Oct. 9, 1962 J. F. BYRNE ETAL 3,057,719

PROCESS FOR FORMING ELECTROSTATIC IMAGES

Filed July 9, 1958 2 Sheets-Sheet 1

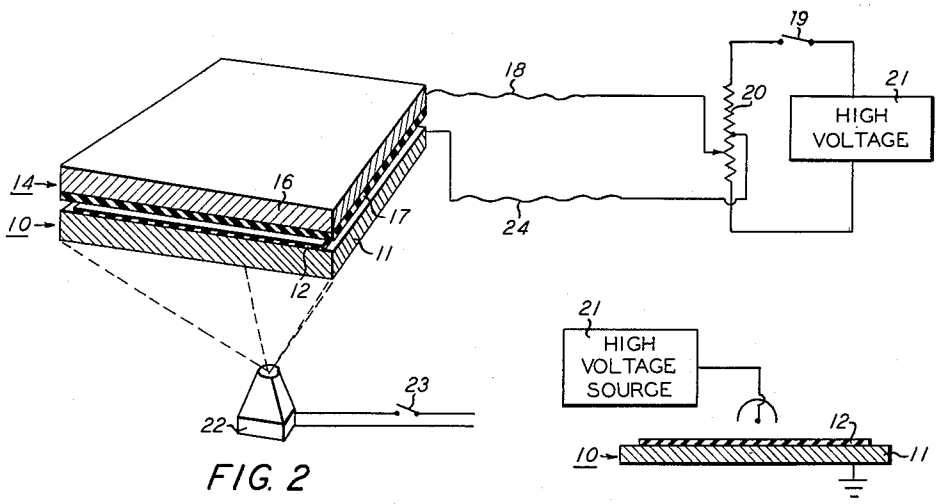



FIG. 2




FIG. 5a

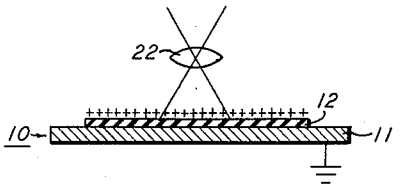



FIG. 5b

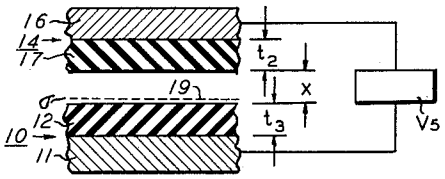



FIG. 3

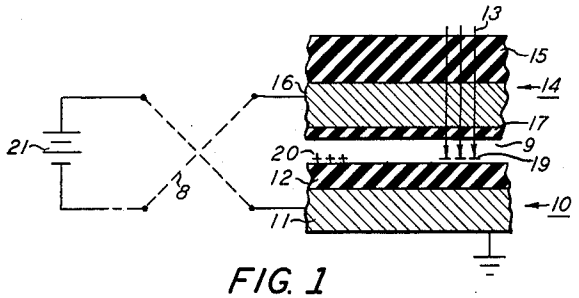



FIG. 1

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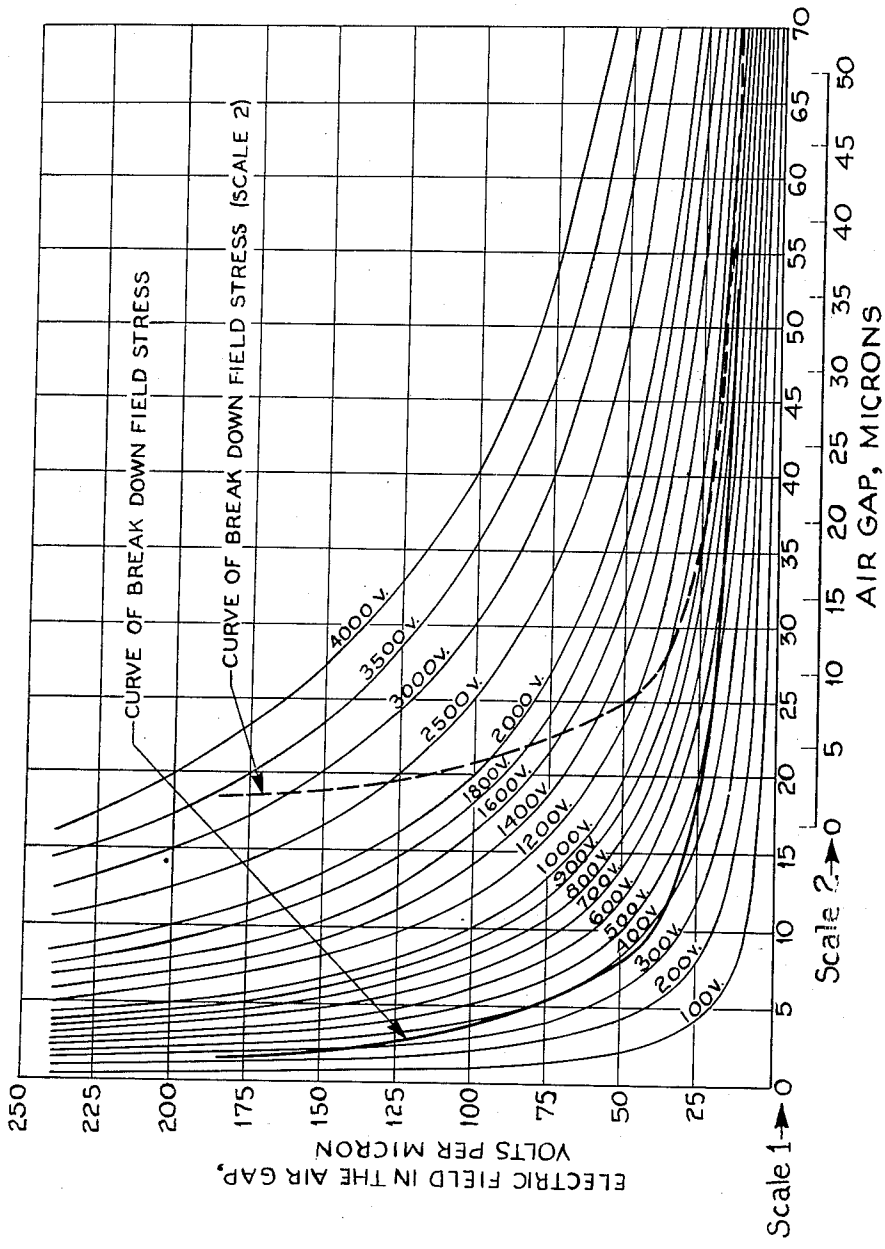



FIG. 4

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United States Patent Office

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# 3,057,719
# PROCESS FOR FORMING ELECTROSTATIC IMAGES

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Filed July 9, 1958, Ser. No. 747,542
5 Claims. (Cl. 96—1)

This invention deals with xerography and more particularly with the formation or retention of electrostatic charge patterns by optical means.

Xerography was discovered by Chester F. Carlson and is described by him in U.S. Patent 2,297,691. In general, the process comprises placing sensitizing electrostatic charges on the surface of a photoconductive insulating material which is positioned on an electrically conductive support material. The sensitized layer is then illuminated with the pattern of light and shadow to be reproduced. The areas struck by light are rendered conductive so that in those areas sensitizing charges are in effect conducted to the support material leaving on the surface of the photoconductive insulating layer a pattern of electrostatic charges corresponding to the areas of shadow of the original pattern to be reproduced. This electrostatic image is then made visible by contacting the image-bearing surface with a supply of electroscopic marking particles, the particles depositing in accordance with the electrostatic charges to give a visible image conforming thereto. This powder or liquid image may be permanently affixed to the xerographic plate or, if desired, may be transferred to a suitable image support material and affixed thereto. Thus, as customarily used, xerography is a positive to positive process.

If it is desired to place a second electrostatic charge pattern on the surface of a photoconductive insulating material, it has heretofore been necessary to use either one of two techniques: First, both the first and second charge patterns must be formed by exposure to a photographic negative or similar image original wherein the image areas correspond to areas of light. The result is actually not to produce two electrostatic charge patterns but rather to produce two patterns of little or no electrostatic charge on a background consisting of electrostatic charge. However, by a suitable development technique, known as reversal development, such patterns may be made visible. The second process involves the use of TESI techniques (the word TESI being coined from the description of the process, that is, Transfer of ElectroStatic Images). These processes provide means whereby electrostatic charge patterns may be placed on any suitable electrically insulating surface. One such process is described in U.S. patent application Ser. No. 532,534, filed on September 6, 1955, by C. F. Carlson. This process, however, is not optical. Hence, for some time there has been a need for means to place a second electrostatic image, by optical means, on a photoconductive insulating surface already having thereon an electrostatic image. The nature and object of the invention will become apparent in the following specification and drawings and in the appended claims.

In the drawings:

FIG. 1 is a cross-section of apparatus illustrating one method according to the instant invention of optically forming a second electrostatic image on a photoconductive insulating layer;

FIG. 2 represents another form of apparatus for carrying out the process of the instant invention;

FIG. 3 is a cross-sectional view of apparatus according to FIGS. 1 and 2 together with the symbols used in deriving a formula;



FIG. 4 is a graph useful for predicting the operation of the invention;

FIGS. 5(*a*) and (*b*) are schematic representations for optically forming an electrostatic image using convention xerographic techniques.

It is evident that a photoconductive insulating layer having thereon an electrostatic image pattern cannot be exposed in the normal xerographic process to a second pattern of light and shadow without destroying the initial pattern. Thus, a photoconductive insulating layer having an electrostatic image thereon contains electrostatic charges only in the image areas. A subsequent exposure to a second pattern of light and shadow can produce no effective result in the irradiated areas not containing electrostatic charge and insofar as areas containing electrostatic charge are irradiated, the effect is, to that extent, to erase the original electrostatic image pattern. If a second electrostatic charge is placed on the xerographic plate prior to the second exposure, the charging step erases the initial electrostatic charge pattern. Thus, it is irrelevant whether the second exposure is to a photographic positive or negative.

Now, in accordance with the instant invention, there is illustrated in FIG. 1 means for optically forming a second electrostatic charge pattern on a photoconductive insulating surface containing a first electrostatic charge pattern. The initial electrostatic charge pattern may be formed by any of the means known to those skilled in the art such as a TESI process as described in the above mentioned application of C. F. Carlson, Ser. No. 532,534, or preferably by an optical process such as the normal xerographic process. This is illustrated in FIGS. 5(*a*) and (*b*). As there shown, the method comprises placing sensitizing charges on a xerographic plate **10** which comprises a layer of photoconductive insulating material **12** as of vitreous selenium, coated on an electrically conductive backing material **11** as of brass, aluminum, copper, zinc, paper, etc. A preferred method of sensitizing the photoconductive insulating layer **12** is by placing thereon in the dark a uniform positive charge as by corona discharge as disclosed in U.S. 2,777,957 to L. E. Walkup. The thus sensitized plate is exposed to activating radiation through a suitable optical system **22** to create thereon an electrostatic image composed of areas of positive potential arranged on the selenium surface in image configuration. The electrostatic image so formed is a positive reproduction of the original and comprises areas of positive charge **20** as shown in FIG. 1—the electrostatic charges in the background areas having been discharged by the exposure.

The xerographic plate **10** having thereon the electrostatic image area **20** is then used to form a second electrostatic charge pattern as illustrated in FIG. 1. In this process a sheet of highly insulating material **17**, as polyethylene terephthalate, is placed on top of layer **12** with a transparent electrode **14**, as for example comprising a conductive surface **16** as of tin oxide coated on a transparent support base **15** such as glass, on top of sheet **17**. Generally, conductive electrode assembly **14** will constitute an integral structure embodying layers **17**, **16** and **15** as described.

A potential is now applied between layers **16** and **11** by suitable means as a battery **21**. In FIG. 1 the polarity of the applied potential is such that layer **11** is connected to the negative side of potential source **21** and layer **16** to the positive side during exposure. As a result, the polarity of the electrostatic image **19** induced by exposure to radiation **13** will be negative, i.e., opposite in polarity to the charges constituting the initial electrostatic image **20**. If the polarity applied to electrodes **11** and **16** is reversed, the polarity of the electrostatic image **19** induced by exposure to radiation **13** will be positive,

i.e., the same polarity as the charges constituting the initial electrostatic image **20**. Thus, the polarity of the potential applied to electrodes **11** and **16** controls the polarity of the electrostatic image formed by induction.

While the potential is applied, activating radiation **13** illuminates the plate in the image areas as opposed to the normal xerographic exposure step wherein the incident radiation constitutes the background areas. In this type of exposure, the image to be reproduced constitutes areas of light on a dark background. Many types of image source material provide this type of original, as a photographic negative, a transparency, a cathode-ray tube, a light beam galvanometer, etc. Proper registration assures that the second exposure does not erase the initial image.

When the radiation **13** impinges on layer **12**, it creates hole-electron pairs. Under the applied field from source **21** the holes migrate through layer **12** to conductive backing **11** while electrons **19** are retained on the surface of layer **12** thereby creating image areas of negative polarity charges. The time required for charge induction or migration is inversely related to the intensity of applied illumination and it normally ranges from a very small fraction of a second up to several seconds or more. After charge migration is substantially completed in illuminated areas, the illuminating radiation is stopped. It is obviously desirable that the apparatus be in a darkened room or light-tight enclosure, not shown, in order that illumination should reach layer **12** only at the direction of the operator. The voltage applied between electrodes **11** and **16** is then adjusted so as to prevent charge migration, as described hereafter, and induction electrode assembly **14** removed leaving on the surface of layer **12** image areas of both positive and negative electrostatic potentials.

While xerographic plate **10** and induction electrode **14** have been described in terms of rigid flat plate structures it is apparent that they can take other forms as cylindrical, polygonal, etc. and can be flexible as well as rigid. To this end the conductive layers can be made of such materials as conductive rubber, paper, or plastic films with such conductive coatings as opaque or transparent evaporated metal films or transparent conductive coatings as of copper iodide, tin oxide, indium oxide, etc. The conductive layers **16** and **11** need have only sufficient conductivity to behave as equipotential surfaces and may even be replaced by corona devices or other means for maintaining a surface at a uniform potential.

The photoconductive insulating layer **12** of xerographic plate **10** may be any photoconductive insulating material known to those skilled in the xerographic art. Suitable materials include vitreous selenium, sulphur, anthracene, various photoconductive insulating alloys of selenium as selenium-arsenic, selenium-tellurium, etc. as well as dispersions of finely-ground photoconductive insulating materials in insulating binders. This last type of photoconductive insulating surface is described in U.S. 2,663,636 to A. E. Middleton. Suitable pigments include zinc oxide, zinc-cadmium sulfide, tetragonal lead monoxide, etc.

Turning now to FIG. 2 there is shown a slightly different form of apparatus in which the metal or other conductive support layer **11** of FIG. 1 is replaced by a transparent conductive layer **11'** such as those described in connection with the induction electrode assembly **14** in FIG. 1. Induction electrode assembly **14** may consist merely of an electrically insulating layer **17** as of polyethylene terephthalate contacting layer **12** and, on the opposite side of layer **17** an electrically conductive layer **16** either transparent or opaque as of aluminum, copper iodide, graphite, etc. or other suitable equipotential layer as described. Means for controlling the electrostatic potentials applied between the conductive electrode assembly **14** and conductive backing **11'** are also shown. Thus, the conductive backing **11'** is connected by lead **24** to a center tap of a center tapped potentiometer **20** and induction electrode **14** is connected to the slider on potentiometer **20** through lead **18**. A high voltage D.C. power supply **21** is connected to the ends of potentiometer **20** through switch **19**. Other types of power supplies controllable as to voltage and polarity could be substituted for elements **19**, **20** and **21**.

Suitable illuminating means as an enlarger **22** with switch **23** and a power source, not shown, is positioned to shine a light image through transparent conductive support layer **11'**. After charge migration is substantially completed in illuminated areas, switch **23** is opened to prevent further illumination from reaching photoconductive insulating layer **12**. In order to preserve the electrostatic image thus created on photoconductive insulating layer **12** by the induction process herein described, as well as the preexisting electrostatic image, it is essential to control the potential between layer **11'** and **16** as described herein below.

FIG. 3 is a cross-sectional schematic view of apparatus similar to that of FIGS. 1 and 2 and will be used as an aid in analyzing the manipulations described in connection with FIGS. 1 and 2. Layers **17** and **12** are separated by a gap $x$ as shown. A source of D.C. voltage $V_s$, corresponding generally to elements **19**, **20**, **21** of the preceding figures, applied to a voltage $V_s$ between layers **16** and **11** as shown. Layer **17** is of a thickness $t_2$ and layer **12** has a thickness $t_3$ while the gap $x$ separating the two layers has a thickness $x$. For convenience the layers will by assumed of unit area. An electrostatic charge of density $\sigma$ is shown residing on the upper surface of layer **12**. This charge, which is shown as a positive charge for illustrative purposes only, can be placed on the surface of layer **12** by the method described in connection with the preceding figures or by other means as, for example, from the preexisting electrostatic image.

In order to more fully understand this invention there is now derived an expression for the electric field appearing across the gap between layers **17** and **12** as the structure comprising layers **16** and **17** in combination is separated from that comprising layer **12** and **11**. We assume that layer **17** has an elastance, or reciprocal capacitance, per unit area, $S_2$; that layer **12** has an elastance per unit area $S_3$ and that the gap $x$ between layers **17** and **12** has an elastance per unit area $S_a$. The voltage appearing across the gap can be considered the sum of a voltage $V_\sigma$ due to the charge $\sigma$ on layer **23** and a voltage $V_p$ due to the voltage $V_s$ maintained between layers **16** and **11**. Expressed in an equation this relationship is

$$V=V_p-V_\sigma \tag{1}$$

The minus sign appears because, assuming layer **11** to be at a reference potential a positive charge on layer **12** and a positive voltage on layer **16** produce opposing electrical fields in the gap.

The voltage in the gap due to the voltage applied between layers **16** and **11** is simply the applied voltage times the ratio of the elastance of the gap to the total elastance between layers **16** and **11**:

$$V_p=\frac{V_s S_a}{S_2+S_3+S_a} \tag{2}$$

The voltage in the gap due to the charge $\sigma$ is the voltage at the surface of layer **12** due to the charge, times the ratio of the elastance of the gap to the total elastance between the surfaces of layer **12** and layer **16**:

$$V_\sigma=\frac{1}{\frac{1}{S_3}+\frac{1}{S_a+S_2}}\cdot\frac{S_a}{S_a+S_2}=\frac{\sigma S_a S_3}{S_a+S_2+S_3} \tag{3}$$

Substituting Equations 2 and 3 in Equation 1 we get

$$V=\frac{S_a(V_s-\sigma S_3)}{S_a+S_2+S_3} \tag{4}$$

Since, by definition,

$$S_a=\frac{x}{EK_a} \tag{5}$$

$$S_2=\frac{t_2}{EK_2} \tag{6}$$

$$S_3=\frac{t_3}{EK_2} \tag{7}$$

where E is the dielectric constant of free space, $K_a$ is the relative dielectric constant of air or other medium in the gap, $K_2$ is the relative dielectric constant of layer **17** and $K_3$ is the relative dielectric constant of layer **12**, we can write, substituting (5), (6), (7) in (4)

$$V=\frac{\frac{x}{EK_a}(V_s-\sigma S_3)}{\frac{x}{EK_a}+\frac{t_2}{EK_2}+\frac{t_3}{EK_3}} \tag{8}$$

Simplifying, dividing by $x$, and noting that the relative dielectric constant of air, or other gases, is substantially equal to 1, we get

$$\frac{V}{x}=\frac{V_s-\sigma S_3}{x+\frac{t_2}{K_2}+\frac{t_3}{K_3}} \tag{9}$$

Since the gap voltage divided by the gap thickness is the electric field in the gap, $E_a$, and since $t_2/K_2$ and $t_3/K_3$ represent the thickness of air layers having the same elastance or capacitance as real layers **17** and **12** respectively we can write

$$E_a=\frac{V_s-\sigma S_3}{T_{eq}} \tag{10}$$

where $T_{eq}$ represents the thickness of an imaginary layer of air having the same elastance or capacitance as is found between layers **16** and **11**. $T_{eq}$ will always be equal to the actual gap spacing, $x$, plus a constant which depends on the thickness and dielectric constants of layers **17** and **12**. It can also be shown that if a charge, $\sigma'$ is also present on the lower surface of layer **17** that expression 10 becomes

$$E_a=\frac{V_s+\sigma' S_2-\sigma S_3}{T_{eq}} \tag{11}$$

Returning to Equation 10 it can be seen that the term $\sigma S_3$ is simply the voltage which would appear on the surface of layer **12** after the removal of layers **16** and **17**, provided that none of the charges were destroyed or neutralized during the removal. Later, it will be shown that such neutralization is a definite possibility, the avoidance of which is a principle object of the present invention. If the charge $\sigma$ is placed on layer **12** by the process described in connection with FIGS. 1 and 2 its maximum value can be readily calculated to be minus the voltage applied between layers **16** and **11**, times the ratio of the elastance per unit area of layer **12** to the sum of the elastances per unit area of layer **17** and the gap. Substituting in Equation 10 we get

$$E_a=\frac{V_s+\frac{V_i-S_3}{S'_a+S_2}}{T_{eq}} \tag{12}$$

where $V_i$ (which may be different from $V_s$) represents the voltage applied between layers **16** and **11** during the image illumination step described in connection with FIG. 1 and FIG. 2 and $S'_a$ represents the elastance per unit area of the gap at the time of illumination. $\sigma$ will also exhibit lesser values, in proportion to the amount of illumination received. For example, if layers **17** and **12** have the same elastance and the gap is made negligibly small as by placing layers **17** and **12** in virtual contact, then the elastance of the gap will be very small and the maximum possible value of $\sigma S_3$ will be equal to the voltage applied between layers **16** and **11** during illumination. Similarly, if layer **17** is made very thin or eliminated altogether and the gap is again made small, the quantity $\sigma S_3$ can become much larger than the voltage applied between layers **16** and **11** during illumination. On the other hand if either the gap $x$ or layer **17** or both are made large, then the quantity $\sigma S_3$ must be smaller than the applied voltage. All the above expressions were derived on the assumption that only the capacitances between the various layers are of importance and that the capacitance of the layers to surrounding space is negligible. This is a perfectly valid assumption for the range of gap spacings in which all phenomena of interest take place.



From an examination of Equation 10 it can be seen that the field in the gap decreases as the gap spacing increases. It can also be seen that the voltage, $V_s$, applied between layers **16** and **11** can always be chosen equal to $\sigma S_3$ so that there is no electric field in the gap during separation.

It is apparent from the foregoing analysis that it is possible to treat the electric field in the gap of any apparatus such as that of FIGURES 1, 2, or 3, as if the real charge on the surfaces defining the gap were replaced by a fictitious constant increment of voltage applied between the conductive layers. This simplification permits conventional electrostatic data, such as that of FIG. 4, to be employed in predicting the results of the invention.

In FIG. 4 each solid light curve is a curve relating the electric field in a gap to the gap spacing, for a particular voltage. Each curve is a hyperbola of the form $E=V/x$ where E is the field strength in volts per micron read on the ordinate, $x$ is the gap spacing in microns read on scale 1 of the abscissa and V is the voltage across the gap, plus or minus, read on each individual curve. The heavy solid line represents the breakdown field strength as a function of gap spacing for an air dielectric at normal pressure, and is adapted from R. F. Earhart, Phil, Mag. 1 (6), 152 (1901). Obviously, a different line would have to be used for other gases or pressures. At electric field strengths below the heavy solid line air will function as an insulator, but at fields of either polarity above the heavy line, air will break down and become conductive. The type of breakdown observed between plane surfaces at the spacings and fields exemplified by FIGURE 4 is quite different from the usual localized abrupt spark discharge and is rather in the nature of uniform "silent" discharge which tends to cease as soon as the field is reduced to the level given by the solid line.

To illustrate the use of FIG. 4 in a practical example, assume that in FIG. 1 layer **12** is a layer of selenium 50 microns thick with a relative dielectric constant of 6 and layer **17** is a 25 micron layer of an insulating plastic with a dielectric constant of 3. Each layer therefore has an equivalent air thickness of 8⅓ microns (50/6 or 25/3) giving a total equivalent air thickness for the two layers of 16.7 microns. If layers **12** and **17** are brought into apparent contact during exposure by enlarger **22** then the gap between layers **12** and **17**, while not actually zero, will be very small and have an elastance $S_a$ much smaller than that of layers **12** or **17**. If, therefore, layer **16** is held at a voltage of 1,000 volts negative with respect to layer **11** during illumination by enlarger **22** then according to Equations 11 and 12 the product $\sigma S_3$ in areas of maximum illumination will be substantially 1,000 volts. If then the layers are subsequently separated in darkness while still applying the thousand-volt potential to layer **16**, as by leaving switch **19** closed, the maximum electric field in the gap, according to Equation 12, will be 2,000 volts divided by the total equivalent air gap which in turn is the real air gap plus 16.7 microns for this particular example. Therefore to find the field in the gap for a spacing of, say, 10 microns it is necessary only to find 26.7 microns on scale 1 of FIG. 4 and draw a line upwards until it intersects with the 2,000-volt curve where we read on the ordinate a field of 75 volts per micron.

Since the air gap itself, however, is only 10 microns we refer to the 10 microns point on scale 1 and observe that at 10 microns a field of 75 volts per micron is well above the breakdown field strength of air.

The use of FIG. 4 can be considerably simplified through the employment of scale 2 with its associated broken curve. Scale 2 is simply scale 1 displaced to the right a distance equivalent to 16.7 microns and the field strength in the gap can therefore be determined by drawing a line upwards from the actual air gap spacing on scale 2 until it intersects the hyperbolic curve corresponding to the equivalent voltage difference between the conductive layers **16** and **11**, and then reading the field strength on the ordinate scale. Since the broken line is simply the breakdown field strength curve displaced to the right a distance also equivalent to 16.7 microns, it is possible to determine whether the electric field associated with a given air gap spacing exceeds breakdown field without resorting to scale 1. Thus, in terms of the previous example a line may be drawn upwards from 10 microns on scale 2 until it intersects the 2,000 volts hyperbola and the point of intersection is seen to lie well above the broken curve, indicating that the electric field in the gap exceeds the breakdown field and therefore cannot be supported by the gap. Scale 2 and the broken curve of FIG. 4 were drawn to correspond to the specific example used. In general, however, scale 2 will be displaced to the right of scale 1 and the broken curve will be displaced to the right of a solid breakdown field curve by an amount corresponding to the equivalent air thickness of the particular layers lying between the conductive layers.

Returning to the previous example, it is obvious from an inspection of Equation 10 that in both the areas illuminated through the induction image formation process and the areas non-illuminated, there will remain after separation a uniform potential of −150 volts. Therefore, no useful electrostatic image is to be found on the photoconductive insulating surface after separation and, accordingly, this process of operation is to be avoided in accordance with the teaching of the present invention.

Let us now consider an example identical with the foregoing except that before separation the voltage applied between the two conductive layers is reduced to zero, as by opening switch **19** in FIG. 2. For those areas of the photoconductive insulating surface corresponding to the dark areas of the projected light image, there will be no induced surface charge $\sigma$, no electric field in the gap during separation (assuming also no electrostatic field in this area from the initial image formation step), no breakdown of the gap and no potential on the surface after separation. In the areas corresponding to the brightest portion of the projected light image, the product $\sigma S_3$ may be as high as 1,000 volts. However, from an inspection of the −1,000 volts hyperbola illustrated in FIG. 4, breakdown will occur reducing the potential in the brightest areas to 850 volts after separation. On the other hand, those areas of the photoconductive insulating surface on which the illumination induces a charge $\sigma$ giving a product $\sigma S_3$ of up to 850 volts will not be subjected to breakdown in the gap and will retain the same charge $\sigma$ throughout separation, whereas those areas on which a greater charge is induced will experience a reduction in charge during separation due to breakdown in the gap which will result in a potential after separation of no greater than 850 volts.

The same considerations apply with respect to the electrostatic image pre-existing on the surface of the photoconductive insulating layer prior to the induction image process, that is, insofar as the initial electrostatic image has a potential no greater than 850 volts (the polarity may be either the same or different from the polarity of the charges constituting the induced electrostatic image) there will be no breakdown in the gap and, hence, no reduction in the electrostatic contrast of the initial electrostatic image. However, if the initial electrostatic image exceeds 850 volts of either positive or negative polarity, breakdown will occur with a reduction in electrostatic contrast. Thus, we have formed only an imperfect electrostatic charge representation of the projected light image and variations of illumination in the high-light areas of the image are not reflected in variations of charge or potential on the photoconductive insulating surface after separation.

As an example of the contemplated mode of operation of the invention, we consider an example identical to the foregoing ones except that prior to separation a voltage of +500 volts is applied between the conductive layers, the voltage being opposite in polarity to that used during image illumination. From an inspection of Equation 10 and FIG. 4, it follows that there will be no breakdown of the air gap either in areas of maximum or minimum illumination in the example given.

In those portions of the photoconductive insulating surface which contain charge patterns as a result of the initial image formation process, if the charges are of the same polarity as the charges resulting from the induction image formation process and the magnitude of the maximum voltage of this initial image is greater than the maximum voltage resulting from the induction image process, then $\sigma_{max}$ is determined by the initial image formation process and, hence, the voltage to be applied between the conductive layers during separation will be determined by the pre-existing electrostatic image. If the maximum potential resulting from the initial image formation process is less than the maximum potential created by the induction image process, then, clearly, all portions of the gap are subjected upon separation to fields lying between 0 and the 500 hyperbola and again, no breakdown occurs in any portion of the gap.

In the situation where the pre-existing electrostatic image is of opposite polarity to that of the induction image, a different situation may pertain. Assume a pre-existing electrostatic image of −500 volts with the induction image process as before, then if a +500 volts is applied during separation, in those portions of the photoconductive insulating surface subject to the induction image process all charge values will be between 0 and 500 volts. However, in those areas having the maximum pre-existing electrostatic charge, the field will be given by an appropriate point on the 1,000 volt hyperbola (that is, −500 to +500). An inspection of the 1,000 volt hyperbola shows that this is large enough to cause breakdown in charge transfer. As a result, the pre-existing electrostatic image will be reduced from 500 to 350 volts (this does not consider the effect of the presence of a dielectric layer in the gap between the induction electrode and the photoconductive insulating surface), thus, suffering a significant reduction in electrostatic contrast. Therefore, in determining the potential to be applied to prevent charge transfer during separation, both the magnitude and polarity of the pre-existing charge pattern should be considered. In the instant case assuming an induced charge of +1,000 volts and a pre-existing charge pattern of −500 volts, it is evident that applying +250 volts between the conductive layers will prevent charge transfer in both the induced image areas and the pre-existing charge areas.

In general, where the induced charge densities of interest range from a minimum value of $\sigma_{min}$ through a median value of $\sigma_{med}$ to a maximum of $\sigma_{max}$ (both the magnitudes and relative polarities of the pre-existing electrostatic image and the induced electrostatic image being considered in determining the values of $\sigma_{min}$ and $\sigma_{max}$) the optimum voltage to be maintained between the conductive layers during separation will be $\sigma_{med}S_3$. The permissible range of voltage will then be in the range $\sigma_{med}S_3 \pm J$, where "J" is an arbitrary symbol representing the difference in voltage between $(\sigma_{max}-\sigma_{med})S_3$ or $(\sigma_{med}-\sigma_{min})S_3$ and the voltage of an hyperbola which just grazes the appropriately displaced breakdown field

curve on a plot such as FIG. 4. If real charges are also present on the opposite side of the gap, the optimum voltage to be maintained between the conductive layers during separation becomes in accordance with Equation 11, $(\sigma-\sigma')_{med}S_3$, where $\sigma'$, is the charge density on the opposite surface. In some cases it may be found that the quantity "J" as defined above is negative, since the hyperbolas corresponding to

$$(\sigma_{max}-\sigma_{med})S_3$$

and

$$(\sigma_{med}-\sigma_{min})S_3$$

cross the breakdown field curve. This indicates that the electrostatic image contrast $(\sigma_{max}-\sigma_{min})S_3$ is too great to permit separation without any breakdown in the gap. In such cases the electrostatic image contrast can be reduced by using a shorter image exposure, by altering the thickness of the layers, by reducing the voltage during illumination, or by other means.

The thicknesses of the layers previously given by way of example are typical of useful ranges of operation but substantial departures may be made therefrom. Photoconductive insulating layer thicknesses from about 10 to about 300 microns are useful with 50 microns representing a typical value. It is apparent from the theoretical discussion that the thinner the insulating layer the more voltage can be induced onto the surface of the photoconductive insulating layer for a given value of voltage applied between the conductive layers, and it would also appear desirable from the theory to eliminate the insulating or dielectric layer entirely. However, as the insulating layer becomes thinner both its own thickness and that of the air gap become increasingly significant in determining the value of voltage ultimately induced onto the photoconductive insulator and it becomes increasingly more important and also more difficult to maintain the insulating or dielectric layer and the air layer of uniform thickness or to measure their thickness. Failure to maintain these thicknesses uniform results in variations in the induced charge in addition to those of the desired image pattern. If the dielectric layer is eliminated entirely the thickness of the air layer in the gap becomes particularly critical. It would be almost impossible to maintain the photoconductive insulating layer and its facing conductive layer at a measurable but uniform spacing, particularly in view of the fact that neither layer is likely to be absolutely smooth and flat to limits of the order of a micron. If the layers are put into apparent contact it is generally found that there exists a minute but variable air film between the layers but that actual contact occurs at isolated points and that the unprotected conductive layer tends to drain charges off the photoconductive insulator at these points. For these reasons it is generally desirable to employ a dielectric layer at least of the same order of thickness as that of the photoconductive insulating layer since such layers can be made quite uniform in thickness and have sufficient elastance to substantially mask the effect of minute irregularities in the gap spacing. While it is convenient to place the photoconductive insulating layer into apparent contact with the dielectric layer during image illumination such contact is not actually required. It is, however, quite difficult to uniformly maintain narrow spacings and it can be seen from an examination of FIG. 4 and Equation 12 that gap spacings of more than 5 to 10 microns necessitate the employment of large voltages between the conductive layers in order to induce a useful amount of charge and furthermore that such large voltages tend to cause a breakdown of the gap even before image illumination or separation are attempted. For these reasons it is generally preferred to place the photoconductive insulating layer into apparent contact with the dielectric layer.

Thus, the instant invention provides means for optically forming a second electrostatic image on a photoconductive insulating surface having thereon a pre-existing electrostatic image. The second electrostatic image may be of the same or opposite polarity as that of the pre-existing electrostatic image. The resulting electrostatic images may be made visible by contacting the image-bearing surface with an electroscopic marking material as disclosed for example in U.S. 2,297,691 or in the co-pending application of William E. Bixby, filed herewith. The resulting visible image may be permanently affixed to the photoconductive insulating layer or may be transferred to an image support material as paper, plastic, metal, etc. as is well known to those skilled in the art. The activating radiation used in forming the electrostatic image may be in the infra-red, the visible spectrum, ultraviolet or X-ray radiation, depending on the spectral response of the photoconductive insulating material.

This application is a continuation-in-part of our previously filed co-pending application Ser. No. 718,247, filed February 28, 1958, which in turn is a continuation-in part of Ser. No. 633,261, filed January 9, 1957, now Patent No. 2,937,943.

We claim:

1. A process for optically forming a second pattern of electrostatic charges corresponding to a pattern of activating radiation and shadow to be reproduced in added composite registration to a first electrostatic charge pattern previously formed on a photoconductive insulating surface, whereby said patterns are unaffected by each other and together form a combined pattern of electrostatic charges sufficient to attract electroscopic particles, said process comprising positioning a conductive induction electrode in spaced relation but in apparent contact to said photoconductive insulating surface containing said first pattern, and while in said last-recited relation illuminating said surface in said registered relation to said first pattern with said pattern of activating radiation and shadow wherein the areas to be reproduced are areas of radiation, and simultaneously maintaining a voltage between the induction electrode and a conductive backing for the photoconductive insulating surface insufficient for charge transfer between the surfaces to thereby form on said photoconductive insulating surface said second charge pattern corresponding to said areas of radiation and being formed in composite registration to said first charge pattern such that said first and said second charge patterns are each as independently formed identifiably unaffected in said combination, said photoconductive insulating surface thereby having areas of electrostatic charge having maximum, minimum and median charge densities of $\sigma_{max}$, $\sigma_{min}$, and $\sigma_{med}$, respectively, and in which the photoconductive insulating surface has an elastance per unit area $S_3$, and separating the photoconductive insulating surface from the induction electrode while maintaining during separation a voltage in the range of values centered about $\sigma_{med}S_3$, with width of such range of values being such that at either extremity thereof change transfer is just avoided in areas of charge density $\sigma_{max}$ and $\sigma_{min}$.

2. A process according to claim 1 wherein said conductive induction electrode is transparent, said photoconductive insulating surface being illuminated with said pattern of activating radiation and shadow through said transparent conductive electrode.

3. A process according to claim 1 wherein said photoconductive insulating surface is positioned on a transparent electricall conductive support member whereby said photoconductive insulating surface is illuminated with said pattern of activating radiation and shadow through said transparent electrically conductive support member.

4. A process according to claim 1 wherein the voltage maintained between said induction electrode and said conductive backing of the photoconductive insulating surface is such that the charge pattern resulting from exposure to said pattern of activating radiation and shadow

is opposite in polarity to said first electrostatic charge pattern.

5. A process according to claim 1 wherein the voltage maintained between said induction electrode and said conductive backing of the photoconductive insulating surface is such that the charge pattern resulting from exposure to said pattern of activating radiation and shadow has the same polarity as said predetermined pattern of electrostatic charges.



**References Cited** in the file of this patent

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# UNITED STATES PATENT OFFICE
# CERTIFICATE OF CORRECTION

Patent No. 3,057,719 October 9, 1962

John F. Byrne et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 4, line 25, strike out "to"; lines 67 to 70, equation (3) should appear as shown below instead of as in the patent:

$$V_\sigma = \frac{\sigma}{\frac{1}{S_3} + \frac{1}{S_a + S_2}} \cdot \frac{S_a}{S_a + S_2} = \frac{\sigma S_a S_3}{S_a + S_2 + S_3}$$

column 10, line 67, for "electricall" read -- electrically --.

Signed and sealed this 22nd day of October 1963.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

EDWIN L. REYNOLDS
Acting Commissioner of Patents