June 17, 1958 A. J. MONCRIEFF-YEATES 2,839,400

ELECTROSTATIC PRINTING

Filed Oct. 30, 1953 3 Sheets-Sheet 1

Fig. 1.

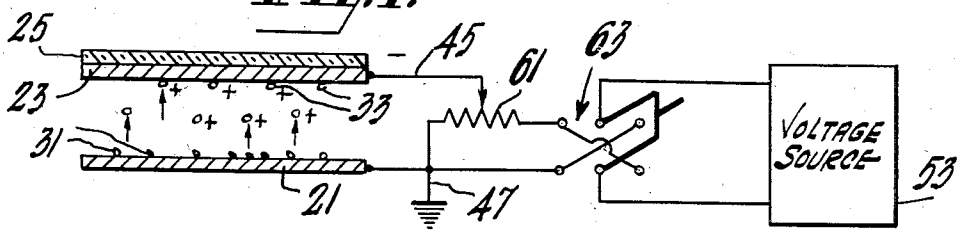


Fig. 2.

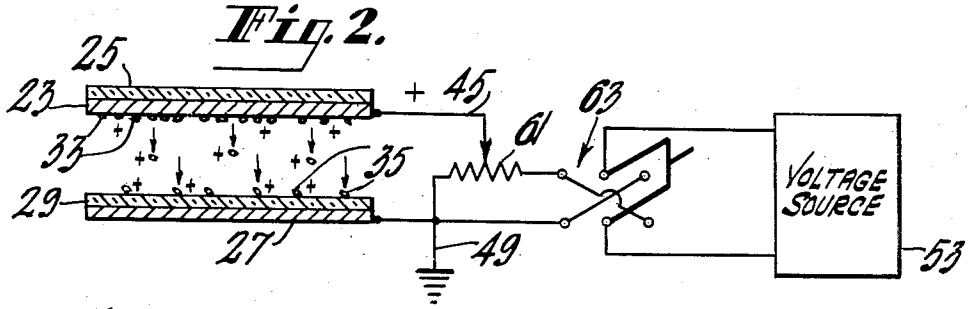


Fig. 3.

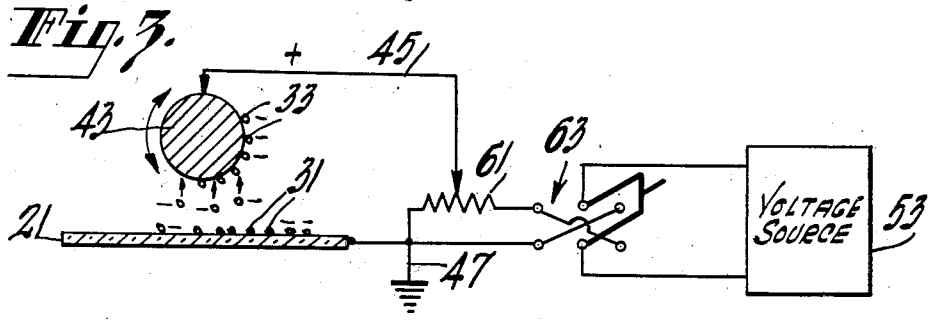
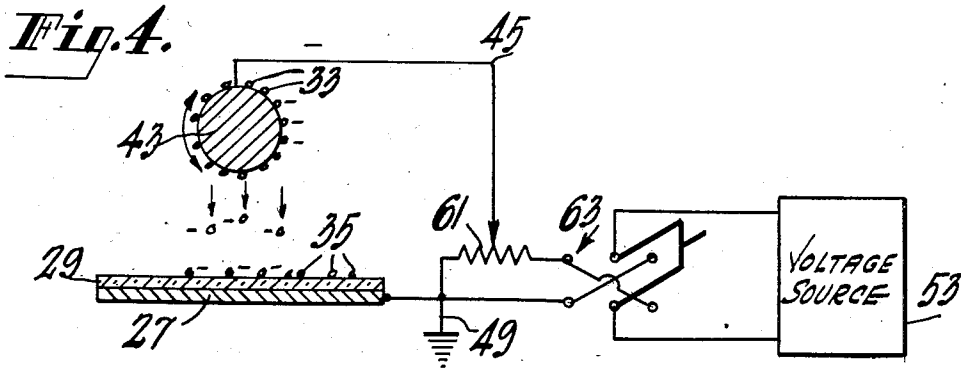


Fig. 4.



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Fig. 5.

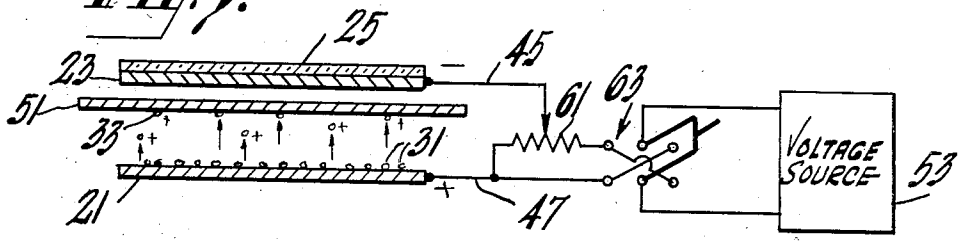


Fig. 6.

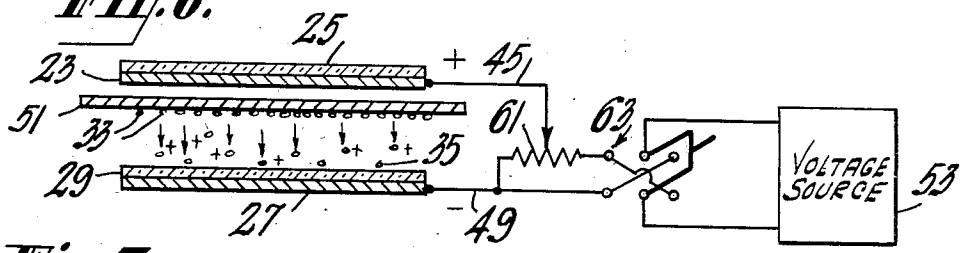


Fig. 7.

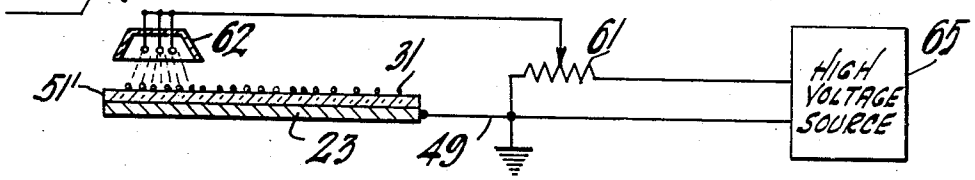
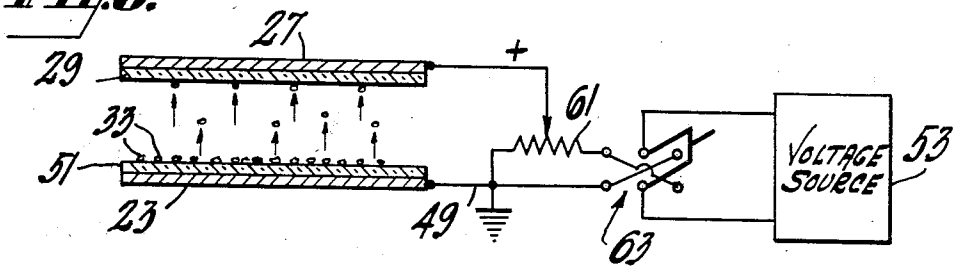


Fig. 8.



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ELECTROSTATIC PRINTING

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FIG. 9.

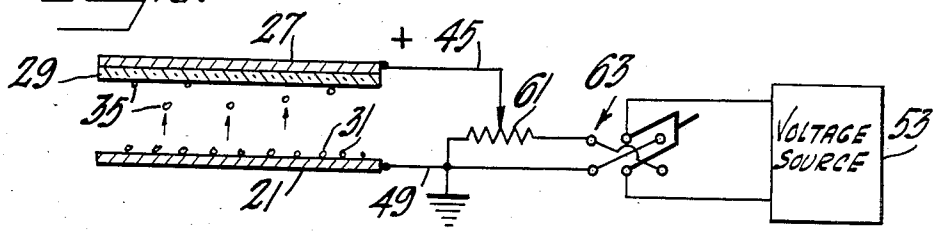


FIG. 10.

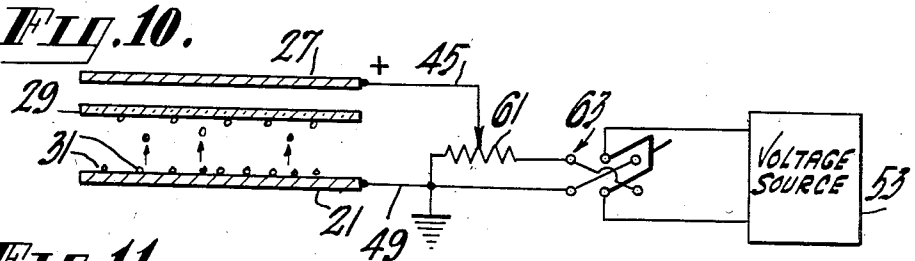


FIG. 11.

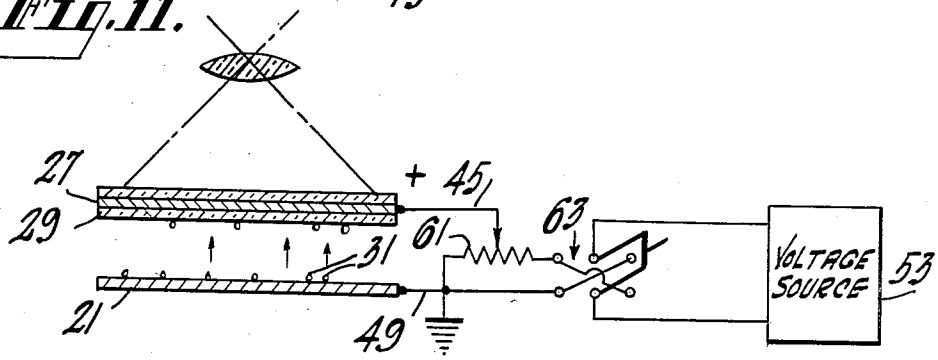
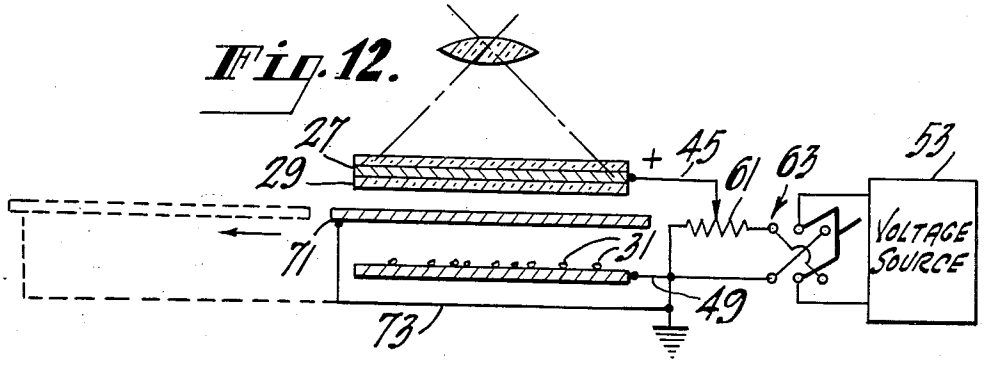


FIG. 12.



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2,839,400

ELECTROSTATIC PRINTING

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Application October 30, 1953, Serial No. 389,347

6 Claims. (Cl. 96—1)

This invention relates to electrostatic printing and more particularly to methods and means for developing electrostatic images.

An electrostatic printing process is, generally speaking, that type of process for producing a visible image, reproduction, or copy which includes as an intermediate step converting a light image or electrical signal into an electrostatic charge pattern on an insulating surface. 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 of a different size.

A typical electrostatic printing process may include the steps of providing a conductive backing plate having a surface coated with a photoconductive insulating material such as selenium, anthracene or sulphur, applying a blanket electrostatic charge to the surface of the photoconductive coating, focusing a light image on the charged surface in order to discharge the portions irradiated by light rays, while leaving the unexposed areas of the surface in a charged condition thereby forming an electrostatic image. The electrostatic image is made visible by the application of a developer powder which is held electrostatically to the 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 is desired and then fixed thereon. A detailed description of the steps of this process may be found in U. S. Patent No. 2,297,691, issued October 6, 1942, to C. F. Carlson.

Several different methods are presently used to render the electrostaic image visible. One method for developing the electrostatic image is to dust a developer powder on the image. By gentle blowing, the excess developer powder is removed, leaving a visible image of powder that is held electrostatically to the charged areas of the image. A variation on this type of development is to blow a powder cloud across the electrostatic image whereby the powder in the cloud is attracted and held to the charged areas of the image. The developer powder may be coated on a smooth or knurled roller and then rolled across the electrostatic image whereby the powder on the roller is brought in contact with the electrostatic image, and held by electrostatic attraction.

Another method for developing the electrostatic image is to mix the developer powder with small glass beads or other suitable granular carrier material. The mixture is cascaded across the surface having the electrostatic image, transferrng particles of developer powder to the charged areas of the electrostatic image. Another method of developing the electrostatic image is to mix magnetic carrier particles, such as iron, with a developer powder. This mix is carried by a magnet to form a developer brush. The brush is rubbed across the surface having the elastrostatic image, whereby the developer powder in the brush is transferred to the charged areas of the electrostatic image, thus forming a visible powder image.

With the exception of the magnetic brush process, many of the processes produce a powder image that has a streaky appearance. Furthermore, these processes tend to overdevelop the edges of the charged areas while leaving solid areas relatively underdeveloped. Thus it is difficult to obtain good continuous tone prints. The magnetic brush process overcomes many of these difficulties. However, in the magnetic brush process, the ratio of developer powder to magnetic carrier particles must be maintained within a very narrow range in order to obtain the best results. It is therefore, necessary to regenerate the brush frequently by a process which requires careful attention.

All of the above-mentioned methods of rendering visible the electrostatic image have a relatively low sensitivity. That is, the magnitude of charge in the image areas must be relatively high in order to transfer and to hold the developer powder. This, in turn, makes it necessary to lay down a blanket electrostatic charge of relatively high potential at the start of the process and to provide a photoconductive layer of relatively high insulating value in order to hold the charge.

One method of increasing the sensitivity is to provide a developing powder that is itself electrostatically charged. There are several methods by which developer powders obtain an electrostatic charge. Certain powders are charged because of their chemical structure. Other powders may be given an electrostatic charge by friction or triboelectric charging. The use of a charged developer powder permits the development of electrostatic image areas having relatively lower magnitudes of charge, thus increasing the sensitivity of the developing process. The difficulty with the triboelectric charging is that the developer particles are not uniformly charged and such charging is not easily controlled. Hence although the development with charged powders has advantages over development with uncharged powders, the developed image may be streaky in appearance and tends to overdevelop the edges of the charged area of the image and to underdevelop solid areas.

An object of the present invention is to provide an improved electrostatic printing process.

A further object is to provide improved methods of and means for developing electrostatic images.

Another object is to provide improved methods of and means for developing electrostatic images of high sensitivity that yields a powder image that is a substantially faithful reproduction of the original optical image.

A further object of this invention is to provide improved methods of and means for charging developer powders for electrostatic printing.

Another object is to provide improved methods of and means for producing a uniformly charged electrostatic developer powder.

The foregoing objects and other advantages may be accomplished in accordance with the present invention which comprises novel methods and apparatus for establishing an electrostatic image on the surface of a dielectric image sheet, bringing a uniformly charged developer substance into closed spaced relation with the electrostatic image and applying an electric field to the developer substance whereby the developer substance is attracted uniformly to and deposits uniformly upon the electrostatic image. By a first embodiment of the present invention the developer powder is charged by applying an electric field to a layer of powder resting on a lower electrode whereby the powder becomes charged and is attracted away from the lower electrode. The charged powder attracted away may be collected on an upper electrode which may be a flat plate or a roller, or may be caught on an insulating sheet interposed between the lower electrode and an upper electrode. By a sec-

ond embodiment the developer powder may be charged by exposure to an ion-producing or an electron source such as a corona discharge. The charged powder is brought into close spaced relation with the electrostatic image and an electric field is applied to the developer powder whereby the developer powder is attracted to and deposits upon the electrostatic image. By a third embodiment, an electrostatic image is interposed between a pair of electrodes. A powder lying on the upper surface of the lower electrode is charged and attracted to the electrostatic image in a single step when a potential is applied to the electrodes. The combination of the applied electric field and the attraction of the charged developer powder for the electrostatic image make it possible to develop areas of relatively low potential. The amount of powder deposited is a direct function of the magnitude of electrostatic charge on the elemental areas of the electrostatic image.

The invention will be described in greater detail by reference to the accompanying drawings in which:

Figure 1 is a sectional view of one embodiment for charging a developer powder by a method of this invention.

Figure 2 is a sectional view of an apparatus for developing an electrostatic image using the charged powder of Figure 1.

Figure 3 is a sectional view of another apparatus embodiment for charging a developer powder by a method of this invention.

Figure 4 is a sectional view of an apparatus for developing an electrostatic image using the charged developer powder of Figure 3.

Figure 5 is a sectional view of a third apparatus embodiment for charging a developer powder by a method of this invention.

Figure 6 is a sectional view of an apparatus for developing an electrostatic image using the charged developer powder of Figure 5.

Figure 7 is a sectional view of a fourth apparatus for charging a developer powder by a method of this invention.

Figure 8 is a sectional view of an apparatus for developing an electrostatic image using the charged developer powder of Figure 7.

Figure 9 is a sectional view of a fifth apparatus for simultaneously charging a developer powder and developing an electrostatic image by a method of this invention.

Figure 10 is a sectional view of another apparatus for simultaneously charging a developer powder and developing an electrostatic image by a method of this invention.

Figure 11 is a sectional view of a sixth apparatus for simultaneously forming an electrostatic image charging a developer powder and developing the electrostatic image with the charged developer powder.

Figure 12 is a sectional view of a seventh apparatus for electrostatic printing utilizing photoconductors having short relaxation times.

Similar references figures are applied to similar elements throughout the drawing.

Example 1

Referring to Figures 1 and 2, a lower electrode comprising a brass plate **21**, held at ground potential through a lead **47**, supports a thin layer **31** of polyvinyl formal powder on its upper surface. An upper electrode comprising a glass plate **25** having an electrically-conducting coating **23** on its lower face is held at a negative potential of about 600 volts with respect to ground by a voltage source **53** connected thereto through a lead **45**, a voltage dividing potentiometer **61** and a double-pole double-throw reversing switch **63**. The upper electrode **23** is brought parallel to and about ⅛" away from the powder layer **31** in the lower electrode **21**. The electrodes **21** and **23**, acting as plates in a condenser, charge the powder particles **31** positively. The charged powder particles move upwards through the electric field, formed between electrodes **21** and **23**, depositing as a thin layer **33** on upper electrode **23**. When a sufficiently thick layer of charged particles has formed, which is of the order of 10 to 12 layers of particles, the negative potential and the lower electrode **21** are removed. An insulating layer **29**, having an electrostatic image previously established thereon, on a second lower electrode **27** that is grounded through a lead **49**, is brought parallel to and within ⅛" of the layer of charged particles **33** and a positive potential, of about 100 volts with respect to ground, is applied to the upper electrode **23**. Since polyvinyl formal powder loses its charge rather rapidly, it is necessary to bring the electrostatic image close to the charged particles **33** within about 30 seconds after charging. On bringing the electrostatic image close to the charged powder, the combination of the electric field formed by the electrodes **23** and **27**, and the attraction of the positively-charged developer powder for the negatively-charged area of the electrostatic image, the positively-charged developer powder is attracted to and deposits upon the negatively-charged areas of the electrostatic image, thereby producing a powder image of particles **35**.

Example 2

Referring to Figures 3 and 4, a lower electrode comprising a brass plate **21**, held at ground potential through a lead **47**, supports a thin layer **31** of finely powdered colored nylon on its upper surface. The powder layer **31** is exposed to the negative discharge from a high voltage source (not shown), for example, a corona discharge apparatus, charging the nylon powder particles negatively. An upper electrode comprising a brass roller **43**, is connected through lead **45**, a voltage-dividing potentiometer **61** and double-pole, double-throw reversing switch **63**, to a source **53** of potential positive with respect to ground. The roller **43** is rolled out of contact with, but close to, the charged powder layer **31**. As the roller **43** passes above the powder **31**, the negatively-charged powder particles **31** are attracted to the positively-charged roller **43**. The powder particles **31** move across the gap and settle on the roller **43** forming a coating thereon of charged powder particles **33**. Next a negative potential with respect to ground of about 200 volts is applied to the roller **43**. The roller **43** is brought close to the surface of a grounded plate **27** coated with an insulating layer **29** having a positive electrostatic image previously established thereon. The roller **43** is spaced about ⅛" from the insulating surface **29** which is held at ground potential through a lead **49**. The electric field formed as a result of the potential difference between the roller **43** and the ground plate **27** combined with the attraction of the negatively-charged particles coated on the roller **43** for the positively-charged areas of the electrostatic image, produce a sufficient attraction to move the developer particles **33** from the roller **43** to the electrostatic image. The developer powder particles **35**, attracted to the positively-charged areas of the electrostatic image, from a powder image thereon.

Example 3

Figures 5 and 6 show an apparatus similar to the apparatus of Figures 1 and 2. In the apparatus of Figures 1 and 2, the charge on the developer powder particles **33** leaks off to the upper electrode **23** on which they are resting. Hence, the charged developer powder must be used promptly after charging. In order to store the charged powders for longer periods of time, an insulating dielectric layer **51** such as acrylic plastic, is interposed between the upper electrode **23** and the lower electrode **21**. When the powder becomes charged and moves upwards toward upper electrode **23**, it is inter-

cepted by the dielectric layer **51**. The powder lying on the dielectric layer will hold its charge for longer periods of time. An electrostatic image on an insulating layer **29** may be developed by the method described in Example 1. It will be understood that the interposed dielectric layer **51** may be a separate sheet or may be a coating upon the conducting coating **23**, and may be any material having dielectric properties. The higher the dielectric strength generally the longer the developer powder may be stored.

Example 4

Referring to Figures 7 and 8, a layer of developer powder **31** is placed on a dielectric coating **51'** which is superimposed on a grounded lower brass electrode **23**. The powder layer **31** is uniformly subjected to the negative discharge from a corona apparatus **62** connected to a high voltage source **65** through a voltage-dividing potentiometer **61**. The powder particles **31** thereby obtain a uniform high voltage charge. A previously established electrostatic image on the lower surface of an insulating coating **29** on the lower surface of an upper brass electrode **27** is brought parallel to and approximately ⅛ inch away from the charged powder layer **31**. A positive voltage with respect to ground is applied to the upper electrode **27** by means of the voltage source **53** connected through the voltage-dividing potentiometer **61** and the double-pole, double-throw reversing switch **63**. The voltage is gradually increased until the combination of the electric fields from the charged powder **31**, the electrostatic image and from the electrodes **23** and **27** causes the powder particles to rise from the lower electrode to the electrostatic image, forming a powder image thereon which is a faithful visible reproduction of the electrostatic image.

Example 5

For certain purposes, it may be desirable to charge the developer powder and develop the image simultaneously. Figure 9 shows an apparatus identical to the apparatus of Figure 8 except that an uncharged powder **31**, for example, black copper oxide rests on a lower brass electrode **21**. When a positive voltage is applied to upper electrode **27**, the powder **31** becomes negatively charged and is attracted to the positive areas of the electrostatic image thereby forming a powder image.

A variation of the same principle as employed in the apparatus of Figure 9 is shown in Figure 10. A developer powder **31** rests on the upper surface of a lower brass electrode **21**. The lower electrode is grounded, and closely spaced thereto is an upper brass electrode **27** which is connected to the voltage source **53** through the reversing switch **63**, the potentiometer **61** and the lead **45**. The insulating sheet **29**, having an electrostatic image previously established thereon, is separate from the upper electrode **27** and is inserted between the electrodes **21** and **27**. A positive voltage, with respect to the ground electrode **21**, applied to the upper electrode **27** causes the powder **31** on the lower electrode **21** to become negatively charged. The charged powder moves upwards and is attracted to the electrostatic image due to the electric fields present, thereby forming a powder image on the copy sheet **29**.

Example 6

Referring to Figure 11, it is sometimes desirable to establish an electrostatic image, to charge the developer powder and to develop the electrostatic image in a single operation. The apparatus of Figure 11 is similar to the apparatus of Figure 9 except that the upper electrode comprises a transparent electrically-conductive layer **27**, for example, a layer of tin chloride coated on glass, and a layer of a photoconductive insulating material **29**, for example, selenium thereon. The lower electrode **21**, having an uncharged developer powder **31** on its upper surface, is grounded and a positive voltage with respect to ground is applied to the conductive layer **27**. An optical image is projected from above through the conductive layer **27** onto the photoconductive layer **29**. The irradiated areas of the photoconductive layer permit a positive charge to form on the lower surface of the photoconductive layer. Simultaneously a negative charge, attracted to the lower electrode due the capacitance of the apparatus, charges the developer powder **31** negatively. The negatively-charged-particles **31** attracted by the electric fields between the electrodes and from the electrostatic image, move upwards and deposit upon the positively-charged areas of the photoconductive layer **29**.

Ordinarily the apparatus described requires the use of photoconductors having relatively long relation times. The relaxation time a photoconductor is the period of time in which an arbitrary percent of a charge stored on it will leak off. Photoconductors with very short relaxation times may be used in the apparatus of Figure 12. The apparatus of Figure 12 is similar to the apparatus of Figure 11 except that a slidable conducting plate **71** is interposed between the photoconductive layer **29** and the lower electrode **31**. A flexible lead **73** connects the conducting plate **71** to ground. When a voltage is applied to the conductive layer **27** of the upper electrode and an optical image projected upon the photoconductive layer **29**, an electrostatic image forms on the lower surface of the photoconductive layer as previously described. This electrostatic image is held on the surface by the capacitance between the image, the lower electrode **21** and the conducting plate **71**. The close spaced relation of the conducting plate **71** to the electrostatic image allows a greater charge to be stored on the photoconductor. When the conducting plate **71** is slid out, the developer powder **31** is attracted to the electrostatic image thereby developing the image. It is only necessary for the leakage time of the charges in lighted areas be less than the response time of the developer powder which should be less than the relaxation time of the photoconductor. By this arrangement, the slightly charged areas of the photoconductive layer **29** will lose their charge before the powder responds but the powder will nevertheless develop the more highly charged areas of the image. The method using photoconductive layers with short relaxation times works equally well when other methods of image formation are used.

Almost any powder may be charged positively or negatively by the methods of this invention. However, materials that have a relatively low resistivity will lose their charge very rapidly and therefore development must be carried out very soon after charging. It is preferred to use materials of resistivity of at least 10^{10} ohm-centimeters. There are numerous examples of materials that have a resistivity to hold a charge sufficiently long to allow development by the disclosed methods. Examples are: polyvinyl acetate and polyvinyl chloride resins, sawdust, magnesium silicate, bentonite, shellac, black copper oxide, and glass. Low-resistivity materials that have been used successfully include graphite, iron, zinc and copper. Besides powders, finely divided liquids may also be employed.

Electrostatic images developed by the method of the instant invention have several distinct advantages. Most of the field for attracting the developer powder to the electrostatic image is provided by the separate electric field between the electrodes. Thus, areas of an electrostatic image having relatively low potential which are not properly developed by previously known processes may now be developed more readily. Another advantage in the instant invention is that the amount of powder attracted to elemental areas of the image is a function of electric potential difference between that area and the developer particles. The instant processes do not tend to overdevelop the edges of the electrostatic image area or

to leave the solid areas of the image relatively undeveloped. Hence, subtle differences in shading or in color tones as well as lines and solid areas may be reproduced more faithfully.

The instant processes have the further advantage in that there is considerably less spurious deposit in the non-charged image areas of the print. One explanation is that in prior processes the developer particles were brought into contact with the image bearing surface by mechanical means. Some of the powder may be held to the surface by triboelectric or other surface forces. Since the instant process utilizes only electrostatic attraction for moving the powder particles to the image, the effects of triboelectric attraction is reduced to a minimum.

There has thus been described improved methods and means for developing electrostatic images and for charging electrostatic developer powders. The method for developing electrostatic images has a relatively high sensitivity and yields powder images that are substantially more accurate visual reproductions of the original optical images.

What is claimed is:

1. A method of rendering visible a pattern of electrostatic charges on an electrically-insulating sheet which comprises charging a layer of dry powder, subjecting the charged powder to a first electric field thereby attracting the powder through said first electric field, intercepting the charged powder on an intermediate surface, closely spacing said pattern of electrostatic charges from the intercepted powder, removing said first electric field, and applying a second electric field which is reverse in direction to said first electric field between said pattern of electrostatic charges and said intermediate surface whereby the intercepted powder is attracted to and deposits in the configuration of said pattern of electrostatic charges.

2. In an electrostatic printing process, a method of rendering visible a pattern of electrostatic charges on an electrically-insulating sheet which comprises charging a layer of dry powder having a bulk resistivity of at least 10^{10} ohm-centimeters, subjecting the powder layer to a first electric field thereby attracting the powder through said first electric field, intercepting the charged powder on a suitable surface, closely spacing said pattern of electrostatic charges from the intercepted powder, removing said first electric field, and applying a second electric field which is reverse in direction to said first electric field between said pattern of electrostatic charges and said surface whereby the powder is attracted to and deposits in the configuration of said pattern of electrostatic charges.

3. In an electrostatic printing process, a method of rendering visible a pattern of electrostatic charges on an electrically-insulating sheet which comprises subjecting a layer of dry powder having a bulk resistivity of at least 10^{10} ohm-centimeters lying on a lower electrode to a first electric field between said lower electrode and a closely spaced upper electrode thereby charging the powder and attracting the powder to the upper electrode, closely spacing said pattern of electrostatic charges below the charged powder on said upper electrode, removing said first electric field, and applying a second electric field which is reverse in direction to said first electric field between said electrodes whereby the powder is attracted to and deposits in the configuration of said pattern of electrostatic charges.

4. In an electrostatic printing process, a method of rendering visible an electrostatic image on an electrically-insulating sheet which comprises exposing a layer of dry powder having a bulk resistivity of at least 10^{10} ohm-centimeters to a corona discharge thereby charging the powder, closely spacing successive areas of a surface having the opposite polarity of charge from said powder layer thereby attracting a coating of charged powder to said surface, reversing the polarity of charge of said surface and closely spacing successive areas of said powder-coated surface from said electrostatic image whereby the powder is attracted to and deposits in the configuration of said electrostatic image.

5. In an electrostatic printing process, a method of rendering visible a pattern of electrostatic charges on an electrically-insulating sheet which comprises subjecting a layer of dry powder having a bulk resistivity of at least 10^{10} ohm-centimeters lying on a lower electrode to a first electric field between said lower electrode and a closely spaced upper electrode thereby charging the powder and attracting the powder to the upper electrode, interposing a thin sheet of dielectric material between the electrodes, intercepting the powder moving to the upper electrode, closely spacing said pattern of electrostatic charges below the intercepted powder on said dielectric material, removing said first electric field, and applying a second electric field which is reverse in direction to said first electric field between the electrodes whereby said intercepted powder is attracted to and deposits in the configuration of said pattern of electrostatic charges.

6. A method of electrostaitic printing which comprises applying a blanket electrostatic charge to the surface of a photo-conductive insulating material coated on a conducting sheet, projecting a light image upon said photo-conductive coating thereby producing an electrostatic image, exposing a layer of dry nylon powder to negative ions from a corona discharge thereby charging the powder, rolling a roller having a positive polarity of about 400 volts about ⅛ inch away from said powder layer thereby attracting a coating of powder to the roller surface, applying a negative polarity of about 200 volts to said coated roller, rolling said coated roller about ⅛ inch away from said electrostatic image whereby powder coated on said roller is attracted to and deposits in the configuration of said electrostatic image, transferring the deposited powder image to a record-receiving surface, and then fixing said transferred powder image thereon.

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