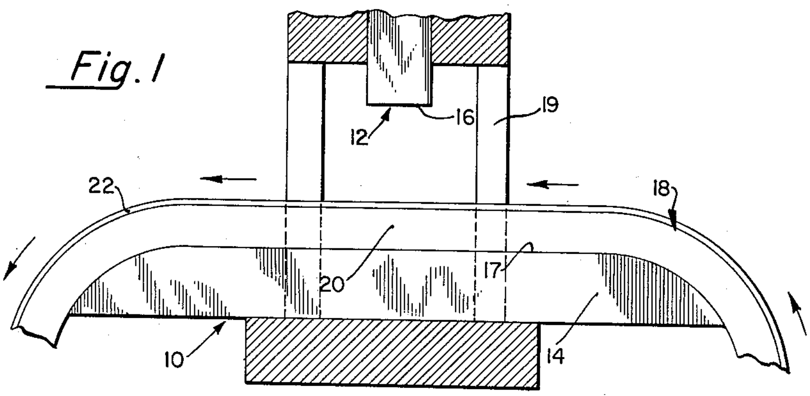
July 13, 1965 R. E. BENN ETAL 3,195,142

ELECTROGRAPHIC RECORDING PROCESS AND APPARATUS

Filed April 21, 1958 2 Sheets-Sheet 1

Fig. 1



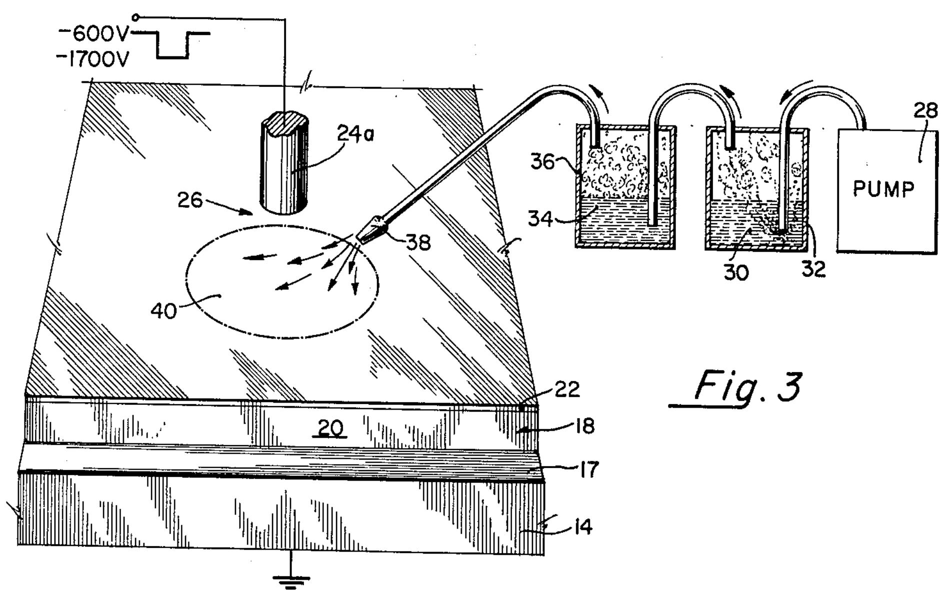


Fig. 3

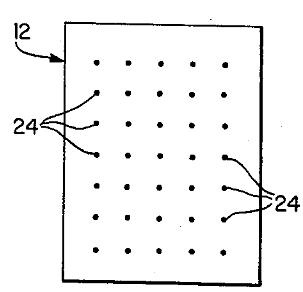


Fig. 2

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2 Sheets-Sheet 2

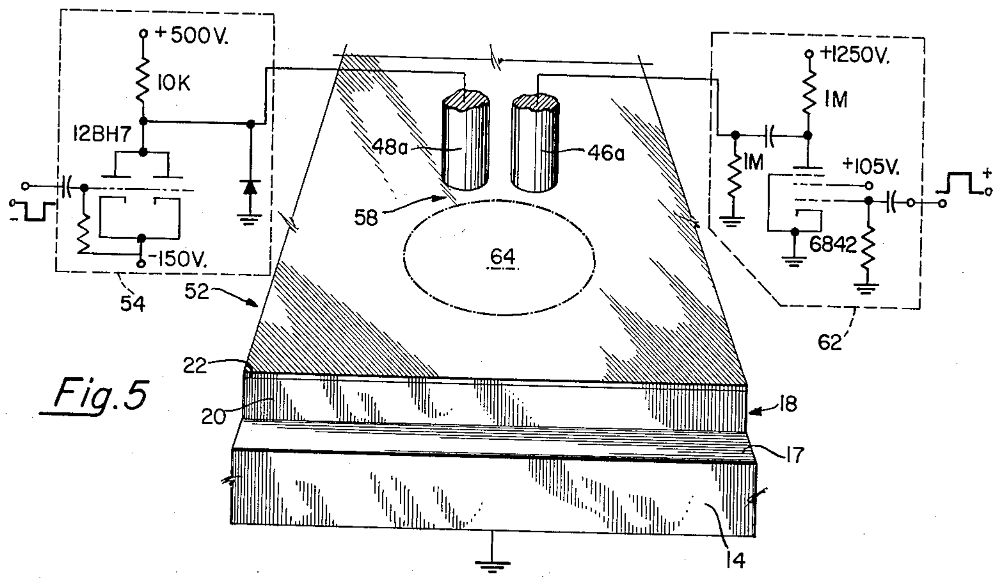

Fig.5

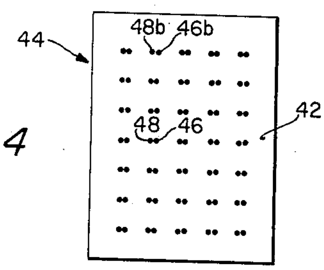

Fig.4

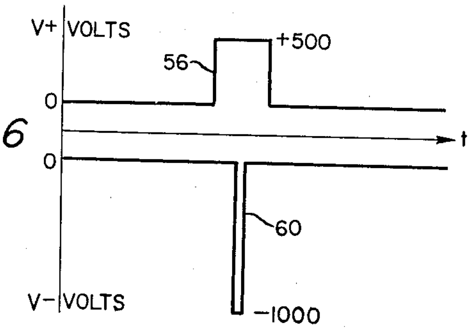

Fig.6

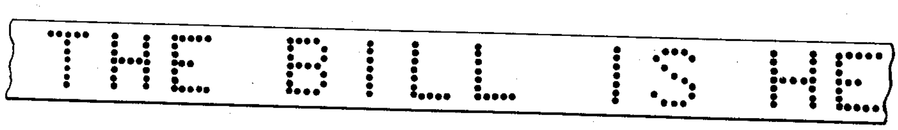

Fig. 7

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ELECTROGRAPHIC RECORDING PROCESS AND APPARATUS

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9 Claims. (Cl. 346—74)

This invention relates to electrographic recording process and apparatus and more particularly to improvements in the process and apparatus for establishing electrically charged areas on a charge retentive surface of a recording medium.

The electrographic recording process consists broadly of three steps. The first step comprising establishing, or printing, at the printing station electrically charged areas on selected portions of a recording medium, which areas are representative of information. The second step consists of developing such charged areas on the recording medium, by making them visible, for example. The third step, which is optional, consists in fixing or rendering, such developed areas substantially permanent. In the electrographic recording process these three steps take place sequentially and at physically separate locations.

The establishment of an electrically charged area on a recording medium at the printing station has heretofore been caused by creating a sufficiently intense electric field between a print electrode and the back electrode between which the recording medium is placed to guarantee that a charged particle, or particles, will be introduced into the gap between the electrodes by field emission. These particles initiate cumulative ionization of the gas molecules in the gap and an avalanche of charged particles is propagated from the print electrode toward the back electrode until the avalanche strikes the recording medium and establishes a charged area on the medium.

The intensity of the electric field necessary to sustain cumulative ionization, or a Townsend discharge, is considerably less than that necessary to introduce charged particles into the gap by the field effect. Also, the precise voltage at which charged particles are introduced in the gap by the field effect has a random variation. Therefore, the intensity of the electric field in the gap at the time the charged particles are produced varies. The size of the charged areas established on the charge retentive surface of the recording medium, the printed spots, is a function of the electric field intensity in the gap at the time the cumulative ionization commences. As a result, the size of the charged areas established on the recording medium has heretofore lacked uniformity.

It was discovered that by increasing the amount of water vapor in the otherwise ambient atmosphere existing betwen the print electrode and surface of the recording medium, the voltage at which field emission of the charged particles from the print electrode occurred is lowered, and that the presence of an electronegative gas in the gap reduced the size of the charged area established on the recording medium and reduced variations in size between printed spots.

It is therefore an object of this invention to provide an improved apparatus and process for establishing electrically charged areas on a recording medium.

A still further object of this invention is to provide improved process and apparatus for initiating a non-disruptive discharge in a gas at substantially ambient pressures and temperatures.

It is still a further object of this invention to provide a printing station for an electrographic printer in which it is not necessary to provide a specialized atmosphere to control the size of the printed latent images.

It is still another object of this invention to provide process and apparatus for electrographically recording information in which the amplitude of the print voltages across the print and back electrodes is reduced.

It is another object of this invention to provide methods and apparatus for initiating a non-disruptive discharge at the printing station of an electrographic recording which produces reliable and uniform printing and in which contamination of the print electrodes produces no deleterious effects.

It is a further object of this invention to provide in the electrographic recording process and apparatus, improvements in the printing station which produce reliable electrostatic latent images of uniform quality at substantially lower print voltages and without the necessity of providing a modified atmosphere.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same become better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

FIG. 1 is an enlarged schematic side elevation of a portion of the printing station of an electrographic recording device;

FIG. 2 is an enlarged view of the printing face of a prior developed matrix print head;

FIG. 3 is a greatly enlarged schematic perspective view illustrating how the printing step was accomplished in prior developed electrographic recording devices;

FIG. 4 is an enlarged view of the printing face of a print head incorporating auxiliary initiating electrodes;

FIG. 5 is a greatly enlarged schematic perspective view of the printing station illustrating operation of the printing heads incorporating initiating electrodes;

FIG. 6 is a graph of the voltages applied to the print and initiating electrodes of FIG. 5; and

FIG. 7 is an example of electrographic recording produced by a matrix type print head.

In order to set forth the invention and the advantages of the invention claimed herein with greater clarity, the prior art process and apparatus for establishing electrically charged areas on a recording medium are set forth. In particular, the structure of FIGS. 2 and 3 are characteristic of the prior art printing heads. In FIG. 1, two of the elements of printing station 10 are illustrated; they are the print head 12 and the back electrode 14. Print face 16 of print head 12 is substantially planar and spaced a uniform distance from support face 17 of back electrode 14 by any conventional mounting means such as holder 19. Recording medium 18 is located in the space between the print head 12 and back electrode 14. Recording medium 18 is comprised of a backing layer 20 to one side of which is secured a dielectric layer 22. Backing layer 20 is a relatively good conductor of electricity and dielectric layer 22 has a very high resistivity, or is a very poor conductor of electricity. Conventional means for moving recording medium 18 through printing station 10 in the direction indicated by the arrow are not illustrated. In operation, backing layer 20 is caused to be substantially in contact with support face 17 of back electrode 14.

FIG. 2 is an enlarged view of print face 16 of matrix print head 12. The print or pin electrodes 24 terminate substantially flush with print face 16, and at print face 16, electrodes 24 are arrayed substantially equidistantly from one another and in 5 columns and 7 rows. A print head having pin electrodes arranged at the print face as illustrated in FIG. 2 is sometimes referred to in the art as being a 5 x 7 matrix print head. By energizing selected ones of print electrodes 24, legible alphanumeric symbols can be printed on the recording medium as is well known in the art. An example of such printing is illustrated in FIG. 7.

Referring to FIG. 3, a single print electrode 24*a* is illustrated. The other electrodes and the structure of head 12 have been eliminated to simplify the illustration and description of the printing process. Spaced from the end of print electrode 24*a* is the back electrode or anvil 14. The space between anvil 14 and print electrode 24*a* defines a gap 26. The recording medium 18 is located within the gap with its backing layer 20 substantially in contact with support face 17 of back electrode 14.

In order to reduce the amplitude of the print voltage pulse and to maintain a greater degree of uniformity in the size of the electrically charged areas established on the exposed surface of dielectric layer 22, the atmosphere in the gap 26 is modified. Pump 28, which, in a preferred example, is electrically powered, forces ambient air through a layer of water 30 in container 32. The air is then bubbled through a layer of an electronegative chemical 34 such as trichloroethylene in container 36. The modified air is directed by nozzle 38 to flow in the space between the print face 16 and the dielectric layer 22 of recording medium 18.

Back electrode 14 may be connected to a point at reference potential, or ground. Print electrode 24*a* may be maintained at a substantially constant bias potential of, for example, −600 volts, by a suitable source of direct current potential which is not illustrated. When an electrically charged area is to be established on the recording medium 18, under electrode 24, a print pulse of, for example 1100 volts is applied to electrode 24, which increases the potential difference between electrodes 24*a* and 14 to 1700 volts. The source of the pulse is a conventional pulse driver circuit which is not illustrated.

A potential difference of 1700 volts under these conditions is normally more than the threshold value at which electrons are emitted from printed electrode 24*a* when electrode 24*a* is negative, as illustrated. It takes a short but still finite time for the potential difference between electrodes 24*a* and 14 to reach its maximum values. As a result, the precise voltage across the gap 26 at the time electrons are emitted from print electrode 24*a* is not a constant and varies with the material and history of electrode 24*a*, assuming that all other factors remain the same. The time it takes for a non-disruptive discharge to propagate across gap 26 and establish charged area 40 on dielectric layer 22 is of the order of 10^{-9} seconds or less. Compared with this period of time, the rise time of the print voltage pulse is quite long. As a result, there is a random variation in the strength of the electric field when charged particles are first emitted from electrode 24*a* and the sizes of the printed spots 40 produced by each point pulse are not necessarily uniform. Each of the printed spots 40 printed by electrode 24*a*, for example, will be substantially circular and the center of spot 40, as it is formed, will be substantially under the center of pin 24*a*, or on the extended longitudinal axis of pin electrode 24*a*.

The presence of water vapor in gap 26 reduces the maximum voltage at which field emission occurs. The effect of electronegative material in gap 26 is to increase the field strength necessary to sustain cumulative ionization and thus the dimensions of the avalanche are decreased, which decreases the size of electrically charged area 40 established, or printed, on the surface of charge retentive layer 22 of the recording medium 18. The particular advantage of the presence of water vapor and an electronegative material is set forth in greater detail in U.S. Patent No. 2,931,688, issued April 5, 1960 to Frank T. Innes, Herman Epstein and Robert J. Phelps for Electrographic Printer and in patent application Serial No. 660,408, filed May 20, 1957, entitled "Atmosphere for Electrographic Printing" by Robert E. Benn, now U.S. Patent No. 3,023,070, issued February 27, 1962, which patents are assigned to the assignee of this application.

FIG. 4 is a view similar to FIG. 2 showing the print face 42 of print head 44. Print head 44 is a 5 x 7 matrix print head in which there is provided an initiating electrode 46 for each of the print electrodes 48. The print and initiating electrode terminals terminate substantially flush, or coplanar, with print face 42 of print head 44. Print electrodes 48 are substantially equidistantly spaced from each other and are arranged in 5 columns and 7 rows. In a preferred example, electrodes 46, 48, are each 3 mils in diameter, the distance between centers of the print electrodes 48 is 16 mils and the distance between a print electrode 48*a* and initiating electrode 46*a* is approximately 2½ mils.

FIG. 5 is a greatly enlarged schematic diagram of a portion of print station 10 with print head 44 substituted for print head 12 and only a single print electrode 48*a* and its associated initiating electrode 46*a* of print head 44 illustrated. The rest of the structure of head 44 is not illustrated in order to simplify the illustration and description of the improved process and apparatus for establishing electrically charged areas on recording medium 18. Back electrode 14 is located so that planar support surface, or face, 17, whose surface dimensions are at least on the order of magnitude, or greater than the diameter of either print electrode 48*a* or initiating electrode 46*a* is spaced and maintained at a substantially uniform distance from print face 42 of print head 44.

A print voltage pulse may be applied to print electrode 48*a* by low impedance print pulse driving circuit 54 which is illustrated schematically. In a preferred example, the amplitude of the print pulse 56 may be approximately +500 volts and pulse 56 may be approximately 500 microseconds wide. The presence of print voltage pulse 56 on pin 48*a* establishes a unidirectional divergent electric field between print electrode 48*a* and planar surface 17 of back electrode 14, or within gap 58. Electrode 48*a*, comparatively speaking, can be considered a point source, or a point electrode. The maximum intensity of this field at electrode 48*a* is, however, insufficient to cause the emission of charged particles by the field effect. The intensity of the field is of sufficient value to sustain cumulative ionization within gap 58 once electrically charged particles are introduced into gap 58. To introduce charged particles into gap 58, an initiating pulse 60 is applied to initiating electrode 46*a* by relatively high impedance initiating pulse driving circuit 62 which is illustrated schematically. The amplitude of the initiating pulse 60 may be on the order of −1000 volts, and its pulse width, in one embodiment, is on the order of 50 microseconds, so that it is substantially less than the pulse width of the print voltage pulse. The electric field strength between initiating electrode 46*a* and back electrode 14 is below the threshold value at which charged particles are produced by the field effect.

In FIG. 6 the relative polarities, amplitudes and timing of the print voltage pulse 56 and initiating pulse 60 are illustrated. When an initiating pulse 60 is applied to initiating electrode 46*a* and a print pulse 56 is simultaneously applied to print electrode 48*a*, the voltage between them is sufficient to promptly initiate a disruptive, or spark, discharge. The duration of the disruptive discharge is very short, on the order of 10^{-9} seconds or less. In order for printing to occur with the new head, it is necessary that the print and initiating pulses be applied simultaneously to an associated pair of print and initiating electrodes. Thus the widths of both pulses may be made equal, or the initiating pulse can be made wider than the printing pulse.

Although not illustrated in FIG. 6, electrodes 46*a* and 48*a* are insulated from each other by a material having high resistance such as the epoxy resin from which the principal part of head 44 is formed. As a result, the disruptive discharge takes place substantially between the ends of electrodes 46*a*, 48*a* substantially in the plane of print face 42 of head 44.

Each disruptive breakdown introduces a larger number of charged particles into gap 58 and in particular in that portion of the gap between electrode 46*a*, electrode 48*a* and back electrode 14, where the intensity of the electric field is near its maximum value. As soon as charged particles are introduced into gap 58, the field between the print electrode 48*a* and the back electrode 14, due to the existence of print voltage pulse 56 at print electrode 48*a* is sufficient to cause the propagation of an avalanche of charged particles across gap 58 and the establishment of a charged area 64 on the surface dielectric layer 22. The printed spot 64 will be substantially circular. However, it appears that the center of the spot as it is produced is not directly under print electrode 48*a*, but somewhere between the centers of electrodes 46*a* and 48*a*, or to state it another way, the origin of the avalanche probably lies along the path of the disruptive discharge between the initiating electrode 46*a* and print electrode 48*a*. The polarity of charge area 64 is the same as that of print electrode 48*a*. In FIG. 5, with polarities of the pulses as illustrated, the charge of the printed spot 64 will be positive.

An explanation of the manner of the propagation of negative charge across gap 26 of FIG. 3 (for example) is relatively easily understood as being due to the acceleration of electrons emitted by the field effect from electrode 24*a* by the electric field so that these electrons have sufficient energy to ionize gas molecules in the gap 26. The process of ionization of the gases in the gap produces more electrons, which are, in turn, accelerated to produce still more electrons, etc. However, when a positive print voltage is applied to print electrode 48*a*, the explanation is not as simple since the intensity of the field in gap 58 of FIG. 5 between electrode 48*a* and back electrode 14 is believed to be insufficient to cause the positively charged ions existing in gap 58 to be accelerated to produce further ionization.

An explanation of how a positively charged area 64 is established, or printed, is as follows. The presence of positive ions introduced into the gap 58 by the disruptive discharge distorts the electric field in gap 58 to a point that electrons are emitted from gas molecules ahead of the bulk of positive ions, and ahead of the boundary of the avalanche. This forms more positive ions, and since the electrons emitted move rapidly to the print electrode 48*a*, the charge of the ions is not neutralized. The additional positive ions further distort the field, establish a new boundary, and the process continues until the avalanche has propagated across the gap and strikes recording medium 18. This explanation can account for the propagation of the positive ions across gap 58 in a manner which appears to be substantially like the Townsend avalanche produced when the print electrode is negative.

Because of the high impedance of initiating pulse driver 62, the disruptive discharge between electrodes 46*a*, 48*a*, is of very short duration. The time constant of the circuit including initiating pin 64*a* and the time both print pulse 56 and initiating pulse 60 are simultaneously present at their respective electrodes, determines whether more than one disruptive discharge can be produced each time print electrode 48*a* and initiating electrode 46*a* are simultaneously energized. Each disruptive discharge will initiate an avalanche of charged particles. Each additional avalanche has the result of increasing the charge density of printed spot 64 and also of slightly increasing its size. In order to achieve a high order of uniformity, it is desirable that each printed spot be produced by substantially the same number of avalanches. This is accomplished by controlling the widths and timing of the pulses and the impedance of the initiating electrode circuit.

One of the advantages of using a disruptive, or arc, discharge between the initiating electrode 46*a* and print electrode 48*a* to introduce charged particles in the gap 58 is that the intensity of the unidirectional field between the print electrode 48*a* and the back electrode 14 is established and has a substantially fixed value at the time these charged particles are introduced into the gap by the disruptive discharge. Since the electric field strength is substantially constant and known, the size of the charged area 64 established, or printed, by each such combination of print and initiating pulses will be substantially constant. Also, since the discharge is not initiated by the field effect, it is not necessary to apply very high voltage print pulses to the print electrodes. As a consequence, apparatus for providing modified air to the printing station is no longer needed.

Another one of the problems encountered in using prior type print heads is that the presence of certain materials, or contaminants raised the voltage at which charged particles are emitted by the field effect. In some cases the presence of contaminants raised the minimum value of the potential to a value greater than those applied by the pulse driver, with the result that no charged particles are emitted and the print head failed to print. It has been observed that the disruptive discharge between the initiating electrode and the print electrode has a self-cleansing action so that contamination no longer tends to make the printing electrodes inoperative.

When the print head such as that illustrated in FIG. 4 is in printing station 10, a print pulse driver will be associated with each of the print electrodes 48 and an initiating pulse driver will be associated with each of the initiating electrodes 46. Whenever a charged area is to be established under print electrode 48*b* and initiating electrode 46*b*, for example, it is necessary that a print and initiating pulse simultaneously be applied to these respective electrodes. In printing an alphanumeric character, those print and initiating electrodes which must be energized to print the character on the recording medium are energized by conventional control circuit means which are not illustrated herein but are well-known in the art and produce recording such as that illustrated in FIG. 7.

From the foregoing, it should be clear that the polarities of the print and initiating pulses can be reversed. When a negative print voltage is applied to the print electrode, negatively charged areas will be established on recording medium and when positive print pulses are applied to the print electrode, positively charged areas will be printed or established on the recording medium. The impedance of the pulse drivers energizing an electrode determines the electrode's function, with a high impedance pulse driver being used with an initiating electrode and a low impedance pulse driver being used with a print electrode. Thus the function of electrodes 46*a*, 48*a*, can be interchanged if their respective pulse drivers are interchanged.

While the print and initiating electrodes are illustrated and described as being pin electrodes, other physical arrangements, such as having the initiating electrode concentric with the print electrode, for example, may be used and be within the scope of the invention.

The explanation of the manner in which electrically charged areas are established on the dielectric layer are the best explanations that have been developed to date. They are believed to be accurate and are supported by tests. They are, however, only the best known to the inventors at this time.

From the foregoing, it is believed obvious that the advantages of the use of initiating electrodes to introduce charged particles in the gap between the print electrode and back electrode, to initiate the discharge at a predetermined field strength, have greatly improved the usefulness of the electrographic printing devices.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is, therefore, to be understood that within the scope of the appended claims the invention may be practiced other than as specifically described and illustrated.

What is claimed is:

1. In combination: an electrographic recording printing head having a print face, a print electrode having an end substantially at said print face; an initiating electrode having an end substantially at said print face, the ends of said initiating and print electrodes being closely spaced and separated by electrical insulating means, a back electrode having a support face; means mounting said back electrode so that the support face is substantially uniformly spaced from the print face of the print head; means for establishing a voltage difference between the print electrode and the back electrode, the magnitude of said voltage being less than that necessary to introduce charged particles into the space between print electrode and the back electrode by the field effect, and means for establishing a potential difference between the initiating electrode and print electrode to cause a very short disruptive electrical discharge to occur between the initiating electrode and the printing electrode.

2. An electrographic recording printing station comprising: a back electrode having a support face, a print head forming a print face, said back electrode and print head adapted to be mounted so that said print face is spaced a fixed distance from and opposite to said support face, a print electrode terminating at said print face, an initiating electrode terminating at said print face, said initiating electrode being insulated from and spaced close to said print electrode, a first low impedance pulse driver, means connecting said first pulse driver to apply, when energized, a voltage between said print electrode and said back electrode, the magnitude of said voltage being less than the threshold value necessary to introduce electrically charged particles in the space between the print and initiating electrode and said back electrode; a second high impedance pulse driver, means connecting said second pulse driver to apply, when energized, a voltage between said initiating electrode and said print electrode, of sufficient amplitude, in conjunction with the voltage produced by said first pulse driver when energized, to produce a disruptive electrical discharge between said print electrode and said initiating electrode.

3. A matrix print head comprising: a body portion which has a print face, a plurality of print electrodes which intersect said print face and terminate substantially at said print face and form in their intersection with the said print face an array in which each said print electrode is substantially equidistantly spaced from the other print electrodes nearest it and in which the said print electrodes are arranged in rows and columns substantially at right angles to each other; and a plurality of initiating electrodes, each operatively associated with an individual one of the print electrodes, and each of which intersect said print face and terminate substantially at said print face in closely spaced electrically insulated relation to the print electrode with which it is associated.

4. An electrostatic printing head comprising, in combination, a body having a print face and carrying a plurality of print electrodes which terminate substantially at said print face and form therewith a matrix array in which the print electrodes are located at the intersections of rows and columns of the matrix, and a plurality of initiating electrodes carried by the body, each of which is operatively associated with an individual one of the print electrodes and terminates substantially at said print face closely adjacent to but electrically insulated from its associated print electrode.

5. Electrostatic printing apparatus comprising, in combination, a printing head having a print face and carrying a plurality of print electrodes which terminate substantially at said print face and form therewith a matrix array in which the print electrodes are located at the intersections of rows and columns of the matrix, a plurality of initiating electrodes carried by the printing head, each of which is operatively associated with an individual one of the print electrodes and terminates substantially at said print face closely adjacent to but electrically insulated from its associated print electrode, means for applying selectively to the print electrodes an electromotive force to create an electric field extending substantially perpendicularly away from said print face and into the proximate atmosphere, and means for applying between each print electrode and its associated initiating electrode a second electromotive force coincidentally in time with the first electromotive force and sufficient to create a short disruptive electrical discharge therebetween to initiate cumulative ionization in the atmosphere of the electric field established by the print electrode.

6. Electrostatic printing apparatus comprising, in combination, a printing head having a print face and carrying a plurality of print electrodes which terminate substantially at said print face and form therewith a matrix array in which the print electrodes are located at the intersections of rows and columns of the matrix, a plurality of initiating electrodes carried by the printing head, each of which is operatively associated with an individual one of the print electrodes and terminates substantially at said print face closely adjacent to, but electrically insulated from, its associated print electrode, means for applying selectively to the print electrodes an electromotive force to create an electric field extending substantially perpendicularly away from said print face and into the proximate atmosphere, and means for selectively applying between print electrodes and selected ones of their associated initiating electrodes a second electromotive force coincidentally in time with the first electromotive force and sufficient to create a discontinuous disruptive electrical discharge therebetween to initiate cumulative ionization in the atmosphere of the electric field established by the print electrode so as to cause a desired symbol in a desired location.

7. An electrographic recording printing station comprising: a back electrode having a support face, a print head forming a print face, said back electrode and print head adapted to be mounted so that said print face is spaced a fixed distance from and opposite to said support face, a print electrode terminating at said print face, an initiating electrode terminating at said print face, said initiating electrode being insulated from and spaced close to said print electrode, a first low impedance pulse driver, means connecting said first pulse driver to apply, when energized, a voltage between said print electrode and said back electrode, the magnitude of said voltage being less than the threshold value necessary to introduce electrically charged particles in the space between the print and initiating electrode and said back electrode; a second high impedance pulse driver, means connecting said second pulse driver to apply, when energized, a voltage between said initiating electrode and said print electrode, of sufficient amplitude, in conjunction with the voltage produced by said first pulse driver when energized, to produce a disruptive electrical discharge between said print electrode and said initiating electrode but not of sufficient amplitude without said voltage produced by said first pulse driver when energized to produce said disruptive electrical discharge.

8. An electrographic recording printing station comprising: a back electrode having a support face, a print head forming a print face, said back electrode and print head adapted to be mounted so that said print face is spaced a fixed distance from, and opposite to, said support face, a plurality of pairs of electrodes, each pair comprising a print electrode terminating at said print face and an initiating electrode terminating at said print face, in each pair said initiating electrode being insulated from, and spaced close to, said print electrode, first low impedance pulse driver means, means connecting said first pulse driver means to apply selectively, when energized, a voltage between a selected print electrode, selected print electrodes, or all of said print electrodes and said back electrode, the magnitude of said voltage being less than

the threshold value necessary to introduce electrically charged particles in the space between the print and initiating electrode pair and said back electrode; second high impedance pulse driver means, means connecting said second pulse driver means to apply selectively, when energized, a voltage between a selected initiating electrode, selected initiating electrodes or all of said initiating electrodes and the print electrode corresponding thereto, of sufficient amplitude, in conjunction with the voltage produced by said first pulse driver means, when energized, to produce a disruptive electrical discharge between each pair of said print electrodes and said initiating electrodes to which both pulse driver voltages are applied such that discharge towards the back electrode occurs only at selected locations of pairs wherein both print and initiating voltages have been applied.

9. The process of establishing electrically charged areas on a dielectric recording medium comprising the step of establishing an electric field insufficient alone to cause ionization of the atmosphere ambient about the said dielectric recording medium and having a component normal to the surface of the said dielectric recording medium, and the step of producing an avalanche of electrical charges toward the said dielectric recording medium by causing a discontinuous disruptive electrical discharge in the said ambient atmosphere to introduce into the said electric field a copious supply of charged particles.

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