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[54] **METHOD AND APPARATUS FOR GENERATING ELECTROSTATIC IMAGES USING IONIZED FLUID STREAM**

[75] Inventors: **Peter J. Magill**, Endwell; **Robert E. McCurry**, Vestal; **Charles A. Speicher**, Endwell, all of N.Y.

[73] Assignee: **International Business Machines Corporation**, Armonk, N.Y.

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[51] **Int. Cl.**..**G03g 15/00**

[58] **Field of Search**....346/74 ES, 74 EB; 340/324 R; 178/15, 30, 93; 101/DIG. 13, 1

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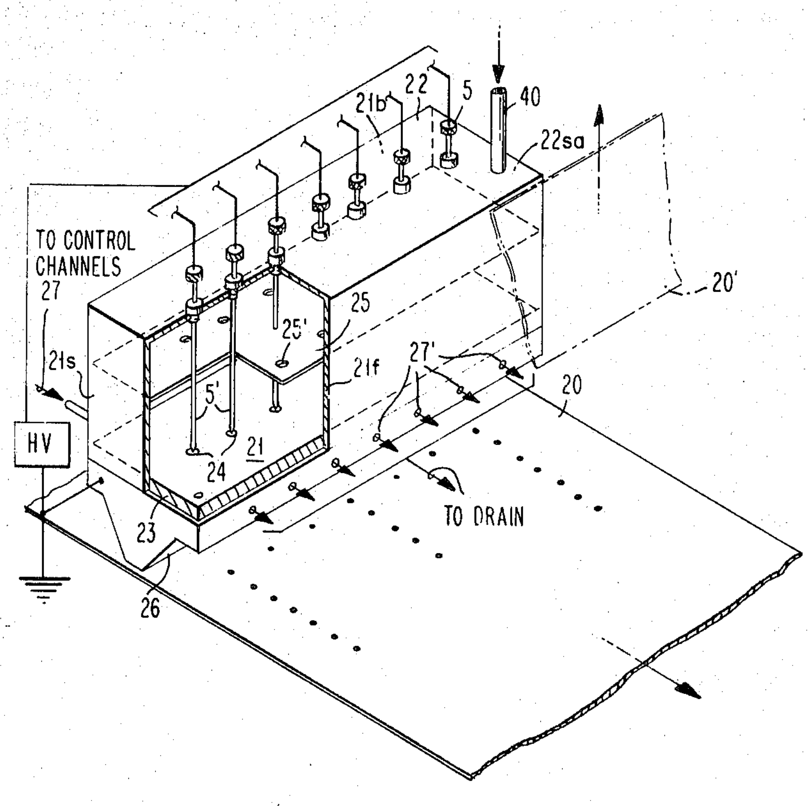
Primary Examiner—Howard W. Britton

Attorney—Hanifin and Jancin and Andrew Taras

[57] **ABSTRACT**

An ionized stream is selectively channeled through a "printing head" to cause image formation on a precharged dielectric coated sheet or to a drain when it is desired to interrupt image formation. The ionized stream, in one embodiment, is channeled directly to the dielectric sheet to cause image formation and is interrupted by a control stream that diverts the ionized stream to the drain. An alternative embodiment provides for a reversal in the functions of the control stream and the ionized stream so that image formation is obtained only when the ionized stream is diverted.

8 Claims, 4 Drawing Figures



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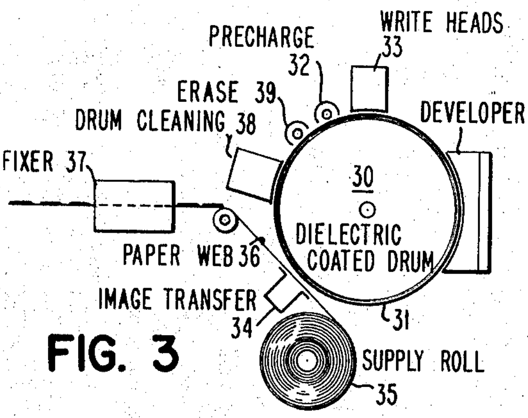


FIG. 3

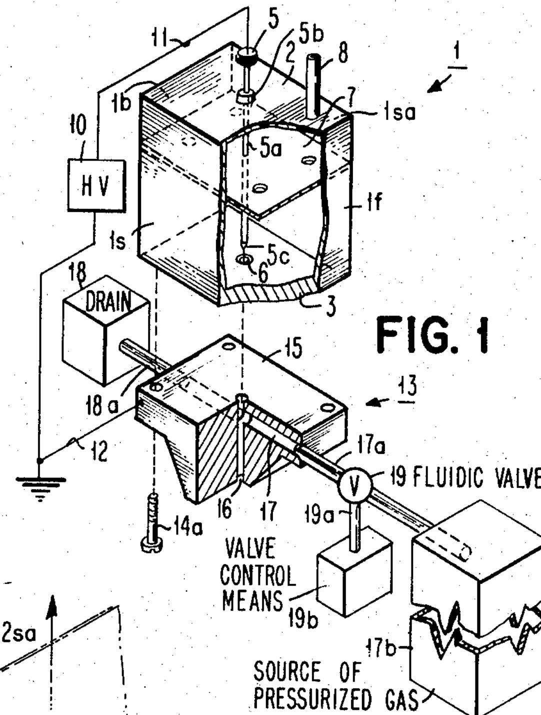
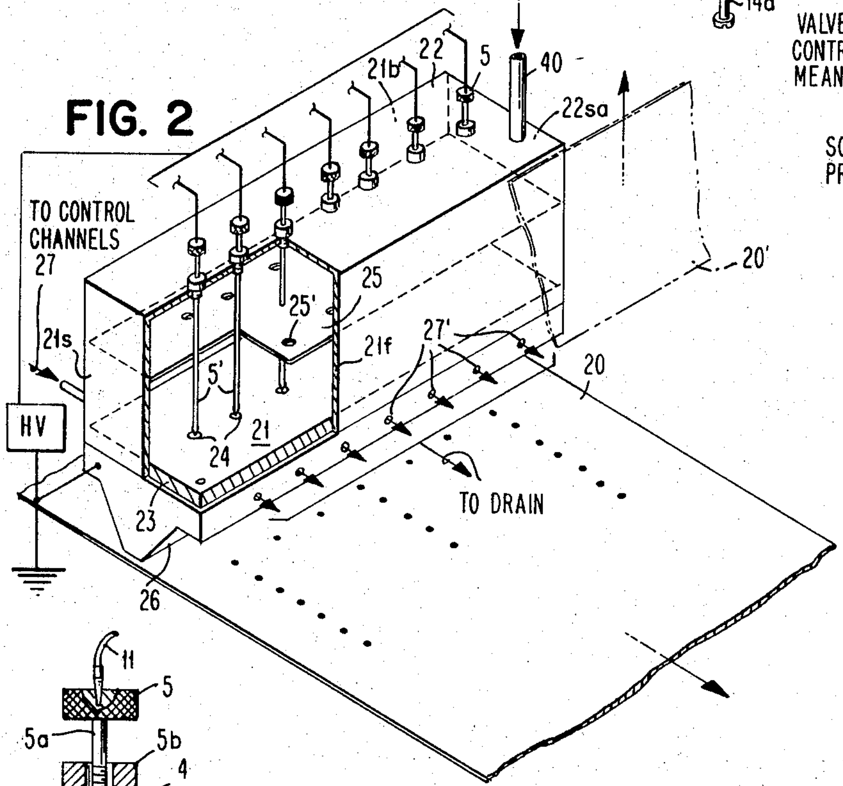


FIG. 1

FIG. 2



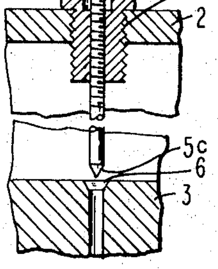


FIG. 4

INVENTORS
PETER J. MAGILL
ROBERT E. McCURRY
CHARLES A. SPEICHER

BY Andrew Taras

AGENT

METHOD AND APPARATUS FOR GENERATING ELECTROSTATIC IMAGES USING IONIZED FLUID STREAM

The invention relates to a method and apparatus for forming a latent electrostatic image on a moving dielectric surface by selectively directing an ionized gas away from or toward said dielectric surface.

BACKGROUND OF THE INVENTION

There are a number of methods which can be used to produce electrical charge patterns on dielectric (or insulation) surfaces.

Optical methods such as those employed in xerography and electrofax utilize photoconductive (pc) insulators. These techniques utilize an electrically precharged pc insulating layer coated on a conductive backing (or relatively conductive paper). The charge pattern is generally produced by exposing the uniformly charged pc surface to a pattern of light, i.e., an optical image. Since the layer is photoconductive, the charge decay rate is increased as the light intensity is increased. After the optical exposure, the pc layer contains a charge pattern; the surfaces areas receiving less light are at a larger electrical potential than those areas which have received more light. (The exposure or amount of light being defined as the product of light intensity and time.)

Electrostatic images may also be produced by electrographic methods in which electrical potentials are applied to styli and/or shaped characters.

In this case, the applied potential produces an electrical breakdown resulting in electrical charge flow to the dielectric surface layer coated on a conductive base layer. Control of the charge pattern is obtained by switching high voltage (the electrical potential) on and off, either directly by connection of the "write" electrode to a high voltage pulser or indirectly by, for example, charging conductive pins located in the face of a cathode ray tube.

SUMMARY AND OBJECTS OF INVENTION

The fluidic ion method of electrostatic image formation by means of the present invention utilizes the deposition of unipolar ions, carried by a fluid stream, to a dielectric surface layer coated on a conductive base layer. The control of the charge pattern is obtained by switching the gas stream which carries the ion so that it impinges on the dielectric surface only when it is desired to "write" an image. This method has the advantage over optical methods in that the sensitive layer can be, but does not necessarily have to be, a photoconductive insulator and it does not require a light pattern to form the electrostatic image. This fluidic ion method has advantages over electrographic printers in that it obviates high voltage switching and the critical writing head to surface gap control.

It is therefore the primary object to provide a novel printing scheme which avoids the disadvantages of the prior art non-impact printing methods.

Another object is to provide a novel printing method in which an electrostatic image is formed by selectively directing a fluid stream of charged ions upon a surface so as to avoid the necessity of switching high voltages as required by the prior art.

Yet another object is to provide a novel method of printing which is highly reliable and less costly than prior art non-impact printing schemes.

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings.

DESCRIPTION OF THE DRAWINGS

FIG. **1** is a detail of a single writing head used in the formation of an electrostatic image.

FIG. **2** is a writing head assembly having a plurality of corona discharge wires housed in a single chamber for forming a plurality of electrostatic images.

FIG. **3** is a schematic arrangement of a printing apparatus utilizing the writing heads constituting the present invention.

FIG. **4** is a detail drawing of the corona discharge wire.

A writing head assembly which is essentially an ion generating chamber **1** is comprised of front **1***f*, back **1***b* and side walls **1***s*, **1***sa* covered by a top plate **2** and a grounded base plate **3**. Except for the grounded base plate which consists of metal, all walls including the top plate are comprised of an electrical insulating material all held together by suitable means, not shown. As shown in greater detail in FIG. **4**, the upper plate **2** has a centrally located threaded opening **4** for receiving a corona wire assembly **5** comprised essentially of a long thin wire **5***a* to which is secured a threaded screw portion **5***b* that engages with threaded opening **4** by virtue of which the lower end portion **5***c* of the corona wire can be adjusted relative to a central orifice **6** in the grounded base plate **3**. An insulating spacer **7** snugly fitted against the interior wall surfaces of the chamber is positioned to provide rigidity to and maintain the location of the corona wire relative to the center of the orifice **6** in the base plate **3**.

Pressurized gas, for example air, is admitted into the chamber by way of line **8**. A source of high voltage **10** is interconnected in the manner shown by means of lines **11** and **12** to the corona wire and to the grounded base plate. The electrical potential and physical position of the point of the corona wire are adjusted so as to provide a corona discharge. The generated ions emerge from the chamber by way of orifice **6** in the base plate.

A lower head portion **13** is secured by means of screws **14***a* to the grounded base plate **3**. This lower head portion is comprised of a configured block **15**. This includes a vertical channel **16** which is co-extensive with the orifice **6** in the base plast **3**. A control channel **17** is arranged to intersect the vertical channel **16** through which control channel a gas under pressure is admitted when it is desired to divert the ion stream from the vertical channel **16** to the horizontal control channel **17**. The control channel, in this instance, discharges into a drain **18** by way of line **18***a*. For other considerations, including design, the angle of intersection of these two channels **16**, **17** may be other than that shown. The ratio of the diameters of these channels **16**, **17** may be chosen to provide different conditions of printing. Also it may be desirable to provide vertical channels of smaller diameters relative to the diameter of the orifice **6** in the base plate **3**. This flexibility is achieved by having a variety of removable head portions. The particular embodiment shown enables printing to be accomplished by way of the vertical channel **16** under control of the horizontal control channel **17**. The channel **17** is interconnected via a line **17***a* to a source **17***b* of pressurized gas. Interposed in the line **17***a* is a fluidic control valve **19** interconnected to and controlled by a suitable valve control means **19***b*. This means **19***b* may be any electromechanical structure responsive to control signals related to printing functions. With the valve **19** closed, the ion stream passes unhindered through the vertical channel **16** to impinge and thus cause discharge of a discrete portion of the precharged sheet. Opening of the valve **19** interrupts this action by allowing the pressurized gas in the line **17***a* to pass through channel **17** and divert the ion stream into the drain **18** by way of line **18***a*. Beneath the printing head **15**, means, not shown, are provided to move the precharged sheet, such as the sheet **20** shown in FIG. **2**. The impinging ions exiting from the vertical channel **16** cause a reduction in surface potential of the opposite polarity precharged sheet portions to form an electrostatic image, for example the dotted pattern E, which upon subsequent processing by prior art means produces a visible print of the electrostatic image. Thus, the invention, by selectively discharging discrete portions of precharged surface by means of a controlled ion stream, provides for the generation of an electrostatic image.

Although the single head arrangement in FIG. **1** can be utilized to print a series of dots or lines, a plurality of these individual heads **1** can be suitably arranged in a single line (or any other desired arrangement) and held together to provide a multiple recording head assembly to print a plurality of dots, lines or characters.

The arrangement in FIG. **2** shows a plurality of corona wires **5** supported in parallel fashion in a single chamber **21** formed of insulating front and back walls **21***f*, **21***b*, side walls **21***s*, **21***sa*, a top plate **22** and a conducting base plate **23**, all held together by suitable means not shown. The corona wire structure is the same as that used in the single head configuration in FIG. **1**. These corona wires are positioned in a line and are maintained in position relative to orifices **24** in the base plate **23** by means of the top plate **22** in conjunction with a perforated insulating separator **25** provided with appropriate openings to receive the corona wires. The orifices **24** lead to vertical channels each similar to the channel **16** shown in FIG. **1**. Although not shown in FIG. **2**, these vertical channels are contained in a lower head assembly **26** further containing a plurality of horizontal control channels **27**, one of which is shown entering the back wall **21***b*, each control channel **27** intersecting a vertical channel. Valve means, not shown, similar to that utilized in FIG. **1**, are employed to control the introduction of pressurized gas into the horizontal channels to cause diversion of the ion streams from the vertical channels to and through the horizontal channels. A suitable source of high potential is connected between the corona wires **5'** and the base plate **23** which is held at ground potential. Each vertical channel exits at the bottom adjacent to which is located a sheet **20** upon which the exiting ion stream impinges upon the precharged sheet **20** to form an electrostatic image, pressurized gas in this arrangement being admitted by way of line **40**. Each vertical channel is controlled by a horizontal channel which is similar to the horizontal channel **17** employed in the head configuration of FIG. **1**. Thus in construction, the arrangement of FIG. **2** is similar to the multiple head arrangement previously described hereinabove except that the latter uses a single compartment for each corona wire, whereas the arrangement of FIG. **2** utilizes a single compartment to house the plurality of corona wires.

Another embodiment of the invention provides for a reversal in the function of the channels **16**, **17** to control the formation of the electrostatic image. This is achieved by disconnecting the control lines **27'** from the drain and by relocating the precharged sheet **20** to that of **20'**, partially shown in FIG. **2**, adjacent to the output ends **27'** of the horizontal control channels from which the diverted ions emerge; the vertical channel **17** in this instance being connected to a drain. The formation of the electrostatic image by this embodiment is achieved by somewhat diluted ion streams because of the mixture of the control stream with the ion stream.

A printing structure employing the device of a present invention is shown in FIG. **3**. This structure employs a rotating grounded conductive cylinder **30** having a dielectric surface coating **31** which is precharged to a uniform surface potential by way of a precharge station **32**. The precharged surface then passes under a station **33** comprised of a write heads corresponding to the write heads of the present invention and by means of which desired electrostatic images are formed on the drum surface. The drum surface bearing the images passes under a developer which can be of any type well known in the art. Following development, the image bearing surface passes through a transfer station **34** whereat the electrostatic image is transferred to a web of paper **36** issuing from a supply roll **35**. Following the transfer operation, the web **36** passes through a fixing station **37** which fixes the transfer image. A drum cleaning station **38** and an erase station **39** are provided to clean the drum surface and discharge the previously formed images in preparation for a new image formation cycle.

Some of the various parameters dealing with the concentration of and removal of ions from the ion stream will now be considered in an embodiment of the invention utilizing a unipolar precharged dielectric surface with deposition of opposite polarity ions controlled fluidically to produce regions having reduced electrical potential. The amount of reduction (i.e., the voltage contrast) depends on the time of exposure (i.e., control pulse length), the concentration of ions in the fluid stream, the efficiency with which ions are removed from the fluid stream, and the fluid stream velocity. The relationship is given by the equations below.

$$\Delta V = 1/C_s \alpha Q_s \quad (1)$$

Where V is the electrical potential across the dielectric surface layer, C_s is the electrical capacitance per unit area of the dielectric, and Q_s is the electrical charge density per unit area.

From 1, the voltage contrast ΔV produced by fluidic ion deposition of surface charge density Q_s is directly proportional to ΔQ_s and inversely proportional to the capacitance per unit area.

Neglecting relative motion between the surface and head, the dependence of charge deposition on ion concentration, fluid velocity, efficiency, and control pulse length is indicated below.

$$\Delta Q_s = q \cdot N_I \cdot V \cdot t_p \cdot (f/100) \quad (2)$$

N_I is unipolar ion concentration at the surface per unit volume of fluid, q is the charge per ion, V is the fluid velocity, t_p is the pulse length or "on-time" and f is the deposition efficiency in percent.

Under normal conditions ion concentrations change with time. In particular, large ion concentrations in flowing gases are reduced by recombination with charge carriers of opposite polarity and by neutralization at the conduit walls. Assuming unipolar ions only at the entrance to a conductive tube, one can neglect recombination and consider all loss of ions is due to neutralization at the chamber walls. In this case and for cylindrical symmetry, the output ion concentration should be

$$N_I = K_o N_{Io} V / K_o V + q \mu_I N_{Io} L \quad (3)$$

Where K_o is the permitivity of free space, N_{Io} is the ion concentration at the entrance, μ_I is the ion mobility in an electrical field, L is the tube length, and the other symbols being defined hereinabove. The simplifications involved in the derivation of 3 are such that observed ion concentration are in excess of those predicted by 3.

Combining the above results and expecting a deposition efficiency of 100 percent (for the preferred embodiment), and neglecting spreading, the voltage contrast is expressed as:

$$\Delta V = (1/C_s)\, K_o V^2 t_p N_{Io} / K_o V/e + N_{Io} \mu_I L \quad (4)$$

Hence to produce a particular voltage contrast with a specified short time control pulse, one must select the parameters of input ion concentration, fluid velocity, ion mobility, path length through the write head, and the capacitance of the insulating layer on which the image is to be formed, the layer capacitance being defined as:

$$C_s = K_s K_o / d_s \quad (5)$$

Wherein K_s is the dielectric constant and d_s thickness of the insulator and K_o is the permitivity of free space.

Typical values of dielectric constants for many dielectric materials are in the range of 2 to 4. In the MKS (meter, kilogram, second) system of units K_o has the values of 8.85 × 10–12 farads/meter. Hence, typical values of C_s are

$$1.77 \text{ to } 3.54 \times 1/d \times 10^{-11}\ \text{F/M}^2 \quad (6)$$

or for a 1 mil=25 micron=25×10^{-6}m thick films

$$C_s \cong 2.66\times10^{-11}/25\times10^{-6} = 1.06\times10^{-6}\ \text{F/m}^2 = 1.06\times10^{-10}\ \text{F/cm}^2 = 106\ \text{pico (Z)/cm}^2 \quad (7)$$

From 1, to produce a change in electrical potential of 50 volts across a sample having the capacitance per unit area given by 7 would require

$$\Delta Q_s = 50\times1.06\times10^{-6}\ \text{F}\cdot\text{V/m}^2 = 5.3\times10^{-5}\ \text{coul/m}^2 = 5.3\times10^{9}\ \text{coul/cm}^2$$

Referring now to 2 and assuming the deposition $f = 100$ percent, and singly charged ions so that $q = e = 1.6\times10^{-19}$ coul, i.e., electronic charge, the product of ion concentration, fluid velocity, and pulse length must be

$$N_I \times V \times t_p = \Delta Q_s/e = 5.3\times10^{-9}/1.6\times10^{-19} = 3.31\times10^{10}\ \text{cm}^{-2}$$

For a pressure differential ≅ 3psi, $V = 2\times10^3$ cm/sec. Hence for a 1 millisec pulse = 1×10^{-3} sec, the ion concentration required is

$$N_I = 3.31\times10^{10}/2 = 1.6\times10^{10}\ \text{ions/cm}^3 \quad (8)$$

to produce the 50 volt surface potential change in a millisecond time interval. Since ion current density is given by

$$j_I = N_{I\,vq} \quad (9)$$

The ion current density for the case above at the write head outlet would be

$$j_I = 1.6\times10^{10}\times1.6\times10^{19}\ \text{coul/ion ion/cm}^3 \times 2\times10^3\ \text{cm/sec} = 5.32\times10^{-6}\ \text{A/cm}^2 \quad (10)$$

As an example, one would need an ion current through a 30 mil diameter area of magnitude

$$I_I = j_I A = j_I\,(3\times10^{-2}\times2.54)\,2\pi/4 = 5.32\times10^{-6}\times4.56\times10^{-3} = 2.42\times10^{-8}\ \text{Amperes} \quad (11)$$

This ion current is of the same order as the maximum values obtained experimentally, hence, a valid conclusion is that ion concentrations of ≅ 1×10^{10} ions/cm³ are obtained.

Due to the presence of a velocity gradient across the length of the write head tube, ion concentration near the walls at the exit is reduced below that near the tube center. This effect results in "writing" dots that are smaller than the write head tube diameter.

ION GENERATION

A number of methods may be used to generate ions in a moving gas stream, triboelectricity, radiation (α, β, γ, X, U, V), corona discharge, microwave breakdown, etc.. For a high speed printer operating in air and near atmospheric pressure, however, one is limited to techniques which will yield high ion concentrations ≅ 10^9 or 10^{10} ions/cm³ or higher at the drum or coated paper surface. This means that ion generation must occur close to the surface in order to minimize ion concentration decay as discussed above. Such decay of ion concentration results from recombination with oppositely charged particles and from loss to the walls of the generator and writing head passages through which the ionized gas moves.

The most desirable source of corona discharge appears to be that obtained from a discharge point to an orifice at the entrance to the head-set control occurring immediately at the downstream side of the orifice. Typical operating conditions are ≅ 3KV at the point producing ≅ 6×10^{-6} A corona current at the tip and ≅ 10^{-8} to 10^{-7} A ion current depending on air pressure in the range from 1 to 15 psi above atmospheric pressure through a 0.030 inch inside dia. head. Such currents, although low, produce adequate voltage contrast with 2ms pulses so that a toned dot can be obtained with cascade development. The charge involved in this case is ≅ 2×10^{-11} coul. distributed on an area of ≅ 2×10^{-2} cm², hence surface charge density is ≅ 10^{-9} coul/cm².

When utilizing a unipolar precharged dielectric layer, either high concentrations of opposite polarity unipolar ions in the fluidic gas stream or bipolar (plasma type having both positive and negative polarity charge carriers) ions may be used. On the other hand, a dielectric surface that has been electrically neutralized so as to have a zero potential, either uni-polar or bipolar ions may be used. In this instance, however, the resulting electrostatic image may not have the resolution obtainable by utilizing a precharged dielectric surface.

While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that the foregoing and other changes in form and details may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. The method of forming an electrostatic image on the surface of a dielectric comprising the steps of generating a stream of ions from the pressurized gas, and

selectively directing stream of ions to impinge upon discrete portions of said surface to cause the formation of said image by directing a stream of relatively inert gas against the ion stream to divert the latter from impinging upon said surface.

2. The method of claim 1 further including the step of precharging the surface of said dielectric prior to directing thereon said stream of ions.

3. The method of claim 1 further including the step of electrically neutralizing the surface of said dielectric prior to directing thereon said stream of ions.

4. The method of claim 1 in which a pressurized gas stream is utilized to selectively control said stream of ions by directing the gas stream against the ion stream to cause the latter to impinge upon said discrete portions of said surface.

5. Apparatus for generating an ion stream comprising:

an ion generating chamber enclosed by electrically non-conducting walls, a top plate and a conducting bottom base plate containing a central opening from which said ion stream emerges,

a corona discharge wire means supported by said top plate and having an end portion thereof disposed in axial alignment with and in close proximity to said central opening,

an opening in said chamber for admitting pressurized gas, and

a source of high potential connected across said corona wire and said conducting base plate to cause the generation of said ion stream in the region around said central opening and end portion of said corona wire, a lower head assembly, secured to said bottom base plate, having a vertical channel communicating with said central opening through which said ion stream emerges, and a horizontal channel intersecting said vertical channel; and means for introducing a pressurized gas into said horizontal channel to divert said ion stream from the vertical channel to the horizontal channel.

6. Apparatus for forming an electrostatic image on a precharged dielectric surface comprising:

an ion generating means for issuing an ion stream,

a head assembly secured to said ion generating means and having a vertical channel through which said ion stream passes and emerges to impinge upon portions of said dielectric surface thereby discharging said portions,

said assembly further having a horizontal channel intersecting said vertical channel, and

means for introducing a pressurized gas into said horizontal channel when it is desired to selectively interrupt the flow of said ion stream on said dielectric surface thereby selectively interrupting the discharging of said surface to cause formation of said electrostatic image.

7. Apparatus for forming an electrostatic image on a precharged dielectric surface comprising:

an ion generating means for issuing an ion stream,

a head assembly secured to said ion generating means and having a vertical channel through which said ion stream passes and emerges,

said assembly further having a horizontal channel intersecting said vertical channel, and

means for selectively introducing a pressurized gas into said horizontal channel when it is desired to selectively divert the flow of said ion stream from said vertical channel to and through said horizontal channel and directing a mixture of said streams upon said dielectric surface thereby selectively discharging said surface to cause formation of said electrostatic image.

8. Apparatus for forming an electrostatic image on a precharged dielectric surface comprising:

an ion generator for issuing a plurality of individually controlled ion streams;

a head assembly secured to said generator and having a plurality of vertical channels through which said ion streams pass and emerge, said assembly further including a plurality of horizontal channels each intersecting a different one of said vertical channels; and

means for selectively introducing a pressurized gas into said horizontal channels to selectively divert desired ion streams from their respective vertical channels to and through said horizontal channels and upon selected portions of said dielectric surface to cause formation of said image by selective discharge of said precharged surface.

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