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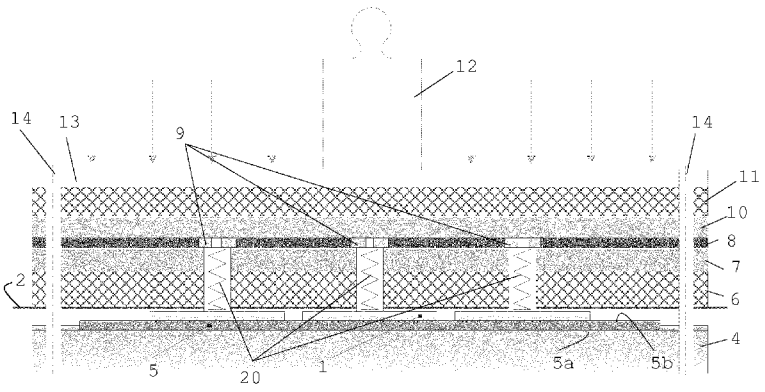

FIG. 4

(57) Abstract: The invention is related to a method for producing a pre-formed deformable mirror, comprising the steps of providing a substrate (5) with a mirror surface (5a) and a back surface (5b), placing a plurality of patches (1) of an electrostrictive material on the back surface, with an electrically non-conductive adhesive in between the patches and the back surface (5b), applying a pressure on the patches (1) thereby pushing the patches against the back surface (5b), during a time interval sufficient to allow polymerization of the adhesive, applying individual voltages to at least a group of the patches (1) during said time interval, said voltages being configured to cause a deformation of the patches in the plane of the back surface (5b),removing the voltages when the adhesive is polymerized, to thereby obtain a pre-formed mirror. According to a preferred embodiment, the voltage is applied through a PCB mounted on a stack of layers, and with the contact to the patches being established via spring contacts mounted in holes in said stack of layers.

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DEFORMABLE MIRROR AND METHOD TO PRODUCE IT

Field of the invention

[0001] The present invention is related to deformable mirrors, applicable in a variety of adaptive optics applications.

State of the art.

[0002] In deformable mirrors of the bimorph type, small deformations are established by actuating an array of actuators, mostly PZT (Pb-zirconate-titanate) actuators, in the plane of the mirror. In some applications, for example in the production of mirror segments which are to be assembled into a larger mirror surface, the mirrors need to be produced with an initial non-planar surface, with respect to which the actuators are able to deform the mirror in operation.

[0003] The production of freeform mirrors, which have an initial shape that is not formed according to a circumferential symmetry (parabolic, spherical for example) is difficult to realize. Polishing represents a difficult operation that stands in the way of producing such freeform mirror substrates at a lower cost.

[0004] Document WO2009/007447 is related to a deformable bimorph mirror comprising several segments, each segment comprising a mirror substrate with an array of piezo-strictive actuators attached to the backside of the

substrate. Segments are described which have a so-called 'coarse curvature', i.e. a curvature that exists without actuating the actuators. The document however describes only one way of attaching the actuators to the mirror substrate, namely be a screen printing technique. According to this technique, an array of green PZT patches is screen printed on a gold electrode and sintered at 900°C to transform the green material into ceramics. It was found however that this technique introduced severe residual stresses during cooling after the sintering process, leading to a mirror with a convex spherical shape which was impossible to correct with the PZT actuators.

Summary of the invention

[0005] The invention is related to a new method for producing deformable mirrors. The method of the invention does not require polishing while being able to produce freeform mirror shapes of any desired initial form. The invention is particularly related to a method and apparatus as disclosed in the appended claims.

[0006] The invention is thus related first to a method for producing a pre-formed deformable mirror, comprising the steps of:

- providing a substrate with a mirror surface and a back surface,
- placing a plurality of patches of an electrostrictive material on the back surface, with an electrically non-conductive adhesive in between the patches and the back surface,
- applying a pressure on the patches thereby pushing the patches against the back surface, during a time interval sufficient to allow polymerization of the adhesive,

- applying individual voltages to at least a group of the patches during said time interval, said voltages being configured to cause a deformation of the patches in the plane of the back surface,
- removing the voltages when the adhesive is polymerized, to thereby obtain a pre-formed mirror. The shape of the pre-formed mirror is defined by the fact that when the voltages are removed, the mirror undergoes a deformation due to the patches wishing to return to their initial shape, but being obstructed to do so by the polymerized adhesive.

[0007] According to a preferred embodiment, the voltages are applied between a mass electrode attached to the substrate and contacts placed in electrical connection with the patches on the side of said patches opposite the side that is attached through said adhesive to the back surface. The mass electrode may be a single layer or it may consist of a plurality of separate layers attached to the mirror substrate. The mass electrode preferably covers the totality of the substrate's back surface, with the electrostrictive patches being placed on said mass electrode. For contacting the patches by said contacts, the patches are preferably provided with counter-electrodes on their surfaces opposite the surface that is attached to the substrate's back surface.

[0008] According to an embodiment, said contacts are part of a printed circuit board placed on top of the patches during said time interval, the PCB further comprising conductors and a connection means, the conductors connecting the contacts to said connection means, the connection means being suitable for connecting the contacts to a means for applying said voltages to the patches.

[0009] Said PCB may be part of a stack of layers comprising:

- at least one first flexible layer provided with a plurality of holes,
- on said first flexible layer, a rigid layer provided with a plurality of holes aligned with the holes in the first flexible layer,
- on the rigid layer, the PCB,
- spring contacts mounted in said holes, for electrically connecting the contacts of the PCB with the surface onto which the stack is placed,
- on the PCB, at least one further flexible layer,

wherein the stack is placed on top of the patches after the patches have been placed on the back surface and wherein said pressure is applied on top of the stack, to thereby compress the spring contacts and establish an electrical connection between the PCB's contacts and the patches.

[0010] According to an embodiment, the step of placing the patches on the back surface is done by first placing the patches on an adhesive foil through a template, after which the adhesive foil is placed with the patches facing downward, on the back surface of the substrate.

[0011] According to an embodiment, different individual voltages are applied to said plurality of patches.

[0012] The method of the invention may comprise the step of calculating the individual voltages required to obtain a pre-formed mirror of a desired shape, and wherein said calculated voltages are applied to the patches.

[0013] According to an embodiment, the mirror substrate remains flat during said polymerization time interval. The pre-formed mirror produced by the method of the invention may be a free-form mirror.

[0014] The invention is further related to an apparatus for producing a pre-formed deformable mirror, comprising:

- a support structure suitable for receiving thereon a mirror substrate having a mirror surface and a back surface, with the mirror surface facing down on said support, the back surface having a plurality of electrostrictive patches thereon, with an electrically non-conductive adhesive between the patches and the back surface. The support structure may have a flat surface.
- a means for exerting a pressure on said plurality of patches, thereby pushing the patches against the back surface,
- a means for applying individual voltages to at least a group of the patches while the pressure is applied, said voltages being configured to cause a deformation of the patches in the plane of the back surface.

[0015] In apparatus according to an embodiment of the invention, the means for applying individual voltages comprises:

- a stack of layers configured to be placed on top of the patches, the stack comprising at least one printed circuit board provided with contacts configured to be in electrical connection with the patches, when said pressure is applied on top of the stack, the PCB further comprising conductors and a connection means, the conductors connecting the contacts to said connection means, the connection means being suitable for connecting the contacts to a means for applying individual voltages to the patches,
- a power source suitable for applying said individual voltages to the connection means of the PCB.

[0016] Said stack may comprise:

- at least one first flexible layer provided with a plurality of holes,
- on said first flexible layer, a rigid layer provided with a plurality of holes aligned with the holes in the first flexible layer,
- on the rigid layer, the PCB, its contacts located above said holes,
- spring contacts mounted in said holes, for electrically connecting the contacts of the PCB with the surface onto which the stack is placed,
- on the PCB, at least one further flexible layer.

Brief description of the figures

[0017] Figure 1 illustrates a manner of placing patches of PZT material onto an adhesive foil through a template.

[0018] Figures 2 and 3 illustrate the template and the resulting patches attached to the foil.

[0019] Figure 4 illustrates a way of gluing the patches to the backside of a mirror surface, while applying a voltage to the PZT patches by using a specifically designed PCB.

[0020] Figure 5 shows a design for the PCB used in the method illustrated in Figure 4.

[0021] Figure 6 shows a mirror produced according to the method of the invention after it has been shaped into a hexagonal form.

[0022] Figure 7 illustrates the good agreement between the obtained shape of a mirror segment produced by the method of the invention and the pre-calculated shape.

Detailed description of the invention

[0023] According to the invention, patches of electrostrictive material are glued to a mirror substrate (e.g. a monocrystalline Si or glass substrate) by applying an adhesive between the patches and the substrate and exerting pressure while the adhesive dries to form a fixed connection. The term 'electrostrictive' is defined in the present context as any material that undergoes a deformation under the influence of an electrical field, wherein the deformation is substantially perpendicular to the direction of the field. The most common examples of such materials are based on a piezo-electric effect, as is the case for the PZT material which is a preferred choice for use in the method of the invention, even though other materials may be applied.

[0024] During the curing time of the adhesive between the patches 1 and the mirror substrate's back surface 5b, a DC voltage is applied to the patches before the adhesive is fully polymerized. The voltage causes a deformation of the patches in the plane of the patches. When the polymerization of the adhesive is completed, the voltages are removed, after which the mirror undergoes a deformation due to the patches wishing to return to their initial shape, but being obstructed to do so by the polymerized adhesive. The result is a residual deformation of the mirror. The inventors have found that there is an excellent agreement between a predicted residual deformation and the actual residual deformation occurring. This invention therefore makes it possible to obtain a variety of freeform mirrors, by applying a set of different voltages to the electrostrictive patches during polymerization of the adhesive.

[0025] In practice, the method of the invention can be applied in various ways. One embodiment is illustrated

in Figures 1 to 5. With reference to Figure 1, hexagonal PZT patches 1 are temporarily attached to an adhesive foil 2, by placing them into the openings of a template 3. Images of the template 3 and the resulting group of PZT patches on the foil 2 are shown in Figures 2 and 3. The template defines the size of the gap between two adjacent patches. An example of a suitable gap size is given further in this description. As shown in Figure 4, the foil 2 with the patches attached is then glued face down to the back side of a mirror substrate 5, for example a monocrystalline silicon wafer with a reflecting front surface 5a and with an Aluminium layer (not shown) at the back surface 5b. The Al-layer will act as the mass electrode with respect to which individual voltages are applied on the individual patches 1. The patches 1 have an electrically conductive layer (not shown) at least on the side opposite the side that is attached to the back surface 5b. Said conductive layer will act as the counter electrode on each individual patch. Droplets of a non-conductive adhesive may be placed on the Al layer before the foil with the PZT patches 1 is placed onto said Al layer.

[0026] The mirror is then placed with the reflecting surface 5a facing downwards on a stable structure 4 having a flat support surface. Then a stack of layers is placed on top of the adhesive foil 2, the stack comprising a flexible mat 6, e.g. a Sorbothane® mat, provided with openings above (preferably the centre of) each PZT patch 1. A rigid plastic plate 7, equally provided with openings aligned with the openings in the mat 6, is placed on the flexible mat 6, and on top of the plastic plate 7, a printed circuit board 8 is placed, the PCB 8 being provided with electrical contacts 9 at each of the locations of the openings in the plate 7 and the mat 6. Another rigid plate 10 and another flexible mat 11 are placed above the PCB and on this second

mat 11 a compressive force 12 is applied during a suitable time required for the adhesive between the PZT patches 1 and the mirror 5 to polymerize. The compressive force is schematically shown as a weight exerted on a plate 13, but it may be brought into practice in any suitable way known in the art. The stack of layers is provided with openings 14, aligned with openings in the support structure 4 for centering the stack on the support surface.

[0027] During the polymerization, a voltage is applied between the contacts 9 of the PCB and the mass electrode formed by the Al-layer on the back surface 5b of the mirror substrate. An electrical connection between the PCB 8 and the PZT patches 1 is established through spring contacts 20 arranged in the openings that run through the PCB 8, the plastic plate 7 and the first flexible mat 6. The adhesive foil 2 is equally provided with holes to allow the passage of the springs. The plastic plate 7 has the function of lending a degree of rigidity to the structure so as to guide the spring contacts 20 and thereby ensure their vertical compression. The second rigid plate 10 lends further stiffness to the structure as the PCB itself may lack sufficient stiffness. Depending on the size of the mirror and other circumstances, a single rigid plate 7 underneath the PCB may however be sufficient.

[0028] The design of a PCB 8 that is suited for this purpose is shown in Figure 5. The position of the PZT patches 1 is shown in dotted lines. Separate conductors 15 run from the contacts 9 to a connector 16 that is attachable to a suitable power electronics arrangement, for applying a required voltage to each of the contacts 9. Holes 17 are placed in the corners of the PCB for centering, one of which holes is provided with an insert 18 linked to an additional conductor line 19 for grounding the PCB.

[0029] During the polymerization of the adhesive, the mirror surface remains flat, given that the mirror substrate is placed on a flat surface of the support structure 4, and because the patches are deformed in the plane of the mirror's surface during this whole time. It is only when the voltages are removed, that the mirror is deformed and acquires a given shape. It is not excluded that the support structure 4 may have a slightly curved surface. The pressure 12 must then be able to push the mirror substrate against this curved surface so that it contacts the support surface over the full mirror surface. It is of course also possible to apply the method to a mirror substrate that already has a given curvature. In that case, the support surface 4 preferably has a curved shape that corresponds to the initial mirror curvature.

[0030] The invention is not limited to hexagonal PZT patches but is applicable to any shape of the electrostrictive actuator patches. The adhesive used between the patches 1 and the mirror 5 must be electrically non-conductive, in order to avoid creating a current through the patches, but otherwise any suitable type of adhesive is usable in terms of its composition. The polymerization time may be anywhere between a few minutes and several days depending on the type of glue that is used. An example of a suitable glue is EPO-TEK®301-2.

[0031] The method preferably takes place at room temperature. The voltages applied to the patches can be the same for all patches or different according to a predefined pattern, in order to obtain a mirror that is pre-formed according to a pre-defined shape, for example for producing a free-form mirror. Preferably a voltage is actively applied to all the patches, though it is not excluded that some patches are not connected to a voltage. The voltages applied to the various patches are preferably calculated

beforehand through a suitable calculation method, such as a finite element calculation, taking into account the dimensions of the mirror substrate and the patches, the temperature, the materials and the type of adhesive used between the patches and the mirror, and starting from a desired mirror shape.

[0032] The pre-formed mirror obtained by the method of the invention is further subjected to known process steps for producing a deformable mirror, such as the segmentation into mirror segments, to be assembled into the large segmented mirror of a telescope. For example segments are produced having suitable forms for being assembled, such as a hexagon shape, illustrated in Figure 6. This can be done for example by laser cutting. The mirror substrate may be further processed so as to produce a bimorph mirror wherein the electrostrictive patches can be individually addressed during operation of the mirror, to thereby deform the mirror with respect to its pre-form obtained through the method of the invention. This processing can be implemented according to methods known in the art and therefore not described here in detail.

[0033] The invention is related to an apparatus for producing a pre-formed deformable mirror according to the method of the invention, i.e. to an apparatus comprising a support for placing thereon the mirror substrate with electrostrictive patches 1 glued to its back surface, and a means for applying individual voltages to the patches while the adhesive applied between the patches and the mirror polymerizes under an externally applied pressure. Such means may comprise a stack of layers comprising at least one PCB arranged to apply individual voltages to the electrostrictive patches while they are glued to the mirror's backside. The stack of layers may be according to the embodiment of Figures 4 and 5, the description given

with respect to these figures being applicable to the apparatus. The invention is however not limited to such an apparatus, nor to a method involving a PCB. Other configurations are possible under which a voltage can be applied to the patches while they are being glued to the mirror and subjected to an external pressure. For example, individual wires may be connected to the backsides of the patches 1, and led towards the periphery of the mirror where they are connected to a power source, after which a pressure is applied on top of the wires, by placing a sufficiently thick flexible mat onto the wires and exerting the pressure on said flexible mat. The wires could be guided in a suitable guide means which may be incorporated in the mat.

Example

[0034] Figure 6 shows an example of a hexagonal mirror segment after laser cutting and obtained by the method of the invention. The mirror segment was produced from a single crystal silicon wafer, 700 μm thick, covered by an array of hexagonal piezoelectric PZT patches (PIC-255 from PI Ceramic) of 200 μm thickness provided with Ni-Cu electrodes. The dimensions are shown by way of example. These dimensions illustrate suitable values of the PZT patch size and the gap between adjacent patches. The sizes of the gap can differ from these values and can for example be between 0.5mm and 2mm.

[0035] The Si wafer is covered by an Al ground electrode as described above. The PZT patches are attached to an adhesive foil by use of the template shown in Figure 2. At this stage, three ground connectors 200 are equally attached to the foil, see also Figure 3. A calibrated quantity (of the order of 3 microlitres) of EPO-TEK®301-2 is deposited with a dispenser onto the ground electrode,

with a similar template as the one of Figure 2, positioning droplets in the middle of the template openings. The viscosity of the droplets is the viscosity of the applied glue at room temperature. The PZT-patches are then pressed against the substrate, using an apparatus as illustrated in Figures 4 and 5, while a voltage of 180 V is applied between the ground electrode and each of the patches, causing the patches to shrink in size, due to the negative piezo-electric coefficient d_{31} of the applied material. The glue is cured at room temperature. After curing of the glue, the voltage is removed, resulting in a residual curvature as illustrated in Figure 7, as a consequence of the patches wishing to return to their original size but being constricted by the cured adhesive.

[0036] Line 100 shows the mirror's curvature before applying the method. The dotted line 101 in Figure 7 shows the measured curvature after application of the method, while the full line 102 shows the numerical prediction, illustrating a good match. The method is thus capable of producing a mirror segment with a well-defined curvature. The curvature is concave and spherical due to the application of the same voltage to every patch. By applying different voltages to different patches, other shapes can be obtained.

[0037] While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive. Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure and the appended claims. In the claims, the word “comprising” does not exclude other elements or steps, and the indefinite article “a” or “an”

does not exclude a plurality. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. Any reference signs in the claims should not be construed as limiting the scope.

[0038] The foregoing description details certain embodiments of the invention. It will be appreciated, however, that no matter how detailed the foregoing appears in text, the invention may be practiced in many ways, and is therefore not limited to the embodiments disclosed. It should be noted that the use of particular terminology when describing certain features or aspects of the invention should not be taken to imply that the terminology is being re-defined herein to be restricted to include any specific characteristics of the features or aspects of the invention with which that terminology is associated.

[0039] Unless specifically specified, the description of a layer being deposited, placed or produced 'on' another layer or substrate, includes the options of

- said layer being placed, produced or deposited directly on, i.e. in contact with, said other layer or substrate, and
- said layer being produced on one or a stack of intermediate layers between said layer and said other layer or substrate.

CLAIMS

1. A method for producing a pre-formed deformable mirror, comprising the steps of :

- providing a substrate (5) with a mirror surface (5a) and a back surface (5b),
- placing a plurality of patches (1) of an electrostrictive material on the back surface, with an electrically non-conductive adhesive in between the patches and the back surface (5b),
- applying a pressure on the patches (1) thereby pushing the patches against the back surface (5b), during a time interval sufficient to allow polymerization of the adhesive,
- applying individual voltages to at least a group of the patches (1) during said time interval, said voltages being configured to cause a deformation of the patches in the plane of the back surface (5b),
- removing the voltages when the adhesive is polymerized, to thereby obtain a pre-formed mirror.

2. Method according to claim 1, wherein the voltages are applied between a mass electrode attached to the substrate (5) and contacts (9) placed in electrical connection with the patches (1) on the side of said patches opposite the side that is attached through said adhesive to the back surface (5b).

3. Method according to claim 2, wherein said contacts (9) are part of a printed circuit board (8) placed on top of the patches (1) during said time interval, the PCB further comprising conductors (15) and a connection means (16), the conductors connecting the contacts (9) to said connection means (16), the connection means (16) being suitable for connecting the contacts (9) to a means for applying said voltages to the patches (1).

4. Method according to claim 3, wherein said PCB (8) is part of a stack of layers comprising :

- at least one first flexible layer (6) provided with a plurality of holes,
- on said first flexible layer, a rigid layer (7) provided with a plurality of holes aligned with the holes in the first flexible layer (6),
- on the rigid layer (7), the PCB (8),
- spring contacts (20) mounted in said holes, for electrically connecting the contacts (9) of the PCB with the surface onto which the stack is placed,
- on the PCB, at least one further flexible layer (10),

wherein the stack is placed on top of the patches (1) after the patches have been placed on the back surface (5b) and wherein said pressure is applied on top of the stack, to thereby compress the spring contacts (20) and establish an electrical connection between the PCB's contacts (9) and the patches (1).

5. Method according to any one of the preceding claims, wherein the step of placing the patches (1) on the back surface (5b) is done by first placing the patches on an adhesive foil (2) through a template (3), after which the adhesive foil (2) is placed with the patches facing downward, on the back surface (5b) of the substrate (5).

6. Method according to any one of the preceding claims, wherein different individual voltages are applied to said plurality of patches (1).

7. Method according to any one of the preceding claims, comprising the step of calculating the individual voltages required to obtain a pre-formed mirror of a desired shape, and wherein said calculated voltages are applied to the patches (1).

8. Method according to any one of the preceding claims, wherein the mirror substrate (5) remains flat during said polymerization time interval.

9. Method according to any one of the preceding claims, wherein the pre-formed mirror is a free-form mirror.

10. Apparatus for producing a pre-formed deformable mirror, comprising :

- a support structure (4) suitable for receiving thereon a mirror substrate (5) having a mirror surface (5a) and a back surface (5b), with the mirror surface facing down on said support, the back surface having a plurality of electrostrictive patches (1) thereon, with an electrically non-conductive adhesive between the patches and the back surface,
- a means for exerting a pressure on said plurality of patches, thereby pushing the patches (1) against the back surface (5b),
- a means for applying individual voltages to at least a group of the patches (1) while the pressure is applied, said voltages being configured to cause a deformation of the patches in the plane of the back surface (5b).

11. Apparatus according to claim 10, wherein the means for applying individual voltages comprises :

- a stack of layers configured to be placed on top of the patches (1), the stack comprising at least one printed circuit board (8) provided with contacts (9) configured to be in electrical connection with the patches (1), when said pressure is applied on top of the stack, the PCB (8) further comprising conductors (15) and a connection means (16), the conductors connecting the contacts (9) to said connection means,

the connection means (16) being suitable for connecting the contacts (9) to a means for applying individual voltages to the patches,

- a power source suitable for applying said individual voltages to the connection means (16) of the PCB (8).

12. Apparatus according to claim 11 wherein said stack comprises :

- at least one first flexible layer (6) provided with a plurality of holes,
- on said first flexible layer, a rigid layer (7) provided with a plurality of holes aligned with the holes in the first flexible layer (6),
- on the rigid layer, the PCB (8), its contacts (9) located above said holes,
- spring contacts (20) mounted in said holes, for electrically connecting the contacts (9) of the PCB with the surface onto which the stack is placed,
- on the PCB, at least one further flexible layer (10).

13. Apparatus according to any one of claims 10 to 12, wherein said support structure (4) has a flat surface.

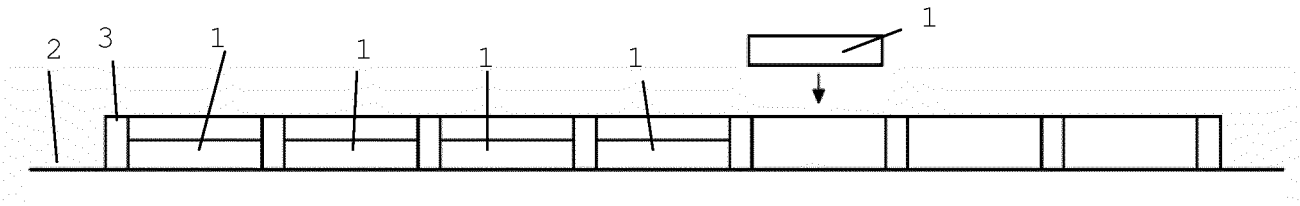

FIG. 1

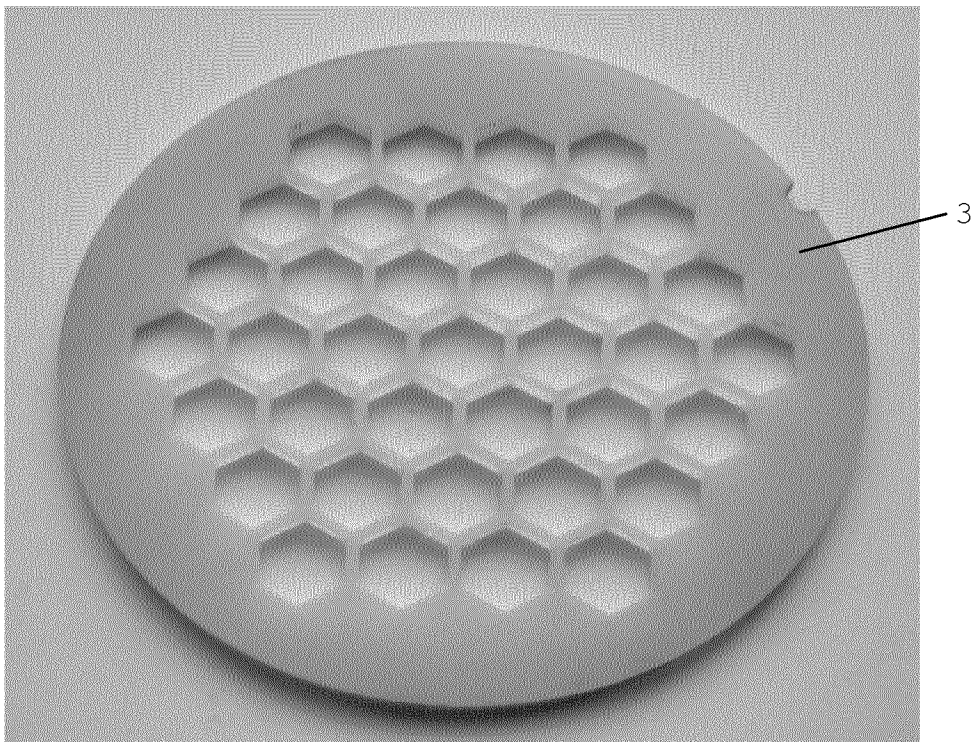

FIG. 2

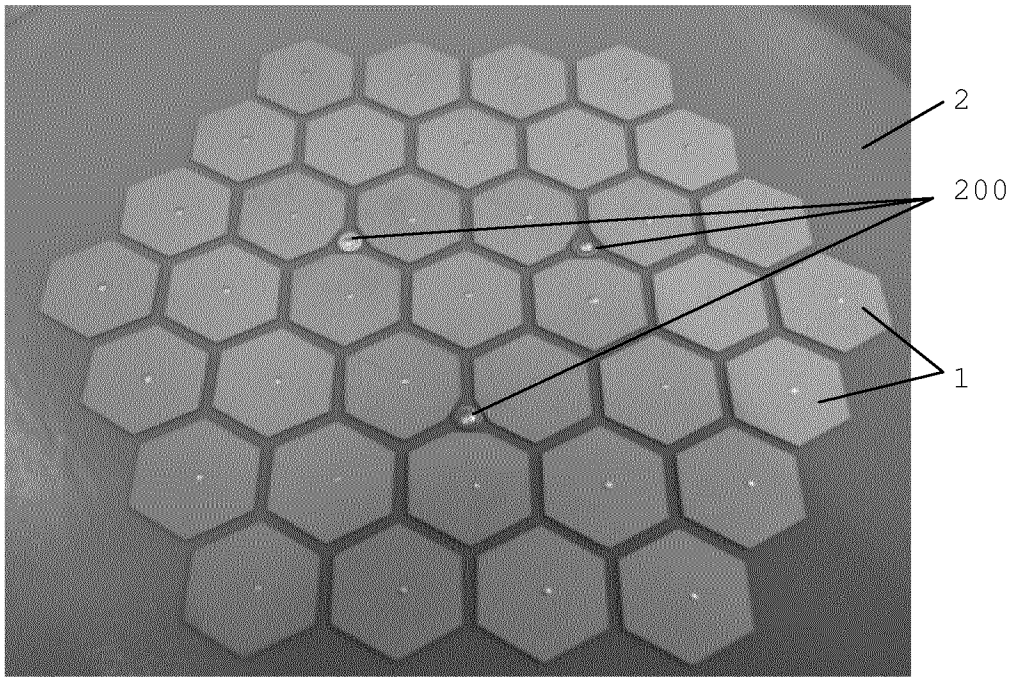

FIG. 3

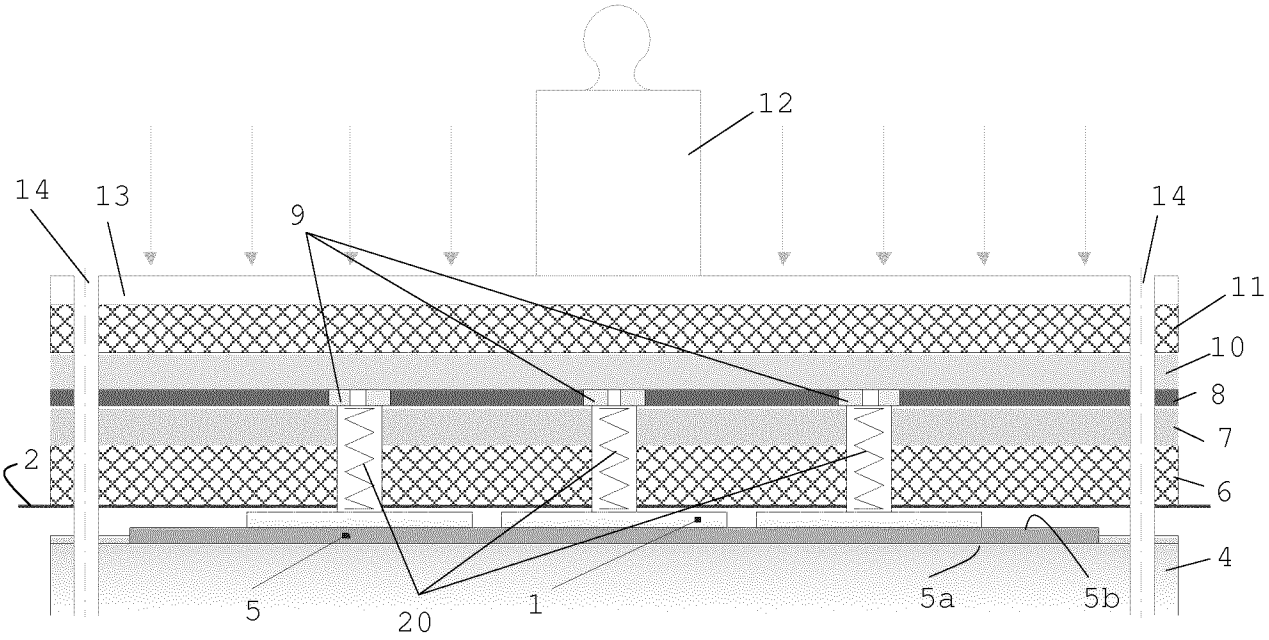

FIG. 4

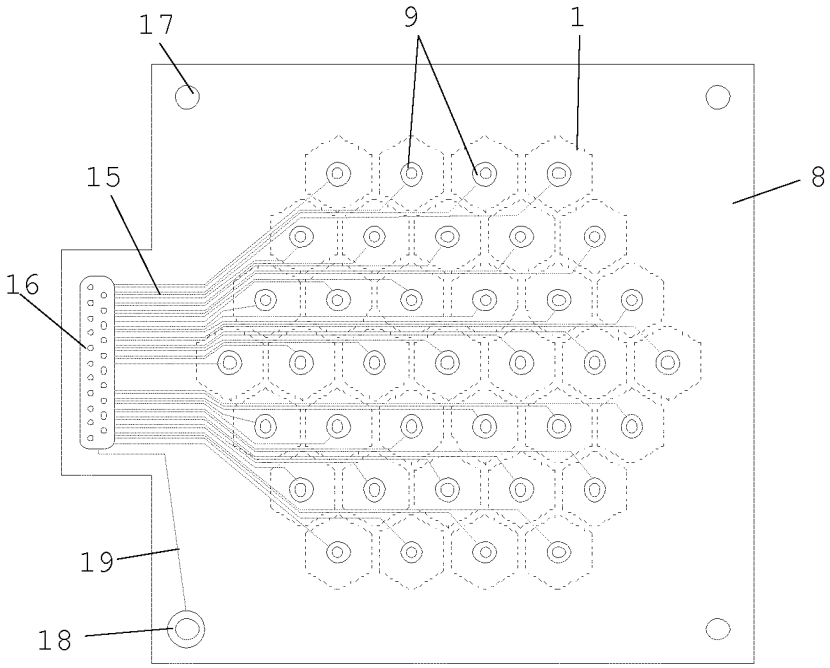

FIG. 5

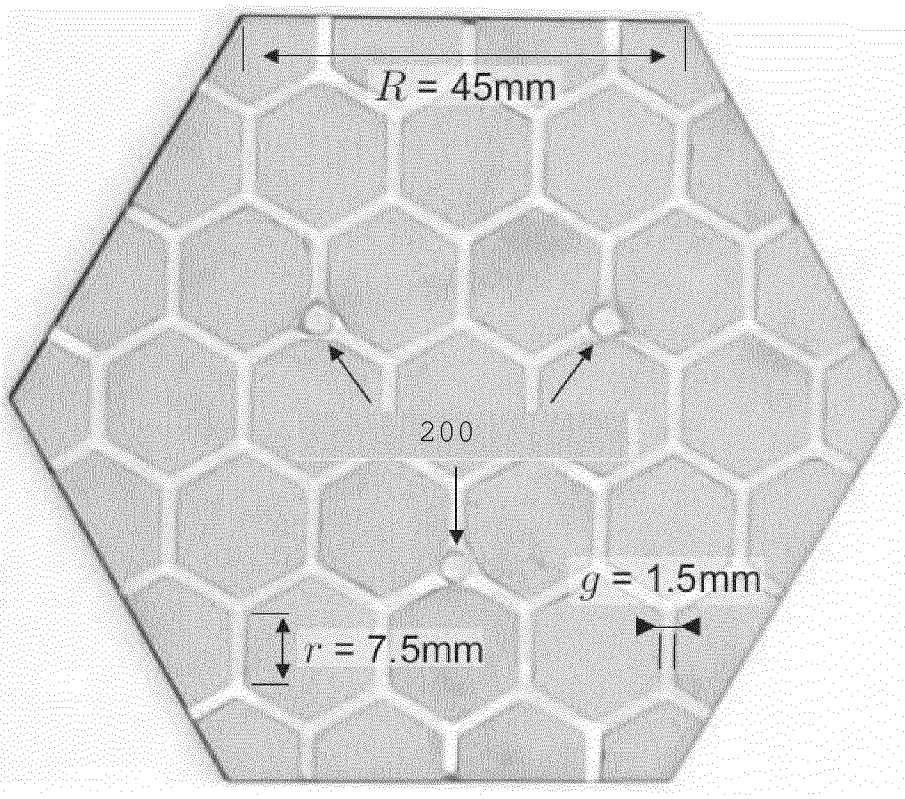
R = 45mm
200
g = 1.5mm
r = 7.5mm

FIG. 6

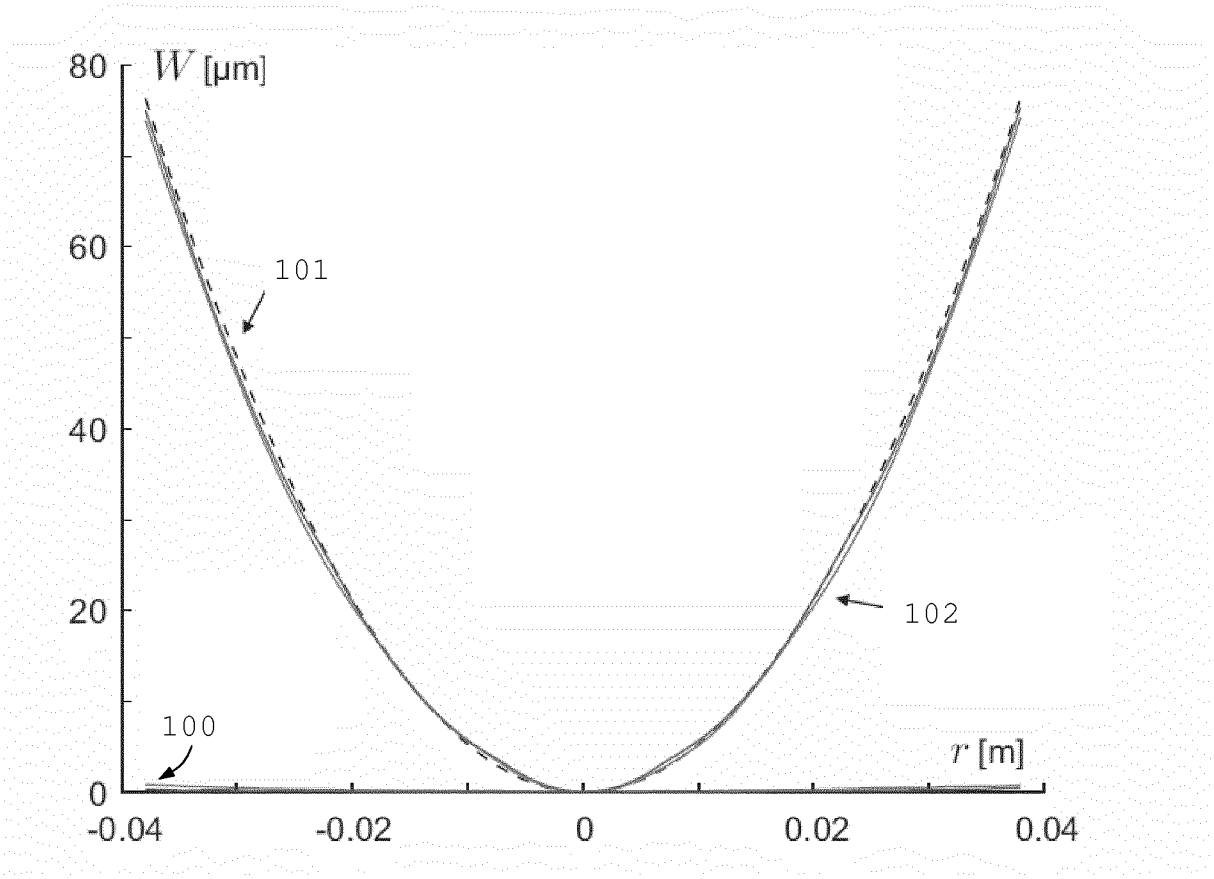
W [µm]
80
60
40
20
0
101
102
100
r [m]
-0.04
-0.02
0
0.02
0.04

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/071406

A. CLASSIFICATION OF SUBJECT MATTER
INV. G02B5/10 G02B26/08
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2009/007447 A2 (UNIV BRUXELLES [BE]; PREUMONT ANDRE [BE]; RODRIGUES GONCALO [BE]) 15 January 2009 (2009-01-15)	1-3,6-10
Y	page 10 - page 21; figures 3,5,7	4
Y	WO 2005/040885 A2 (BAE SYSTEMS PLC [GB]; GRIFFITH MICHAEL STEWART [GB]; LAYCOCK LESLIE CH) 6 May 2005 (2005-05-06) pages 10-12,19; figure 20	4

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 January 2015	21/01/2015

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Feeney, Orla

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/071406

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GEBHARDT ET AL: "PZT thick films for sensor and actuator applications", JOURNAL OF THE EUROPEAN CERAMIC SOCIETY, ELSEVIER SCIENCE PUBLISHERS, BARKING, ESSEX, GB, vol. 27, no. 13-15, 1 January 2007 (2007-01-01), pages 4177-4180, XP022143718, ISSN: 0955-2219, DOI: 10.1016/J.JEURCERAMSOC.2007.02.122 page 4178 - page 4179; figure 3	1,10
A	US 2005/200984 A1 (BROWNE ALAN L [US] ET AL) 15 September 2005 (2005-09-15) paragraph [0032] - paragraph [0055]; figures 2,3	1-13
A	WO 2004/057398 A1 (BAE SYSTEMS PLC [GB]; GRIFFITH MICHAEL STEWART [GB]; ARCHER NICHOLAS J) 8 July 2004 (2004-07-08) page 7 - page 8; figures 5,6	1,10

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2014/071406

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		WO 2005040885 A2	06-05-2005
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WO 2004057398 A1	08-07-2004	AU 2003290284 A1	14-07-2004
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		US 2006082909 A1	20-04-2006
		WO 2004057398 A1	08-07-2004