

[54] **ELECTROGRAPHIC RECORDING PROCESS AND APPARATUS USING CONDUCTIVE TONER SUBJECT TO A CAPACITIVE FORCE**

3,721,553 3/1973 Giaimo, Jr. 346/74 ES

Primary Examiner—Bernard Konick
Assistant Examiner—Jay P. Lucas
Attorney, Agent, or Firm—Alexander, Sell, Steldt & DeLaHunt

[75] Inventor: Arthur R. Kotz, White Bear Lake, Minn.

[73] Assignee: Minnesota Mining and Manufacturing Company, St. Paul, Minn.

[22] Filed: Apr. 20, 1973

[21] Appl. No.: 353,139

[52] U.S. Cl. 346/74 ES, 96/1.4

[51] Int. Cl. G01d 15/06, G03g 13/14

[58] Field of Search..... 346/74 ES, 74 E, 74 R, 346/74 S, 74 SB; 355/3, 12; 96/1.4

[56] **References Cited**

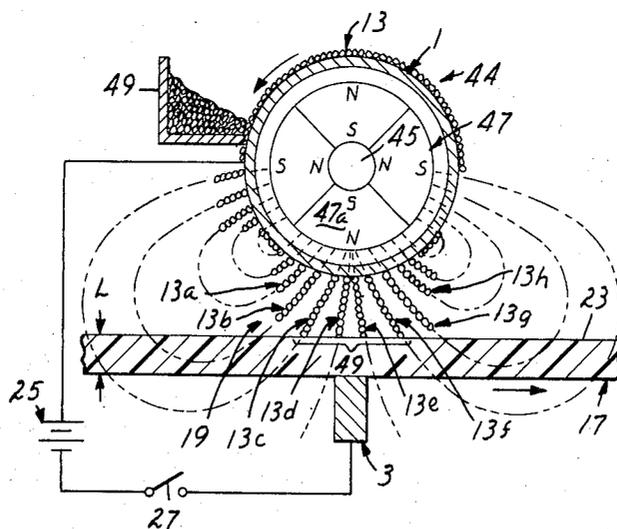
UNITED STATES PATENTS

2,890,968	6/1959	Giaimo, Jr.	346/74 ES
2,930,351	3/1960	Giaimo, Jr.	346/74 ES
3,182,591	5/1965	Carlson	346/74 ES

[57] **ABSTRACT**

An electrographic process and device are provided wherein a dielectric recording member is arranged between two electrodes to one of which is adherably bound electronically conductive toner powder, the toner powder providing an electronically conductive path between the electrode to which it is bound and the adjacent surface of the dielectric member, and a voltage applied to the electrodes for a time and of a magnitude sufficient to generate a force pattern of intelligence on the toner which enables toner deposition on the recording member in accordance with the force pattern. The force pattern is generated directly on the toner rather than on the recording member which is passive in the operation of this invention.

25 Claims, 18 Drawing Figures



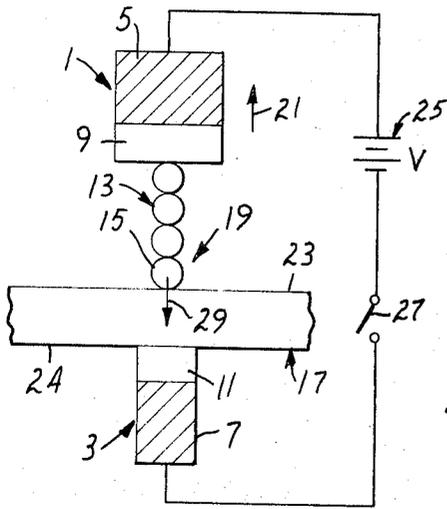


FIG. 1

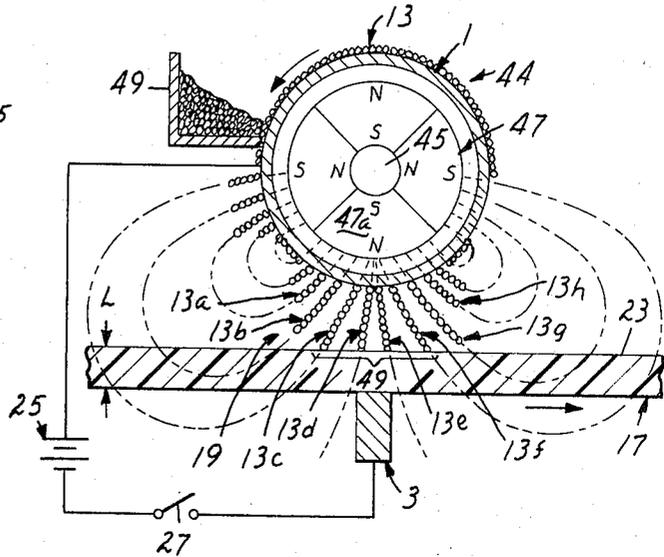


FIG. 9

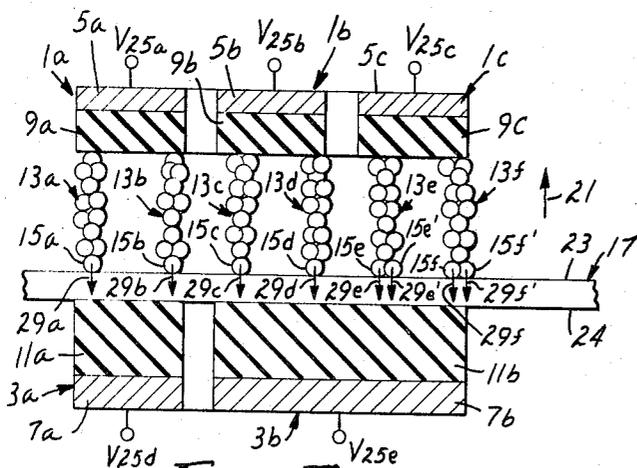


FIG. 7

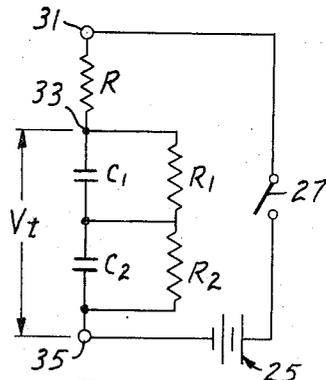


FIG. 2

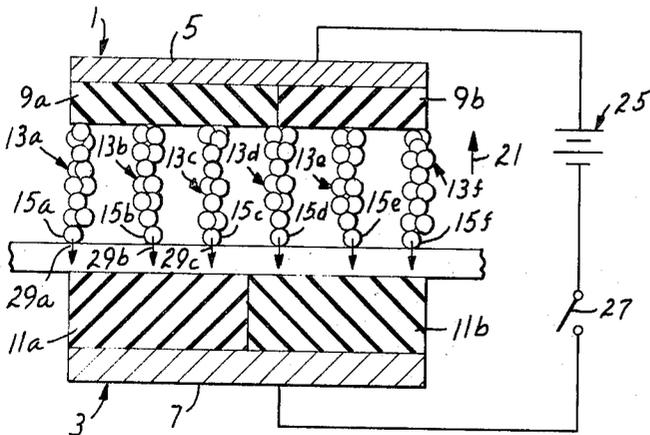


FIG. 8

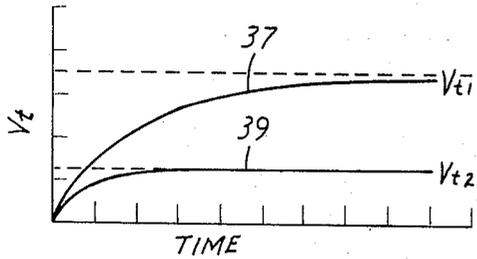


FIG. 3

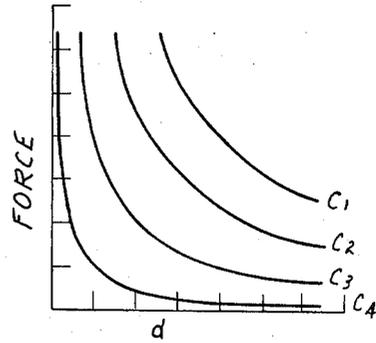


FIG. 5

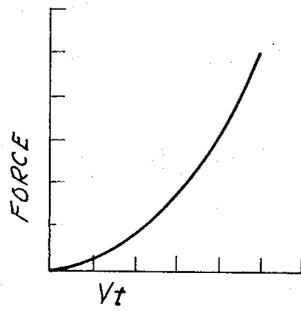


FIG. 4

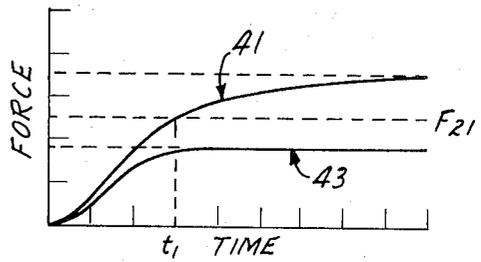


FIG. 6

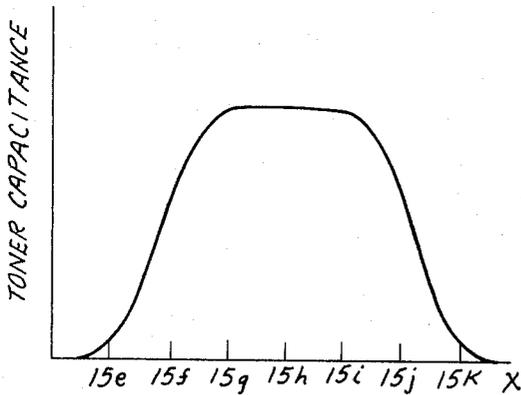


FIG. 11

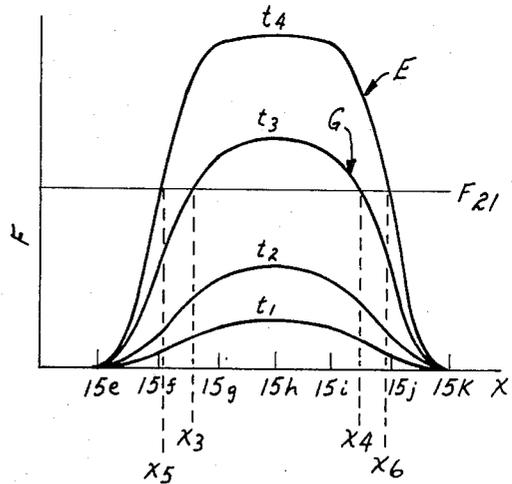


FIG. 13

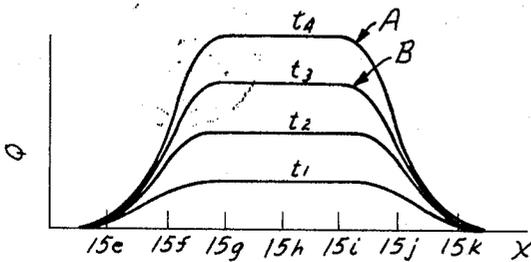


FIG. 12

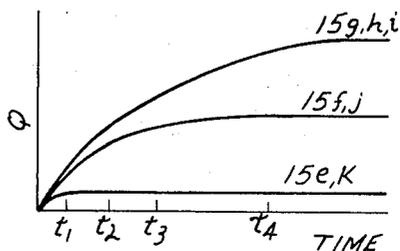


FIG. 14

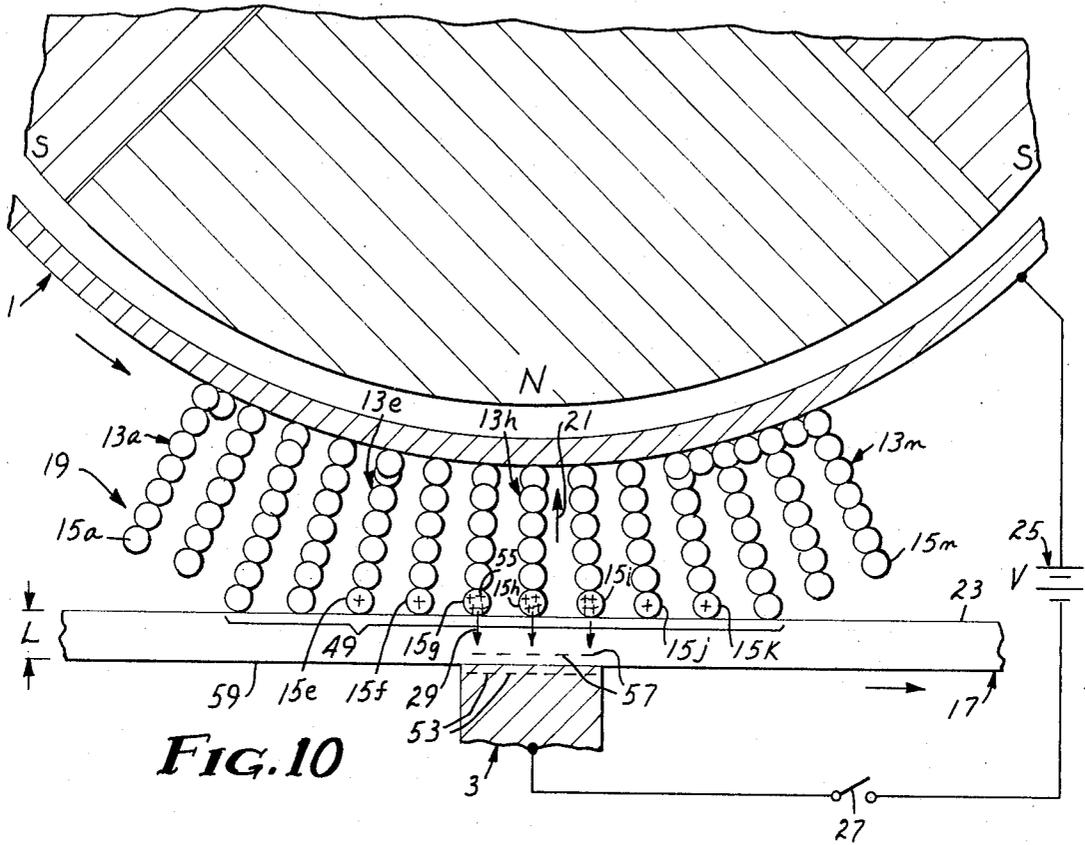


FIG. 10

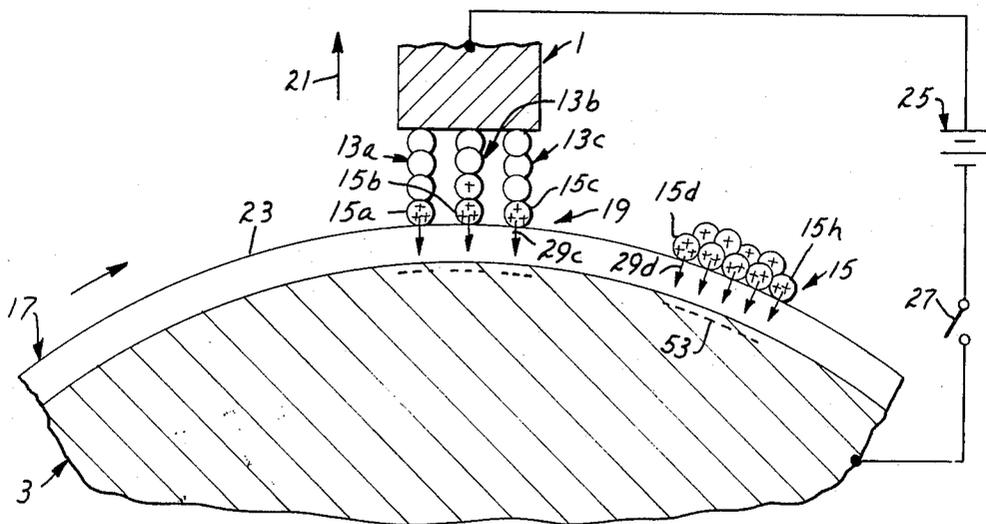
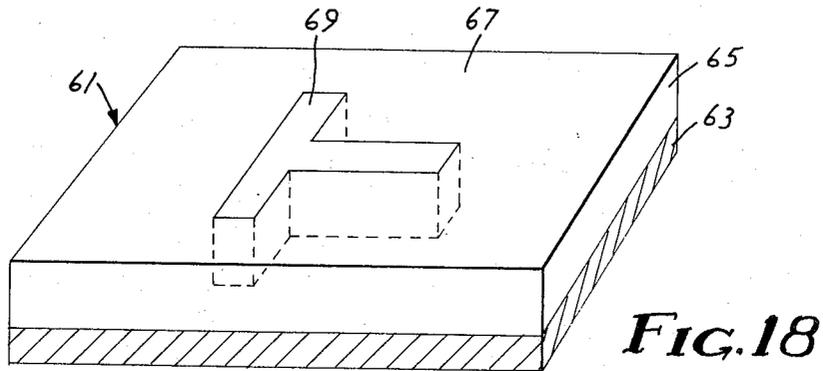
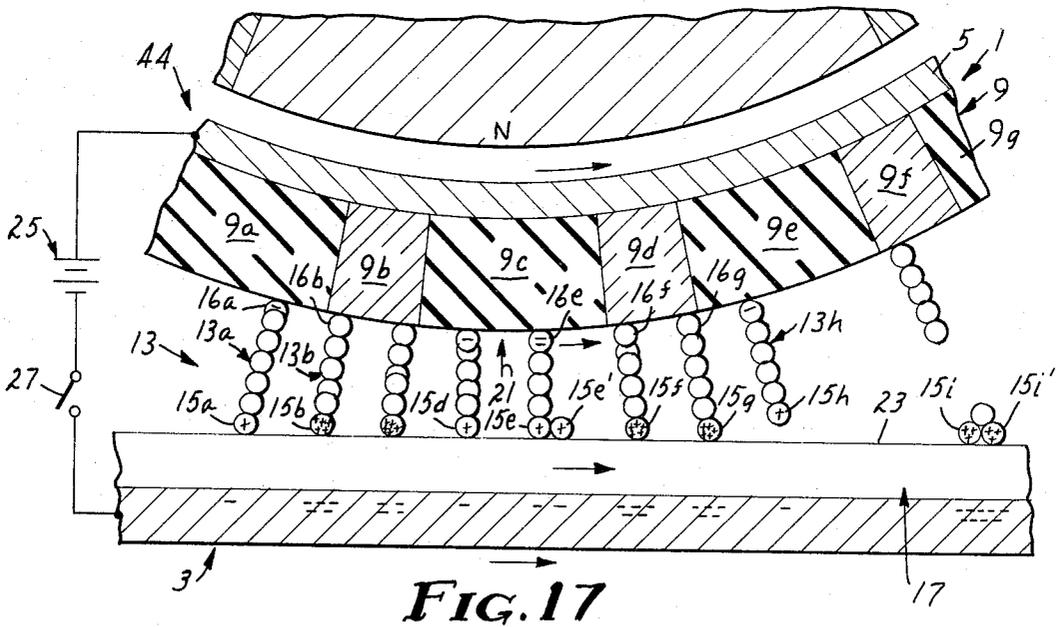
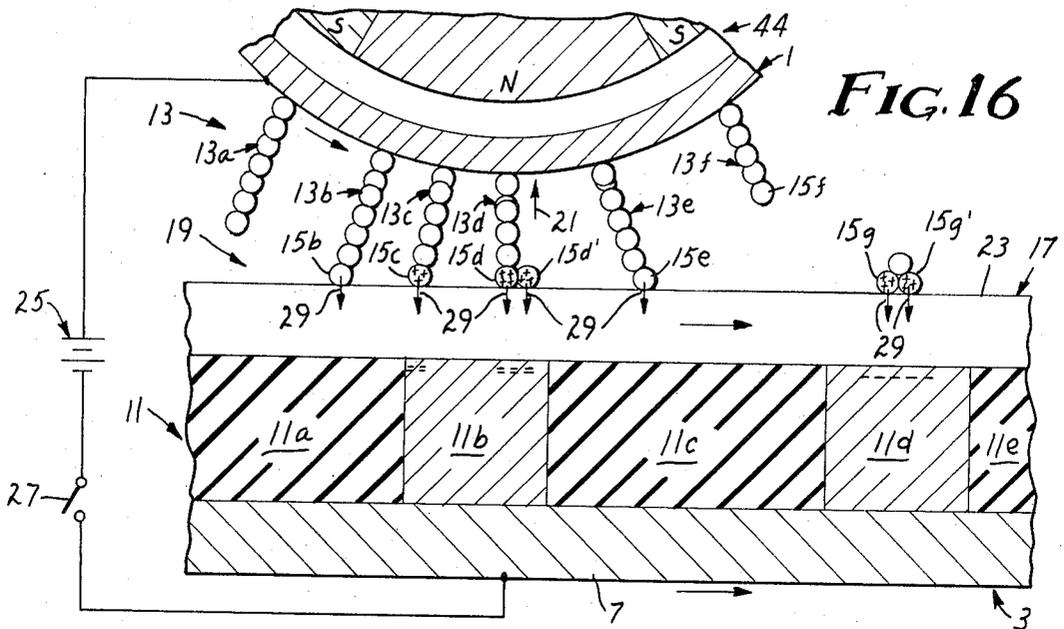


FIG. 15



**ELECTROGRAPHIC RECORDING PROCESS AND
APPARATUS USING CONDUCTIVE TONER
SUBJECT TO A CAPACITIVE FORCE**

This invention relates to the field of electrographics; more particularly, it relates to a method and apparatus for recording information in the form of toner images on a recording member by the formation of a force pattern of intelligence on toner and deposition of toner on a recording member in accordance with such pattern.

The broad field of electrographics may be regarded as involving creation of an image pattern through electrical means which image pattern is utilized to create a sensible form of the subject matter desired to be recorded. Undoubtedly, the most widely used area of electrographics is that known as electrophotographics wherein the image pattern is created by directly subjecting a photosensitive recording member to a combination of electrical means and a light image. In electrostatic electrophotography the image pattern exists as a pattern of electrostatic charges on the recording member.

Another broad area of electrographics, and the one to which this invention relates, does not necessarily rely upon the direct focusing of a light image on a photosensitive recording member but rather forms the image pattern by electrical means alone.

Electrographic systems not utilizing direct light imaging find their major usage in oscillographic recording, computer printers, and facsimile recording. The major systems in use can be characterized as spark recording (see U.S. PAT. Nos. 2,035,474 and 3,355,473); electrolytic recording (see U.S. Pat. No. 3,075,193); electrostatic stylus recording (see U.S. Pat. Nos. 2,932,690 and 2,932,548); and electrophoretic recording (see U.S. Pat. Nos. 3,121,375; 2,035,475; and 2,932,690).

The present invention obviates the disadvantages of these known electrographic recording systems by avoiding reliance on sparking, high voltage, liquid developers or vapors, mass transfer by flight or migration of electrostatically charged particles through a liquid or other space, electrostatic precharging with high voltage followed by subsequent development with electrostatically charged particles, specially formulated recording members, active receptors having a latent conductivity pattern or a latent charge pattern, or electrolytic plating of the electrode material.

The present invention allows electrographic recording at very high speeds, with low voltage and low current. The low voltage allows the use of low voltage transistors and integrated circuits to be used in conjunction with the apparatus of this invention and the fact that very low current is simultaneously involved means that the power required to record information or make copies, for example, is very low even though extremely high speeds can be attained. Furthermore the present invention allows a continuous range of optical densities to be recorded (continuous tone) without an edge effect.

In other prior art related to the more specific field of electrophotography, Shely, U.S. Pat. No. 3,563,734, requires a photosensitive receptor having a latent conductivity pattern at least at the surface of the receptor which contacts the toner powder, and Gundlach, U.S. Pat. No. 3,166,432, involves the development of latent

electrostatic charge patterns. The present invention, by contrast, involves recording by novel means on an electrically passive dielectric recording member not requiring that any intelligence be associated with the recording member such as a conductivity pattern or latent charge pattern prior to or simultaneous with the development step.

In accordance with the foregoing, a process is provided comprising:

1. arranging first and second electrode means in spaced opposing relationship to provide a recording region therebetween, said first and second electrode means each having at least one electronically conductive portion,

2. arranging a passive dielectric recording member in said recording region with a first surface thereof in electronic contact with said second electrode means,

3. providing electronically conductive toner between said first electrode means and a second surface of said dielectric recording member to form an electronically conductive path between said first electrode means and said second surface, said toner including at least a portion thereof in physical contact with said second surface of said dielectric recording member, whereby at least one electrical circuit between said electronically conductive portions of said first and second electrode means is provided, said toner being attracted to said first electrode means by a first force,

4. applying an electrical potential to at least one of said circuits to cause electronic current to flow in said circuit whereby said portion of said toner in physical contact with said recording member is subjected to an electrical force pattern of intelligence determined by the electrical potential difference between said portion of said toner and second electrode means and the electronic capacity of said portion of said toner with respect to said second electrode means, said force pattern including at least one of (a) a first portion exerting a force on said portion of said toner in contact with said dielectric recording member having a magnitude greater than and opposed to said first force and (b) a second portion exerting a force on said portion of said toner in contact with said dielectric recording member having a magnitude less than said first force, and

5. removing said dielectric recording member from said recording region at a time after application of said electrical potential while said force pattern is present whereby toner is selectively deposited on said dielectric recording member in regions corresponding to said first portion of said force pattern.

There is also provided as part of this invention an apparatus comprising:

1. first and second electrode means each having at least one electronically conductive portion, said first and second electrode means being in spaced opposing relationship to provide a recording region therebetween,

2. toner supply means for supplying electronically conductive toner to said first electrode means,

3. first force means associated with said first electrode means providing a first force holding said toner in association with said first electrode means,

4. transport means for providing relative transport of a passive dielectric recording member relative to at least one of said first and second electrode means through said recording region, said electronically conductive toner providing an electronically conductive

path between one surface of said dielectric recording member and said first electrode means when said dielectric recording member is in said recording region, said second electrode means being in electronic contact with the surface of said dielectric recording member opposing said one surface, said arrangement providing at least one electrical circuit between said electronically conductive portions of said first and second electrode means,

5 5. electrical potential means adapted to apply an electrical potential to at least one of said circuits to cause electronic current to flow in said circuits whereby said portion of said toner in physical contact with said one surface of said recording member is subjected to an electrical force pattern of intelligence determined by the electrical potential difference between said portion of said toner and said second electrode means and the electronic capacity of said portion of said toner with respect to said second electrode means, said force pattern including at least one of (a) a first portion exerting a force on said portion of said toner in contact with said dielectric recording member having a magnitude greater than and opposed to said first force and (b) a second portion exerting a force on said portion of said toner in contact with said dielectric recording member having a magnitude less than said first force, and

6. means for relative transport of said dielectric recording member from said recording region at a time after application of said electrical potential while said force pattern is present whereby toner is selectively deposited on said dielectric recording member in regions corresponding to said first portion of said force pattern.

The invention will be better understood by reference to the drawings wherein:

FIG. 1 is a schematic cross-sectional view of the elements of the invention;

FIG. 2 is an electrical circuit diagram representation of the elements of the invention;

FIG. 3 is a graph of electrical toner potential versus time;

FIG. 4 is a graph showing the electrical force dependence upon the electrical toner potential on the toner;

FIG. 5 is a graph representing the electrical force on the toner as a function of the capacitor thickness for four different capacities;

FIG. 6 is a graph representing the electrical force on the toner as a function of time for two cases;

FIG. 7 is a schematic cross-sectional view of an embodiment of the invention;

FIG. 8 is a schematic cross-sectional view of another embodiment of the invention;

FIG. 9 is a schematic cross-section view illustrating a detailed form of the embodiment of FIG. 7;

FIG. 10 is a schematic cross-sectional view of the recording region of the embodiment of FIG. 9;

FIG. 11 is a graph representing the capacity of the toner as a function of position;

FIG. 12 is a graph representing the charge accumulated on the toner as a function of position for four different times;

FIG. 13 is a graph representing the resultant electrical force acting on the toner as a function of position for the four different times;

FIG. 14 is a graph representing the charge buildup as a function of time on different toner particles;

FIGS. 15-17 are schematic cross-sectional views of embodiments of the invention; and

FIG. 18 is a perspective view of an electrode element employed in the practice of this invention.

Referring to FIG. 1, there is shown a pair of electrodes 1 and 3 in opposed, spaced relationship. Electrodes 1 and 3 include electronically conductive portions 5 and 7, respectively, and, in electronic contact therewith, portions 9 and 11, respectively. The term "in electronic contact" is herein defined as that contact between two materials wherein the charge transport across the interface between the two materials is determined solely by the electronic properties of the two materials and not by other intervening or surrounding materials. Portions 5 and 9 and 7 and 11 may be of the same or different composition and portion 9 and 11 may be composed of either electronically insulating or conducting materials or mixtures thereof. Extending from electrode 1 is electronically conductive toner 13 in the form of a plurality of electronically contacting particles providing an electronically conductive path between the portion 9 of electrode 1 and the adjacent surface 23 of a dielectric recording member 17 which is arranged between electrodes 1 and 3 in a recording region 19. Toner 13 is attracted and bound to the first electrode means 1 by a force designated by the numeral 21 acting in the direction of the arrow, such force being adapted to maintain the toner 13 in association with the electrode 1 until and unless this force is overcome by a force acting in a direction to break the association at least for one toner particle 15 in contact with surface 23 of recording member 17.

In electronic and substantially physical contact with the surface 24 of dielectric recording member 17 is portion 11 of electrode 3. The arrangement of the foregoing elements provides an electrical circuit including, in sequence, the electrode 1, toner 13, dielectric recording member 17 and electrode 3. The electronically conductive portions 5 and 7 of electrodes 1 and 3 are connected to a source of electrical potential 25 through a switch 27.

Operation of the elements depicted in FIG. 1 involves arranging the various elements in the configuration shown and then closing the switch 27 to apply an electrical potential to the circuit. Thereafter at least toner particle 15 of toner 13 acquires electrical charge and consequently an electrical toner potential V_t with respect to portion 7 of member 3 as a consequence of electronic current flowing in the circuit. The amount of toner potential V_t so acquired depends upon the applied voltage V , time elapsed since voltage application, and the electronic properties of the elements of the circuit. As a further consequence of voltage application, an electrical force designated by arrow 29 is imposed on the toner 15, this force being determined by the toner potential V_t acquired by the toner particle 15 and the electronic capacity of that toner particle 15 with respect to the electrode 3.

The force 29 is interpreted by the system in such a manner that toner deposition occurs in accordance with a desired or pre-determined scheme. Specifically, the force 29 on a given particle 15 may be of a magnitude either greater or less than the first force 21. (Theoretically, these opposing forces 21 and 29 could be equal but such a result would rarely if ever be encoun-

tered, especially in view of the nature of the process.) If force 29 exceeds force 21, then the particle 15 in question will be deposited on surface 23 as a consequence of this process. If, on the other hand, force 21 exceeds force 29 for toner particle 15, toner particle 15 will retain its association with the electrode 1 and will not be deposited on surface 23. By deposition it is meant that the toner particle 15 will reside on the dielectric member 17 after the dielectric member 17 is removed from the recording region 19. As will be explained in greater detail hereinafter, the force 29 is not instantaneous but rather develops in time after application of the electrical potential to the circuit. Removal of the dielectric recording member 17 from the recording region 19 should be timed so that the force 29 then present is of a magnitude to provide the intelligence desired.

Removal of the dielectric recording member 17 from the recording region 19 may be accomplished in a variety of ways. For example, the first electrode 1 may be displaced in a direction away from its recording region-defining location or the dielectric recording member 17 may be displaced from the recording region 19. In these cases, as will be noted, the first electrode 1 has been moved relative to said dielectric recording member 17 so as to increase the distance between such elements relative to their location in the recording region 19.

The principles of the invention as depicted in FIG. 1 may be better understood by reference to the circuit diagram of FIG. 2.

This circuit, with the electronic components indicated, is a simplified description of the circuit comprising the above mentioned components of FIG. 1 for the one particular electronically conductive toner path of FIG. 1. In this case, however, electrode 1 is taken as an integral, uniformly electronically conductive element. The resistance R represents the electronic resistance of the toner path, where, for purposes of illustration and simplicity, we have assumed a pure resistance that is not electric field dependent, whereas in practice most of the toners employed in the preferred embodiments of the present invention have a resistance that decreases as the electric field across that resistance increases.

The resistances R_1 and R_2 and the electronic capacities C_1 and C_2 represent the resistance and capacity of the circuit from toner particle 15 to the electronically conductive portion 7 of electrode 3. R_1 and C_1 represent the resistance and capacity contributions from the dielectric recording member 17 and R_2 and C_2 represent the contributions from the portion 11 of electrode 3. As noted above, these resistances may be field dependent.

In using the above-mentioned circuit components it is recognized that actual materials employed in the present invention may have a more complex electronic behavior, such as distributed resistance and capacity, frequency and electric field dependence of resistance and capacity, and semiconductive rectification properties of interfaces between regions of different material composition.

At the moment a voltage is applied between points 31 (corresponding to electrode 1) and 35 (corresponding to the electronically conductive portion 7 of electrode 3) of the electronic circuit, current begins to flow. There is a period of time when this current is changing

rapidly in a transient manner after the voltage is applied, whereas after a sufficiently long time the current is essentially constant in time. This flow of current causes the herein defined toner potential V_t between points 33 (corresponding to the toner 15) and 35 to change in time. This voltage V_t , over capacities C_1 and C_2 , represents the voltage of the toner 15 on the surface of the dielectric recording member 17 with respect to the portion 7 of electrode 3. Also this voltage V_t corresponds to an electronic charge Q on toner 15 which is given by the equation $Q = CV_t$ where

$$C = C_1 C_2 / (C_1 + C_2),$$

the charge Q varying in time according to the time variation in V_t . The toner potential V_t creates an electric force 29 on the toner 15 which opposes first force 21. The magnitude of the electric force 29 at a given time is determined by the magnitude of toner potential V_t on the toner 15 and the spatial gradient of the capacity C with respect to a virtual displacement of the toner. In practice this electric force 29 depends upon many electronic parameters such as the size of the toner, which will usually be from about 0.5 micrometer to 100 micrometers in diameter, the electronic properties of the dielectric recording member 17 and the electrode 3, as well as the physical shape, size and arrangement in space of these parts. For example, in the particular case in FIG. 2 when R_2 is zero and R_1 is infinite, as would be the case when the dielectric recording medium is very insulating and portion 11 of electrode 3 is electronically conductive, the force on the toner 15 directed toward member 3 builds up in time approximately according to the formula

$$F = \frac{1}{2} V^2 (1 - e^{-td/\epsilon AR})^2 \epsilon A/d^2,$$

where A is the effective area of capacitor C_1 , ϵ and d are the dielectric constant and thickness respectively of the capacitor C_1 , and V is the externally applied dc voltage between the points 31 and 35.

When the circuit is broken such that the flow of current is at least momentarily stopped, the toner 15 has a toner potential V_t and hence a net force. The amount of net force, that is the difference between the first force 21 and the electric force 29, depends upon all of the electronic properties of the circuit. If the net force is in the direction of the dielectric recording member, the toner under or subject to such net force will deposit on the dielectric recording member. If the net force is in the direction of the force 21, i.e., towards the electrode 1, then the toner will remain associated with electrode 1 and will not be deposited on the dielectric recording member 17. Thus, by varying the voltage applied to the circuit and the resistances and capacities of the circuit in a predetermined manner, sensible intelligence in the form of a force of a given magnitude is created which determines whether a toner particle will or will not deposit on the dielectric recording member 17 when the dielectric recording member 17 is removed from the recording region. The intelligence referred to may be considered a force pattern which for a given toner particle will be either a force greater or less than the first force 21 but for the aggregate of toner particles will be a plurality of such forces. Image defining variations may be produced by varying any or all of the electric force determining components. These various techniques are illustrated and explained in the following embodiments of the present invention.

The relatively rapid creation of the electric force 29 on the toner 15 in contact with a particular small area of the dielectric recording member 17 in time is further illustrated by FIGS. 3-6. FIG. 3 is a plot of toner potential V_t on a toner 15 (FIG. 1) versus time after current begins to flow in the circuit. Two curves 37 and 39 are shown representing two different possible situations for the toner potential buildup on toner 15, V_{t1} and V_{t2} , the difference being due to a difference in capacities from the toner 15 to the portion 7 of electrode 3 or to the applied voltage V between members 1 and 3 of FIG. 1 or to both.

The potential V_t depicted in FIG. 3 results in an electrical force on the toner 15 which depends approximately on the toner potential and the capacity in the manners illustrated in FIGS. 4 and 5. In FIG. 4 is shown the manner in which the force increases with the square of toner potential V_t and in FIG. 5 is shown how the force depends upon the electronic capacities illustrated by curves labelled C_1 , C_2 , C_3 , and C_4 , and the effective minimum distance d between the toner particle 15 and the electronically conductive portion 7 of electrode 3. As a consequence of these relationships, the force 29 on the toner builds up in time for the two cases depicted in FIG. 3. If the magnitude of the first force 21 (F_{21}) is that illustrated in FIG. 6, then for times greater than t_1 the electric force 29 for curve 41 (corresponding to the situation depicted by curve 37 of FIG. 3) is sufficient to overcome the first force (F_{21}) whereas the electric force 29 for curve 43 (corresponding to the situation depicted by a curve 39 of FIG. 3) is insufficient to overcome the first force (F_{21}). Thus, for the case depicted by curve 41, the toner particle 15 would be subjected to intelligence involving a force 29 greater than the force 21 and would be ultimately deposited on dielectric recording member 17. Similarly, for the case depicted by curve 43, the toner particle 15 would be subjected to intelligence involving a force 29 less than the force 21 and would remain associated with the electrode 1.

FIG. 7 illustrates an embodiment of this invention wherein relatively slow changes in voltage applied to the electrodes 1 and 3 determine the force pattern of intelligence. By relatively slow changes we mean slow relative to the above mentioned electronic current transient of charge buildup Q on toner 15. For clarity purposes, like numerals to those used in FIG. 1 are employed throughout. Three electrodes 1a, 1b and 1c are shown opposing two electrodes 3a and 3b. Six chains of toner 13a-13f provide electronically conductive paths between portions 9a, 9b and 9c and the surface 23 of dielectric recording member 17. In electronic contact with the surface 24 of recording member 17 are portions 11a and 11b of electrodes 3a and 3b. Each of the electrodes is connected independently to a source of electrical potential V_{25a} to V_{25e} through appropriate electronic circuitry. For each toner chain 13a-13f, the force on the particle 15 contacting the upper surface 23 of recording member 17 is determined essentially by the electric potential difference between the portions 5a, 5b and 5c and portions 7a and 7b nearest to the given toner chain, e.g., for toner chain 13c the force determining potential difference is $V_{25b} - V_{25e}$.

For explicitness, the multiple electronic circuits formed by the arrangement depicted in FIG. 7 will be described in detail. As the term circuit is used in conjunction with this invention, there are three distinct cir-

cuits formed between the electrode members 1 and 3 taken pairwise, namely (1) between electronically conductive portions 5a and 7a, where the applied voltage is the potential difference $V_{25a} - V_{25d}$, containing two parallel sub-circuits as a part of the over-all circuit in the form of electronically conductive toner chains 13a and 13b, (2) between electronically conductive portions 5b and 7b, where the applied voltage is the potential difference $V_{25b} - V_{25e}$, containing two parallel sub-circuits in the form of electronically conductive toner chains 13c and 13d, and (3) between electronically conductive portions 5c and 7b, where the applied voltage is the potential difference $V_{25c} - V_{25e}$, containing two parallel subcircuits in the form of electronically conductive toner chains 13e and 13f. While other pairwise combinations of the electrode member 1 and 3 could be considered, such as the electronically conductive portions of 5a and 7b taken together, they are not oppositely disposed, i.e., they do not have any overlap in each other's geometric shadow extended substantially perpendicularly toward the recording member, and their potential difference with respect to each other influences the current flow in the toner chains to only a very small and negligible degree. By appropriate electronic switching and control circuitry applied independently to 5a, 5b, 5c, 7a and 7b, a predetermined spatial pattern of intelligence in the form of electric potentials is transformed into a force pattern of intelligence on the toners. This force pattern (forces 29a-29f') will include portions exerting a force greater than the force 21 and portions exerting a lesser force than force 21. For example, forces 29a-29b and 29e-29f' may be greater than force 21 and forces 29c-29d may be less. The pattern in this case is one wherein the image area on the surface 23 of recording member 17 will be provided by at least the toner particles 15a, b, e, e', f and f' and the background will be provided by areas of the surface 23 adjacent toners 15c and d.

In this particular example, the individual applied potential differences can be varied in time, independently of each other, which give both a spatially varying force pattern of intelligence at any particular instant of time, and a relatively slowly time varying force pattern of intelligence at any particular point within the development region. As the dielectric recording member moves through the recording region, as in a direction perpendicular to the page, a two dimensional pattern of toner deposition results corresponding to the force pattern of intelligence generated by the independently varying applied potentials applied to the plurality of electrode means.

Preferably, the process and apparatus of this invention are such that the force pattern is adapted to be varied by varying at least one of the electrical toner potential of the portion of toner contacting the surface 23 of the recording member 17, and the electronic capacity of that portion relative to the electrode member 3. The electrical force pattern of intelligence is varied in at least one of time or space and usually both which, when coupled with the removal and more generally, the continual entry and removal, of the dielectric recording member from the development region, results in a spatial pattern of deposition of the toner particles corresponding to the force pattern of intelligence.

The elements of FIG. 8 illustrate a counterpart to those depicted in FIG. 7 in that in FIG. 8 the force pat-

tern of intelligence is determined by varying the electronic properties, generally the electronic resistivity and dielectric constant, of the portions 9a, 9b, 11a, and 11b in a predetermined manner to provide a corresponding variation in the toner potential on the toner 15 contacting surface 23 in the chains 13a-13f and the capacity of these toners with respect to portions of electrode 3. As a consequence, toners 15 are subjected to a corresponding force pattern of intelligence. Again, for explicitness, the individual electronic circuits will be described for this figure. There is only one over-all main circuit between the electronically conductive portions 5 and 7 of the electrode members 1 and 3 respectively, and thus only a single applied voltage will be applied to the portions 5 and 7. However, there are six parallel sub-circuits within the one over-all circuit, namely the electronically conductive toner chains 13a-13f, each of which will have a different total charge flow through it governed by (1) the resistance and/or capacity of the portions 9a and 9b with which the individual toner chains are in electronic contact, and (2) the resistance and/or capacity of the portions 11a, and 11b which are disposed directly on the opposite side of the recording member from the toner chain in question, that is, within the geometrical extension of the chain to the other surface of the recording member. The electronic properties of portions 9a, 9b, 11a, and 11b may be varied in a number of ways. For example, portions 11a may be substantially more electronically conductive than 11b whereby for a particular electrical potential 25 and force 21, at least the toners 15a, 15b, and 15c will be subjected to a force 29 greater than force 21 which will cause their ultimate deposition on surface 23 of recording member 17.

Referring to FIG. 9 a developer roll 44 is depicted having a center circular cylinder magnet support member 45 whose axis runs perpendicular to the page supporting the cylindrical permanent magnet sectors 47 which run parallel to the axis of support member 45. Electrode 1 is a nonmagnetically permeable, long, circular, cylindrical electronically conducting shell in which the portions corresponding to portions 5 and 9 of FIG. 1 are of an integral or unitary construction. Electrode 1 is provided with a layer of magnetically attractable, electronically conducting toner 13 which is metered onto the surface of electrode 1 by a doctor blade 49 which is extended in an axial direction but at a fixed space from electrode 1. The toner 13 is held and attracted to electrode 1 by the magnetic field exerted by magnet sectors 47. In this embodiment the electrode 1 is arranged to rotate in a counterclockwise manner around its axis thus maintaining an effectively constant supply of toner 13 throughout the surface of electrode 1. Rotation of the magnet sectors 47 alone or together with the electrode 1 in either direction may also be done. A suitable developer roll of the type described is disclosed in Anderson, U.S. Pat. No. 3,455,276.

The dielectric recording member 17 is a web, moving in the direction shown, of thickness (L) positioned in a recording region 19 parallel to the axis of support member 45. The electrode 3 is an integral, electronically conductive pin or stylus connected by a switch 27 and a source of electric potential 25 to the electrode 1. In recording region 19 the toner 13 is formed in chains and is aligned more or less in a direction perpendicular to the recording member 17. This is accomplished by the flux lines of the magnetic field emanating from the

magnet sector 47a and by controlling the spacing of the gap between the electrode 1 and the surface 23 of the recording member 17. The region between the electrode 1 and the recording member 17 over which electronically conductive toner chains 13c-13f are formed is defined as the development region 49 of this embodiment.

For purposes of clarity and illustration these toner chains or paths 13a-13h are shown to consist of essentially only one toner connected to another. In general, in the practice of this embodiment, the toner paths 13a-13h may be many toners thick or just one toner thick. While only one toner particle, i.e., a monolayer of particles, need be in the development region, it would be very difficult as a practical matter to adjust the spacing between the electrode 1 and the surface 23 so that the single particle or monolayer contacted both surfaces simultaneously. Moreover, irregularities in the surface of the electrode 1, the surface 23 of the recording member 17, and varying toner particle sizes would make reliable contact between both surfaces virtually impossible. For this reason, the magnetic chains of toner particles are ideally suited to this process since they automatically adjust their lengths to bridge the gap between the two surfaces (electrode 1 and surface 23) provided a sufficient and accurate amount of toner is metered into the development region.

Thus as the recording member 17 moves in its plane, perpendicular to the axis of member 45, and electrode 1 rotates about its axis, a constant amount of toner 13 is metered into and out of the development region 49. The toner, while in the development region, forms the above-mentioned and illustrated electronically conductive paths 13c-13f.

In the embodiment depicted in FIG. 9 and a similar embodiment shown in greater detail in FIG. 10, the electrodes 1 and 3 remain in a stationary spatial configuration with respect to each other as a function of time, while the dielectric recording member 17 generally moves with respect to both of them through the development region 49. This relative motion is either continuous or stepwise. The cylindrical shell 1 revolves about its axis to meter and deliver a uniform and controlled quantity of conductive toner 13 into and out of the recording region 19. Since the electrode configuration does not change in time, due to rotation of member 3 about its own axis, in this case, due to the cylindrical symmetry of the electrode 1, the electrode configuration in the recording region 19 can be considered to be stationary.

The toner particles 15a-15n each have a well defined capacitance with respect to the electrode 3, determined by (a) the shape of the electrode 3, (b) the toner's position relative to the electrode 3, and (c) the dielectric constant of the intervening materials.

FIG. 11 is a graphical plot of the capacitance of the toner particles 15e-15k with respect to the electrode 3, plotted as a function of their position X along surface 23 of recording member 17. Upon application of a potential V to the electrode 3 with respect to the electrode 1, as by closure of switch 27, a time dependent electronic current will flow.

The total integrated charge Q which flows as a result of this current through each toner chain 13 and which accumulates on the toner particles 15 is plotted for four different times in FIG. 12 where the designated points on the curves are for similarly designated toner parti-

cles. For example, the particle 15h of toner chain 13h has a relatively high capacitance with respect to electrode 3, resulting in a relatively large total charge flow through this chain to the particle 15h after a given time interval t_3 . On the other hand, the particle 15e of chain 13e has a relatively low capacitance with respect to electrode 3, resulting in a relatively low total charge accumulation after the time interval t_3 . This total charge Q, in each chain, accumulated on the particles 15 of each chain after a given time t_3 , increases with the produce of the capacitance of each particle 15 with respect to the electrode 3 and the potential V and is shown as curve B in FIG. 12 as a function of position. The electrical force F on these particles 15 is directed toward the dielectric recording member 17 and the electrode 3 and is, in turn, a function of both the total charge which has flowed onto the particles 15 and the capacity of these particles with respect to the electrode 3 and is proportional to the square of the total charge accumulated on these particles. This is shown as curve G of FIG. 13 as a function of position.

If the above-mentioned force 21 holding the toner particles 15 toward the electrode 1 is of a magnitude F_{21} of FIG. 13, (shown here as a constant force as a function of position, even though it may spatially vary, albeit effectively constant in time), then all particles 15 in the region between the position X_3 and X_4 will have a sufficient force 29 directed toward the recording member 17 to cause deposition of these particles on the recording member 17. These particles would remain held and attracted to the recording member 17 if the arrangement were disassembled as by moving the above-described section of the dielectric recording member out of the development region at time t_3 , or if switch 27 were opened at t_3 . Toner particles 15 outside of the region from X_3 to X_4 would remain bound to the electrode 1.

If a time interval longer than t_3 passed before disassembling, say t_4 , the charge on the toner particles 15 would have increased to that represented by curve A of FIG. 12 and the force on these particles represented by curve E of FIG. 13 would have increased to a magnitude greater than the constant force F_{21} . In this case a somewhat wider region of toner particles would be deposited, as over the region from X_5 to X_6 of FIG. 13. In practice, the amount of toner deposited is more than a monolayer, that is, more than just the toner particles 15 are deposited on the recording member. There are at least two reasons for this: (1) the extremal toner particles 15 may not completely electrically shield or screen the particles above them in the chain, that is, some of the charge which flowed into the toner chain resides on particles immediately above the extremal particles even though most of it resides on the extremal particles, and (2) in the case where the counterforce 21 is a magnetic force, upon separation of the arrangement, the toner particle chains, which are held together magnetically, break at some weak link which is determined magnetically in addition to electrically, so those extremal particles which are electrically bound to the recording medium take along other toner particles magnetically upon separation from the development region.

It should be pointed out that while perhaps most of the charge 53, being image charges to the charge 55 on toner particles 15, resides on the conductive surface of the electrode 3, in certain cases a portion of this charge

53 actually crosses the interface between the electrode 3 and the dielectric recording member 17 and deposits or is injected on or near the surface of the dielectric recording member 17 closest this interface as charge 57. In these cases, when this section of dielectric recording member 17 is moved from the recording region, the toner particles 15 remain electrically bound to the recording member. It should be stressed that in these cases the charge 57 is injected into the dielectric member, or at least onto its surface 59, concurrent with and as a consequence of the buildup of charge on the toner particles 15 of the toner chains and is not in any sense a latent bound charge pattern deposited at an earlier time.

In these cases where a sufficient quantity of charge 57 becomes injected into the dielectric recording member 17, the electrodes 1 and 3 can be shorted together, i.e., an electric potential difference of 0 volts applied, and a sufficient quantity of charge 57 remains trapped in or on the dielectric recording member, thereby binding the toner particles 15 immediately on the opposite surface 23. Since the current which flows in the circuit is dependent upon the magnitude of the applied voltage, the rate of accumulation of charge on the toner 15 can be substantially varied by varying the applied voltage. Thus, it is possible to apply very short duration voltage pulses of a high enough magnitude to cause sufficient charge accumulation in the toner particles 15 opposite the thus-energized electrodes during the pulse to result in an electrical force greater than the magnetic counterforce, and thereafter move the thus recorded section of recording member out of the recording region with the toner particles still bound to it due to the injected charge above-described in those cases where sufficient charge injection takes place. Furthermore, by controlling the magnitude of the applied voltage any amount of toner deposition can be achieved, allowing continuous tone recording.

FIG. 15 illustrates still another embodiment of the invention. Electrode 1 is an integral, electronically conductive element which is preferably magnetically permeable or permanently magnetized. In such a preferred case, magnetic means not shown is present. Electrode 3 is an integral, electronically conductive, cylindrical drum rotating in the direction shown. Circumferentially disposed around electrode 3 is dielectric recording member 17 in the form of an adherently bound layer. Dielectric recording member 17 may be an independent web of dielectric material moving in the direction shown and in such case electrode 3 may rotate as shown or may be held stationary. Extending from electrode 1 are toner chains 13a, 13b and 13c providing separate electronically conductive paths between electrode 1 and surface 23 of recording member 17. Electrodes 1 and 3 are connected to a source of electrical potential 25 through switch 27. At this stage, toner 13a-13c is bound to electrode 1 by a force 21 which is magnetic in the preferred embodiment.

Upon application of an electrical potential as by closure of switch 27, an electronic current flows in the electronic circuit whereupon electric charge accumulates on the toners 15a, 15b, and 15c as shown resulting in an electric toner potential V_t on these toner particles. It is to be understood that in all embodiments of this invention the polarity may be the reverse of that illustrated. In general, the source of potential 25 is a d.c. electrical potential source. It is un-

derstood that an a.c. source may be employed by providing proper synchronization of the switching means. Also illustrated in FIG. 15 are toner particles 15 which had previously been deposited in accordance with the principles of this invention. Upon attaining the desired force pattern of intelligence, the dielectric recording member 17 is removed from the recording region 19 and a steady, uniform supply of toner 13 is maintained in the recording region by suitable toner transport means not shown. In this embodiment, the electronic capacity of the toner particles 15 to the electrode 3 is approximately the same for each toner particle. Therefore the force pattern of intelligence is essentially completely determined by the toner potential on the various toner particles 15. Note that the image charges 53 move in or with the electrode 3 in correspondence with the deposited toner particles 15d-15h thereby retaining at least a portion of the electric force 29 so as to keep the toner particles 15d-15h bound to the surface 23 of recording member 17 after the member 17 is removed from the recording region 19. Further, in this embodiment, only a single electrode 1 is shown whereas numerous electrically isolated electrodes 1 may be present. In such a case, the toner associated with each such electrode should be substantially electrically isolated and disposed essentially perpendicular to the plane of the dielectric recording member in the development region, a result surprisingly readily achieved by employing magnetic means having lines of force into the dielectric recording member to provide force 21.

FIG. 16 illustrates a specific embodiment of the invention wherein the force pattern of intelligence is determined substantially by variations in the electronic capacity of the toner contacting the dielectric recording member 17 to the underlying electrode 3. A developer roll 44 as described in FIGS. 9 and 10 is provided with a constant, metered supply of toner 13 forming toner chains 13a-13f. Dielectric recording member 17 moves through recording region 19 in the direction shown. Underlying recording member 17 is electrode 3 having a uniformly electronically conductive portion 7 and another portion 11 which consists of a distribution of electronically insulating regions 11a, 11c and 11e and electronically conducting regions 11b and 11d. Electrodes 1 and 3 are connected through a switch 27 to a source of electrical potential 25. Both the recording member 17 and the electrode 3 are designed to move in the same direction as indicated at the same rate relative to electrode 1 either continuously or stepwise although some difference in rate is permissible if an extended or compressed developed image is desired. The electrode 1 is rotated counterclockwise so as to provide a steady supply of toner 13 in the development region as previously explained. By this means the toner 15b making initial contact with surface 23 will be transported in contact with the surface 23 in the direction of recording member 17 travel across the development region to the position of final contact occupied by toner 15e. In this embodiment the effective development time is a complicated function of both the time interval for toner to make this transport, and the time interval for a given small area of the dielectric recording member 17 to traverse the development region. It has been found useful for most cases to define the development time t_{DEV} as that time for a small area of the dielectric recording member to traverse the develop-

ment region (the distance from 15b to 15e), i.e., $t_{DEV} = W/S$ where W is the extremal width of the development region in the direction of motion of the dielectric recording member, and S is the average speed of the recording member through such region.

After switch 27 is closed and after the development time t_{DEV} , the amount of magnetic force 21 and electric force 29 on the toner such as toner 15e will determine whether such toner 15e remains held in association with and attracted to the electrode 1 as is the case of toner 15f, or remains held and attracted to the surface 23 of the dielectric recording member 17 as is the case for toners 15g and 15g'. In this embodiment the electronic current begins to flow in a transient manner as in the previous embodiment of FIGS. 9 and 10 and at the end of the time t_{DEV} the electric force 29 on the toner 15e is again determined by the toner potential V_t on the toner particle 15e and the electronic capacity of toner 15e to the electrode 3. In particular this capacity is determined by portion 11b since the preponderance of the capacity from toner 15e to electrode 3 is to that portion of electrode 3 closest to toner 15e, i.e., portion 11b of electrode 3. In FIG. 16 the toners 15c, 15d' and 15d have a substantially higher capacity to the electrode portion 11b than toners 15b, and 15e. Therefore after the time t_{DEV} , the voltage V is chosen so that for the toners 15c, 15d and 15d' the electric force 29 is greater than the opposing magnetic first force 21 and these toners remain held and attracted to the recording member surface 23 thereby defining image areas whereas for the toners 15b and 15e the first force 21 remains greater than the second force 29 and these toners remain associated with and attracted to the electrode 1. As a result, no toner is deposited on the corresponding regions of the surface 23, thus defining non-image or background areas. In this manner, as the recording member 17 moves through the recording region, a pattern of toner is laid down on the surface 23 in substantial conformity with the pattern displayed by the arrangement of the portions 11a, 11b, 11c etc. of portion 11 of electrode 3. The portions 11b and 11d may be insulating regions of relatively high dielectric constant compared to regions of relatively low dielectric constant 11a, 11c and 11e with essentially equivalent results.

In FIG. 17 an embodiment is depicted similar to that shown in FIG. 16 except that electrode 1, and specifically the portion 9 thereof, contains the image and non-image determining elements. Developer roll 44 is the same as described above in conjunction with FIGS. 9 and 10 except that electrode 1 includes two distinct portions 5 and 9. Portion 5 is an electronically conductive, non-magnetically permeable shell and portion 9 is a series of sub-portions 9a-9g, 9a, 9c, 9e, and 9g being relatively electronically insulating regions and 9b, 9d, and 9f being relatively electronically conducting. Electrode 3 is an integral, electronically conducting member. Electrode member 1 rotates such that the surface speed and direction of this member is the same as the translational speed and direction of recording member 17 and electrode member 3. Electrode member 3 can remain stationary relative to the motion of the recording member 17 in some cases. In this embodiment, the capacity of the toners contacting surface 23 of recording member 17, i.e., toners 15a-15g, with respect to electrode 3 is essentially the same for each. Thus, in this embodiment the force pattern of intelligence is de-

terminated by varying the electric toner potential on the particles 15. This toner potential variation is brought about by the variation in the capacity of toners 16a-16g to the portion 5 of electrode 1. For example, toner 16f has a substantially higher capacity to electrode portion 5 than does toner 16e due to its proximity to sub-portion 9d. Therefore, the toner potential buildup on toner 15f will be substantially greater than that on toners 15e and 15e' thereby resulting in the ultimate deposition of toner 15f as was the case for toners 15i and 15' whereas toners 15e and 15e' will be retained in association with electrode 1 as was the case for toner 15h. In this manner, as the recording member 17 moves through the recording region a pattern of toner is laid down on the surface 23 in substantial conformity to the pattern displayed by the arrangement of the sub-portions of portion 9 of electrode 1. The portions 9b, 9d, and 9f may be insulating regions of relatively high dielectric constant compared to portions 9a, 9c and 9e which are regions of relatively low dielectric constant with essentially equivalent results.

The electronically conductive toner used in this invention must be conductive enough so that current is allowed to flow in the toner chains or paths. Thus, a substantial electric charge and hence toner potential may be built up at the time of development, t_{DEV} , so that in image areas enough electric force is present to overcome, preferably by a factor of 2 or greater, the first force opposing toner deposition. This current flow does not depend solely on the resistance of the toner but also on the other resistances and capacities in the circuit. Thus, the upper limit of resistivity of the toner will depend on the particular embodiment of the present invention. Of course the resistance of the toner path as a whole is the determining factor and therefore the thickness and length of the toner path must also be considered. The toner must have sufficient resistivity that, in conjunction with the resistivity of the recording member, the necessary force-producing charge on the extremal toners contacting the dielectric member surface does not flow into the dielectric recording member during the above-mentioned time interval. Since the resistivity of the recording member is generally very large compared to the resistivity of the toner, the recording member is the limiting factor in this charge exchange and the toner can have quite a low resistivity when used with recording members having a high resistivity.

A preferred toner is that described in Nelson, U.S. Pat. No. 3,639,245, incorporated herein by reference. Such toners are heat fusible, spherical in shape, have a relatively insulating core and relatively electronically conductive peripheral surface, and are magnetically attractable. The electronic resistivity of the toner should be less than about 10^{10} ohm-cm. and preferably less than 10^9 ohm-cm. The major dimension of the toner particles may suitably range from about 0.5 micrometers to about 300 micrometers, preferably from about 2 to about 30 micrometers. Spherical shaped particles are preferred. In some embodiments of this invention, it is preferred to have a wide distribution of particle sizes, for example where continuous tone rendition is desired, while for other embodiments a very narrow particle size distribution is desired.

The dielectric recording member of this invention may be composed of a variety of materials including paper, polymeric sheets, especially polyester sheets,

elastomeric materials, glass, dielectric coatings such as aluminum oxide, silicon dioxide, zinc oxide, and the like. Also, the dielectric recording member may be composed of a photoconductive material either alone or disposed in an insulating binder, for example, arsenic selenide, titanium dioxide, selenium, cadmium sulfide, and organic photoconductors such as poly-N-vinylcarbazole, alone or in combination with trinitrofluorenone. However, it is to be understood that the process of this invention does not require that the dielectric recording member bear any pattern of intelligence, latent or otherwise, and in that sense the dielectric recording member is regarded for purposes of this invention as electrically passive. Typical patterns of intelligence which could occur on a recording member are an electrostatic charge pattern such as disclosed in Middleton, U.S. Pat. No. 3,121,006 and a conductivity pattern as disclosed in Shely, U.S. Pat. No. 3,563,734. These and other patterns may be present but do not constitute the pattern of intelligence reproduced by means of this invention.

The electronic properties of the dielectric recording member affect the operation of the present invention and again the limits placed on these properties depend on the specific embodiment. However, the limits in most cases arise from the following considerations.

The electronic capacity of the dielectric recording member must be low enough to allow, in the time interval t_{DEV} , sufficient toner potential build-up and sufficient force build-up on the toner positioned in electronic contact with the surface of the recording member. This capacity is determined by the dielectric constant and the size and configuration of the dielectric recording member with respect to other parts of the circuit. The capacity should be high enough to permit, in conjunction with the rest of the circuit elements, sufficient charge buildup on the external toner particles at the applied voltage chosen for operation. For low voltage operation, which is desirable from an economic and reliability standpoint, it is desirable to have a high electronic capacity for the dielectric recording member. It is more advantageous to achieve this through thin recording members than through a large dielectric constant coupled with a thick recording member.

The resistivity of the dielectric recording member should be sufficiently high to prevent charge from flowing off of the toner into the dielectric recording member thereby reducing the electrical force to a level insufficient to overcome the first force in image areas. The electronic resistivity of the dielectric recording member, in most embodiments of this invention, should be at least about 10^7 ohm-centimeters. Preferably, its resistivity should be at least 10 times the resistivity of the toner at electric fields comparable to those experienced by the materials in the practice of this invention. The dielectric recording member may be self-supporting or be supported by electrode means during development. The dielectric recording member should be sufficiently thick to withstand the voltages applied during the process. A suitable thickness is at least 5×10^{-8} centimeters (500 Angstroms). The thicker the dielectric recording member is above the minimum thickness the greater the voltage necessary to produce a given force for the same dielectric constant. In general, for practical reasons, the thickness of the dielectric recording member is kept to a minimum above that at which electrical breakdown would occur. In embodi-

ments such as those illustrated in FIGS. 9 and 10, the thicker dielectric recording members result in reduced resolution of the developed pattern. The dielectric recording member may be a uniform or homogeneous material exhibiting the above stated characteristics or it may be a multi-component or heterogeneous material.

The electrodes employed in the practice of this invention are each composed of at least one portion which is electronically conductive. In many cases, an electrode will be composed of two portions, one which is electronically conductive and one which is electronically insulating. The voltage source is, of course, connected to an electronically conductive portion of the electrodes. The electronically conductive portions of the electrodes should have a time constant (resistivity times dielectric constant) substantially less than the time constant of the dielectric recording member and any insulating portion of the electrodes. A suitable time constant for such conductive portions is less than 10^{-3} seconds and preferably less than 10^{-6} seconds. The resistivity of these conductive portions should be less than about 10^{-2} ohm-cm. and preferably less than about 10^{-4} ohm-cm. As noted, an electrode may also contain portions more insulating than the specified electronically conductive portion. The increase in resistivity of these relatively insulating portions may serve to provide variations in capacity of the toners contacting either or both of the electrode 1 and the surface 23 of the recording member 17 and hence determine the configuration of the force pattern to be developed. In certain cases this variation in conductivity is sufficient to control the amount of toner deposited continuously from no deposition to maximum deposition.

The electrodes may be provided in a variety of shapes and sizes. The electrodes determining the recording region may be the same or different in design depending at least in part upon the pattern desired to be developed. Electrode configurations employed in the practice of this invention may be curved or flat and include such design as one or more elongated pins or styli, cylinders, and flat plates. An electrode may be composed of a single element such as a stylus, a cylindrical shell, an alpha-numeric shaped member or some other single design or a plurality of elements such as an array of electronically isolated styli, for example, a row of styli disposed transverse to the longitudinal direction of the recording member, or more than one alpha-numeric or other shaped element.

By "electronically isolated" as used herein is meant the capability of having different potentials applied to different electrodes. This is somewhat dependent upon the resistance (or impedance) of the potential sources connected to the isolated electrodes. For most practical purposes, electrically isolated herein means having a resistance of at least 100 ohms and preferably at least 1000 ohms from any one electrode to its nearest neighbor electrodes. For minimizing the buildup of static electrical charges on insulators it is sometimes convenient to provide a slight conductivity in the material surrounding the electronically conducting electrode.

The electrode may be constructed of one or a plurality of materials having the above-mentioned electronic characteristics. Suitable electronically conductive materials include metals such as iron, steel, copper, aluminum and photoconductive materials such as selenium, arsenic selenide, inorganic oxides and salts such as zinc

oxide, titanium dioxide, cadmium sulfide, and organic materials such as poly-N-vinylcarbazole alone or in combination with additives such as trinitrofluorenone. The electrically conductive material may be surrounded by air or a fluid or may be embedded in a solid matrix having the desired electronic properties. In instances where the electronically conductive portion of the electrode is provided by a photoconductive substance, such substance must be activated by exposure to light at the proper time so that the conductivity will be present during image development. Suitable electronically insulating materials which may provide portions of the electrodes include thermoplastic and thermosetting polymeric materials including, e.g., polystyrene, acrylic polymers, phenolic polymers, polyesters, fluorinated polymers, silicone elastomers, polyurethanes, epoxy resins, natural rubber, polyimides, glass, and cellulosic-based materials such as paper and wood. In embodiments such as those depicted in FIGS. 9 and 10, it is preferred that the electrode member 3 be non-magnetically permeable so it does not reduce the force 21 acting on the toner, or reverse its direction as might be the case if small, magnetically permeable wires were used as the electrode member 3.

Another type of electrode employed in the practice of this invention is one having an electronically conductive portion and an electronically insulating portion, the latter having regions of relatively high and relatively low dielectric constant. Toners contacting the dielectric recording member which are under the electrical influence of the regions having a relatively high dielectric constant will have a relatively high capacitance with respect to the electronically conductive portion of the electrode resulting in a larger force as compared to toners under the influence of lower dielectric constant regions. A preferred electrode of this type is depicted in FIG. 18 wherein the electrode 61 has an electronically conductive portion 63 and an electronically insulating portion 65. The latter includes region 67 of low dielectric constant and region 69 in the form of a block T of a high dielectric constant. Suitable high dielectric constant materials include barium titanate, lead titanate, rutile titanium dioxide, and photodielectric materials such as zinc sulfide and doped cadmium sulfide.

The gap between the opposing face of electrodes 1 and 3 which define the recording region should, at the minimum, be such that the recording member and at least one toner particle can fit therein. As noted above, however, it is as a practical matter extremely difficult to maintain an electronically conductive path between the toner applicator electrode and the surface of the recording member with a single toner particle. Thus, the gap should be such that a plurality of toner particles forming at least one elongated toner chain can be accommodated in the recording region. A suitable range for the distance between the upper surface of the recording member and the applicator electrode is from about 25-5000 micrometers, preferably from 50-700 micrometers. In general, the larger the toner particle, the wider this distance should be for a particular situation.

The force designated 21 in the figures should be such as to substantially overcome gravity and any other forces favoring transfer of toner to the recording member except for the electrical force which is of a magnitude adapted to provide the desired image pattern. The

magnitude of said first force is determined essentially by the source of said first force, for example a magnetic field with magnetically attractable toners, and should be large enough to overcome Van der Waal's forces on said toners, various other adherent forces on said toners and random electrostatic charge determined forces on said toner that may occur during the operation of this invention. These types of forces are undesirable in the present process because they are essentially uncontrollable. A magnetic force is highly preferred for a variety of reasons including ease of control, and the ability to arrange the toner in chains as schematically illustrated in the drawings to provide the requisite electronically conductive paths. The force **21** is suitably on the order of 10^{-5} dynes or more.

Particularly significant features of this invention are the extremely low voltage and current requirements. The voltage is determined by the resistances and capacities of the elements in the circuit, viz., the electrodes, toner, and dielectric recording member, and the first or counterforce opposing toner deposition and in no way necessarily depends upon various threshold voltages and electric fields for non-linear and breakdown effects for materials such as the dielectric breakdown of insulators and gases in the case of some other electrographic processes. The voltages employed in this process may be adjusted over a wide range by adjusting the electronic properties, shapes and spatial relationships of the above-mentioned circuit elements. For example, a very low applied voltage is possible with a particular combination of electronically conductive electrodes, thin, high capacity dielectric recording member, and relatively electronically conducting toner, whereas higher voltages are required in an embodiment with thick, low capacity dielectric recording members or less conductive toner or electrodes contributing a relatively low electronic capacity to the circuit. The voltages may thus be from at least 0.5 volts to 5000 volts or higher, preferably from 2 to 1000 volts. The lower voltages, from 2 to 300, preferably 2-100, are preferred for economy, reliability, mechanical simplicity, and image resolution. The amount of electronic current required in the operation of this invention is very small due to efficiency in utilizing current. This, coupled with the low voltage capability, results in extremely small power dissipation even at high recording speeds.

A typical voltage source is a low voltage power supply connected through a transistor switch to an electrode wherein the transistor resistance is controlled by suitable electronic circuitry. The composite power supply and transistor switches when more than one are used can be thought of as a plurality of variable voltage sources which can be individually applied to the electrodes. It has been found useful to apply a continuous direct current bias voltage to the electrodes which results by itself in a force below the counterforce, and then simply to apply an additional voltage to those electrodes which are to determine the pattern of deposition. Various multiplexing techniques can be employed to control deposition if desired. Since neither flight nor mass transfer of toner across a distance is involved in this process and since well controlled electronic circuits are present, toner deposition can be effected with voltage pulses as short as 25 nanoseconds.

The duration of time during which a toner deposition-determining voltage is applied to the circuit may be substantially shorter than the time t_{DEV} , the only re-

quirement being that sufficient charge be present on the toner contacting the dielectric recording member at time t_{DEV} .

The process of this invention has the capability of attaining high speeds, on the order of 2000 cm. per second. The limiting factor, in general, is the rate of movement of the dielectric recording member in the case of webs or sheets of material. The process is also adapted to proceed very slowly, on the order of 4×10^{-2} cm. per second or slower.

The developed toner defined images may be bonded to the dielectric recording member directly or transferred to a secondary substrate for bonding thereto or for further transfer if desired. The developed image may provide a temporary display either on the dielectric recording member or another substrate, such display being viewed or recorded by other means such as cameras, magnetic means, photocells, the human eye, or by any other means for sensing the presence or absence of toner. In cases where the toner is neither permanently bonded to the dielectric recording member nor transferred to a receptor surface, the toner can be removed from the recording member with a brush or by magnetic means exerting a force greater than the force holding the toner on the dielectric recording member. The recording member can then be reused. In cases where the recording member is integrally bonded to an electrode, erasure or toner removal can be accomplished by the means which initially provided the counterforce to deposition provided the toner retaining force has dissipated below the force exerted by such means as for example, through charge leakage into the recording member or through other means.

Permanent bonding of the toner to a substrate can be accomplished by conventional fixing techniques such as pressure, heat, or combinations thereof, or by use of chemical bonding agents or by bonding a sheet or film over the surface bearing the toner image.

Typical uses of the process of this invention include a variety of uses in the printing and copying field such as facsimile printing, copying (local or remote), computer output to microfilm wherein the recorded image is photographed, non-impact printing such as computer print-out printing and cathode-ray tube terminal hard copy printing. A variety of inputs can be utilized to which the potential source is responsive such as signals from a computer or electrical signals from an optical scanner or a communication line such as telephone or telegraph wires, or any other form of data communication which can be detected and transformed into a potential signal.

The following non-limiting examples are not provided.

EXAMPLE 1

This example involves use of an apparatus as depicted in FIG. 10. The electrode 1 is a grounded toner applicator roll having an electronically conductive shell rotating with a surface speed of about 8 cm./sec. and eight stationary magnetic sections interior thereof as described in Anderson U.S. Pat. No. 3,455,276. Electrode 3 consists of a row of six electronically conductive alpha-numeric characters disposed perpendicular to the line of travel of the recording member with the character producing face 0.3 cm. high parallel to the line of travel. corresponding recess of the bottom plate, and from the head of The dielectric recording member

is a polyester film 1.2×10^{-3} cm. thick having a resistivity greater than 10^{14} ohm-cm. traveling at a speed of about 10 cm./sec. with respect to the row of characters. The minimum gap between the upper surface of the recording member and the surface of electrode 1 is 3.8×10^{-2} cm. The toner powder, of the type described in Nelson U.S. Pat. No. 3,639,245 having a static conductivity of about 8×10^{-4} (ohm-cm.)⁻¹ at an applied field of about 500 volts/cm., is metered onto the rotating shell applicator electrode forming a plurality of toner chains which generate a development region width of approximately 0.5 cm. at the surface of the polyester film. A 2 millisecond duration pulse of 1000 volts positive is applied to the alpha-numeric characters with respect to the grounded applicator roll. The applied voltage is essentially zero at all times except during the pulse. The force exerted on the extremal toner particles (the particles contacting surface 23 of recording member 17) by the magnets within the applicator roll is approximately 10^{-5} dynes. Sharp, well-defined, high density alpha-numeric characters are formed on the recording member. The developed range is subsequently fused to the recording member by heating the film over a hot plate at about 125°-150° C. for about 5 seconds.

EXAMPLE 2

The apparatus employed in Example 1 is used except that the alpha-numeric character electrode is replaced with a row of non-magnetic stainless steel wire pins of circular cross-section. The recording member is a 2.5×10^{-3} cm. thick polyester film traveling at 20 cm./sec. with respect to the pins whose ends are disposed in a row parallel to the axis of the cylindrical applicator roll and perpendicular to the direction of travel of the recording member. A series of 2 millisecond duration pulses of 500 volts positive is applied to the row of wire pins with respect to the grounded applicator roll. In this and all other examples where voltage pulses are used, the applied voltage is essentially zero at all times except during the pulse, that is, the electrodes are essentially shorted together except during the voltage pulse. A row of sharp, high density dots are printed for each stylus.

EXAMPLE 3

The conditions of Example 2 are employed except that a number of the wire pins are grounded and the remainder are repetitively pulsed with a voltage of + 500 volts. The pins that are pulsed produce a series of dots on the moving dielectric recording member and the grounded pins do not.

EXAMPLE 4

The conditions of Example 2 are repeated except that a series of 10 microsecond duration repetitive pulses of 1200 volts positive are applied to the row of pins with respect to the grounded toner applicator roll and the 2.5×10^{-3} cm. thick polyester recording member is traveling at a speed of 275 cm./sec. with respect to the row of pins. A series of rows of sharp, well-defined dots are deposited.

EXAMPLE 5

The conditions of Example 3 are repeated except that a series of repetitive 2 millisecond duration pulses of 640 volts positive is applied to the pins with respect

to the grounded toner applicator roll. The recording member, traveling at a speed of 20 cm./sec., is bond paper having a bulk resistivity of about 5×10^{11} ohm-cm. and is treated on the backside with electronically conductive carbon. The carbon treatment on the back side of the bond paper assists charge exchange between the energized pin and the paper during the course of current flow without causing lateral conductivity parallel to the paper surface. Again, rows of sharp, well defined dots are deposited. These are subsequently fused on a hot plate.

EXAMPLE 6

Using the conditions described in Example 5 above, but with a calendered Crocker-Hamilton 45 lb. paper recording member having a resistivity of about 1×10^{12} ohm-cm., rows of high contrast, sharp dots are again deposited and later fused on a hot plate.

EXAMPLE 7

The conditions described in Example 5 are employed using a 2.5×10^{-3} cm. thick polyester dielectric recording member traveling at 20 cm./second through the recording region. The pins are subjected to repetitive pulses of + 1000 volts with varied pulse duration from a few milliseconds to several seconds. For each energized pin, a series of dots and lines are recorded on the moving paper, the dots corresponding to the shorter pulses, and the lines corresponding to the longer pulses. These are subsequently fused on a hot plate.

EXAMPLE 8

This example employs an apparatus as depicted in FIG. 16. The toner has a static electronic conductivity of about 8×10^{-4} (ohm-cm.)⁻¹ at an applied field of about 500 volts/cm. and an average diameter of about 1.5×10^{-3} cm. The magnetic toner applicator is the same as employed in Example 1; the conductive shell rotating at a surface speed of about 12.5 cm./sec. The toner powder is metered onto the applicator with a doctor blade set at 3.8×10^{-2} cm. which is also the minimum distance between the conductive shell and the surface of the dielectric recording member. The recording member is a polyester film 1.2×10^{-3} cm. thick having a resistivity greater than 10^{14} ohm-cm. The electrode in physical contact with the underside of the polyester film is functionally of the type depicted in FIG. 16, having vapor coated aluminum as the electronically conductive portions 11b and 11d in contact with the recording member and Plexiglass 1.2 cm. thick (tradename for a polymethyl methacrylate polymer) as the electronically insulating portions 11a, 11c, and 11e. Underlying the vapor coated aluminum-Plexiglass composite is an aluminum sheet, to which connection is made from the vapor coated aluminum portions. The recording member and the underlying electrode 3 travel at a speed of about 35 cm./sec. with respect to the conductive shell 1. A constant voltage of 1500 volts positive is applied to the conductive shell 1 with respect to the grounded electrode 3. A sharp, high contrast pattern is developed and subsequently fixed on the polyester recording member conforming to the location thereunder of the conductive portions such as 11b and 11d of the electrode 3. It should be observed that since the pattern determining element 11 of electrode 3 and the recording member 17 move together in a fixed relationship to each other, the pattern can be larger than

the width of the recording region since all areas of the pattern sweep through the recording region sequentially.

EXAMPLE 9

The conditions of Example 8 are repeated employing bond paper treated with electronically conductive carbon black traveling at 15 cm./sec. as the recording member with similar results. The paper has a thickness of about 7.5×10^{-3} cm. and a bulk resistivity of about 5×10^{11} ohm-cm. The paper is dusted on one side with conductive carbon (tradename Cabot XC-72R) to form particulate or discrete conductors in a transverse direction (perpendicular to the surface of the paper), but not laterally conductive for any great distance along the surface thereof. The carbon-treated surface is placed in contact with the vapor coated aluminum-Plexiglass composite electrode member. These carbon particles on the back-side of the paper improve the ability of the image charges from the conductive electrode portions 11b, 11d, etc., to transfer to the carbon particles such that when the recording member is removed from contact with electrode 3 the toner defining developed image does not scatter and remains firmly bound to the paper.

EXAMPLE 10

Using electronically conductive toner powder as described in Nelson, U.S. Pat. No. 3,639,245, with a static conductivity of about 1.5×10^{-5} (ohm-cm.)⁻¹ (at an applied field of about 1000 volts/cm.) in an apparatus similar to that depicted in FIG. 15, a DC voltage of 15 volts positive with respect to ground is applied to a row of electronically conductive, magnetically permeable, iron wire styli through individual transistor switches. The recording member is a layer about 2.5×10^{-5} cm. thick of anodized aluminum formed on the surface of the grounded cylindrical drum rotating with a surface speed of about 3 cm./sec. The minimum gap between the styli and the recording member is about 5.1×10^{-3} cm. A series of lines are deposited on the electrically insulating Al_2O_3 surface of the drum beneath the styli that had 15 V. applied and no lines are deposited on the moving drum beneath the styli which had zero volts applied. The toner is subsequently removed with transparent pressure-sensitive adhesive tape from the drum surface and the tape bearing the toner laminated to plain paper.

EXAMPLE 11

An apparatus as depicted in FIG. 15 is employed using as a recording member a polyester film substrate which has a layer of vapor coated aluminum on one surface. On the aluminum surface a thin layer of silicon dioxide (quartz) has been sputtered which is about 1.25×10^{-4} cm. thick, and functions as the dielectric layer. The recording member is taped to the cylindrical aluminum drum with the silicon dioxide surface on the outside. An electrical connection is made between the aluminum vapor coated layer which serves as the electronically conductive electrode 3 and the underlying drum. The toner powder is electronically conductive as described in Nelson, U.S. Pat. No. 3,639,245 with a static conductivity of about 6×10^{-6} (ohm-cm.)⁻¹ at an applied field of about 1000 volts/cm. A series of 10 millisecond duration repetitive pulses of 60 volts is applied to a row of electrically isolated, electronically conduc-

tive, magnetically permeable, metal pins or styli with respect to the grounded electrode 3. A series of toner delineated dots are printed on the silicon dioxide covered surface of the recording member, the toner being subsequently transferred by means of pressure-sensitive transparent adhesive tape to plain paper as described in Example 10.

EXAMPLE 12

An apparatus as depicted in FIG. 16 is employed together with a 1.3×10^{-3} cm. thick polyester recording member having a resistivity greater than 10^{14} ohm-cm. The electrode 3 consists of a top layer of photoconductive zinc oxide disposed in an insulating resin binder, an intermediate layer of vapor coated aluminum, and a bottom support layer of a polyester film. The intermediate vapor coated aluminum layer is electrically connected to a grounded metal drum support. The drum supporting the photoconductive electrode member rotates with a surface speed of 135 cm./sec. The toner powder is the one designated C in Table 1 of Nelson, U.S. Pat. No. 3,639,245. The photoconductive zinc oxide layer is first exposed to a resolution test chart pattern, the maximum exposed regions receiving about 16 fcs. illumination. The conductivity pattern so produced is retained during development of the recording member in which a potential of 400 volts positive is applied to the toner applicator roll with respect to the grounded aluminum layer underlying the zinc oxide photoconductive layer. A low contrast, readable image is produced wherein more toner is deposited in regions of the recording member corresponding to light-exposed regions of the photoconductive zinc oxide layer of electrode 3.

EXAMPLE 13

This example involves use of the apparatus of Example 3 except that the row of wire pins is made of copper wire and the toner applicator electrode 1 is not grounded but has a continuous dc bias voltage of negative 500 volts applied with respect to ground. The dielectric recording member is paper 4.1×10^{-3} cm. thick known as High K paper from Peter J. Schweitzer Division of Kimberly Clark Corporation. The bulk resistivity of the paper is about 4×10^{12} ohm-cm., and the recording member moves through the recording region with a speed of about 15 cm./sec. The toner powder, of the type described in Nelson, U.S. Pat. No. 3,639,245, has a static conductivity of about 8×10^{-5} (ohm-cm.)⁻¹ at an applied field of about 1000 volts/cm. The minimum gap between the upper surface of the recording member and the cylindrical toner applicator electrode is about 4.6×10^{-2} cm., the doctor gap is about 3.8×10^{-2} cm., and the surface speed of the applicator electrode is about 6 cm./sec.

The copper wire pins are pulsed repetitively with a voltage of 250 volts positive with respect to ground, with each pulse of a duration of about one millisecond, that is, the wire pins are maintained at ground potential (zero volts) except during the voltage pulses. Sharp, well defined dots of toner are deposited on the moving paper during the voltage pulses which correspond to an over-all applied voltage of 750 volts, that is, $+250 - (-500 \text{ V}) = 750$ volts where the -500 volts is the applicator electrode bias voltage. Only a very faint trace of toner powder is deposited during the time the pins are maintained at zero potential. The over-all applied volt-

age in this case (no deposition case) is 500 volts; $O V - (-500 V) = 500$ volts, which is insufficient for depositing large amounts of toner under the particular operating conditions described. In this example, while an over-all voltage of 750 volts is used for toner deposition, the individual wire pins are merely switched from zero volts to 250 volts to give no-deposition or deposition respectively.

With electrodes employed in this invention having two portions, one electronically conductive and the other having regions of relatively high and low conductivity or high and low dielectric constant, the ratio of high to low conductivity or dielectric constant is preferably at least 5:1. In general, the regions having a relatively high conductivity or dielectric constant have a conductivity or dielectric constant of at least 10^{-10} (ohm-cm.)⁻¹ and 15, respectively. These regions of high conductivity should be at least 10 times the conductivity of the dielectric recording member.

What is claimed is:

1. A process comprising:

1. arranging first and second electrode means in spaced opposing relationship to provide a recording region therebetween, said first and second electrode means each having at least one electronically conductive portion,
2. arranging a passive dielectric recording member in said recording region with a first surface thereof in electronic contact with said second electrode means,
3. providing electronically conductive toner between said first electrode means and a second surface of said dielectric recording member to form an electronically conductive path between said first electrode means and said second surface, said toner including at least a portion thereof in physical contact with said second surface of said dielectric recording member, whereby at least one electrical circuit between said electronically conductive portions of said first and second electrode means is provided, said toner being attracted to said first electrode means by a first force,
4. applying an electrical potential to at least one of said circuits to cause electronic current to flow in said circuit whereby said portion of said toner in physical contact with said recording member is subjected to an electrical force pattern of intelligence determined by the electrical potential difference between said portion of said toner and said second electrode means and the electronic capacity of said portion of said toner with respect to said second electrode means, said force pattern including at least a first portion exerting a force on a part of said portion of said toner in contact with said dielectric recording member having a magnitude greater than and opposed to said first force, and
5. removing said dielectric recording member from said recording region at a time after application of said electrical potential while said force pattern is present whereby toner is selectively deposited on said dielectric recording member in regions corresponding to said first portion of said force pattern.

2. The process of claim 1 wherein said first force is magnetic and said toner is magnetically attractable.

3. The process of claim 1 wherein said first electrode means has a relatively electronically conducting portion and a relatively electronically insulating portion.

4. The process of claim 1 wherein said first and second electrode means are stationary relative to each other and said dielectric recording member moves through said recording region.

5. The process of claim 1 wherein said dielectric recording member and said second electrode means are moving in the same direction relative to said first electrode means.

6. The process of claim 1 wherein said dielectric recording member has an electronic resistivity of at least 10^7 ohms-centimeters.

7. The process of claim 1 wherein at least one of said first and second electrode means is composed of a photoconductive substance having an electronic resistivity in the dark of at least 10^8 ohms-centimeters.

8. The process of claim 1 wherein said dielectric recording member is a web.

9. The process of claim 1 wherein said first electrode means comprises an electronically conductive, cylindrical member.

10. The process of claim 1 wherein said toner has an electronic resistivity less than about 10^{10} ohm-cm. at an applied field of about 500 volts/cm.

11. The process of claim 1 wherein said second electrode means comprises an electronically conductive, cylindrical member.

12. The process of claim 1 wherein said dielectric recording member is bonded to said second electrode means.

13. The process of claim 1 wherein at least one of said first and second electrode means is a plurality of electronically conductive, electrically isolated styli.

14. The process of claim 13 wherein a time varying electrical potential is individually applied to said styli.

15. The process of claim 14 wherein said first force is magnetic, said toner is magnetically attractable, and at least one of said first and second electrode means is magnetically permeable.

16. The process of claim 1 wherein said first electrode means comprises a rotating, non-magnetically permeable electronically conductive cylindrical member, said second electrode means comprises a linear array of integral, electronically conductive, individual electrically isolated styli, said first force is magnetic, said toner is magnetically attractable, said first and second electrode means are stationary relative to each other and said dielectric recording member is a uniform web having a resistivity of at least 10^7 ohms-cm. moving through said recording region, and a time varying electrical potential is individually applied to said styli.

17. The process of claim 1 wherein said first electrode means comprises at least one magnetically permeable, electronically conductive, electrically isolated styli, said second electrode means is an electronically conductive rotating cylinder, said dielectric recording member has a resistivity of at least 10^7 ohms-cm. and is bonded to said second electrode means, said first force is magnetic, said toner is magnetically attractable, and a time varying electrical potential is applied to said styli.

18. The process of claim 1 wherein said second electrode means comprises relatively electronically con-

ducting portions and relatively electronically insulating portions, and said second electrode means moves together with said dielectric recording member.

19. The process of claim 1 wherein at least one of said first and second electrode means has a second portion comprising regions of high conductivity and regions of low conductivity overlying an electronically conductive first portion.

20. The process of claim 1 wherein at least one of said first and second electrode means has a second portion comprising regions of relatively high dielectric constant and relatively low dielectric constant overlying an electronically conductive first portion.

21. The process of claim 1 wherein at least one of said electrode means has a unitary construction.

22. An apparatus comprising:

- 1. first and second electrode means each having at least one electronically conductive portion, said first and second electrode means being in spaced opposing relationship to provide a recording region therebetween,
- 2. toner supply means for supplying electronically conductive toner to said first electrode means,
- 3. first force means associated with said first electrode means providing a first force holding said toner in association with said first electrode means,
- 4. transport means for providing relative transport of a passive dielectric recording member relative to at least one of said first and second electrode means through said recording region, said electronically conductive toner providing an electronically conductive path between one surface of said dielectric recording member and said first electrode means when said dielectric recording member is in said recording region with a portion of said toner in physical contact with said one surface, said second electrode means being in electronic contact with the surface of said dielectric recording member opposing said one surface, said arrangement provid-

ing at least one electrical circuit between said electronically conductive portions of said first and second electrode means,

- 5. electrical potential means adapted to apply an electrical potential to at least one of said circuits to cause electronic current to flow in said circuit whereby said portion of said toner in physical contact with said one surface of said recording member is subjected to an electrical force pattern of intelligence determined by the electrical potential difference between said portion of said toner and said second electrode means and the electronic capacity of said portion of said toner with respect to said second electrode means, said force pattern including at least a first portion exerting a force on a part of said portion of said toner in contact with said dielectric recording member having a magnitude greater than and opposed to said first force, and
- 6. means for relative transport of said dielectric recording member from said recording region at a time after application of said electrical potential while said force pattern is present whereby toner is selectively deposited on said dielectric recording member in regions corresponding to said first portion of said force pattern.

23. The apparatus of claim 22 wherein said first force means is magnetic.

24. The apparatus of claim 22 wherein at least one of said first and second electrode means is at least one electronically conductive styli.

25. The apparatus of claim 22 wherein at least one of said first and second electrode means is an electronically conductive, circular, cylindrical shell and said first force means is a cylindrical magnetic member providing substantially radial lines of magnetic flux in said recording region, and said toner is magnetically attractable.

* * * * *

45

50

55

60

65

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,816,840 Dated June 11, 1974

Inventor(s) Arthur R. Kotz

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 11, lines 10 & 11, change "produce" to --product--.

Col. 12, line 18, change "spplied" to --applied--;

lines 61 & 62, delete "assumulates";

line 62 after "accumulates" insert --in--.

Col. 20, line 52, change "not" to --now--;

line 66 & 67, delete "corresponding recess
of the bottom plate, and from the head of".

Signed and sealed this 1st day of October 1974.

(SEAL)

Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,816,840 Dated June 11, 1974

Inventor(s) Arthur R. Kotz

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 11, lines 10 & 11, change "produce" to --product--.

Col. 12, line 18, change "spplied" to --applied--;

lines 61 & 62, delete "assumulates";

line 62 after "accumulates" insert --in--.

Col. 20, line 52, change "not" to --now--;

line 66 & 67, delete "corresponding recess
of the bottom plate, and from the head of".

Signed and sealed this 1st day of October 1974.

(SEAL)

Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents