Aug. 14, 1956 M. L. SUGARMAN, JR 2,758,939

ELECTROSTATIC PRINTING

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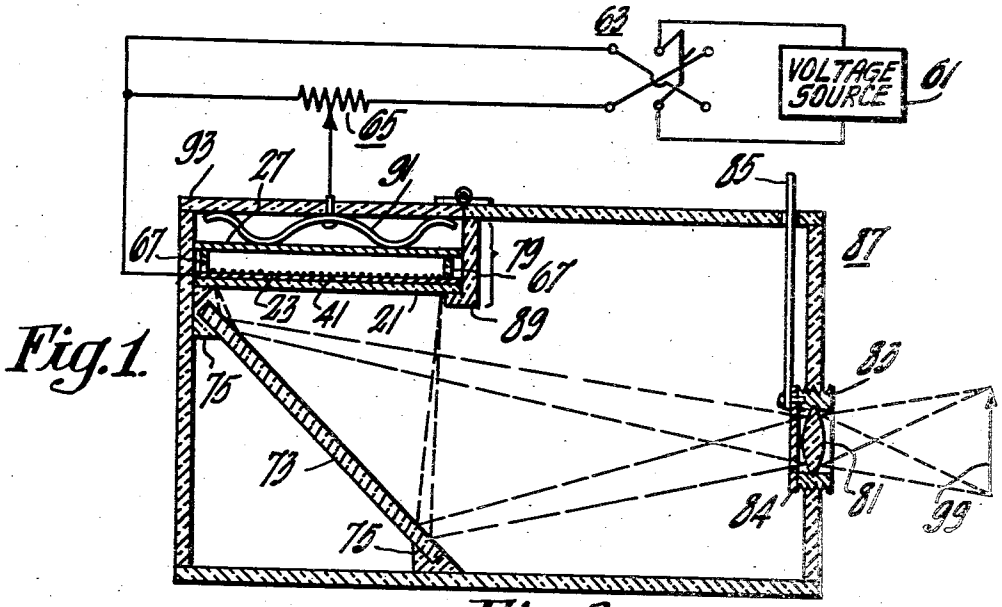


Fig. 1.

Fig. 2.

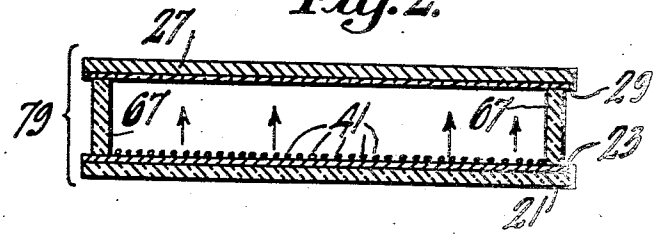
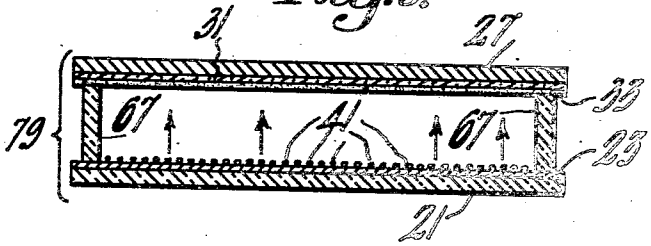


Fig. 3.



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ELECTROSTATIC PRINTING

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This invention relates to improved methods and means of electrostatic printing.

An electrostatic printing process is that type of process for producing a visible record, reproduction or copy which includes as an intermediate step, converting a light image or electrical signal into an electrostatic charge pattern on an insulating base. The process may also include the conversion of the charge pattern into a visible image which may be a substantially faithful reproduction of an original except that it may be a different size.

A typical electrostatic printing process may include coating a surface of a conductive backing plate with a photoconductive insulating material such as selenium, anthracene, or sulphur, and then providing an over-all electrostatic charge on the surface of the photoconductive material. An optical image is focused on the charged surface, discharging the portions irradiated by the light rays, while leaving the remainder of the surface in a charged condition thereby forming an electrostatic image. The electrostatic image is rendered visible by applying a developer powder which is held electrostatically to charged areas of the sheet. The powder image thus formed may be fixed directly to the photoconductive coating or it may be transferred to another surface upon which the reproduced image may be desired and then fixed thereon. A detailed description of the steps of this process may be found in U. S. Patent 2,297,691 issued October 6, 1942, to C. F. Carlson.

In the process above described, the steps of electrostatic image formation and subsequent development of the electrostatic image are separate and distinct operations. For example, the electrostatic image is formed utilizing apparatus for giving the photoconductive surface an overall charge and apparatus for projecting an optical image on the charged surface. When the electrostatic image has been formed, additional apparatus is employed to render the electrostatic image visible.

Because these steps are separate and distinct operations, the photoconductive layer must have the ability to store the electrostatic image at least for the period of time necessary to form and to develop the electrostatic image. By combining the two steps in a single operation, photoconductive materials having very short storage times, that were hitherto impractical, may be used. It is also commercially desirable to combine these steps into a single operation in order to speed up the printing process and simplify the required apparatus.

In those presently known processes in which selenium coatings are used to make the electrophotographic plate, the photoconductive coating becomes "fatigued" after a relatively few uses and either must be permitted to rest for a considerable period or must be regenerated. Where a large volume of work is to be handled, a number of photoconductive plates must be rotated in use unless some method of regeneration is used. The use of an electrophotographic plate including a selenium surface has the further disadvantages that the selenium surface must be

cleaned frequently and that it is subject to wear from use and handling.

Heretofore used electrostatic printing processes are capable of producing either a positive or a reverse visible image in a single operation, but not both. Whether the image is positive or reverse is determined by which areas of the electrostatic image bearing sheet are charged, the polarity of the charge of the image areas and the polarity of the charge on the developer powder.

An object of this invention is to provide improved methods and means of electrostatic printing.

Another object is to provide a single, simplified electrostatic printing apparatus for accomplishing the steps of forming and rendering visible an electrostatic image.

An object is to provide methods and means of electrostatic printing using photoconductive developing powders.

Another object is to provide methods and means of electrostatic printing that may use photoconductive materials having relatively short storage times.

A further object is to provide methods and means of electrostatic printing for producing both a positive and a negative visible image in the same operation.

In accordance with the present invention, a visible powder image may be produced by establishing an electric field across a layer of a normally insulating photoconductive developer powder. An optical image is projected upon said photoconductive developer powder layer whereby the powder lying in the illuminated areas of the optical image becomes charged and attracted away to a region of opposite polarity. By one embodiment of the invention the powder remaining comprises the visible powder image. By a second embodiment powder attracted away is intercepted upon a surface closely spaced from said powder layer producing a visible powder image thereon. By this second embodiment both a positive and a reverse visible powder image may be produced. By a third embodiment the powder attracted from illuminated areas of the powder layer is caused to oscillate in the electric field until the lateral movement accompanying said oscillatory movement deposits the oscillating powder particles in the non-illuminated areas of the optical image. By the third embodiment, the oscillating powder particles may deposit upon the developer powder layer in the non-illuminated areas of the optical image or upon the non-illuminated areas of a surface in closely spaced relation to said developer powder layer.

The invention will be more easily and fully understood from the following detailed description in conjunction with the accompanying drawing in which:

Figure 1 is a partially schematic sectional elevational view of a camera embodying this invention, and

Figure 2 is a sectional elevational view of a second electrophotographic pack that may be used in the camera of Figure 1, and

Figure 3 is a sectional elevational view of a third electrophotographic pack that may be used in the camera of Figure 1.

Similar reference characters are applied to similar elements throughout the drawing.

Referring to Figure 1, an electrophotographic pack **79** comprises an upper brass electrode **27** spaced about ⅛" above a lower electrode by means of spacers **67**. The lower electrode comprises a transparent backing plate **21**, such as glass, a transparent electrically conducting layer **23**, such as a NESA coating, marketed by the Pittsburgh Plate Glass Co., Pittsburgh, Pa., superimposed thereon. A thin even layer of a photoconductive developer powder **41**, such as lead iodide, is placed upon the upper surface of the lower electrode. The powder may be applied, for example, by sprinkling the powder from a suitable shaker before the electrophotographic pack **79** is assembled. A camera is provided comprising a lens **81**, a

lens holder **83**, a shutter **84**, a shutter merchanism 85, an enclosure **87**, a pack holder **89** disposed in the upper rear portion of the enclosure **87**, and a spring clip **91**. The electrophotographic pack **79** is mounted horizontally in the pack holder **89** by means of a hinged door **93** where it is held firmly in place by the spring clip **91**. The upper electrode **27** and the transparent coating **23** of the lower electrode are connected to a voltage source **61** through a double-pole, double-throw switch **63** and a potentiometer. A miror **73** mounted diagonally upon mirror holders **75** is disposed at the back of the enclosure 87, such that an optical image passing horizontally through the lens 81 is directed upwards to the electrophotographic pack **79**.

A negative voltage of about 1600 volts is applied to the upper electrode **27** by throwing the switch **63** and adjusting the potentiometer **65**. The shutter 84 is opened by means of the shutter mechanism **85** allowing the image of an object **99** to fall upon the photoconductive powder layer **41** on the lower electrode. The electrical resistance of the photoconductive powder in the illuminated areas of the image is reduced due to the presence of light, allowing a charge in the same polarity as the electrode upon which it rests to pass into the powder particles. The powder thus charged is attracted upwards due to the electric fields present including the relatively strong field existing between the upper electrode **27** and the transparent conductive coating **23** on the lower electrode. When the charged powder particles reach the upper electrode **27**, they are discharged and return to the lower electrode and this process is repeated, causing the powder particles in the illuminated areas of the image to oscillate between the electrodes. During the oscillations the particles have a certain amount of lateral movement, causing the particles to drift out of the illuminated areas in the optical image. The oscillating particles finally come to rest upon the developer powder layer in the non-illuminated areas of the optical image, thereby producing a powder image upon the lower electrode. The electric field is disestablished by opening the switch **63** and the electrophotographic pack **79** is removed from the camera. The visible powder image may be fixed to the surface upon which it rests, or it may be transferred to another surface and fixed thereon by any of the conventional methods. For example, an adhesive may be sprayed on the powder image, or, if the powder is fusible, it may be fused to the surface upon which it rests by the application of heat.

Almost any photoconductive material in powdered form may be used as the developer powder. For example, a pure photoconductor such as an oxide, sulphide, selenide, telluride, or iodide of cadmium, zinc, mercury, antimony, bismuth, thallium, indium, molybdenum, aluminum and lead may be used. In addition, arsenic trisulphide, cadmium arsenide, lead chromate, selenium, anthracene, or sulphur may be used. Mixtures of one or more photoconductors may also be used. Alternatively, a non-photoconductive powder coated with a photoconductive film on its surface may be employed. For example, powdered magnesium silicate coated with cadmium sulphide may be used. Such a coating may be produced by evaporating a film of cadmium sulphide onto the surface of the magnesium silicate powder.

Another alternative is a ground composition comprising a photoconductor dispersed in a resin or a wax. Examples of suitable resins are the vinyl resins, silicone resins, phenol formaldehyde, cellulose ether, and cellulose esters. Shellac is an example of a suitable natural resin. Examples of suitable waxes are paraffin, carnauba wax and beeswax. Inorganic materials such as sodium silicate may be used. Mixtures including one or more waxes or resins may be used. The photoconductor may be dispersed in the wax or resin in any of several ways. The simplest way is to dissolve the wax or resin in an organic solvent capable of effecting solution, mixing in the powdered photoconductive material and then evaporating the mixture to drive off the solvent. Alternatively, the photoconductor may be dry blended by kneading the wax or resin to a sufficiently high temperature to render it plastic. Waxes and other materials having a low melting point may be melted and the photoconductor mixed with the melt. The blended mixture is then permitted to cool. In either case the resulting block is broken up and grounded to a fine powder, for example, by ball-milling.

The proportion of photoconductor of wax or resin in the final powder may vary over a very wide range. The preferred ranges are 50 to 90% of photoconductor and 50 to 10% of film of wax or resin. The optimum proportions are dependent upon the nature of the photoconductor and the wax or resin, and upon the results desired.

The speed of response of the photoconductive powder is particularly dependent upon the nature of the photoconductive material, the nature of the wax or resin and the ratio by weight of photoconductor to wax or resin. Since the speed of response depends upon a balance of characteristics of these factors, almost any desired response may be obtained by a proper selection of materials and compositions. The speed of response is often measured by the relaxation time of the material. It is commonly expressed as the period of time in which an arbitrary per cent of a charge stored on its surface will leak off. By using a photoconductive material having a relatively short relaxation time, it is possible to obtain very fast responses to light. By choosing a photoconductive material having a relatively long relaxation time, it is possible to obtain slower responses.

Whereas presently known processes utilize photoconductive layers and require the photoconductive material to have the ability to store an electrostatic image at least for a limited time, this requirement is not present in the instant invention. Photoconductive materials having relatively long, intermediate or relatively short relaxation times may be used. Photoconductive materials that had a relatively high dark current were not practical in the photoconductive layers of presently known processes. This is because photoconductive materials having a high dark current are not able to store a charge for a reasonable period of time. However, in the instant invention the dark current of the photoconductive material is not a limitation since the electric potential need only be applied for the duration of the exposure. For a photoconductive material having a very high dark current, the switch **63** may be synchronized with the shutter 84 so that the electric field is established simultaneously for the short interval of the exposure. Since images are presently obtainable for exposure speeds as fast as one hundreth of a second, materials with relatively high dark currents may be used.

It is preferred to use powders with a particle size range between 10 and 100 microns. Surface forces interfere with the processes when the powder is too fine. Particles that are too coarse, are difficult to handle and tend to lose definition in the image.

In order to increase the contrasts of the powder image against its background, it is frequently desirable to include a dye in the photoconductive material. Any dye or colorant which does not interfere with the process may be included when the developer powder is prepared.

It has been found that many photoconductive powders prefer to remain on a surface of a particular polarity. For example, lead iodide prefers to remain upon a positive electrode, while cadmium sulphide prefers to remain upon a negative electrode. This is consistent with the N and P type characteristics of these materials. Thus, in choosing the photoconductive material, the polarity preference of the photoconductive material should be kept in mind. In the above-described example, lead iodide was used to produce an image on the positively charged lower electrode. A powder image may be produced on the upper electrode by reversing the electric

field between the electrodes such that the upper electrode is positive and that the lower electrode is negative. In this case the lead iodide, which prefers to remain upon a positively charged electrode, will oscillate in the electric field until it comes to rest in the non-illuminated areas of the positively charged upper electrode. An example of another method for producing a powder image upon the upper electrode is to substitute cadmium sulphide powder in the above-described example. Since cadmium sulphide prefers to remain upon a negatively charged electrode, the illuminated powder will oscillate in the electric field until it comes to rest in the non-illuminated areas of the negatively charged upper electrode.

The photoconductive material will determine the spectral response of the developer powder. Most photoconductive materials absorb light in the shorter wavelengths. As the wavelengths become longer, a point is reached where the absorption of radiation drops off sharply as the photoconductive material ceases to absorb. This point is called the absorption edge of the material. It is an advantage in the present invention that by making a proper selection of the photoconductive material, one may obtain any desired light absorption characteristic and desired spectral sensitivity. For example, thallium iodide has a peak response around 4130 A. Silver sulphide has a peak response around 13,500 A., while other photoconductors may have their peak responses at other points of the electromagnetic spectrum and over a narrow or wide band of frequencies. By selecting a photoconductor or mixture of photoconductors having the desired response over the desired bandwidth, one may obtain the desired result.

While any type of electromagnetic radiation may be projected upon the photoconductive powder layer, the spectral range of the radiation must be within the range of sensitivity of the photoconductive material. Thus, the choice of the photoconductive material and the radiation are interdependent.

The spacing of the electrodes and the appled voltage are not critical. It is only necessary to provide an electric field which, when added to the smaller field present, will cause the charged powder to move away from the electrode. A preferred spacing is 1/16" to 1/8". The electric fields should be adjusted to the highest field possible without causing the photoconductive powder to migrate in the dark. Electric fields of the order of about 0.5 to 30 kilovolt per inch electrode spacing are preferred for lead iodide powders. It is preferred to use electric field strengths of about 15 kilovolts per inch for lead iodide. For cadmium sulphide powders it is convenient to use electric field strengths of about 0.5 to 0.8 kilovolt per inch. Either direct or alternating current may be applied to the electrodes.

The electrodes may be made of any conducting material. However, it is preferred to make one electrode transparent. For this purpose a NESA coating is found to be convenient. The other electrode may be made of any material, however, for certain photoconductive powders, such as cadmium sulphide, electrodes made of indium or other low work function materials have been found to reduce the threshold voltage appreciably. There is some evidence that a thin coating of a low work function material, such as indium, evaporated upon the photoconductive powder will aid in transferring the electric charge between the powder particles and the electrode, thus increasing the effective light sensitivity of the process.

In the above-described example the lower electrode is transparent and the photoconductive powder rests thereon. The camera may be arranged such that the mirror **73** reflects the optical image downward and the electrophotographic pack **79** is below the mirror **73**. By this second arrangement the upper electrode is transparent

and the optical image irradiates the powder layer from above. This arrangement works equally well and may be preferred for certain purposes. By another arrangement the photoconductive powder layer is located on the upper electrode. In such an arrangement increased sensitivity is obtained since gravity aids in moving the illuminated particles. Further increases in sensitivity may be obtained by starting the process with particles having an electric charge that is attractive to the opposite electrode.

One method for producing a powder layer upon the upper electrode is to sprinkle the photoconductive powder **41** on the lower electrode as previously described. A relatively high potential is applied to the electrodes and the entire photoconductive powder layer is exposed to a blanket illumination. By choosing the photoconductive powder such that it prefers to remain upon the upper electrode, the powder will commence to oscillate in the electric field between the electrodes. The voltage is reduced and the photoconductive powder will come to rest upon the upper electrode which it prefers. The resulting powder layer on the upper electrode is now in condition for use in producing electrostatic images. The use of a photoconductive powder layer upon the upper electrode may be used in either arrangement, that is, where the optical image strikes the powder layer from below or from above.

The above-described embodiments discuss methods of producing visible powder images wherein a photoconductive powder makes a plurality of traverses within an electric field. By a second series of embodiments a visible powder image may be produced wherein a photoconductive powder makes a single traverse in the electric field.

Referring to Figure 2, an electrophotographic pack **79** similar to the apparatus of Figure 1 except that the upper electrode is coated with a thin electrically insulating layer **29**. The coating may be a resin or paper, for example, and it may be coated upon the electrode as shown or it may be a sheet placed upon the upper electrode. The electrophotographic pack **79** is placed in the camera of Figure 1 and exposed as described above. The powder **41** resting upon the layer **23** becomes charged where it is illuminated by an optical image and is attracted away from the lower electrode. The powder **41** thus attracted away comes to rest upon the insulating layer **29** where it is held by electric field, thus forming a visible powder image on the upper electrode. This image is the reverse of the images produced by the above-described process.

Referring to Figure **3**, an electrophotographic pack **79** similar to the electrophotographic pack of Figure 1 is provided except that in front of the upper electrode is a carrier sheet **31** having a layer of a sticky substance **33**. The sticky substance may be a glue, or a syrup. Alternatively, the carrier sheet **31** may be impregnated with water thereby making it somewhat adhesive. As described in Figure 2, the pack **79** is placed in the camera and exposed so that the illuminated photoconductive powder lying on the lower electrode becomes charged and attracted away from the lower electrode. The powder attracted away moves upwards and comes to rest in the sticky layer **33**, thereby forming a visible powder image.

Referring to Figure 1, another embodiment is to utilize the apparatus as described above except that either the voltage or the light or both are pulsed such that the duration of the pulse is only sufficient for the illuminated powder to become charged and to move up to the upper electrode. By this method the illuminated powder becomes charged, moves up to the upper electrode and is held there by electric field forces.

Under certain circumstances the images produced by the methods of this invention lack contrast and possess excessive spurious powder in the background areas. In order to improve the contrast and to remove this background appearance, the potential normally applied to the electrodes is reversed after the completion of the im-

age formation. A pulsed over-all illumination is applied to the powder image causing a single layer of powder particles over the entire powder image to become charged and attracted away from the powder image. In this way the contrast between light and dark areas is improved. By a second method the completed powder image is exposed to blanket illumination and a reverse electric field is pulsed such that a single layer over the entire powder image becomes charged and attracted away from the powder image.

There has been described improved methods and means of electrostatic printing. The apparatus described is simple in construction, rapid in operation, and permits the use of photoconductive materials having relatively short relaxation times that were hitherto impractical to be used. By the described methods and means either a positive or a negative image or both a positive and negative visible powder image may be obtained in the same operation.

What is claimed is:

1. A method of electrostatic printing comprising projecting a light image upon a layer of a photoconductive insulating developer powder, charging in one polarity the developer powder lying in the illuminated areas of the light image, and then establishing an electric field across said developer powder layer whereby the charged developer powder is attracted away to a region of opposite polarity.

2. A method of electrostatic printing comprising establishing an electric field across a layer of a photoconductive developer powder, projecting a light image upon said developer powder layer, and then charging in one polarity the developer powder lying in the illuminated areas of the light image whereby the charged powder is attracted away to a region of opposite polarity.

3. A method of electrostatic printing comprising establishing an electric field across a thin layer of a normally insulating photoconductive developer powder, projecting a light image upon said developer powder layer whereby the powder lying in the illuminated areas of the light image becomes charged and attracted away to a region of opposite charge.

4. A method according to claim 3 wherein the developer powder lying in the non-illuminated areas of the light image comprises a visible powder image.

5. A method according to claim 3 including intercepting the powder attracted away upon a surface in closely spaced relation to said developer powder layer thereby producing a visible powder image upon said surface in substantial configuration with said light image.

6. A method according to claim 3 wherein said powder attracted away is caused to oscillate in the electric field until the lateral movement accompanying said oscillatory movement deposits the oscillating powder particles in the non-illuminated areas of the light image.

7. A method according to claim 3 wherein said developer powder attracted away is caused to oscillate in the electric field until the lateral movement accompanying said oscillatory movement deposits the oscillatory powder particles upon the developer powder layer in the non-illuminated areas of the light image.

8. A method according to claim 3 wherein said powder attracted away is caused to oscillate in the electric field until the lateral movement accompanying said oscillatory movement deposits the oscillating powder particles upon the non-illuminated area of a surface in closely spaced relation to said developer powder layer.

9. A method of electrostatic printing comprising establishing an electric field across a thin layer of a photoconductive developer powder upon the surface of an electrode, projecting a light image upon said developer powder layer, alternately charging and discharging the powder particles in the illuminated areas of the light image causing the powder particles to oscillate in the electric field until the lateral movement accompanying said oscillatory movement deposits the oscillating powder particles in the non-illuminated areas of the light image leaving a visible powder image.

10. A method according to claim 9 including fixing the powder image to a substrate.

11. A method of electrostatic printing comprising establishing an electric field of the order of eleven kilovolts per inch across a thin layer of powdered lead iodide upon the surface of an electrode, projecting a light image upon said powder layer, alternately charging and discharging the powder particles in the illuminated areas of the light image causing the powder particles to oscillate in the electric field until the lateral movement accompanying said oscillatory movement deposits the oscillating powder particles in the non-illuminated areas of the light image leaving a visible powder image.

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