United States Patent

Kinoshita

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[54] **PERSISTENT INTERNAL POLARIZATION PROCESS IN ELECTROPHOTOGRAPHY**

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Sept. 5, 1967 Japan....................................42/56947

[52] **U.S. Cl.**..**96/1**
[51] **Int. Cl.**..**G03g 13/00**
[58] **Field of Search**..96/1, 1.5

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[57] **ABSTRACT**

In a method of forming an electrostatic latent image wherein a first electric field of one polarity is applied across a perfectly insulated type photosensitive element or an element including a transparent highly insulative layer integrally bonded to a photoconductive layer and then a second field of the opposite polarity is applied concurrently with the projection of a light image onto one side, uniform light is irradiated upon the opposite side of the photosensitive element concurrently with or before or after application of the first field but before application of the second field to improve the image forming property.

7 Claims, 5 Drawing Figures

PATENTED APR 11 1972 3,655,369

FIG. 1

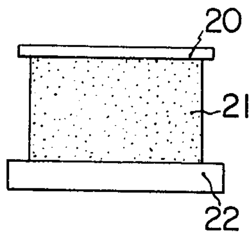


FIG. 2

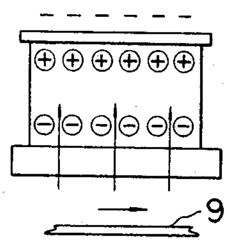


FIG. 3

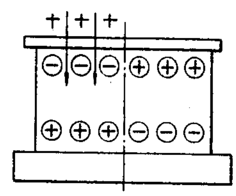


FIG. 4

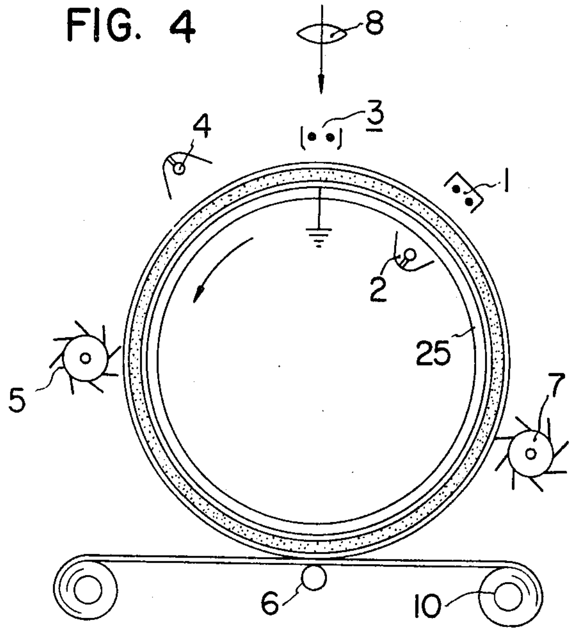
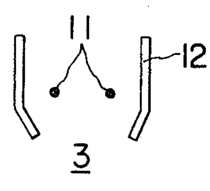


FIG. 5



PERSISTENT INTERNAL POLARIZATION PROCESS IN ELECTROPHOTOGRAPHY

BACKGROUND OF THE INVENTION

This invention relates to a method of electrophotography wherein the image forming property is greatly improved at the stage of forming an electrostatic latent image on a perfectly insulated type photosensitive element.

More particularly, this invention contemplates elimination of a defect of the prior method of electrophotography wherein the image forming ability is decreased due to the fact that in a perfectly insulated type photosensitive element it is impossible to greatly increase the thickness of the photoconductive layer with reference to that of the high insulation layer. According to this invention a step is added to the image forming steps wherein uniform light is irradiated upon the side of the photosensitive element layer opposite to the side on which a light image is projected whereby to greatly improve the image forming ability.

The method of forming an electrostatic latent image characterized by being not released or erased by light on an insulating thin layer integral with a photoconductive layer can be outlined as follows: More particularly, the perfectly insulated type photosensitive element includes as its basic elements a layer of a photoconductive material and a thin layer of a highly insulative transparent material. The method of forming an electrostatic latent image comprises a first step of applying a field of one polarity across the photosensitive element in the direction of the thickness thereof, and a second step of applying a field of the opposite polarity across the photosensitive layer concurrently with the projection of a light image on the photoconductive layer of the photosensitive element whereby to form the electrostatic latent image corresponding to the projected light image on the surface of the highly insulative thin layer.

Such a perfectly insulated type photosensitive element is equivalent to a combination comprising a capacitance of the highly insulative layer and a parallel combination of a capacitance and a resistance representing the photoconductive layer serially connected with the firstly mentioned capacitance. Accordingly, the electric field applied across the photosensitive element is shared by respective layers in proportion to their capacitances. For this reason, unless the photoconductive layer is made sufficiently thicker than the highly insulative layer, almost all of the impressed field is shared by the highly insulative layer.

Under these conditions, whether the photoconductive layer is irradiated by light or not the surface of the photosensitive element becomes charged to a high voltage so that the potential difference between portions irradiated and not irradiated with the light image becomes small thus degrading the image forming ability. To avoid this difficulty, in the perfectly insulated type photosensitive element, it is desirable to make thin the highly insulative layer and to use sufficiently high insulating materials. However, it is difficult to decrease the thickness of the highly insulative layer to less than several microns so as to assure sufficiently high resistance for a transparent thin layer of substantially uniform thickness.

On the other hand, generally, as the photoconductive layer has higher dielectric constant than the highly insulative layer, from the standpoint of the share of electric field described above it is desirable for the photoconductive layer to have a thickness of more than several tens of microns.

According to the prior method, in order to further decrease the dielectric constant of the photoconductive layer and to cause it to operate at higher photosensitivities a field of the polarity essentially opposite to that of the field applied in the first step is applied in the second step to establish a polarization phenomenon in the photoconductive layer caused by charge trapping. Upon application of the field of the opposite polarity free electrons in the photoconductive layer will migrate in response to the applied d.c. field and while migrating they are trapped by trap levels in the photoconductive material to form the so-called persistent internal polarization. Different from the so-called dielectric polarization the polarization created by the trapped charge is not released even when the field is removed or even when the polarity of the applied field is reversed unless it is released by reexcitation by heat or light. Thus, the persistent internal polarization remains over a long period of time without any change under the field of the opposite polarity which is applied in the second image forming step, and since the polarity of the polarization caused by the trapped charge is opposite to that of the dielectric polarization to be established by the field applied during the image forming step, it will result in the same effect as if the capacitance were reduced greatly. By suitable selection of the intensities of the fields impressed in the first and second steps it becomes possible to vary to any desired value the polarity and the intensity of the field applied across the highly insulative layer of the photosensitive element during the second step. Furthermore, as the trapped charge is released by light irradiation to form free electrons at portions irradiated by light during the second step the dielectric constant of the photosensitive layer increases rapidly to share a large portion of the applied field to the highly insulative layer thus charging a large quantity of charge. This variation in the dielectric constant is effective not only to release the persistent internal polarization established by the second step but also to cause new maldistribution of the free charge formed by said release and these phenomena cooperate cumulatively to manifest extremely high photosensitivities. Notwithstanding various advantages over other methods, this method of electrophotography still has following defects.

First, when the photoconductive layer of a practical photosensitive element receives light on its one surface, due to large light absorption of the photoconductive material the light excitation will be biased to that side thus preventing uniform excitation throughout the photoconductive layer. In an extreme case, some portions may act as a mere insulator without being excited by light.

Second, where the photoconductive layer is made of a P-type photoconductor, for example, in the first step wherein the polarity of the field is selected such that the surface of the highly insulative layer assume a negative polarity, positive free charge carriers among free charge pairs formed by light irradiation have much larger mobility than the negative charge. However the positive charge migrating toward the highly insulative layer is blocked thereby so that it can not migrate over a long distance. Whereas the negative charge can not migrate so far owing to its low mobility. This is the reason why a large polarization can not be formed. Subsequently, when a field of the opposite polarity is applied concurrently with local light irradiation, at portions irradiated by light, trapped charge is readily released and the positive charge migrates over a long distance toward the backing electrode where it disappears by recombination or is trapped. Portions wherein the positive charge is trapped correspond to portions which have not been subjected to light excitation or subjected to slight light excitation. For this reason during the first image forming step trapped charge remains or preserved over a long period of time until it is released termally so that repeated image forming operations cause accumulation of the residual charge until finally the photoconductive layer becomes non-operative. In addition, it has been impossible to completely eliminate the hysteresis of the image formed in respective cycles, thus gradually increasing the effect of the so-called residual image. Similar problems occur for field of opposite polarity. These problems have not been solved in a perfectly insulated type photosensitive element wherein use of a thick photoconductive layer is essential.

SUMMARY OF THE INVENTION

One object of this invention is to provide a novel method of forming latent images by means of which the residual trapped charge can be positively released at each image forming operation whereby to unexpectedly improve the photosensitivity.

According to this invention there is provided in a method of electrophotography comprising a first step of applying a first electric field across a photosensitive element, which element includes a photoconductive layer manifesting persistent internal polarization and a thin transparent highly insulative layer integrally bonded to one side of said photoconductive layer, to deposit charges of one polarity on said highly insulative layer, and a second step of applying a second electric field across said photosensitive element to deposit charges of the opposite polarity on said highly insulative layer concurrently with the projection of a light image upon said photoconductive layer through said highly insulative layer whereby to form an electrostatic latent image corresponding to said light image on the surface of said highly insulative layer, the improvement which comprises irradiating said photoconductive layer with uniform light from the side thereof remote from said insulative layer before application of said second electric field. line 15, correct the spelling of "convenient."

The electric fields may be applied by any convinient means such as electrodes placed upon the photosensitive element or corona discharge units. The electrostatic latent image can be developed in the conventional manner.

BRIEF DESCRIPTION OF THE DRAWING

The invention can be more fully understood from the following description taken in connection with the accompanying drawing in which:

FIGS. 1 to 3 diagrammatically show enlarged section of a perfectly insulated type photosensitive element illustrating charge distribution at various steps of the novel method;

FIG. 4 is a diagrammatic representation of an electrophotographic apparatus employed for carrying out the novel method and

FIG. 5 shows a corona discharge unit employed in the apparatus shown in FIG. 4.

Referring now to the accompanying drawing, FIGS. 1 to 3 diagrammatically show distribution of electric charge in a perfectly insulated type photosensitive element to explain the basic concept of this invention. As shown in FIG. 1, the photosensitive element comprises a photoconductive layer **21** comprised by a P-type photoconductor, for example, a highly insulative layer **20** integrally bonded to one surface thereof and a transparent backing electrode **22** on the opposite side. FIG. 2 shows the distribution of electric charge when a dc field of such a polarity that the surface of the highly insulative layer assumes positive polarity is applied across the photosensitive element concurrently with uniform light illumination through transparent backing electrode as shown by arrows. In this case, among free charge pairs created by the uniform light projected through the transparent backing electrode, the positive charge having a high mobility in the P-type photoconductor migrates over a long distance and is trapped near the interface between the highly insulative layer and the photoconductive layer thus forming polarization charge at a high sensitivity. As shown in FIG. 3, during the second step light is irradiated locally (or to the left hand half) through the highly insulative layer and a field of the polarity opposite to that of the first field is applied across the photosensitive element. As a result, the polarization charge formed by the first step is readily released at portions irradiated by light whereas at portions not irradiated by light (right hand half) the trapped charge remains to prevent the highly insulative layer from being positively charged. This charge distribution can readily be restored to the condition shown in FIG. 2 prior to subsequent image forming step.

Thus, the photosensitive element is restored to perfectly charge-free condition at the end of each image forming operation, thus eliminating troubles caused by the residual trapped charge. Moreover, as the quantity of charge shifted during each step is large the photosensitivity of the photosensitive element can be substantially improved.

In order to have better understanding of this invention following illustrative example is given.

Referring to FIG. 4, a layer **21a** of selenium was vapor deposited at room temperature to a thickness of 70 microns on one surface of a polyethylene telephthalate film **20a** of 6 microns thick and a layer **22a** of aluminum was vapor deposited on the exposed surface of the selenium layer to a thickness having a light transmittance of 50 percent to complete a photosensitive element. The photosensitive element was wrapped around a glass cylinder **25** of 3 mm thick and about 150 mm diameter with the highly insulative layer **20a** faced outwardly. The resulting photosensitive drum was rotated at a uniform speed. As shown in FIG. 4 a negative corona discharge electrode **1**, a positive corona discharge electrode **3**, a releasing light source **4**, a developing magnet brush **5**, a transfer roller **6**, a cleaning brush **7** and a transfer paper supply means **10** were disposed around the photosensitive drum. A source of uniform light **2** was disposed within the glass cylinder to oppose negative corona discharge electrode **1**. The light image of an object **9** which was moved synchronously with the glass cylinder was projected upon the photosensitive drum through corona discharge electrode **3** by means of a lens **8** as shown by an arrow in FIG. 4.

As shown in FIG. 5, positive corona discharge electrode **3** comprised a hollow conductive shield **12** surrounding discharge electrodes of fine wires **11**.

With the backing electrode grounded a voltage of + 6,000 volts was applied to the positive corona discharge electrode whereas a voltage of −6,000 volts to the negative corona discharge electrode.

The photosensitive drum was rotated at a peripheral speed of 80 mm per second in the direction shown by an arrow. Object **9** and transfer paper were also moved at the same speed as said peripheral speed. The brightness at bright portions of the light image was about 7 luxes and the intensity of uniform light supplied from sources **2** and **4** was about 10 luxes. The image forming property of the photosensitive drum was tested by continual image forming operations of more than several thousand cycles. In image forming operations for different objects under uniform light projection from light source **2** images corresponding to objects were reproduced at high fidelities at all times. The intensity of the latent image at portions corresponding to bright portions of the light image was about +200 volts when measured after irradiation of uniform light for releasing emitted from source **4** whereas that at portions corresponding to dark portions was about −50 volts. These potentials were always the same from the first image forming operation to the final operation.

In a series of tests performed without utilizing uniform irradiation from light source **2**, at the first image forming operation the surface potential of the photosensitive drum was +180 volts at portions corresponding to bright portions of the light image whereas that of portions corresponding to dark portions of the light image was +50 volts. At the second image forming operation potentials of portions corresponding to bright and dark portions, respectively of the light image changed respectively to +230 volts and +160 volts, thus decreasing the potential difference. After about 20 image forming operations these potentials were changed to +270 volts (bright portions) and +250 volts (dark portions) and substantially the same potentials were obtained during subsequent operations. Thus the quality of the developed images was so inferior that they could be scarcely identified.

This invention is particularly advantageous where photoconductive materials manifesting high dark resistance are used. This can be understood from the depth of charge trap levels of these materials. Further, this invention is more effective for photosensitive elements utilizing vapour deposited layers of Se, CdS, CdSe, etc., sintered layers of powders of materials of high photoconductivity such as CdS, ZnO, CdSe, etc., and layers comprising powders of CdS, ZnO, CdSe, etc. bonded by a suitable binder than those utilizing photosensitive layers comprising powdered crystals of phosphors bonded by an insulative binder, because in photosensitive layers comprised by photoconductive materials the distance of migration of charge is longer. It is to be understood that the thickness of the photoconductive layer should not be so large that there may remain portions in which charge is not caused to migrate by light excitation from either side of the photosensitive element.

The method of this invention can also be applied to a photosensitive element having highly insulative transparent thin layers integrally bonded to opposite surfaces of the photoconductive layer. In this modified form an additional highly insulative transparent layer is interposed between the photoconductive layer **21** and the electrode **22**. The principle of forming the latent image in this case is identical to that employing a photosensitive element having a current blocking layer on one side alone.

Any photoconductive material having trap levels may be used to form the photosensitive layer so that this invention is not limited to the specific materials described above.

Further, it is to be understood that the invention is not limited to the type of activating rays, method of applying electric fields, the presence or absence of the backing electrode, or to a particular theory of operation described above.

Irradiation of uniform light during the first step may be performed in various ways. Thus the effect of uniform light irradiation is the same whether it is made prior to or after application of the first electric field, because the photoeffect persists. This invention can also be carried out by reversing the polarities of the first and second fields from those described above.

It was also found that where an ac field is employed as the second field, substantially the same result was obtained. This is because that half cycles of the ac field having the same polarity as the first field do not alter the distribution of charge and only other half cycles of the opposite polarity contribute to the formation of the latent image. Therefore the second field may be a pure dc field or a pulsating or alternating field so long as they contain field component of the opposite polarity as the first field.

I claim:

1. In a method of electrophotography comprising a first step of applying a first electric field across a photosensitive element, which element includes a photoconductive layer manifesting persistent internal polarization and a thin transparent highly insulative layer integrally bonded to one side of said photoconductive layer, to deposit charges of one polarity on said highly insulative layer, and a second step of applying a second electric field across said photosensitive element to deposit charges of the opposite polarity on said highly insulative layer concurrently with the projection of a light image upon said photoconductive layer through said highly insulative layer whereby to form an electrostatic latent image corresponding to said light image on the surface of said highly insulative layer, the improvement which comprises irradiating said photoconductive layer with uniform light from the side thereof remote from said insulative layer before application of said second electric field, said uniform light having an intensity sufficient to cause substantially complete separation of any majority and minority charge carriers in said photoconductive layer, said photoconductive layer having a thickness such that said uniform light if projected thereon through said transparent highly insulative layer does not cause substantial excitation of said photoconductive layer on the side opposite said highly insulative layer.

2. The method according to claim **1** wherein said photosensitive element is provided with thin transparent insulative layers on both sides of said photoconductive layer.

3. The method according to claim **1** wherein the photosensitive element includes a transparent backing electrode on the side of said photoconductive layer remote from said insulative layer, said photosensitive element is wrapped with said electrode innermost around a transparent rotary cylinder, a source of uniform light is positioned in said cylinder to irradiate said photosensitive element through said backing electrode and through said cylinder, and said first and second fields are applied across said photosensitive element by corona discharge units located outside said rotary cylinder.

4. The method according to claim **1** wherein said photosensitive element is provided with a transparent backing electrode on the side of said photoconductive layer remote from said highly insulative layer and said irradiation with said uniform light is performed through said transparent backing electrode.

5. The method according to claim **1** wherein said irradiation with uniform light is performed concurrently with the application of said first electric field.

6. The method according to claim **1** wherein said irradiation with uniform light is performed before application of said first electric field.

7. The method according to claim **1** wherein said irradiation with uniform light is performed after application of said first electric field.

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