purple protrusions forming the digit "0" and a red background formed by the base layer 29. Typically the red background will have a less intense colour tone than the protrusions 21b, due to the difference in relative heights and therefore the absolute amount of pigment present in the respective parts of the surface relief structure.

For pigment particles which deviate significantly from a spherical shape, their dimensions may be parameterized using the known Feret diameter terminology. A Feret diameter of a particle is the distance between two tangents to the contour of the particle which are parallel to one another, i.e. a dimension which might in theory by measured by a slide gauge. Figure 41 shows a schematic pigment particle 31 and two Feret diameters of the particle to illustrate this. Each one is measured between a parallel pair of straight lines which are tangential to points on the particle edge. The two diameters illustrated are the largest such diameter (or “Feret maximum”, F_{MAX}) and the smallest such diameter (or “Feret minimum”, F_{MIN}) for the particle in question (assume that the z-axis dimensions of this particle are intermediate). F_{MAX} and F_{MIN} can be measured for any particle shape, spherical or non-spherical, although for truly spherical particles they will of course have equal values. For any sample of particles, there will be a range (distribution) of sizes and shapes present, and hence a range of F_{MAX} and F_{MIN} values. Useful parameters are the average F_{MAX} and the average F_{MIN} for a pigment sample.

In the context of the present invention, in order for any two pigments to become non-homogenously distributed by the casting process, at least one of the average Feret maximum diameter (F_{MAX}) and the average Feret minimum diameter (F_{MIN}) should differ between the two pigments. Preferably, the average Feret minimum diameter (F_{MIN}) will be different between the two pigments since in many cases it is this which can determine whether a particle will fit within a certain space or not. In particularly preferred cases, the pigment having the largest average Feret maximum diameter (F^1_{MAX}) has an average Feret minimum diameter (F^1_{MIN}) which is larger than the other pigment’s average Feret maximum diameter (F^2_{MAX}). This removes any overlap between the dimensions of the two pigments’ average particle dimensions and hence improves the ability of the process to separate the different pigments from one another in certain part(s) of the relief structure. Hence in preferred cases, the “larger” pigment (i.e. the pigment having the greater average F_{MAX}) has an average F_{MIN} which is larger than the average F_{MAX} of the other pigment. For instance, if the first pigment 31 is larger (as in Figure 17), its average Feret minimum diameter (F^1_{MIN}) is preferably greater than the average Feret maximum diameter (F^2_{MAX}) of the second pigment 32. That is the case in the Figure 17 example, where the first pigment 31 has average Feret maximum and minimum diameters (F^1_{MAX} and F^1_{MIN}) of 5 µm, while the second pigment 32 has an average Feret maximum diameter (F^2_{MAX}) of 4 µm and an average Feret minimum diameter (F^2_{MIN}) of 0.1 µm.

The above principles can be extended to control the placement of any number of different pigments with different size and/or shape characteristics. For example, Figures 18, 19, 20 and 21 depict embodiments in which the curable material comprises three different pigments, each with a different detection characteristic (e.g. colour) and different average size and/or shape.

In the Figure 18 embodiment, the curable material 205 applied to the substrate 2 comprises a homogenous mix of first, second and third pigments 31, 32 and 33 in a colourless binder 39. The first pigment 31 is larger than the second pigment 32, which is larger than the third pigment 33. For instance, the first pigment 31 may be a magenta pigment of average size 8 µm, while the second pigment 32 may be a cyan pigment of average size 4 µm and the third pigment may be a yellow pigment of average size 1 µm. The cast structure 20, as shown in Figure 18(b), comprises a plurality of protrusions of different height and/or width. A first set of protrusions 21a have a height and width of 8 µm or more so that they can accommodate all three pigment types. For instance the first protrusions 21a could be 20 µm in width. A second set of protrusions 21b are sized so as to accommodate the second and third pigment types 32, 33 but not the first pigment 31. In this case, this is achieved by arranging the width of the protrusions 21b to be less than 8 μm and the height remains the same as that of the first protrusions, but in other cases the height could be reduced as well as or instead of the width to exclude the first pigment. For instance, the second protrusions could be between 4 and 7 μm in width. A third set of protrusions 21c are sized so as to accommodate only the third pigment type 33 and not the first or second pigment 31, 32. Again this can be achieved via selection of the height and/or width of the protrusions. For instance, the protrusions 21c could have a width between 1 and 3 μm. The base layer 29 is sized so as to exclude all three pigment types.

Hence each set of protrusions 21a, 21b, 21c will provide a different appearance in the finished product. As shown in the plan view of Figure 18(c), the first protrusions 21a will display a mixed colour, dominated by the intense magenta pigment, resulting in a purple appearance. These are configured as line elements forming the digit “0” in the security device. The second protrusions 21b will appear green-blue, resulting from the mixture of second and third pigments present. The third protrusions 21c will appear yellow, since only the third pigment is present there. The second and third protrusions 21b, 21c are configured to form line elements creating the digit “1” in the final image, which is multi-coloured.

Figure 19 shows a more complex image formed on the same principles. Here the curable material 205 applied to the substrate 2 comprises a homogenous mix of first, second and third pigments 31, 32 and 33 in a colourless binder 39. The first pigment 31 is larger than the second pigment 32, which is larger than the third pigment 33. For instance, the first pigment 31 may be a dark green pigment of average size 8 μm, while the second pigment 32 may be a blue pigment of average size 4 μm and the third pigment may be an orange pigment of average size 1 μm. As in the previous example the structure into which the material is cast comprises protrusions of different sizes so that different pigment type(s), or mixtures thereof, are accommodated in each. The first protrusions

21a, e.g. 20 µm wide, contain all three pigment types, while the second protrusions 21b, e.g. 4 to 6 µm wide, contain only the second and third pigment types 32, 33, and the third protrusions 21c, e.g. 1 to 2 µm wide, contain only the third pigment type 33. Again, the choice of pigment colour strength, opacity, size, size distribution and density is important in order to get the desired result in terms of the colours seen by the viewer in the final product. In this case, the strong green and blue pigments will overpower the orange. As a result the first protrusions 21a appear blue-green, the second protrusions 21b appear blue and the third protrusions 21c appear orange. All three pigments are excluded from the base layer 29 which appears colourless.

The protrusions can be laterally configured to form a multi-coloured, multitonal complex image of the sort described with reference to Figure 5 and shown in Figure 19(c). In this example the second protrusions 21b are used to form the lettering “De La Rue” and accompanying logo rather than forming part of the complex image itself. Hence the kingfisher image appears in green and orange, while the text is in blue.

Whilst the exemplary surface relief structures 20 depicted so far have typically comprised protrusions of standard cross-section (e.g. substantially square or rectangular), this is not essential and more complex effects can be achieved through the use of more complex surface profiles. These may be created using base layers 29 of varying height and/or individual protrusions which themselves have non-uniform height and/or width. A first example is shown in Figure 20, where the curable material 205 applied to the substrate is of the same sort already described in relation to Figure 18, comprising a first magenta pigment 31 of greatest size, a second cyan pigment 32 of intermediate size and a third yellow pigment 33 which is the smallest. The binder 29 is preferably colourless.

The surface relief structure 20 into which the material is cast includes a base layer which varies between three heights. At the outermost part of the security

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device, the base layer 29a is so thin as to exclude all three pigments. Next, an annular region 29b of the base layer has a greater height which is able to accommodate all three pigments. On an inner portion of this region 29b, a first set of protrusions 21a are provided which are each sized so as to accept the cyan and yellow pigments 32, 33 but not the magenta pigment 31. Inside annular region 29b is a still higher circular region 29c of the base layer which too can accommodate all three pigments. On top of this region, second protrusions 33 are provided which are sized to accommodate only the yellow pigment 33. The second and third protrusions 32, 33 are also arranged in this example on a scale which is too small for them to be individually resolved by the human eye although this is not essential.

Figure 20(c) shows the appearance of the device 10 in plan view. The device exhibits a set of concentric circles of differing colour. The centre circular area appears yellow since its detection characteristics are dominated by the significant height of the third pigment 33 provided in second protrusions 21b (and in this case largely masking the other pigments below it). The adjacent annular region appears green-blue as a result of the mixture of the second and third pigments in protrusions 21a which again mask the underlying base layer. The outermost annular region appears purple, corresponding to the uncovered portion of raised base layer 29b containing all three pigments. The surroundings are colourless, as a result of base layer region 29a excluding all three pigments.

Figure 21 illustrates a still more complex surface relief structure 20 which could be deployed in another embodiment of the invention. Again the curable material used comprises three different pigments as in the Figure 20 embodiment. The surface relief structure includes a variety of protrusions of different widths and heights, as well as variations in the base layer height. Each part of the structure is configured to accept or exclude one or more of the pigments as necessary to achieve the desired detection characteristics (e.g. colour) for that part of the device. It will be noted that the exemplary structure includes a protrusion 21' which has a height that varies along its width (or equivalently, a width which varies along its height), being substantially triangular in cross section in this case. As a result the concentration of each pigment which can be accommodated within the protrusion 21' also varies. For instance, in this case the left-most part of the protrusion where the height is lowest can only accommodate the second and third pigment and will hence appear in one colour, whereas the right-most part can accommodate all three pigments and will therefore appear in a different colour. It will be appreciated that highly complex arrangements of the pigments can be achieved through control of the surface relief structure.

Depending on the desired appearance of the security device 10, there may be a need to include image elements which are of sufficient dimension to be visible to the naked eye, at least under low magnification (e.g. having a line width of 50 μm, 100 μm of more) at the same time as utilising pigments which have much smaller dimensions (e.g. pigments with an average size of 20 μm or less). In such scenarios, if a single protrusion 21 is used to form the image element, e.g. having a width of 50 μm or more, all such pigments in the curable material will be able to be accommodated and the desired level of control over colour placement may not be achieved. Figure 22 illustrates this: Figure 22(a) shows an embodiment of a security document 100 in plan view, having a security device 10 similar to that described above with reference to Figure 14. An enlarged part of the device 10 is shown in Figure 22(b) and it will be seen that it exhibits an arrangement of linear image elements 11. If the individual image elements 11 are intended to be distinguishable to the naked eye, they may have a line width in the region of 100 μm. In this case, the curable material used to form the device 10 comprises a colourless binder 39 containing a first pigment 31 (e.g. orange) which is larger than a second pigment 32 (e.g. green). For instance, the first pigment 31 may have an average size of 20 μm while the second pigment 32 may have an average size of 10 μm. If the image element 11 is formed of a single protrusion 21, both the first and second pigments 31, 32 may be accommodated within that protrusion as shown in Figure 22(c), resulting in a mixed colour. This may not be desirable.

To avoid this, in an alternative embodiment, as shown in Figure 22(d), each image element 11 may comprise a plurality of protrusions 21 each separated from the next by a recess 21’ in the surface relief structure. The protrusions 21 are arranged in a group which has an overall width of 100 μm and will therefore be visible to the naked eye. However, each individual protrusion 21 has a smaller width (e.g. 15 μm) which is configured such that the protrusions 21 can accommodate the second pigment 32 but not the first pigment 31. The first pigment 31 is substantially excluded from the group of protrusions 21 forming image element 11 by the recesses 21’ (which may each have a width of e.g. 6.25 μm). The protrusions 21 are spaced so closely together that they cannot be individually resolved by the naked eye and therefore together they appear to form a single image element 11 of width 100 μm. However, this now contains the second pigment 32 only and therefore exhibits the desired detection properties (e.g. green). Any one or more of the image element 11 making up the security device can be formed of a group of protrusions in this way. The spacing between individual protrusions in such a group will be less (preferably significantly less, e.g. 10 times less) than the spacing from one such group to the next, so that the respective image elements 11 remain distinguishable to the eye. It should be appreciated that sub-structuring of the image elements in this way can be applied to all embodiments to obtain the desired level of control over pigment placement.

In the above embodiments, the security device 10 has been configured largely independent of the substrate 2 on which it is formed. However in some particularly preferred embodiments of the invention, the principles described above can be used in such a way to enable the security device to become integrated with the substrate 2. Examples will be described with reference to Figures 23 to 29.

As already mentioned, polymer document substrates typically comprise a transparent core layer 2a, formed for instance of BOPP, PET or PC, and one or more opacifying layer 2b, 2c on each side. The opacifying layers are typically applied by gravure printing and comprise a light-coloured pigment, e.g. white, off-white or light grey, which acts to increase the opacity of the substrate and provide a suitable background for graphics which may later be printed onto it. The opacifying layers typically cover a large proportion of the substrate area, in some cases the entire substrate. However, it is advantageous to exclude the one or more of the opacifying layers across an area of the substrate which is then left transparent or at least more translucent than the rest of the document. If all the opacifying layers are omitted across an area, a window region is formed and if one or more of the opacifying layers remains, it is a "half-window" region. Window regions and half window regions are valuable security devices in themselves since they cannot be replicated using standard copying techniques.

The presently disclosed security devices can be deployed in such a way as to form such an opacifying layer. In some cases, the security device may perform a dual function, forming both an opacifying layer and a graphic or other feature in a single process. The surface relief structure can also be used to act as a varnish to protect the underlying layer(s) of the substrate and/or other components (such as prints or applied features e.g. a foil) provided on or in the substrate).

Figure 23 shows an embodiment in which the surface relief structure 20 forms an opacifying layer of a security document 100, with varying opacity so as to give rise an integral pseudo-watermark feature, which can be seen at least when the document is viewed in transmitted light. As shown in Figure 23(a), in this case the curable material 205 is applied to a surface of core substrate 2a, which is transparent (e.g. BOPP), although there could be one or more pre-existing opacifying layers present on either surface of the core substrate 2a and/or the core substrate 2a could be pre-coated with a primer layer (or otherwise treated to improve retention of the cured material). The curable material 205 comprises an opacifying pigment 31 in a clear, preferably colourless binder 39. The curable material 205 is cast into a surface relief structure 20 as shown in Figure 23(b), which has a varying height.

Areas 29a of the surface relief structure corresponding to parts of the document which are to have a base level opacity have a first height which is sufficient to accommodate a non-zero concentration of the opacifying pigment 31. Such areas 29a may be configured to cover a large proportion of the document substrate, potentially the whole document substrate with the exception of any window regions provided or further features as will now be described. Selected areas 29b, 29c of the surface relief structure are configured to have a greater height so that a greater amount of the opacifying pigment can be accommodated thereby locally increasing the optical density of the surface relief structure 20. In this example, two different increased heights 29b, 29c are utilised resulting in two different opacity tones which will each appear darker than the base level (area 29a) when the document is viewed in transmitted light. The various areas can be configured so as to give rise to the appearance of a watermark-type feature. For instance, in the present case the areas are arranged to have the appearance of the digit “10” when the feature is viewed in transmitted light, different elements of the image having different tones (i.e. levels of translucency).

In a more complex embodiment, the security device 10 can itself be used to create window and non-window regions, as shown in Figure 24. The curable material 205 used is the same as that in the previous embodiment. The casting structure however is configured to include areas 29d which are unable to accommodate the opacifying pigment 31, e.g. due to their low height. Hence in this example, the area 29a again defines a base level opacity which acts as a background for other features. Areas 29b, 29c of increased height present higher opacify (i.e. darker tones in transmitted light), while areas 29d act as window regions (assuming no other opacifying layers are present which extend across them). Hence as shown in the plan view of Figure 24(c), the security device in this case exhibits an image of the digit "10" of which different image elements have different levels of transparency/translucency, some of which correspond to window regions.

Figure 25 shows a further embodiment in which a feature with different detection characteristics (e.g. a contrasting colour) is integrally formed with the opacifying layer. The curable material 205 applied to substrate 2 comprises a homogenous mix of two pigments 31, 32 in a binder 39 as in previous embodiments, which is preferably colourless. The substrate 2 in this example comprises a polymer core 2a (typically transparent) with opacifying layers 2b, 2c formed by gravure printing on each side. Since a further opacifying layer will be formed by security device 10, it is also possible to omit opacifying layer 2c (and/or layer 2b) if desired.

In this example, the first pigment 31 is an opacifying pigment (e.g. titanium dioxide) of larger average size than the second pigment 32, which is of a contrasting colour. For instance the first pigment 31 may be a white pigment of average size 5 μm, while the second pigment may be a blue pigment of average size 1 μm. The curable material 205 is cast into a surface relief structure 20 as shown in Figure 25(b), which comprises a plurality of protrusions 21 and a base layer 29. The base layer 29 is of sufficient height to accommodate both pigments 31, 32 whereas the protrusions 21 are sized so as to accommodate the second pigment 32 but exclude the first pigment 31, in this case by arranging their width to be greater than or equal to the average size of the second pigment 32 and less than the average size of the first pigment 31. For instance, each of the protrusions 21 may be at least 1μm wide but less than 5μm wide. As a result, the protrusions 21 contain only the second pigment 32 and substantially none of the opacifying first pigment 31. The pigment colours and concentrations are chosen such that the opacifying first pigment will largely overwhelm the colour of the second pigment 32 where both are present, with the result that the base layer 29 has the appearance of a white or off-white opacifying layer. The protrusions 21, meanwhile, exhibit the colour of the second pigment, due to the greater amount of that pigment accommodated by their height.

As shown in Figure 25(c), the resulting security device 10 appears as an image formed by the protrusions 21, in a colour determined by the second pigment (e.g. blue). In this case the protrusions are configured to form line elements arranged to convey the number “10”. The line elements are surrounded by a background formed of the opacifying base layer 29, which is white or off-white.

Figure 26 shows another embodiment in which the sizes of the two pigments are reversed. Thus, here the curable material 205 contains a first larger pigment 31 having a detection characteristic distinguishable from an opacifying layer (e.g. a contrasting visible colour such as green, and/or a fluorescent response), and a second smaller pigment 32 which here is the opacifying pigment. The cast structure, shown in Figure 26(b) is configured to include one or more protrusions 21 of sufficient size to accommodate both pigments 31, 32, the detection characteristics of which will be a mix of those of the two pigments. Preferably the first pigment 31 has characteristics which dominate the properties of the protrusions 21, e.g. a dark colour. The base layer 29, meanwhile, is sized so as to accommodate the second pigment 32 but substantially exclude the first pigment 31, and therefore exhibits the properties of the opacifying pigment only. The result is a detectable feature, such as an image of the digit “10” having image elements corresponding to the protrusions (e.g. green) against a surrounding opacified background (e.g. white). This is shown in Figure 26(c).

It will be appreciated that window or half-window regions could be added to the above embodiment by controlling the lateral extent of the base layer 29 such that the security device 10 does not extend over the whole substrate 2. The gravure-printed opacifying layers 2b, 2c will of course also need to be configured appropriately.

In a more complex embodiment, the security device 10 can itself be used to create both window/non-window regions, and features such as a contrasting image, as exemplified in Figure 27. Here, the curable material 205 applied to substrate 2 is the reverse of that used in the previous embodiment: its larger first pigment 31 is in a colour which will contrast with the opacifying layer, e.g. black, while it is the smaller second pigment 32 which is the opacifying pigment (e.g. white, off-white or grey). The binder 39 in this example must be transparent and is preferably colourless. The substrate 2 comprises a transparent polymer layer 2a and optionally an opacifying layer 2b on the opposite surface from that to which the security device 10 will be applied. The opacifying layer 2b, which typically will have been applied by gravure printing, is omitted over a region 110 which is to form a window region in the finished document, but is present elsewhere (non-window region 105).

The curable material 205 is cast into a surface relief structure 20 as shown in Figure 27(b), which is a cross-section along line Q-Q'. The surface relief structure 20 includes first and second sets of protrusions 21a, 21b as well as a base layer 29 of varying height. Coinciding with window region 105, the base layer 29a is arranged to be too thin to accommodate either the first or the second pigment, such that the security device 10 is transparent and does not obstruct the window region 105. Elsewhere, the base layer 29b is of a greater height which is able to accommodate the second, opacifying pigment 32 but not the first pigment 31. As such, this acts as an opacifying layer across the non-window region 105 of the document.

Within the non-window region 105, on the base layer region 29b, a first set of protrusions 21a is provided which are sized to accommodate both the first pigment 31 and the second pigment 32. The colour of the first pigment 31 is selected to contrast with the opacifying pigment and to dominate the appearance of the first protrusions 21a, which are configured to form an image such as the number “10” in this example. A more complex image such as the multitonal image in Figure 5 could of course be constructed instead. This appears against an opacified white or off-white background provided by base layer region 29b. In the window region 110, on the transparent base layer region 29a, a second set of protrusions 21b is provided which are sized so as to accommodate the second pigment 32 but not the first pigment 31. The second protrusions 21a are arranged to create a design which will be visible in the window region 110 and may mimic existing gravure-printed window designs, appearing to form an extension of the opacifying layer or a separate image such as a portrait (e.g. a cameo portrait) within the window. Optionally, first protrusions 21a could also be provided in the window region 110 to create a more complex, two-coloured design.

The Figure 27 embodiment also demonstrates how the surface relief structure 20 might be used to reveal an underlying feature such as a security element 150 whilst also acting as a protective layer. Figure 27(d) shows a cross-section along line R-R’ through document 100, intersecting security element 150, which could be any type of security device such as a print or an applied element such as a foil, stripe or patch. The element 150 could for instance be a diffractive (e.g. holographic) foil applied to the substrate 2a by stamping or a transfer method, or formed directly on the substrate 2a. The surface relief structure 20 includes a zone 112 of reduced height 29a within which the opacifying pigment 32 cannot be accommodated, and therefore the cured material is locally substantially transparent. The security element 150 is therefore visible through the cured material in the zone 112, which nonetheless acts as a protective layer for the security element 150. It will be appreciated that the zone 112 need not encompass the whole of security element 150, provided that some portion of the security element is located within the zone 112. The zone 112 may or may not coincide with a window region of the security document – in the example shown, the zone 112 is in a non-window region with the opacifying layer 2b on the other side of the substrate continuing across the relevant area.

It should be appreciated that in variants of this embodiment the security device might include only first protrusions 21a or only second protrusions 21b – in the latter case, the curable material would typically comprise only an opacifying pigment and no additional coloured pigment. It is also possible to create more complex effects by providing the curable material with three or more pigments as discussed in previous embodiments.

A still more complex embodiment is shown in Figure 28. Here, the curable material 205 comprises three pigments 31, 32, 33 in a colourless binder 39. The first pigment 31 is of a first colour (e.g. green), the second pigment 32 is of a second colour (e.g. orange) and the third pigment 33 is an opacifying pigment (e.g. white). The first pigment 31 is the largest (e.g. 5 μm), and the third (opacifying) pigment 33 the smallest (e.g. 1 μm), with the second pigment 32 having an intermediate particle size (e.g. 4 μm). Preferably the first colour is a stronger colour than the second colour. As shown in Figure 28(b), the cast structure includes areas of different height. A base level of opacity is provide by base level areas 29a, which have a first height sufficient to accommodate the third pigment 33 but not the first or second pigments 31, 32 (e.g. 3 μm). These areas therefore appear opacified (e.g. white). In other areas 29e, the base layer has a lower height which is still able to accommodate the third pigment (only) but the lesser thickness results in higher translucence than in areas 29a (e.g. 2 μm). Such areas may appear as a watermark type effect in transmitted light. The device is also provided with one or more areas 29d in which the base layer is so thin that the concentration of the third pigment is substantially zero (e.g. less than 1 μm), with the result that the area 29d of the surface relief structure appears transparent and therefore creates a window region of the security document.

Elsewhere, on top of the base layer area 29a, the structure 20 includes one or more first protrusions 21a and one or more second protrusions 21b. The first protrusions 21a are sufficiently large as to accommodate both the first and second pigments 31, 32 (e.g. 20 μm wide) and therefore exhibit a mixed detection characteristic, preferably dominated by that of the first pigment (e.g. appearing green). The second protrusions 21b are smaller (e.g. 4 to less than 5 μm wide) and unable to accommodate the first pigment 31 but do contain the second pigment 32. As such these exhibit the detection characteristic of the second pigment 32 (e.g. orange).

The protrusions 21a, 21b can be configured for example to display a multi-coloured feature 90, e.g. a multi-tonal image as shown best in the plan view of Figure 28(c). Preferably this is located in a non-window region 105 of the document, although it could extend into (or be located in) a half-window region or a window region as well. Figures 28(c) and (d) also show an example of a pseudo-watermark feature 120 formed by providing a region in which the base layer 29e is of reduced height, and a window region 110 where the base layer height is reduced still further.

In each of the embodiments of Figures 23 to 28, a cast structure has been used to form an opacifying layer on one side of a document substrate. The other side of the document structure may be provided with a conventional opacifying layer (e.g. formed by gravure printing) or may also be provided with an opacifying layer formed by the presently disclosed techniques. An example in which this is the case is shown in Figure 29. Here, Figure 29(a) shows the security document before casting takes place, and Figure 29(b) after. For simplicity, here the two curable materials 205-1, 205-2 are depicted as existing on opposite sides of the surface in uncured form at the same time, although this may not be the case. As explained below, if both sides of the substrate are to carry a surface relief structure formed of cured material, these are may be formed sequentially or simultaneously.

The first curable material 205-1 is of the sort described with reference to Figure 27(a) above and comprises a first pigment 31 (e.g. black) which is larger than a second pigment 32, which is the opacifying pigment. The second curable material 205-2, applied to the opposite surface of the substrate, comprises an opacifying pigment 33 only, as in the examples of Figures 23 and 24. Both curable materials comprise a clear binder 39-1, 39-2, preferably colourless. The curable materials 205-1 and 205-2 are cast into respective surface relief structures 20-1, 20-2. The first relief structure 20-1 has the form already described in relation to Figure 27 and includes a window region in which the page layer 29a excludes both pigments, as well as a non-window region 29b and features defined by protrusions 21a, 21b in which one or both pigments are present. The second relief structure 20-2 has a corresponding window region 29f in which no pigment is present, surrounded by a non-window region in which the height of the base layer varies between three different levels 29g, 29h, 29i so as to give rise to a watermark-like feature visible in transmitted light. It will be appreciated that many different configurations are possible and the two surface relief structures 20-1, 20-2 on opposing sides of the substrate 2a could be the same or different from one another. The curable materials 205-1, 205-2 could also be the same as or different from one another.

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Figures 30(a), 30(b) and 30(c) schematically show three examples of suitable apparatus by which the embodiment of Figure 29 could be manufactured. Figure 30(a) illustrates an arrangement for sequentially casting two surface relief structures 20-1, 20-2 on opposing sides of a substrate 2 (which here is in the form of a sheet, and may consist of the core substrate 2a only or could already carry one or more opacifying layers 2b). This may be described as forming the structures in-line in the same pass. The arrangement generally comprises a first print and cast module 410 and a second print and cast module 420. A curable material 205 is first applied to a first side of the sheet substrate 2 as it passes through a nip formed by screen print cylinder 411a and intermediate roller 412a.

However, as previously discussed, other printing techniques such as lithographic, flexographic, offset or inkjet printing could also be used. The sheet 2 is then conveyed to casting tool 421a in the form of a cylinder defining the shape of a surface relief structure which is to be cast into the curable material 205. Having been formed into the desired surface relief structure, the curable material 205 is cured by exposing it to appropriate curing energy such as UV radiation from source 222. This preferably takes place while the curable material is in contact with the surface relief 225 although if the material is already sufficiently viscous this could be performed after separation.

The sheet substrate 2, now carrying the cured first surface relief structure 20-1, is the conveyed to the second print and cast module 420. In a similar manner, a curable material 205 is applied to the second side of the substrate as it passes through nip formed between intermediate roller 412b and second screen print cylinder 411b. The substrate is then conveyed to second casting tool 412b where the curable material is formed into the desired second surface relief and cured via radiation source 222. The substrate 2, now carrying both surface reliefs 20-1 and 20-2 is then conveyed away from the second print and cast module 420 via transfer roller 413.

It is also possible for the surface relief structures to be applied to the opposite surfaces of substrate simultaneously, that is, at the same point along the transport path in the machine direction.

Figure 30(b) shows an example of this in the case where the surface relief structures 20-1, 20-2 are applied to the first and second surfaces, respectively, of a document substrate 2, which in this case is in the form of a web. However the same principles can be applied to the construction of an article such as a security thread, in which case the web substrate 2 will be replaced by some other, typically thinner, transparent film. For clarity, Figure 30(b) depicts only selected components of the apparatus used to form the surface relief structures. Uncured curable material 205 is applied to the first 3a and second 3b surfaces of the web 2 by inkjet printing 250 (although alternative printing processes may be used). The uncured material on the web is transferred along the machine direction MD towards first casting tool 221a and a second casting tool 221b. The first casting tool 221a and second casting tool 221b are arranged on opposite sides of the transport path along which the substrate 2 is conveyed, so as to form a (low pressure) nip through which the substrate 2 passes. At each location along the substrate 2, its first surface 3a therefore comes into contact with the first casting tool 221a at the same time as its second surface 3b comes into contact with the second casting tool 221b. The curable material is cured by radiation from UV lamps 222 located within each casting tool. Thus, the casting tools are made of a UV-transparent material such as quartz such that the curable material may be cured through the tools. As a result, the surface relief structures 20-1, 20-2 are formed on each point of the substrate simultaneously.

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This has the significant advantage that any deformation experienced by the substrate 2, as a result of changes in processing temperature or the like, will be exactly the same when each of the surface relief structures is applied. The substrate has no time to expand or contract between the instants at which the two surface relief structures are applied, since they occur at the same time. As such, a very high degree of register between the two components is automatically achieved.

The arrangement shown in Figure 30(b) has the disadvantage that since the nip between the two casting tools 221a, 221b constitutes the first point of contact between the substrate and the casting tools, the curable material from which the surface relief structures are formed will be substantially uncured when it enters the nip. As such, the pressure applied between the first casting tool 221a and the second casting tool 221b should be low so as to avoid damage to the cast structures.

Figure 30(c) shows an improved arrangement in which formation of the surface relief structures on opposing sides of the substrate can still be considered simultaneous because the curable material is still in contact with the surface reliefs of the casting tools 221a, 221b at the nip location between the two. The substrate 2 is wrapped around a portion of the first casting tool 221a from a first point at lay on roller 61, at which casting of the first surface relief structure 20-1 begins, until the nip with second casting tool 221b at which point the first surface relief structure 20-1 will be relatively well cured, preferably fully cured. As such, the pressure between the two components 221a, 221b can be increased relative to that in the Figure 30(a) embodiment since the material of the first surface relief structure is relatively hard and less prone to damage. This improves the quality achieved in the formation process. A further benefit of the arrangement shown is the increased wrap length of the substrate 2 around second casting tool 221b, allowing for prolonged curing here also. The substrate 2 stays in contact with second casting tool 221b from the nip location until take-off roller 62.In all of the embodiments above, the detection characteristic of each pigment has been a visible colour. However, this is not essential and in all embodiments the relevant characteristic could be anything which is detectable either by sight, by touch and/or by machine. The detection characteristic may or may not be exhibited by the pigment under all conditions – for instance, it may be revealed only in the presence of a certain stimulus such as particular illumination or heating. In general terms, the detection characteristic could for instance be any of:

an optical characteristic, preferably visible colour, luminescent colour and/or wavelength-specific absorption or emission properties (e.g. a UV or IR response);

a magnetic characteristic;

an electrical characteristic, preferably conductivity or anti-static; and

a tactile characteristic.

For instance, in any of the embodiments disclosed herein, the first pigment 31 and/or the second pigment 32 (if provided), as well as any further pigment(s) could comprise any of:

a pigment with a body colour which is visible to the naked eye under white light illumination;

a pigment which visibly or invisibly luminesces in response to a non-visible wavelength, preferably UV illumination (examples are disclosed in WO-A-2004/050376, WO-A-2018/206936 and WO-A-2020/030893);

a pigment which absorbs a non-visible wavelength, preferably IR illumination (e.g. an IR up-converter);

a photochromic or thermochromic pigment;

a metallic pigment;

an optically variable pigment (optionally magnetic), preferably comprising a thin-film interference pigment, a pearlescent pigment or a liquid crystal pigment (examples are disclosed in WO-A-2011/092502);

a plasmonic pigment, preferably exhibiting a visible colour

an electrically conductive pigment, preferably graphite, metal, metal alloy or carbon black;

an anti-static pigment (typically these are not ohmic conductors, but do transmit some static charge);

an opacifying pigment which is preferably white, off-white or grey under white light illumination, the opacifying pigment most preferably comprising titanium dioxide;

a magnetic or magnetisable pigment; and

a tactile pigment such as silica or another hard substance.

Of course, each pigment could also have any combination of the above properties.

As an example, if in the Figure 4 embodiment the first pigment 31 were metallic, the image of the number “10” would appear in a metallic colour with an inherent reflective quality apparent on tiling the device, e.g. gold, silver or bronze. Similarly if the first pigment were formed of a optically variable ink which exhibits different colours at different viewing angles, the number “10” would also appear optically variable, e.g. changing between red and green at different angles of view. Likewise the first pigment 31 could have no body colour but visibly luminesces in response to UV illumination, in which case the image of the number “10” would not be visible under standard white lighting, but would become visible when irradiated with the appropriate UV wavelength. For instance, the first pigment may emit green light when so illuminated.

Some particularly preferred implementations using pigments which respond to or absorb certain non-visible wavelengths will be described with reference to Figures 31, 32 and 33.

In the Figure 31 embodiment, the curable material 205 applied to substrate 2 comprises a homogeneous mix of a first pigment 31 and a second pigment 32, both of which are responsive to a UV waveband and will emit visible light when so illuminated. The first pigment 32 has a larger average size than the second pigment 32. Both the first and second pigments have substantially the same appearance under visible (white) light – for instance they may both be colourless, or may both exhibit substantially the same visible colour as one another (e.g. grey). However, each pigment has a different response to UV illumination. For instance, the first pigment 31 may emit yellow light when excited and the second pigment 32 may emit blue light when excited. The binder 39 is preferably not responsive to UV, and may be colourless or tinted.

The material 205 is cast into the structure shown in Figure 31(b), having first protrusions 21a which can accommodate both the first and second pigments 31, 32 and second protrusions 21b which can accommodate only the second pigment 32. The base layer 29 is sized to exclude both pigments. The appearance of the security device 10 in plan view under standard visible (white) light illumination is shown in Figure 31(c)(i) – both sets of protrusions, which are configured to form the digits “1” and “0” respectively of the number 10, have the same appearance as one another, and may be visible or invisible. When the illumination conditions are changed to UV radiation of the appropriate wavelength (Figure 31(c)(ii)), both sets of protrusions undergo a change in appearance and exhibit different emitted colours. The first set of protrusions 21a, forming the digit “0” appears green due to a combination of the blue and yellow light emitted by the two pigments 31 and 32. The second set of protrusions 21b, forming the digit “1” appears blue due to the second pigment 32. This apparent change from an invisible or single-colour device to a two-colour device offers a particularly high security level.

The variant shown in Figure 32 is of substantially the same construction but here the first and second pigments each have a different visible colour from one another as well as different UV responses. For instance, here the first pigment 31 may have a visible yellow colour and blue emission under UV illumination while the second pigment 32 may appear blue under standard visible lighting and emit red under UV. As shown in Figures 32(c)(i) and (ii), under visible illumination the image of the number “10” is therefore formed of a blue digit “1” and a green digit “0” (resulting from the combination of blue and yellow pigments). Under UV illumination, both areas undergo a colour change, with the digit “1” now appearing red and the digit “0” purple (resulting from the combination of blue and red emissions).

In the Figure 33 embodiment, variations in the pigments’ IR absorption is utilised instead of a luminescent response. The construction is the same as in the previous embodiment but here the first pigment 31 is absorbent to IR radiation whereas the second pigment 32 is not. Preferably both pigments have the same appearance in the visible spectrum. Hence when the device is viewed at a visible wavelength (e.g. by the human eye), as shown in Figure 33(c)(i), both digits “1” and “0” have the same appearance as one another, be it invisible or coloured. However, when the device is viewed at the appropriate IR wavelength (using a suitable camera), the difference in absorption becomes apparent as shown in Figure 33(c)(ii).

Suitable substances for use as the first and/or second pigment include any luminescent, fluorescent or phosphorescent substance, or a material which exhibits Raman scattering, for example. Exemplary phosphors can be any compound that is capable of emitting IR-radiation upon excitation with light. Suitable examples of phosphors include, but are not limited to, phosphors that comprises one or more ions capable of emitting IR radiation at one or more wavelengths, such as transition metal-ions including Ti-, Fe-, Ni-, Co-and Cr-ions and lanthanide-ions including Dy-, Nd-, Er-, Pr-, Tm-, Ho-, Yb- and Sm-ions. The exciting light can be directly absorbed by an IR-emitting ion. Acceptable phosphors also include those that use energy transfer to transfer absorbed energy of the exciting light to the one or more IR-emitting ions such as phosphors comprising sensitizers for absorption (e.g. transition metal-ions and lanthanide-ions), or that use host lattice absorption or charge transfer absorption. Acceptable infrared emitting phosphors include Er-doped yttrium aluminium garnet, Nd-doped yttrium aluminium garnet, or Cr-doped yttrium aluminium garnet.

Another type of pigment that can be used is a direct bandgap semiconductor, for example a group II-VI (e.g. ZnO, ZnS, ZnSe, CdS, CdTe, CdSe etc) or a group II-V (eg GaN, GaAs, AlN, InN etc) semiconductor can show strong luminescence. Another alternative is nanostructured materials (e.g. such as metallic, semiconductor and dielectric materials and combinations thereof), which can show many different types of luminescence such as fluorescence, phosphorescence, elastic and inelastic scattering.

A particularly preferred pigment suitable for use in implementations of the invention is Er-Yb-$KGd(PO_3)_4$ (also known as Er-Yb-KGP). Er-Yb-KGP strongly absorbs in the infra-red portion of the electromagnetic spectrum between about 960 nm and 990 nm. After being excited by appropriate illumination including this waveband, Er-Yb-KGP emits radiation across a range of wavelengths in the infra-red portion of the electromagnetic spectrum and is strongest between about 1520 nm and 1560 nm. A suitable detector sensitive to this range can therefore be used to confirm the presence and spatial arrangement of this pigment.

While in each of the cases described above, a single curable material 205 and corresponding surface relief structure 20 formed thereof have been provided, it is also possible to form security devices with multiple different curable materials and corresponding surface relief structures. Each will have the properties exemplified above. Figure 34 shows an example. Here, two curable materials 205, 206 each comprising a homogenous dispersion of a respective first pigment 31, 51 in a binder 39, 59 are applied to laterally offset regions of the substrate 2, as shown in cross section in Figure 34(a) and in plan view in Figure 34(c). For instance, the first pigment 31 in curable material 205 may be a blue pigment while the first pigment 51 in curable material 206 may be a red pigment. In this case the two pigments may be of substantially the same average size and/or shape but this is not essential. The two curable materials are cast using a common casting tool 225, shown in plan view in Figure 34(d), so as to form respective surface relief structures 20, 40 which may or may not abut one another. In this example each of the surface relief structures is similar to that shown in Figure 4. Thus the first surface relief structure 20 comprises a set of protrusions 21 which accommodate the first pigment 31 of curable material 205 and a base layer 29 which excludes it. Likewise the second surface relief structure 40 comprises a set of protrusions 41 which accommodate the first pigment 51 of curable material 206 and a base layer 49 which excludes it. This results, as shown in Figure 34(c) in a security device 10 having blue protrusions 21 forming the digit “1” and red protrusions 41 forming the digit “0”.

In variants, each of the curable materials 205, 206 could comprise any permutation of pigments, such as:

- Different pigment detection characteristics (e.g. colour) with the same size (as above);
- Different pigment detection characteristics (e.g. colour) with different sizes;
- Same pigment detection characteristics (e.g. colour) of same size; or
- Same pigment detection characteristics (e.g. colour) with different sizes.

It is also possible for each of the curable materials 205, 206 to contain two or more different pigments and/or to utilise more complex surface relief structures such as any of those described in the preceding embodiments.

In many of the previous embodiments, the surface relief structures 20 have been configured such that the protrusions are on a scale such that they are individually discernible to the naked eye, at least under close inspection. However, in other cases it may be desirable to arrange the structure to have a smaller scale so that individual elements are not resolvable but act together to give an area of the security device a certain detection characteristic (e.g. colour). An example of this is shown in Figure 35. Here the curable material 205 comprises a first pigment 31 which is yellow and a smaller second pigment 32 which is cyan. The curable material 205 therefore appears uniformly green when first applied (Figure 35(c)).

The cast structure is shown in Figure 35(b) and it will be seen that this is divided into four regions $R_1 \ldots R_4$, each with a different sub-structure corresponding to a certain pattern of protrusions. Each protrusion may for example be a line element of width less than 100 μm, preferably much smaller. In the first region R_1, only second protrusions 21b are provided at a narrow lateral repeat spacing s_1. The second protrusions 21b are sized to accommodate the second pigment (cyan) 32 but not the first. Thus to the naked eye, region R_1 appears uniformly blue (since the protrusions cannot be resolved). Likewise, in second region R_2 only second protrusions are present but at an increased spacing s_2 from one another, with the result that this region also appears uniformly blue but in a lighter shade than region R_1 since the proportion of area covered by the protrusions 21b is less.

In the third region R_3 a (periodic or aperiodic) pattern of first and second protrusions 21a, 21b is provided, the first protrusions 21a being able to accommodate both pigments and hence appearing predominantly yellow (in this case a strong yellow pigment is selected). In combination with the second protrusions 21a, this region R_3 therefore appears a uniform green colour. Finally in the fourth region R_4, only first protrusions 21a are present and the region therefore appears yellow. In this way, as shown in Figure 35(e) the security device 10 exhibits a gradual change in colour from left (blue) to right (yellow), through green in the middle. Of course, a more discrete (stepwise) colour change could be deployed if desired.

The presently disclosed techniques can also be used in combination with other components to make more complex security devices, such as optically variable devices. In one class of such devices, the disclosed surface relief structure could be combined with some form of optical element, such as one or more lenses, prisms, mirrors or caustic elements. For example, the disclosed surface relief structures 20 could be configured to form image arrays for optically variable devices such as moiré magnifiers and lenticular devices. This is particularly advantageous since the placement of different colours can be controlled via the mechanism described above rather than attempting to register different colours of ink or other materials accurately to one another which is very difficult at the small scale required to form such image arrays. There are also benefits in terms of the level of resolution that can be achieved – this method can produce finer coloured line structures than traditional print methods as there is no ink spread or edge roughness as would be the case with contact printing technologies such as lithograhic, flexographic and gravure printing.

Figure 36 shows an example of a lenticular device having an image array formed in this way. The cured material 20a is of a sort described above, having a first pigment 31 and a smaller second pigment 32 with different detection characteristics. For instance the first pigment 31 may be yellow and the second pigment 32 may be cyan. The material is cast into a surface relief structure 20 which defines the desired image array. Preferably this is constructed from some first protrusions 21a which accommodate both pigments 31, 32 (and hence may appear yellow or green, in this case) and some second protrusions 21b which only accommodate the second pigment 21b (and hence may appear blue). The base layer 29 preferably excludes both pigments and is colourless. The protrusions are arranged to form slices of one or more images and are positioned on a regular 1D or 2D grid. Typically the width of the protrusions will be small e.g. 80 µm or less. A focussing element array 300 is provided on the opposite side of the (transparent) substrate 2, with matching periodicity to the image slices. In this example, the device has two areas A_1 and A_2. In area A_1, image slices formed of second protrusions 21b are located in line with the left half of each lens and in area A_2, image slices formed of first protrusions 21a are located in line with the right half of each lens. When the device is viewed through the lenses from the position of observer O_1, each lens will direct the left half of its footprint to the viewer with the result that the first area A_1 will appear blue (in this case), while the second area A_2 will appear colourless. On changing to the viewing position of observer O_2, the appearance of the device will switch, with area A_1 now appearing colourless and area A_2 now appearing yellow/green.

Moiré magnifier devices can be of a similar construction to that shown in Figure 36, but the protrusions 21 would be configured to form an array of microimages. The pitch and/or orientation of the microimage array would be mismatched with that of the focussing element array 300 (which may comprise 1D or 2D lenses for instance) so as to give rise to a synthetically magnified image via the moiré effect.

The disclosed security device could alternatively or in addition be combined with other components such as a decorative layer, e.g. formed by a conventional technique such as printing or metallisation. Such a decorative layer could be on the same side of the substrate 2 as the surface relief structure 20 and/or on the opposite side, and may overlap the surface relief structure, or be laterally offset (e.g. spaced, partially overlapping, abutting or interleaved). The surface relief structure and the decorative layer could be configured so that together they exhibit a combined image CI. A specific example is shown in Figure 37. Here, the surface relief structure 20, formed for instance as described with reference to Figure 4 above (or any of the other embodiments), is disposed on a first surface of substrate 2 (which is at least translucent). The surface relief structure 20 carries a first pigment (e.g. cyan) which is present only in protrusions 21 and not in the base layer 29 using the mechanism disclosed above. The protrusions 21 are configured both laterally and in terms of their height so as to exhibit one colour working of a muticolour image, here a portrait. This can be achieved through varying the size, shape and/or spacing of the protrusions and/or their height (which in turn affects their colour density as mentioned previously).

On the opposite surface of the substrate, a decorative layer 350 is provided, preferably in register with the surface relief structure 20. In this example, the decorative layer 350 is a print layer, formed for instance by any of lithographic, flexographic, offset, screen or inkjet printing. However in other examples, the decorative layer could be a patterned layer of metal or any other material, which might be formed via a etch process for instance. The decorative layer 350 provides further contributions to the desired image, here in the form of further colour workings of the portrait. For example, the decorative layer 350 may comprise magenta (M), black (K) and yellow (Y) workings of the same portrait, which together with the cyan (C) working provided by the surface relief structure 20 give rise to a full colour combined image CI, as shown in plan view in Figure 37(b). Figure 37(c) shows the various components separated for clarity. It will be appreciated that in variants of this idea, the surface relief structure 20 could comprise more than one pigment (using the principles disclosed above) and could therefore provide more than of the colour workings.

The surface relief structures disclosed herein can also be used to form other types of optically variable device such as latent or transient images, e.g. "venetian blind" or "hide-and-reveal" type devices. For instance, raised elements of the surface relief can be utilised to conceal other features at oblique viewing angles. Figures 38 and 39 show two examples. In the Figure 38 embodiment, as shown in the cross section of Figure 38(a), the surface relief structure 20 comprises a series of raised protrusions 21 spaced along a base layer 29 of the cured material. The composition of the cured material and the dimensions of the cast structure are such that the protrusions 21 accommodate at least one pigment rendering them of increased optical density, while the base layer 29 does not such that it remains transparent or at least translucent. For instance the protrusions may be grey while the base layer 29 is colourless. The surface relief structure 20 is disposed on a graphics layer 80 located between the structure 20 and substrate 2, e.g. formed by lithographic or flexographic printing. In this example the graphics layer 80 displays a first image I_1 in the form of a star.

When the security device 10 is viewed along the normal to the substrate from the position of observer O_1, the graphics layer 80 is visible through the gaps between protrusions 21 and hence the device exhibits the first image I_1 as shown in Figure 38(b)(i). When the security device is tilted so that it is viewed at an off-axis angle from the position of observer O_2, the view of the graphics layer 80 is obstructed by the protrusions 21 and now the device appears uniformly grey (image I_2) as shown in Figure 38(b)(ii). The device can be switched between the two appearances I_1, I_2 by tiling or otherwise changing the viewing angle.

Another example is shown in Figure 39. This operates on the same principles but here the first image I_1 is provided by the surface relief structure 20 itself, so no graphics layer is required. The surface relief structure 20 includes a first set of protrusions 21a as before, sized to receive at least a first pigment (e.g. grey). In some of the spaces between the first protrusions 21a, second protrusions 21b are provided which are shorter than the first protrusions 21a. The second protrusions may contain the same pigment(s) as the first protrusions or may be sized so as to contain a different pigment or pigment mix. For example, in this case the first protrusions are grey while the second protrusions are black. The second protrusions may be laterally configured so as to display an image (e.g. the letters DLR in this case), or could be a set of line elements for instance (effectively an image which is a uniform block of colour). When the device is viewed along the normal from the position of observer O_1, the image I_1 formed by the second set of protrusions 21b is visible in the gaps between the first protrusions 21a such that the image I_1 (here “DLR”) is visible, as shown in Figure 39(b)(i). When the security device is tilted so that it is viewed at an off-axis angle from the position of observer O_2, the view of the graphics layer 80 is obstructed by the protrusions 21 and now the device appears uniformly grey (image I_2) as shown in Figure 39(b)(ii). The device can be switched between the two appearances I_1, I_2 by tiling or otherwise changing the viewing angle.

Suitable apparatus, materials and methods for forming the relief structures disclosed herein are described in WO-A-2018/153840 and WO-A-2017/009616. In particular, the relief structures can be formed by the in-line casting devices detailed in WO-A-2018/153840 (e.g. that designated 80 in Figure 4 thereof), using an embossing tool 85 carrying an appropriately designed micro-optical structure from which can be cast the desired relief structure shape. Similarly, the cast-curing apparatuses and methods disclosed in section 2.1 of WO-A-2017/009616 (e.g. in Figures 4 to 8 thereof) can also be used to form the presently disclosed relief structures, by replacing the relief 225 carried on casting tool 220 with an appropriate relief from which can be cast the desired shapes. In particular it will be noted that whilst WO-A-2017/009616 describes the use of the apparatus to form focussing elements, the same apparatus can be used to form any desired relief structure by appropriate reconfiguration the relief 225, including that envisaged herein.

Whichever casting apparatus is used, the curable material(s) from which the relief structure is cast may be applied either directly to the tool carrying the desired relief shape (e.g. to the embossing tool 85 of WO-A-2018/153840 or to the casting tool 220 of WO-A-2017/009616), or the curable material(s) may be applied directly to the substrate on which the relief structure is to be formed, and then brought into contact with the tool (e.g. by impressing the tool onto the deposited curable material). Both options are described in the aforementioned documents. Preferably, the latter option is employed and the curable material(s) are applied to the substrate by screen printing as detailed in WO-A-2018/153840, before being formed into the desired relief structure. If the former option is employed, it should be noted that there is preferably no wiping of the casting tool surface relief between applying the curable material to it, and bringing it into contact with the substrate, so that a base layer of curable material remains connecting the protrusions of the relief structure together on the substrate (the base layer will be of much lesser height than the protrusions).

Suitable curable materials are disclosed in WO-A-2017/009616, section 2.1. UV-curable materials are most preferred. Curing of the material(s) preferably takes place while the casting tool is in contact with the curable material, against the substrate. In all of the above embodiments, the transparent curable material in which the surface relief structure 20 is formed comprises a binder 39 which can be of various different compositions. The binder 39 is preferably radiation-curable and may comprise a resin which may typically be of one of two types, namely:

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a) Free radical cure resins, which are typically unsaturated resins or monomers, pre-polymers, oligomers etc. containing vinyl or acrylate unsaturation for example and which cross-link through use of a photo initiator activated by the radiation source employed e.g. UV.

b) Cationic cure resins, in which ring opening (e.g. epoxy types) is effected using photo initiators or catalysts which generate ionic entities under the radiation source employed e.g. UV. The ring opening is followed by intermolecular cross-linking.

The radiation used to effect curing will typically be UV radiation but could comprise electron beam, visible, or even infra-red or higher wavelength radiation, depending upon the material, its absorbance and the process used. Examples of suitable curable materials include UV curable acrylic based clear embossing lacquers, or those based on other compounds such as nitro-cellulose. A suitable UV curable lacquer is the product UVF-203 from Kingfisher Ink Limited or photopolymer NOA61 available from Norland Products. Inc, New Jersey.

In each implementation, the size of the pigment(s) provided in the curable material may be selected not only based on the desired outcome of the above casting process (and hence on the dimensions of the structure to be cast), but also on the technique by which the curable material is to be applied to the substrate or casting tool, and/or taking into account the need for the pigment(s) to be able to freely move in the uncured binder. In preferred examples, the first pigment and/or the second pigment, if provided, has an average size between 0.001 µm and 500 µm, preferably between 0.05 µm and 150 µm, more preferably between 0.1 µm and 50 µm, most preferably between 1 µm and 10 µm. If the pigment shape departs significantly from spherical, it is typically the smallest dimension (F_{MIN}) which is of relevance, since this will determine whether there is an orientation in which the pigment can access a part of the relief structure of certain dimensions. Typically the curable material will be applied to the substrate or casting tool via a printing technique. Small pigment sizes will be suitable for application by many techniques, including inkjet printing and gravure printing, whereas larger pigment sizes may require specialised techniques such as screen printing.

The pigment(s) could have various shapes but preferably the first pigment and/or the second pigment, if provided, has a non-platelet average shape, the largest dimension of an individual particle preferably being no greater than 150% of the smallest dimension of the same particle, on average. Platelet (or flake-like) pigment shapes are disadvantageous when used with the presently disclosed technique since their out-of-plane dimension is much smaller than their in-plane dimensions, making it difficult to accurately control their placement. Pigments having shapes which are closer to spheroids are preferred since their ability to fit into a certain space will not depend significantly on their orientation. As discussed above, where one or both of a pair of pigments deviates significantly from spherical, their “average size and/or shape” is considered to be different if at least one of the average Feret maximum diameter (F_{MAX}) and the average Feret minimum diameter (F_{MIN}) differs between the two pigments. Preferably, the average Feret minimum diameter (F_{MIN}) will be different between the two pigments since in many cases it is this which can determine whether a particle will fit within a certain space or not. In preferred cases, the F_{MIN} of the larger pigment is greater than the F_{MAX} of the other.

As already mentioned, in practice any pigment sample is made up of a multitude of pigment particles which will have a range of sizes and shapes. Figure 42 shows a schematic size distribution curve for an exemplary TiO_2-based pigment, typically used as an opacifying pigment. It will be seen that this approximates to a normal distribution curve, in this case having an average diameter of around 0.3 to 0.4 µm (note the logarithmic scale on the x-axis). However, the sample will also contain small amounts of much smaller particles (e.g. 0.1 µm) and much larger particles (e.g. 1 µm or more). Hence where “average” parameters are referred to above, it is meant the average of that parameter over the distribution for the pigment in question, typically calculated as the D50 average value for the distribution (i.e. the median diameter or medium value of particle size distribution - it is the value of the particle diameter at 50% in the cumulative distribution). It will be appreciated that the distribution curves for different pigments can vary not only in terms of the absolute values (e.g. the average size) but also in terms of their width (e.g. how big the size variation within any one pigment type is). Pigments with narrow distribution curves are generally preferred for use in the present invention, since their placement can be more accurately controlled using the presently disclosed techniques.

Examples of pigments which could be used in embodiments of the invention include:

- Kronos™ 2064, from Kronos International Inc of Leverkusen, Germany. This is a white pigment based on TiO_2 having the size distribution shown in Figure 42, and an average size of around 0.3 to 0.4 μm.
- Stanlux™ Gold 12000, from Aldoro of Rio Claro, Brazil. This is a bronze metallic pigment available in a variety of shades, having an average particle size of 16 μm.
- Hostajet™ pigment range, from Clariant Group of Muttenz, Switzerland. This is a range of pigments designed for use in inkjet inks. Examples suitable for use in the presently disclosed devices include:
    - Hostajet™Yellow 4G-PT, average particle size 100 nm
    - Hostajet™ Red D3G-PT VP 5121, average particle size 170 nm
    - Hostajet™ Magenta ESB-PT, average particle size 80 nm
    - Hostajet™ Magenta E-PT, average particle size 70 nm
    - Hostajet™ Cyan BG-PT, average particle size 80 nm
    - Hostajet™ Black O-PT, average particle size 70 nm
- Natural pigment range, available from Natural Pigments Inc, of Burk, Germany. These are mineral-based pigments typically used in paints and the like. Examples suitable for use in the presently disclosed devices include:

    - Volkonskoite. This is a green pigment of average particle size 12 µm
    - Cadmium Red Light. This is a red pigment of average particle size 0.9 µm
    - Azurite. This is a blue pigment of average particle size 25 µm
- OVI™ and SPARK™ pigment ranges, available from SICPA of Lausanne, Switzerland. These are optically variable pigments some of which include magnetisable layers. Some examples are detailed in WO-A-02/073250 and include flake-like particles having average sizes of 20 to 30 µm in the plane of the flake and around 1 µm in the thickness dimension.
- Quantum dot fluorescent pigments such as those disclosed in US-A-2004/0233465, typically having pigment sizes in the range 2 to 6 nm (depending on colour).

In selecting the formulation of the curable material it may also be important to consider the end volume of each part of the structure to be cast, to ensure that there is sufficient space to accommodate the amount of each pigment which will be present. If the concentration of the first pigment in the homogenous, curable material is too high, then it may not be possible for all of the first pigment to fit into the parts of the structure designed to receive it, which will result in a poor quality end product. Likewise, if the concentration is too low, there may be insufficient pigment to fill the parts intended to receive it, again leading to an undesirable result. The correct concentration range can either be determined via appropriate calculations of the structure volume and space occupied by the pigments, or through testing. “Concentration” refers to the percentage of the pigment relative to the curable material as a whole, measured either by weight or by volume.

It is also important to consider the viscosity/rheology of the curable material, to allow for the free movement of the pigment(s) dispersed therein during casting. In preferred cases, at the point of bringing the substrate and the casting tool together, the curable material has a room temperature viscosity in the range 0.1 mPa.s to 3000 mPa.s, preferably 0.1mPa.s to 1000 mPa.s, more preferably 1 mPa.s to 500 mPa.s. Desirably the viscosity is low, so as to better allow for the movement of pigment.

Due to the nature of the cast-cure process, the resulting relief structure will typically include a base layer of material on top of the substrate, connecting the protrusions of the relief at their base. In many cases this base layer is integral with the relief structure and formed of the same curable material(s), resulting from either the shape of the casting relief and/or the manner in which the curable material is pressed between the substrate and the casting tool during processing. An example of such a base layer and its formation is disclosed in WO-A-2017/009619, Figure 8. It is also possible to provide (alternatively or in addition) a base layer in the form of a pedestal layer, applied in a preceding step. Apparatus and methods for providing such a pedestal layer are disclosed in WO-A-2017/09620, Figures 8 to 12.

WO-A-2018/153840 and WO-A-2017/009616 also disclose print stations, which may be disposed downstream of the above-described casting apparatus (but alternatively could be located upstream). Print stations such as these are suitable for applying print elements to the same side of the substrate as the cast relief structure, or to the opposite side. The apparatus disclosed in WO-A-2018/153840 can achieve particularly high registration between such cast relief structures and the printed elements.

Suitable substrates on which the disclosed devices can be formed are disclosed in WO-A-2017/009616, section 1, and apparatus/methods for applying opacifying layers thereto in section 4, including the formation of window regions. Preferably, the opacifying layers are applied before formation of the presently disclosed security devices on the substrate. For instance, the sheet material supplied to the apparatus of WO-A-2018/153840 may comprise a polymer substrate of the sort disclosed in WO-A-2017/009616, already provided with one or more opacifying layers. The security devices disclosed herein may be disposed in a window region defined by the opacifying layers, or in a non-window region.

One or both surfaces of the substrate 2 may be treated to improve adhesion / retention of subsequently applied materials (such as the curable material 205). For example, a primer layer may be applied to all or part of either surface of the substrate, e.g. by printing or coating. The primer layer is preferably also transparent and again could be tinted or carry another optically detectable material. Suitable primer layers include compositions comprising polyethylene imine, hydroxyl terminated polymers, hydroxyl terminated polyester based co-polymers, cross-linked or uncross-lined hydroxylated acrylates, polyurethanes and UV curing anionic or cationic acrylates. Alternatively or in addition to the application of a primer layer, the surface of the substrate may be prepared for onward processing by controlling its surface energy. Suitable techniques for this purpose include plasma or corona treatment. Figures 40(a) to 40(h) show some exemplary manners in which the security devices described above can be arranged in or on a security document 100. In the examples of Figures 40(a) to 40(f), the surface relief structure is formed on the document substrate 2 – i.e. it is cast in-situ onto the document substrate 2 (which may of course carry some intermediate layer so there may not be direct contact between the cast structure and the document substrate 2). Figure 40(a) shows a document substrate 2 having a window region 110 surrounded by a non-window region 105. The window region 110 is formed by local omission of the opacifying layers 2b, 2c on both sides of the transparent core 2a. The surface relief structure 20 is formed in the window region 110, so that the effect exhibited by the security device appears against transparent surroundings.

In Figure 40(b), the document substrate 2 is provided with a half-window region 115 surrounded by a non-window region 105. The half-window region 115 is formed by local omission of the opacifying layer 2c on the same side of the substrate as the surface relief structure 20, which is located in the half-window region. Figure 40(c) shows a variant in which the half-window region 115 is formed by local omission of the opacifying layer 2b on the opposite side of the substrate, instead of layer 2c. The appearance of the configurations shown in Figures 40(b) and 40(c) will be much the same, with the effect exhibited by the security device appears against surroundings which are more translucent than other parts of the document 100. It is also possible to provide the substrate 2 with a watermark or pseudo-watermark type feature, e.g. formed by patterning one or more of the opacifying layers such as exemplified in WO-A-2017/055823. The presently disclosed security device can be configured to interact with the watermark or pseudo-watermark if desired, e.g. together forming an aggregate image.

Figure 40(d) shows the security device formed in a non-window region 105 (as in most previous embodiments), and Figure 40(e) shows the security device having a portion located in a window region 110 and another portion located in a non-window region 105. More generally, the security device can be arrange to extend over any combination of window, non-window and half window regions. The arrangement of window regions may or may not be independent of the configuration of the surface relief structure 20 itself.

In Figures 40(f) to 40(g), the substrate 2 is a conventional fibrous substrate, such as paper. Figure 40(f) shows the security device formed on a non-window region of the substrate 2. Figure 40(g) shows the security device located over a window region 110, formed as an aperture through the substrate 2. The security device is carried on a secondary substrate 2’ affixed to substrate 2 over the aperture, which may be the substrate of a security article 1 such as a thread, strip or patch. Secondary substrate 2’ may comprise a transparent polymer film (e.g. PET). This will typically be thinner than a document substrate 2 (e.g. of the order of 30 to 50 microns thick rather than 100 microns or greater). The surface relief structure may be cast onto secondary substrate 2’ in a separate procedure to form a security article 1 which is later affixed to the document substrate 2 (e.g. by adhesive or via hot or cold stamping). Alternatively, the secondary substrate 2' may be affixed to the substrate 2 and then the surface relief structure 20 cast onto it. It is not essential for such a secondary substrate 2' to be located over an aperture. In other cases, such as is shown in Figure 40(h) the secondary substrate 2' could be located anywhere on the document substrate 2, including in a non-window region. It should be noted that secondary substrates 2' can also be used in conjunction with non-fibrous document substrates 2, such as polymeric substrates 2 of the sort described with reference to any of Figures 40(a) to 40(e), in which case again the security device may be located in a window region, a non-window region, a half-window region or any combination thereof.

Some preferred aspects of the invention are set out in the following clauses:

Clause 1. A security device, comprising:

a surface relief structure formed of a cured material, the cured material comprising a binder and dispersed therein at least a first pigment having a first optical characteristic, wherein the surface relief structure is configured such that part(s) thereof have dimensions sufficient to accommodate a first concentration of the first pigment and other part(s) have dimensions too small to accommodate the first concentration of the first pigment, and preferably too small to accommodate substantially any of the first pigment, whereby the optical characteristics of the surface relief structure vary across the surface relief structure in accordance with the dimensions thereof.

Clause 2. A security device according to clause 1, wherein the cured material further comprises a second pigment having a second optical characteristic, different from the first, wherein the first and second pigments have different sizes and/or shapes from one another, the surface relief structure preferably being further configured such that part(s) thereof have dimensions sufficient to accommodate a second concentration of the second pigment and other part(s) have dimensions too small to accommodate the second concentration of the second pigment, most preferably being too small to accommodate substantially any of the second pigment.

Clause 3. A security device according to clause 1 or 2, wherein the surface relief structure defines a plurality of protrusions which vary in height and/or width across the surface relief structure.

Clause 4. A security device according to clause 3, wherein the plurality of protrusions vary in height, the higher protrusions displaying a greater optical density than the lower protrusions as a result of their containing a greater volume of the first and/or second pigments than the lower protrusions.

Clause 5. A security device according to clause 3 or 4, wherein the plurality of protrusions vary in width, the concentration of the first pigment and/or the second pigment in each protrusion, and hence the optical characteristics of the cured material, depending on the width of the protrusion.

Clause 6. A security device according to any of the preceding clauses, comprising at least one protrusion having a width which reduces along the height of the protrusion, whereby the concentration of the first pigment and/or the second pigment varies along the height of the protrusion.

Clause 7. A security device according to any of the preceding clauses, wherein the surface relief structure includes a base layer, the base layer having dimensions such that the concentration of the first pigment and/or the second pigment is substantially zero in the base layer.

Clause 8. A method of manufacturing a security device, comprising:

providing a casting tool having a relief structure defined in a surface thereof;

applying a curable material to a substrate or to the relief structure of the casting tool;

bringing the substrate and the casting tool together, to thereby form the curable material in accordance with the relief structure and curing the curable material such that a surface relief structure formed of the cured material is retained on the substrate;

wherein the curable material comprises a binder and homogenously dispersed therein at least a first pigment having a first optical characteristic; and

the forming of the curable material causes the first pigment to become non-homogenously dispersed in the cured material whereby the optical characteristics of the surface relief structure vary across the surface relief structure in accordance with the dimensions thereof.

Clause 9. A method according to clause 8, wherein the relief structure is configured such that part(s) thereof have dimensions sufficient to accommodate a first concentration of the first pigment and other part(s) have dimensions too small to accommodate the first concentration of the first pigment, and preferably too small to accommodate substantially any of the first pigment.

Clause 10. A method according to clause 8 or 9, wherein the curable material further comprises a second pigment having a second optical characteristic, different from the first, wherein the first and second pigments have different sizes and/or shapes from one another, the relief structure preferably being further configured such that part(s) thereof have dimensions sufficient to accommodate a second concentration of the second pigment and other part(s) have dimensions too small to accommodate the second concentration of the second pigment, most preferably being too small to accommodate substantially any of the second pigment.

Clause 11. A method according to any of clauses 8 to 10, wherein the relief structure on the casting tool defines a plurality of recesses which vary in height and/or width across the relief structure resulting in corresponding protrusions across the surface relief structure.

Clause 12. A method according to clause 11, wherein the plurality of recesses vary in depth, resulting in protrusions of varying height, the higher protrusions displaying a greater optical density than the lower protrusions as a result of their containing a greater volume of the first and/or second pigments than the lower protrusions.

Clause 13. A method according to clause 11 or 12, wherein the plurality of recesses vary in width, such that the concentration of the first pigment and/or the second pigment entering each recess depends on the width of the recess, resulting in the optical characteristics of the cured material depending on the width of each protrusion.

Clause 14. A method according to any of clauses 8 to 13, wherein the relief structure comprises at least one recess having a width which reduces along the depth of the recess, whereby the concentration of the first pigment and/or the second pigment varies along the depth of the recess, resulting in a protrusion with optical characteristics which vary along the height thereof.

CLAIMS

1. A security device, comprising:

a surface relief structure formed of a cured material, the cured material comprising a binder and dispersed therein at least a first pigment having a first detection characteristic, the surface relief structure defining a plurality of protrusions which vary in height and/or width across the surface relief structure and a base layer integral with and linking the bases of the protrusions, wherein the surface relief structure is configured such that part(s) thereof have dimensions sufficient to accommodate a first concentration of the first pigment and other part(s) have dimensions too small to accommodate the first concentration of the first pigment, whereby the detection characteristics of the cured material vary across the surface relief structure in accordance with the dimensions thereof.

2. A security device according to claim 1, wherein the other part(s) of the relief structure have dimensions too small to accommodate substantially any of the first pigment.

3. A security device according to claim 1 or 2, wherein the cured material further comprises a second pigment having a second detection characteristic, different from the first, wherein the first and second pigments have different average sizes and/or shapes from one another.

4. A security device according to claim 3, wherein the surface relief structure preferably being further configured such that part(s) thereof have dimensions sufficient to accommodate a second concentration of the second pigment and other part(s) have dimensions too small to accommodate the second concentration of the second pigment, most preferably being too small to accommodate substantially any of the second pigment.

5. A security device according to any of the preceding claims, wherein:

the plurality of protrusions vary in height, higher protrusions exhibiting a greater intensity of the first and/or second detection characteristic than lower protrusions of the same width as a result of their containing a greater volume of the first and/or second pigments than the lower protrusions.

6. A security device according to any of the preceding claims, wherein the plurality of protrusions vary in height and/or width, the concentration of the first pigment and/or the second pigment in each protrusion, and hence the detection characteristics of the cured material, depending on the height and/or width of the protrusion.

7. A security device according to claim 6, wherein the plurality of protrusions include one or more protrusions in which the concentration of the first pigment, and of the second pigment if provided, is substantially zero.

8. A security device according to claim 6 or 7, wherein the plurality of protrusions include one or more protrusions in which the first pigment is present and the concentration of the second pigment, if provided, is substantially zero.

9. A security device according to claim 6 or 7, wherein the plurality of protrusions include one or more protrusions in which the second pigment is present and the concentration of the first pigment is substantially zero.

10. A security device according to any of claims 6 to 9, wherein the plurality of protrusions include one or more protrusions in which the first pigment and the second pigment are present.

11. A security device according to any of claims 6 to 10, wherein the plurality of protrusions include a first set of one or more protrusions each of

which has a height and a width which are each greater than or equal to a first predetermined threshold, the first predetermined threshold being approximately equal to the average size of the first pigment.

12. A security device according to any of claims 6 to 11, wherein the plurality of protrusions include a second set of one or more protrusions each of which has a height and/or a width which is less than a first predetermined threshold, the first predetermined threshold being approximately equal to the average size of the first pigment.

13. A security device according to claim 12 and claim 3 or 4, wherein the height and width of each of the second set of one or more protrusions are each greater than or equal to a second predetermined threshold, the second predetermined threshold being approximately equal to the average size of the second pigment.

14. A security device according to any of claims 6 to 13, wherein within a first region of the device, the plurality of protrusions are arranged according to a first repeating pattern, whereby the first region exhibits a first substantially uniform set of detection characteristics.

15. A security device according to any of the preceding claims, comprising:

at least one protrusion having a width and/or length which varies along the height of the protrusion, whereby the concentration of the first pigment and/or the second pigment varies along the height of the protrusion.

16. A security device according to any of the preceding claims, comprising at least one protrusion having a height which varies along the width and/or length of the protrusion, whereby the concentration of the first pigment and/or the second pigment varies along the width and/or length of the protrusion.

17. A security device according to any of the preceding claims, wherein the base layer has dimensions such that the concentration of the first pigment and/or the second pigment is substantially zero in the base layer, optionally wherein the base layer has dimensions such that the first pigment is present in the base layer and the concentration of the second pigment, if provided, is substantially zero in the base layer, or vice versa.

18. A security device according to any of the preceding claims, the plurality of protrusions define a plurality of raised elements spaced from one another, the raised elements corresponding to elements of an image, whereby the size, spacing, shape, detection characteristic and/or intensity of the elements varies across the surface relief structure so as to exhibit a multi-tonal version of the image.

19. A security device according to any of the preceding claims, wherein the surface relief structure defines a tactile structure.

20. A security device according to any of the preceding claims, wherein the surface relief structure defines microscale alphanumeric text, or a micro-graphic.

21. A security device according to any of the preceding claims, wherein the surface relief structure defines an image array which, when viewed in combination with a corresponding array of image selection elements, generates an optically variable effect.

22. A security device according to any of the preceding claims, wherein the detection characteristic(s) are any of:

an optical characteristic;

a magnetic characteristic;

an electrical characteristic; and

a tactile characteristic.

23. A security device according to claim 22 wherein the first and second detection characteristics are first and second optical characteristics.

24. A security device according to claim 23, wherein the first and second pigments have substantially the same appearance as one another under white light illumination, and different appearances from one another when illuminated by a non-visible wavelength, preferably UV radiation.

25. A security device according to claim 24, wherein the first and second pigments each exhibit a change in appearance between white light illumination and illumination by a non-visible wavelength.

26. A security device according to claim 23, wherein the first and second pigments have substantially the same appearance as one another when viewed in the visible spectrum, and different appearances from one another when viewed at a non-visible wavelength.

27. A security device according to claim 3 or any of claims 4 to 26 when dependent on claim 3, wherein the average size of the first pigment is larger than the average size of the second pigment.

28. A security device according to claim 27, wherein the first pigment exhibits a detection characteristic having a greater intensity per unit volume than that of the second pigment.

29. A security device according to any of the preceding claims, wherein the first pigment and/or the second pigment, if provided, comprises any of:

a pigment with a body colour which is visible to the naked eye under white light illumination;

a pigment which visibly or invisibly luminesces in response to a non-visible wavelength;

a pigment which absorbs a non-visible wavelength;

a photochromic or thermochromic pigment;

a metallic pigment;

an optically variable pigment;

a plasmonic pigment;

an electrically conductive pigment;

an anti-static pigment;

an opacifying pigment;

a magnetic or magnetisable pigment; and

a tactile pigment.

30. A security device according to any of the preceding claims, wherein the first pigment and/or the second pigment, if provided, has an average size between 0.001 µm and 500 µm.

31. A security device according to any of the preceding claims, wherein the first pigment and/or the second pigment, if provided, has a non-platelet average shape.

32. A security device according to any of the preceding claims, wherein the binder is colourless to the naked eye under white light illumination, or comprises a visibly coloured tint.

33. A security device according to any of the preceding claims, wherein the first pigment is an opacifying pigment and the surface relief structure is configured to form an opacifying layer of a security document, the surface relief structure including any of:

- a part in which the cured material has substantially zero concentration of the first pigment;

- a part in which the cured material has a non-zero concentration of the first pigment and the structure has a first height; and
- a part in which the cured material has a non-zero concentration of the first pigment and the structure has a second height which is greater than the first height.

34. A security device according to claim 33, wherein the cured material further comprises a second pigment of larger average size than the first pigment, the first and second pigment having different detection properties, and the surface relief structure further includes a part in which both the first and second pigments are present.

35. A security article comprising a security device according to any of the preceding claims.

36. A security document comprising a security device according to any of claims 1 to 34 or a security article according to claim 35.

37. A security document according to claim 36 wherein the security document comprises a document substrate and the security device is in accordance with claim 30 or 31 or 32, forming an opacifying layer on a first surface of the document substrate, and the security document further comprises a security element disposed at the first surface of the document substrate.

38. A security document according to claim 37, wherein the security element is partially or fully covered by a part of the surface relief structure in which the cured material has substantially zero concentration of the first pigment.

39. A method of manufacturing a security device, comprising:

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providing a casting tool having a relief structure defined in a surface thereof;

applying a curable material to a substrate or to the relief structure of the casting tool;

bringing the substrate and the casting tool together, to thereby form the curable material in accordance with the relief structure and curing the curable material such that a surface relief structure formed of the cured material is retained on the substrate;

wherein the curable material comprises a binder and homogenously dispersed therein at least a first pigment having a first detection characteristic; and

the forming of the curable material causes the first pigment to become non-homogenously dispersed in the cured material whereby the detection characteristics of the cured material vary across the surface relief structure in accordance with the dimensions thereof.

40. A method according to claim 39, wherein the relief structure is configured such that part(s) thereof have dimensions sufficient to accommodate a first concentration of the first pigment and other part(s) have dimensions too small to accommodate the first concentration of the first pigment

41. A method according to claim 40, wherein the other part(s) of the relief structure have dimensions too small to accommodate substantially any of the first pigment.

42. A method according to claim 39 or 40, wherein the curable material further comprises a second pigment having a second detection characteristic, different from the first, wherein the first and second pigments have different average sizes and/or shapes from one another,

43. A method according to claim 42, wherein the relief structure is further configured such that part(s) thereof have dimensions sufficient to accommodate a second concentration of the second pigment and other part(s) have dimensions too small to accommodate the second concentration of the second pigment.

44. A method according to claim 43, wherein the other part(s) of the relief structure have dimensions too small to accommodate substantially any of the second pigment.

45. A method according to any of claims 39 to 44, wherein the relief structure on the casting tool defines a plurality of recesses which vary in height and/or width across the relief structure resulting in corresponding protrusions across the surface relief structure.

46. A method according to claim 45 wherein the plurality of recesses vary in depth, resulting in protrusions of varying height, the higher protrusions exhibiting a greater intensity of the first and/or second detection characteristic, preferably a greater optical density, than the lower protrusions as a result of their containing a greater volume of the first and/or second pigments than the lower protrusions.

47. A method according to claim 45 or 46, wherein the plurality of recesses vary in depth and/or width, such that the concentration of the first pigment and/or the second pigment entering each recess depends on the depth and/or width of the recess, resulting in the detection characteristics of the cured material depending on the depth and/or width of each protrusion.

48. A method according to claim 47, wherein the plurality of recesses include one or more recesses configured to accommodate substantially zero concentration of the first pigment, and of the second pigment if provided.

49. A method according to claim 47 or 48, wherein the plurality of recesses include one or more recesses configured to accommodate a non-zero concentration of the first pigment, and substantially zero concentration of the second pigment if provided.

50. A method according to any of claims 48 to 49, wherein the plurality of recesses include one or more recesses configured to accommodate a non-zero concentration of the second pigment, and substantially zero concentration of the first pigment.

51. A method according to any of claims 47 to 50, wherein the plurality of recesses include one or more recesses configured to accommodate non-zero concentrations of the first pigment and of the second pigment.

52. A method according to any of claims 47 to 51, wherein the plurality of recesses include a first set of one or more recesses each of which has a depth and a width which are each greater than or equal to a first predetermined threshold, the first predetermined threshold being approximately equal to the average size of the first pigment.

53. A method according to any of claims 47 to 52, wherein the plurality of recesses include a second set of one or more recesses each of which has depth and/or a width which is less than a first predetermined threshold, the first predetermined threshold being approximately equal to the average size of the first pigment.

54. A method according to claim 53 and claim 40, wherein the depth and/or width of each of the second set of one or more recesses are each greater than or equal to a second predetermined threshold, the second predetermined threshold being approximately equal to the average size of the second pigment,

wherein the second predetermined threshold is preferably in the range 0.1 μm to 4 μm, still preferably about 1 μm.

55. A security device according to any of claims 47 to 54 wherein within a first region of the relief structure, the plurality of recesses are arranged according to a first repeating pattern, whereby the curable material accommodated in the first region exhibits a first substantially uniform set of detection characteristics.

56. A method according to any of claims 39 to 55, wherein the relief structure comprises either:

at least one recess having a width and/or length which varies along the depth of the recess, whereby the concentration of the first pigment and/or the second pigment varies along the depth of the recess, resulting in a protrusion with detection characteristics which vary along the height thereof; and/or

at least one recess having a depth which varies along the width and/or length of the recess, whereby the concentration of the first pigment and/or the second pigment varies along the width and/or length of the recess, resulting in a protrusion with detection characteristics which vary along the width and/or length thereof.

57. A method according to any of claims 39 to 56, wherein the casting tool and the substrate are brought together in a manner resulting in a base layer of the surface relief structure, the base layer having dimensions such that the concentration of the first pigment and/or the second pigment is substantially zero in the base layer, optionally wherein the base layer has dimensions such that the first pigment is present in the base layer and the concentration of the second pigment, if provided, is substantially zero in the base layer, or vice versa.

58. A method according to any of claims 39 to 57, wherein the detection characteristic(s) are any of:

an optical characteristic;

a magnetic characteristic;
an electrical characteristic; and
a tactile characteristic.

59. A method according to claim 58 wherein the first and second detection characteristics are first and second optical characteristics.

60. A method according to claim 42 or any of claims 43 to 59 when dependent on claim 42, wherein the average size of the first pigment is larger than the average size of the second pigment

61. A method according to claim 60, wherein the first pigment exhibits a detection characteristic having a greater intensity per unit volume than that of the second pigment.

62. A method according to any of claims 39 to 61, wherein the first pigment and/or the second pigment, if provided, comprises any of:

a pigment with a body colour which is visible to the naked eye under white light illumination;
a pigment which visibly or invisibly luminesces in response to a non-visible wavelength;
a pigment which absorbs a non-visible wavelength;
a photochromic or thermochromic pigment;
a metallic pigment;
an optically variable pigment;
a plasmonic pigment,
an electrically conductive pigment;
an anti-static pigment;
an opacifying pigment;
a magnetic or magnetisable pigment; and
a tactile pigment.

63. A method according to any of claims 39 to 62, wherein the first pigment and/or the second pigment, if provided, has an average size between 0.001 µm and 500 µm,.

64. A method according to any of claims 51 to 63, wherein the first pigment and/or the second pigment, if provided, has a non-platelet average shape, of an individual particle preferably being no greater than 150% of the smallest dimension of the same individual particle, on average.

65. A method according to any of claims 39 to 64, wherein the binder is colourless to the naked eye under white light illumination, or comprises a visibly coloured tint.

66. A method according to any of claims 39 to 65, wherein at the point of bringing the substrate and the casting tool together, the curable material has a room temperature viscosity in the range 0.1 to mPa.s to 3000 mPa.s.

67. A method according to any of claims 39 to 66, wherein the first pigment is an opacifying pigment and the surface relief structure is configured to form an opacifying layer of a security document, the surface relief structure including any of:

- a part in which the cured material has substantially zero concentration of the first pigment;
- a part in which the cured material has a non-zero concentration of the first pigment and the structure has a first height; and
- a part in which the cured material has a non-zero concentration of the first pigment and the structure has a second height which is greater than the first height.

68. A method according to claim 67, wherein the curable material further comprises a second pigment of larger average size than the first pigment, the first and second pigment having different detection properties, and the surface relief structure further includes a part in which both the first and second pigments are present.

69. A method of making a security document, comprising forming a security device on a document substrate using the method of any of claims 39 to 68.

70. A method of making a security document according to claim 69, wherein the security device is manufactured in accordance with claim 67 or 68, the surface relief structure forming an opacifying layer on a first surface of the document substrate, and the security document is further provided with a security element disposed at the first surface of the document substrate.

71. A method of making a security document according to claim 70, wherein the security element is partially or fully covered by a part of the surface relief structure in which the cured material has substantially zero concentration of the first pigment.