Sept. 20, 1971 M. C. GOURDINE 3,606,531

IMAGE REPRODUCTION USING ELECTROGASDYNAMICS

Filed Sept. 30, 1968 2 Sheets-Sheet 1

Fig. 1.

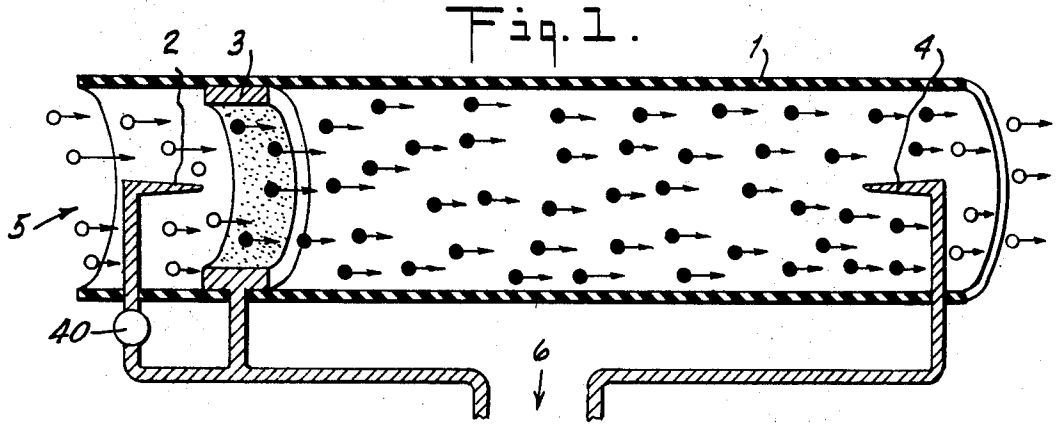


Fig. 2.

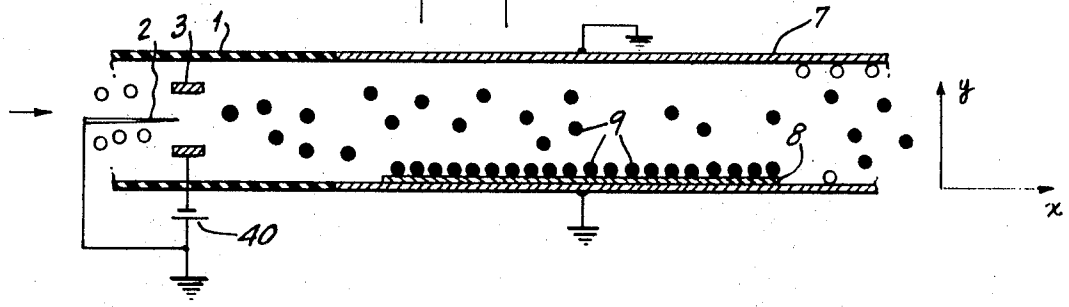


Fig. 3.

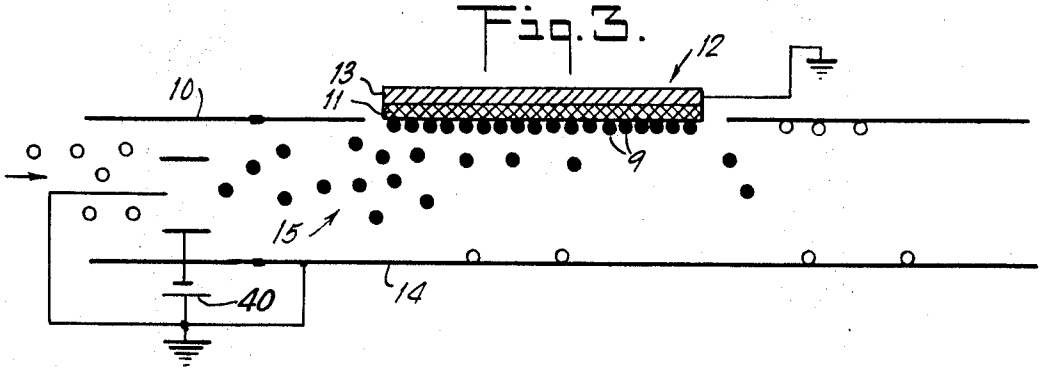


Fig. 4.

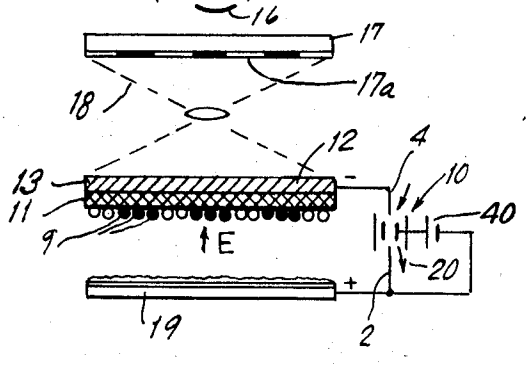
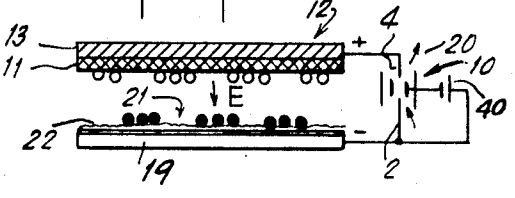


Fig. 5.



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IMAGE REPRODUCTION USING ELECTROGASDYNAMICS

Filed Sept. 30, 1968 2 Sheets-Sheet 2

Fig. 6.

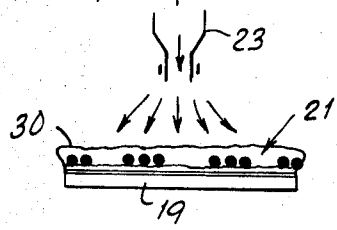


Fig. 7.

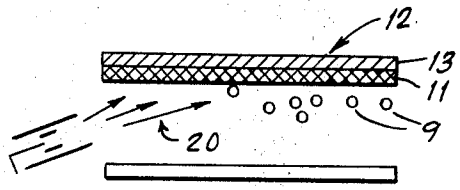


Fig. 8.

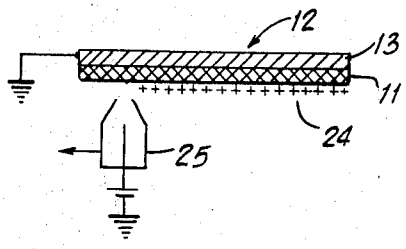


Fig. 9.

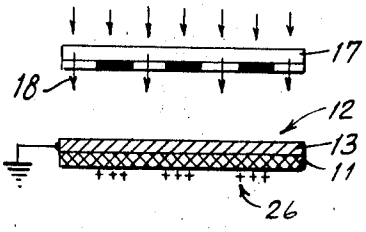
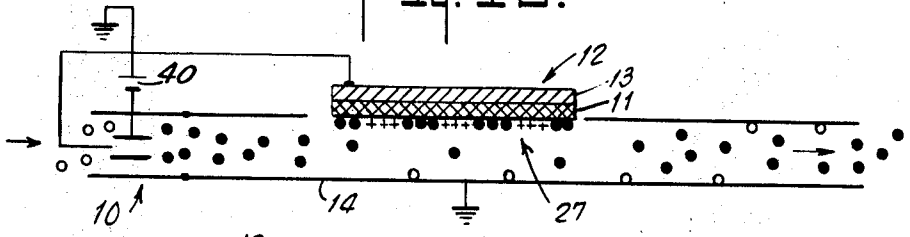


Fig. 10.



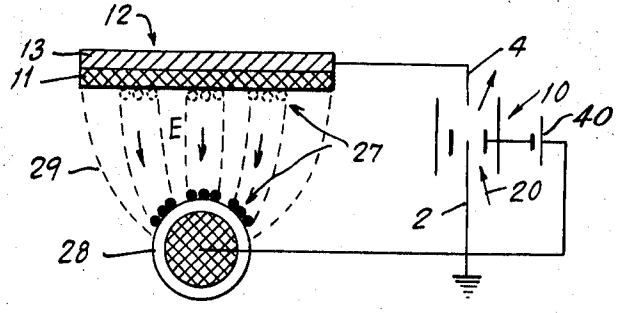


Fig. 11.

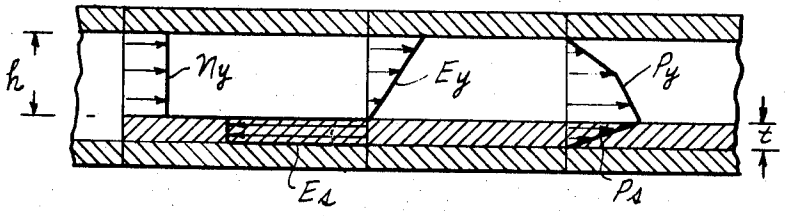


Fig. 12.

United States Patent Office 3,606,531 Patented Sept. 20, 1971

3,606,531

IMAGE REPRODUCTION USING ELECTROGASDYNAMICS

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Int. Cl. G03g 15/00
U.S. Cl. 355—3 10 Claims

ABSTRACT OF THE DISCLOSURE

A method and means for reproducing an image on a dielectric sheet, or irregular or curved surface, comprising the use of an electrogasdynamically produced space charge cloud of ionized ink to develop an image of a light pattern projected onto a conventional xerographic plate. The developed ink image is of improved quality by virtue of the tendency of electrogasdynamically produced particles to achieve a uniform charge distribution on a dielectric surface.

BACKGROUND OF THE INVENTION

The present invention relates to the image reproduction art and more particularly to a method and means for copying an image using an electrogasdynamic generator in cooperation with a conventional xerographic plate.

A number of image reproduction systems have been developed in recent years, including xerography, electrostatic photoconductive printing, smoke printing and the like, which have met with varying degrees of success in attempting to produce satisfactory image reproductions while reducing the speed and complexity of the operations required. One of the most successful is the xerographic process wherein six basic steps are usually followed in the reproduction of an image on paper. The six steps include: (1) the charging of a xerographic plate, i.e., one comprising an insulating photoconductive layer and a transparent conductive layer, with a layer of electrostatic charge on the insulating side; (2) then exposing the plate to light in the image pattern to be reproduced causing the insulating layer to become conductive in the areas exposed to the light and thus neutralizing the layer of electrostatic charge in those areas; (3) the resulting latent electrostatic image is then developed by the application of a triboelectrically charged layer of powder or toner whose oppositely charged particles are attracted by and adhere to the charged areas on the surface of the plate forming a powder image in accordance with the electrostatic image; (4) the powder image is then transferred to a sheet of paper or other material by positioning one side of the paper adjacent the imaged side of the plate and producing a voltage between the two by distributing a layer of charge on the opposite side of the paper; (5) the powder image is then fixed on the paper by any of a number of well known methods, such as by heating; and (6) the remaining powder is cleaned from the surface of the xerographic plate in preparation for rerunning the process.

While this process has had rather wide commercial success, still it has certain drawbacks, particularly with regard to image quality and versatility of use. The quality of image reproduction has been limited by the tendency of the images to develop heavily where contrast is greatest due to fringing effects which produce uneven distribution in the electrostatic charge image. As a result, the developed image tends to exhibit excessive definition at the pattern edges. Also, the weak charge bonding causes poor resolution in the half-tone areas. In addition, the speed of reproduction has been limited by the number of mechanical steps which are required thereby reducing the number of applications in which the process may be used.

The present invention offers a system which improves on the speed of reproduction capable of being achieved with the conventional xerographic process while concomitantly improving on the quality of the miage obtained.

SUMMARY OF THE INVENTION

The apparatus and method of the present invention comprises the use of an electrogasdynamic generator as an EGD spray gun, to produce a space charge cloud of ionized ink particles that develop an image produced on the photoconductive surface of a xerographic plate which is exposed to a light pattern of the image to be reproduced. It has been observed that electrogasdynamically produced charges have the peculiar quality of tending to become uniformly distributed over a dielectric surface and that the amount of surface charge that can be acquired has a particular limit under given conditions. The ion concentration in the cloud determines the maximum potential of the dielectric surface and the maximum surface charge which is deposited. The discharging of the ionized layer in accordance with the light pattern on the photoconductive plate, as a result of this peculiar quality, results in the production of an improved quality image eliminating the fringing effects which occur in conventional xerographic reproduction and improving the resolution in the half tone areas. The ink image thus developed when transferred will distribute itself uniformly rather than selectively over irregular or curved surfaces.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagrammatic view of an electrogasdynamic generator;

FIG. 2 is a diagrammatic view of an electrogasdynamic spray gun with a dielectric surface positioned at one end of the channel;

FIG. 3 shows the first step in the improved reproduction process of the present invention wherein a layer of ionized ink particles is placed on the surface of a xerographic plate;

FIG. 4 shows the second step of the process wherein a light image is projected onto the xerographic plate;

FIG. 5 shows the third step of the process wherein the ink image is transferred to a dielectric surface;

FIG. 6 shows the fixing of the image on the dielectric surface;

FIG. 7 shows the cleaning of the xerographic plate preparatory to the next image reproduction;

FIG. 8 shows the first step of an alternate method of image reproduction wherein a layer of charge is placed on the surface of the xerographic plate;

FIG. 9 shows the second step of the alternate method wherein a light image is projected onto the xerographic plate;

FIG. 10 shows the third step of the alternate method wherein the electrostatic image is developed using a space charge cloud produced by an electrogasdynamic spray gun;

FIG. 11 shows the transferring of the developed ink image to a curved dielectric surface; and

FIG. 12 is a diagrammatic representation of the ion concentration n, electric field E and potential distribution P across the channel shown in FIG. 2.

DETAILED DESCRIPTION

For a full understanding of the present invention, it is first necessary to understand the basic operation of an electrogasdynamic generator. In its most elemental form as shown in FIG. 1, the electrogasdynamic, or EGD, generator comprises a non-conducting duct 1 with a pair of electrodes 2 and 3 at one end and a collector electrode 4

at the opposite end and through which a gas **5** is forced to flow. The gas **5** which is essentially uncharged is blown in at one end and passes between the pair of electrodes **2** and **3**. A very high electric field is set up by means of power supply **40** between the pointed electrode **2** in the center of the duct **1**, which electrode may be positively charged, and the surrounding electrode **3** in the wall of the duct **1**. As the gas **5** passes through the very high electric field, the small number of free electrons which are generally present in any gas, are drawn to the positively charged electrode **2**. In their travel to the positive electrode **2** the free electrons collide with molecules in the gas **5** freeing more electrons which are also drawn to the positive electrode **2**. The number of free electrons tends to increase in this manner until the space between the two electrodes **2** and **3** is filled with a very large number of free electrons resulting in what is called a corona discharge.

The production of a large number of free electrons, of course, conversely produces a number of ionized molecules of the gas which tend to drift toward the negative surrounding electrode **3**. However, due to their much greater mass, the molecules drift at a much slower rate than the electrons. The slowly drifting molecules are consequently caught in the gas flow and carried downstream within the duct **1**. Thus, a current of highly charged ions is produced in the duct which is the prerequisite for the electrogasdynamic effect. By placing an electrode **4** downstream in the center of the duct **1** at a potential equal to or higher than the potential of the positive corona electrode **2**, the work done by the gas flow in pushing the positively charged ions against the electric field between these electrodes produces an electric power output across a load connected between the two electrodes as at **6**.

An apparatus of this type may be used in combination with a xerographic plate in performing the method of the present invention. Before discussing the method, however, we must first consider the electrogasdynamic phenomenon a little further. It will be seen that if the collector electrode **4** is removed from the duct **1** that the generator will act in the manner of a spray gun producing a space charge cloud of highly ionized gas. Such a device is more fully described in my co-pending application Ser. No. 837,562, filed June 30, 1969. It has been observed that the ions in a gas so produced have the peculiar quality of tending to become uniformly distributed over a dielectric surface and that the amount of such charge which will be deposited on the surface has a particular limit under given conditions. It is believed that this phenomenon can be explained by considering the motion of charged particles in a gas flowing between a dielectric plate of finite length and a grounded metal plate such as shown in FIG. 2 wherein a grounded metal duct **7** and a dielectric plate **8** have been located at the downstream end of the duct **1** in place of the collector electrode **4**.

Since the metal duct **7** is grounded the longitudinal component of the electric field in the metal wall is zero and, as a consequence of Maxwell's equations, the longitudinal component of the electric field in the dielectric plate **8** is also zero. Thus, charges **9** deposited on the surface of the dielectric plate **8** attempt to distribute themselves uniformly in order that the longitudinal component of the electric field on the dielectric surface is also zero. When the charge build-up reaches its limit or equilibrium point, then the charges must be distributed uniformly.

Initially, as the gas flows along the duct **7**, charges begin to accumulate at the leading edge of the dielectric plate **8**. The accumulated charges on this edge tend to repel successive charges and direct them downstream so that eventually there is a uniform deposition of charge on the surface of the dielectric plate **8** and other charges are directed downstream where they are eventually neutralized on the metal wall of the duct **7**.

When this equilibrium condition is reached, the relationship between the electric field E_s in the dielectric, the surface charge q_s, and the potential of the surface P_s may be expressed mathematically a follows:

(1) $$E_S = K_1 q_S$$

(2) $$E_S = \frac{P_S}{t}$$

(3) $$q_S = \frac{P_S}{K_1 t} = n_S e$$

Where t is the thickness of the dielectric, K_1 is a constant related to the permittivity of the particular dielectric material, and n_s is the number of ions with unit charge e on the dielectric surface.

Keeping these relationships in mind, we next consider the conditions in the gas across the duct **7**. The potential distribution P_y and the electric field E_y across the duct **7**, i.e., in the y direction, may be expressed mathematically as follows:

(4) $$\frac{\partial E_y}{\partial y} = K_2 q_y = K_2 n_y e \therefore E_y = \int_0^y K_2 n_y e dy = K_2 n_y e y$$

(5) $$\frac{\partial P_y}{\partial y} = -E_y \therefore P_y = -\int_0^y E_y d_y = -\int_0^y K_2 n_y e y dy = -K_2 n_y e \frac{y^2}{2}$$

Whereby y is the height of the duct **7**, K_2 is a constant related to the permittivity of the space in the duct **7**, and n_y is the charge concentration in the duct **7**.

To determine the effect of these quantities at the surface of the dielectric plate **8**, we must consider the boundary layer conditions that apply. The ion current J_y may be expressed as follows:

(6) $$J_y = K_2 n_y e E_y$$

In the equilibrium condition, J_y equals zero at the dielectric surface and therefore E_y must equal zero at the dielectric surface. If we assume that the ion concentration n_y across any section of the channel is uniform, then for any channel of height h, i.e., $y=h$, the electric field E_y and potential distribution P_y across the channel will be as shown in FIG. 12. Therefore, the potential P_s of the dielectric surface and the corresponding surface charge q_s may be expressed as follows:

(7) $$P_s = K_2 n_y e \frac{h^2}{2} = K_3 n_y \frac{h^2}{2}$$

(8) $$q_s = \frac{P_s}{K_1 t} = K_4 \frac{n_y}{t} \frac{h^2}{2}$$

Thus, the charge concentration n_y in the cloud will determine the potential P_s of and the charge deposition q_s on the dielectric plate **8** in a channel of height h.

This phenomenon may be used to achieve improved image reproduction in the following manner. As shown in FIG. 3, an electrogasdynamic generator **10** is used as a spray gun to deposit a layer of ionized ink particles **9** on the insulating photoconductive layer **11** of a conventional xerographic plate **12** which includes a transparent conductive layer **13**. A grounded channel member **14** may be used to confine and direct the space charge cloud **15**, but it is not necessary for the proper performance of the process. Also, the term ink, as used here, is intended to refer to any medium, such as a dye, a powder, or the like which is suitable for use as a printing material and may be ionized in an EGD gun.

The second step of the process is shown in FIG. 4 wherein light is shone from a source **16** through an image **17**, to be reproduced, onto the xerographic plate **12**. The light **18** passing through the translucent areas **17***a* of the image **17** falls on the photoconductive layer **11** of the

plate 12 rendering the corresponding areas thereon conductive in the pattern of the light image 17 and to an amount in accordance with the degree of translucence.

A developer electrode 19 is positioned beneath the xerographic plate 12 and the plate 12 and electrode 19 are respectively connected to the collector electrode 4 and the ionizing electrode 2 of the electrogasdynamic generator 10. The ionizing electrode 2 is made negative and air 20 is blown through the electrogasdynamic generator 10 producing a high voltage electric field E between the plate 12 and the developer electrode 19. The ink particles 9 are held tightly on the surface of the xerographic plate 12 by the field E. The particles 9, which are of a highly dielectric ink, are discharged at the conductive portions of the photoconductive layer 11 producing a charged ink image 21 of the light pattern of the image 17 to be copied. The white circles represent the neutralized ink molecules and the black circles represent the ink ions.

The ink image 21 thus developed on the xerographic plate 12 will be a highly accurate representation of the light pattern as the high field E produced by the electrogasdynamic generator 10 assures that the ink particles 9 completely discharge at the exposed places in accordance with the degree of conductivity of the plate at each place. Moreover, the electrogasdynamic spray gun in producing highly charged particles, assures that every particle on the surface is highly charged and bound thereto.

The next step of the process is shown in FIG. 5 wherein the polarity of the ionizing electrode 2 on the electrogasdynamic generator 10 is reversed, that is, the ionizing electrode is made positive so as to produce an oppositely directed high voltage electric field E which will cause the remaining highly charged ink particles 9 on the surface of the xerographic plate 12 to migrate toward the surface of the developer electrode 19. The developer electrode 19 may be the surface on which the image is to be reproduced or may be disposed behind the sheet which is to be printed. In FIG. 5 the developer electrode is shown having an irregular surface 22. The transfer of the charged ink image 21 to this irregular surface 22 is done more accurately than prior art xerographic methods since the transfer field E is much stronger and the charged particles 9 impact the surface 22 harder and are held tighter by the interacting electrostatic forces. Fixing of the image 21 is also made much easier and may be performed by the application of heat in the case of certain inks or as shown in FIG. 6, by the deposition of a polymer coating 30 using a free radical generator 23, or other means well known to those skilled in the art.

The final step in the process, shown in FIG. 7, is the cleaning of the neutralized ink particles 9 from the surface of the xerographic plate 12 using a blast of air 20 from the electrogasdynamic generator 10. The plate 12 is then ready for a repetition of the reproduction process.

It will be seen that one disadvantage of the above-disclosed process is that a special highly dielectric ink is required to prevent all of the ink particles from becoming discharged during the exposure step. To render the use of the phenomenon more versatile as to the types of inks, dyes, powders, or the like which may be used, the process may be slightly modified as follows. Rather than depositing the ionized ink particles 9 directly on the xerographic plate 12, as shown in FIG. 8, the insulating photoconductive surface 11 may be covered with a charge layer 24 of molecular ions produced by any suitable corona discharge device 25 such as those used in the conventional xerographic process. The xerographic plate 12 is then exposed to light 18 in the pattern of the image 17 to be reproduced by shining light through the image 17 onto the xerographic plate 12, as shown in FIG. 9. The layer of charge 24 will be discharged by the resultant conductivity of the photoconductive layer 11 in the areas on which the light 18 falls producing a latent electrostatic image 26 on the surface of the plate 12.

The electrogasdynamic generator 10 is again used as a spray gun to develop the electrostatic image 26 with a space charge cloud of ionized ink which produces ink image 27 as shown in FIG. 10.

The electrogasdynamic generator 10 is then connected between the xerographic plate 12 and a curved surface 28 on which the ink image 27 is to be printed with the collector electrode 4 attached to the plate 12 and the ionizing electrode 2 connected to the curved surface 28 and positively polarized as shown in FIG. 11. The charged ink image 27 is transferred from the plate 12 to the curved surface 28 along the lines of force 29 of the electrical field E which tend to become concentrated at the curved surface 28. Unlike conventional electrostatic coating methods the ink ions 9 will be deposited uniformly on the curved surface 28 rather than preferentially. This is particularly true on sharply curved surfaces where the electric field E is particularly strong. Also, with the disclosed method, the ink images 27 may be transferred over much greater distances due to the strength of the field E and the high charge on the ink particles 9.

An electrogasdynamic generator used in the present process being a high voltage low current output device can be operated using 10 kilovolts for the corona discharge to achieve suitable results. Also, such a generator is safe to use as the gun cannot produce dangerous sparks or deliver harmful shocks to an operator because the device is current limited and there is hardly any capacitance in the system.

An apparatus and method for reproducing images is thus provided which produces a copy of an image with improved definition and resolution by eliminating fringing effects and weak electrostatic binding while increasing the speed of reproduction by reducing the number of mechanical steps required.

What is claimed is:

1. A method of electrostatic image reproduction comprising:
   (a) highly ionizing a stream of ink particles and confining the ionized stream within a dielectric tube to electrogasdynamically produce a highly charged space charge cloud of ink ions;
   (b) spraying the electrogasdynamically produced ink ions on a surface of an insulating photoconductive plate;
   (c) exposing the plate to light in the pattern of the image to be reproduced thereby discharging the ions in the areas on the surface which are rendered conductive by the light; and
   (d) imposing an electric field between the photoconductive plate and an adjacently disposed surface causing the charged ink ions to transfer to the adjacent surface forming an ink pattern of the image thereon.

2. Method as in claim 1, including the step of imposing an electric field between the photoconductive plate and the adjacent surface to hold the ions on the photoconductive plate during discharging.

3. A method of electrostatically reproducing an image comprising:
   (a) placing a layer of electrostatic charge on the surface of an insulating photoconductive plate;
   (b) exposing the plate to light in the pattern of the image discharging the charge layer in the areas on the surface which are rendered conductive by the light thereby producing a charge image;
   (c) highly ionizing a stream of ink particles and confining the ionized stream in a column within an insulating duct to electrogasdynamically produce a highly charged space charge cloud of ink ions;
   (d) spraying the electrogasdynamically produced space charge cloud of ink ions onto the surface of the plate to develop the charge image; and
   (e) imposing an electric field between the plate and a dielectric sheet causing the charged ink ions to transfer to the dielectric sheet forming an ink pattern of the image thereon.

4. An apparatus for electrostatically reproducing an image comprising:

(a) an electrogasdynamic spray gun comprising:

(i) insulating duct means for confining a stream of ink particles; and

(ii) ionizing means upstream in said duct means for producing a highly charged space charge cloud of ions of the stream of ink particles;

(b) photoconductive means downstream from said electrogasdynamic spray gun having a surface for receiving a layer of the ink ions produced by the electrogasdynamic spray gun;

(c) means for producing a light pattern of the image to be reproduced on the photoconductive means to discharge the ink ions in the areas on the surface which are rendered conductive by light; and

(d) means for producing an electric field between the surface of the photoconductive means and an adjacently disposed surface to transfer the ink ions from the photoconductive surface to the adjacently disposed surface, forming an ink pattern of the image thereon.

5. An apparatus as claimed in claim 4 comprising free radical generator means for fixing the ink ions in the pattern of the image on the adjacently disposed surface.

6. Apparatus as in claim 4, including means for imposing an electric field between the surface of the photoconductive member and the adjacently disposed surface to hold the ions on the photoconductive means during discharging.

7. An apparatus as claimed in claim 6 wherein the means for producing the electric fields is an electrogasdynamic generator.

8. An apparatus for electrostatically reproducing an image comprising:

(a) a plate of insulating photoconductive material;

(b) means for placing a layer of electrostatic charge on a surface of said plate;

(c) means for exposing said plate to light in the pattern of the image to be reproduced thereby discharging the charge layer in the areas on the surface which are rendered conductive by the light producing a corresponding electrostatic image;

(d) means for highly ionizing and confining a stream of ink particles within an insulating duct for electrogasdynamically producing a highly charged space charge cloud of ionized ink for spraying on the charged surface of the plate to develop the electrostatic image thereon;

(e) means for imposing an electric field between the plate and a dielectric sheet causing the ionized ink to be transferred to the surface of the dielectric sheet in the pattern of the image.

9. Apparatus as in claim 4, including an electrode disposed adjacent the surface of said plate and means for imposing an electric field between the plate and the electrode to hold the ions on the plate during developing.

10. An apparatus as in claim 9, wherein the means for imposing the electric fields is an electrogasdynamic generator.

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U.S. Cl. X.R.

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