

(19)



Europäisches Patentamt

European Patent Office

Office européen des brevets



(11)

EP 0 769 384 A2

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:

23.04.1997 Bulletin 1997/17

(51) Int Cl.⁶: **B41J 2/415**

(21) Application number: **96306538.8**

(22) Date of filing: **09.09.1996**

(84) Designated Contracting States:
DE FR GB

(30) Priority: **18.10.1995 US 546166**

(71) Applicant: **Hewlett-Packard Company**
Palo Alto, California 94304 (US)

(72) Inventor: **Lee, Michael H.**
San Jose, California 95120 (US)

(74) Representative: **Williams, John Francis et al**
WILLIAMS, POWELL & ASSOCIATES
34 Tavistock Street
London WC2E 7PB (GB)

(54) **Toner ejection printing**

(57) The present invention provides a method and apparatus for toner ejection printing (TEP) that improves print quality by synchronizing the developer roll (DR) voltage to the gate electrode voltage with the proper phase relationship, providing tonal evenness in the print quality and maximising the development time window. It further provides an improved DR waveform for TEP. The apparatus (100) for toner ejection printing includes a developer supply (102) for providing electrostatically charged toner particles (104), a printhead structure (106) including a plurality of apertures (108) confronting a back electrode (110) disposed in opposite relation with a surface of the printhead structure (106). Electrical signals applied to the printhead include a voltage applied to the developer supply (102) and a voltage applied to

the gate electrode (126) of the printhead, where the voltage applied to the developer supply and the gate electrode are typically synchronized to maximise the development time window and thus maximise the amount of toner deposited. The phase relationship between the DR voltage and the gate electrode voltage is defined so that the gate voltage lags the DR voltage by a predetermined time value. Preferably, the predetermined time delay equal to the transit time between the developer roll and the printhead of the highest electrostatically charged toner particle capable of overcoming electrostatic adhesion to the DR for the voltage condition used, which maximises the amount of toner deposited, a critical factor with the small time development window of TEP processes.

EP 0 769 384 A2

Description

The invention is directed towards the field of printers and more specifically to the field of electrostatic printers.

Electrophotographic (EP) printers, generically called laser printers, are becoming increasingly common. Laser printers employ a photoconductor (PC) which is usually charged negatively and selectively discharged to form a latent image. The PC passes the development zone where (negatively) charged toner is attracted to the discharge areas and repelled from the charged areas. The toner image is then transferred to paper or other substrates and heat is applied to fix the toner image. The PC is cleaned before the process repeats.

Although electrophotography produces high print quality, the process is relatively complex and requires a bulky printing apparatus. An alternative to EP printing is toner ejection printing (TEP), described in U.S. Patent 3,689,935 to Pressman et al. The print quality of the TEP process theoretically should approach that of EP printers. However the TEP process uses only two steps rather than the six steps required by conventional EP processes. This consolidation has attracted increasing interest due to the possibility of reduced costs. In the TEP described in Pressman et al., the printhead has a plurality of apertures that allow toner to pass from the toner supply member to the receiving member. A shield electrode is formed on the surface of the printhead facing the toner supply member. Address electrodes are formed on the surface of the printhead opposite to the shield electrode facing the receiving member. An individual aperture is selectively opened or closed by applying the appropriate voltage to the corresponding address electrode.

Problems associated with the TEP process have prevented a TEP printer from becoming commercially available. One problem addressed in U.S. Patent 4,491,855 to Fuji et al. is the toner supply behind the printhead. An alternating voltage is applied between the toner supply member, typically a developer roll (DR), and the grounded shield electrode to ensure an adequate toner supply at the apertures.

U.S. Patent No. 5,095,322 to Fletcher describes synchronizing the DR voltage to the shield electrode voltage to prevent aperture clogging due to wrong sign toner accumulation on the address electrode structure of the printhead. In the TEP described in Fletcher, a biased AC voltage is applied to the DR while a pulsed DC or DC biased AC voltage is applied to the shield electrode structure. The shield voltage has the same frequency as the AC voltage applied to the DR but is approximately 180 degrees out of phase. The frequency and phase of the address electrode relative to the DR is not discussed.

U.S. Patent 5,329,307 to Takemura et al. describes a printing apparatus where the voltages applied to the DR and address electrode voltages are synchronized.

In particular, the DR voltage follows the clock signal. While the clock signal is on, the voltage accelerates toner from the DR to the printhead. While the clock is off the voltage accelerates toner from the printhead to the DR. If a particular aperture is to be opened, the corresponding address electrode is opened when the clock signal is on, then closed when the clock signal is off. Hence the DR and address electrode voltages mirror each other's changes. Although Takemura et al.'s scheme improves printing uniformity, for reasons discussed below, this implementation does not maximize the development time window which is critical in TEP printing. Furthermore, the DR voltage does not optimize development for TEP.

To understand the TEP development time window, consider first EP printing. In EP printing, the development zone covers several mm. At 5 cm/s process speed, a 2.5 kHz AC on the developer roll forces the toner back and forth between the developer roll and the photoconductor perhaps 150 times, using over 60 ms to define the image. In contrast, for TEP the toner does not return to the developer roll once it passes the orifice. Furthermore, the toner can only be deposited during a small time window, just 0.83 ms at 600 dpi because the receiving substrate (e.g., paper) moves (0.40 ms separate pulses at 2.5 kHz AC). Further, gate capacitance and non-negligible toner transit times shrink this time window for printing even more. Thus a principal problem TEP must overcome is the small time window to address each pixel. U.S. Patent 5,329,307 synchronizes the DR and address electrode voltages so that the relative time positions are fixed. But their phase relationship is not optimized.

A toner ejection printer which provides high print quality and maximizes the development time window is needed. This is achieved by the invention defined in claim 1. The invention also includes the method in claim 9.

The present invention provides a method and apparatus for toner ejection printing that improves print quality by synchronizing the developer roll voltage to the gate electrode voltage with the proper phase relationship, providing tonal evenness in the print quality and maximizing the development time window. It further provides an improved DR waveform for TEP. The apparatus for toner ejection printing includes a developer supply for providing electrostatically charged toner particles, a printhead structure including a plurality of apertures confronting a back electrode disposed in opposed relation with a surface of the printhead structure. A control circuit applies controlled electrical signals to the printhead structure. The toner may be deposited on a receiving media positioned between the apertures and the back electrode or alternatively on the electrode itself. The electrical signals include a voltage applied to the developer supply and a voltage applied to the gate electrode of the printhead, where the voltage applied to the developer supply and the gate electrode are typically synchronized to maximize the development time win-

dow and thus maximize the amount of toner deposited. Furthermore, the DR waveform is shaped to improve developer performance.

The DR waveform extracts particles from the developer supply while the address electrode signal controls the shutter or gate allowing the extracted particles onto the receiving substrate. The DR waveform itself consists of a wavepacket which is initiated by the trigger followed by a constant reverse voltage designed to pull toner back to the DR. In a first embodiment, the phase relationship between the DR voltage and the gate electrode voltage is defined so that the gate voltage lags the DR voltage by a predetermined time value. The amount of toner is maximized if the gate opens just before the first toner burst arrives and remains open until it has to be closed before the next scheduled gate opening. Thus a predetermined time delay equal to the transit time between the developer roll and the printhead of the highest electrostatically charged toner particle capable of overcoming electrostatic adhesion to the DR for the voltage condition used, maximizes the amount of toner deposited, a critical factor with the small time development window of TEP processes. Delaying the voltage applied to the gate means electrostatically charged toner particles are extracted from the DR when the clock triggers and start arriving at the printhead just after the gate opens.

The amount of toner passing through the aperture of the gate electrode is maximized if the gate remains open until just before the toner burst corresponding to the next spot arrives. The minimum amount of toner passes through the gate electrode aperture if the gate electrode opens for a short duration compared to the maximum. Thus to provide gray scaling, the gate opening timing is varied dependent on the darkness of the pixel desired. For example, to obtain the darkest pixel available the gate remains opens for the longest possible time. To provide a grey scale, the gate opening time is selected to decrease the amount of toner deposited. Each gate opening time corresponds to a gray scale level.

The printing method includes the steps of: providing a toner of electrostatically charged particles, a printhead having a surface and apertures therein, and a back electrode disposed in opposed relation with a surface of said modulating electrode member, which is remote from said developer supply; and applying controlled electrical voltages to the printhead structure, the developer supply, and the back electrode, the electrical voltages causing the charged toner particles to flow through selected apertures towards the back electrode, wherein the electrical signals applied to the gate electrode of the printhead structure and the waveform on the developer roll are synchronized with the proper phase difference. Preferably, the electrical signal applied to the gate electrode of the printhead lags the voltage applied to the developer supply means by a predetermined time period. To maximize the amount of toner deposited, the predeter-

mined time period is equal to the transit time from the developer supply to the printhead structure of the highest charged toner particle capable of overcoming the electrostatic adhesion forces for the voltage conditions used.

A further understanding of the nature and advantages of the present invention may be realised with reference to the description of an exemplary embodiment thereof in the specification and the attached drawings, in which:

Figure 1 is a cross-sectional view of a partial schematic of a toner ejection printer according to the present invention.

Figure 2A is a representation of the preferred waveform applied to developer roll of the toner ejection printer according to present invention.

Figure 2B is a representation of the waveform applied to the address electrode of the toner ejection printer according to the present invention.

Figure 2C is a representation of the trigger waveform used for synchronizing the developer roll and address electrode voltages according to the present invention.

Figure 2D is a representation of the waveform applied to developer roll of the toner ejection printer according to an alternative embodiment of the present invention.

The present invention provides a method and apparatus for toner ejection printing that improves print quality by synchronizing the developer roll voltage and the gate electrode with a predefined phase relationship. Referring to Figure 1 shows a cross-sectional view of a partial schematic diagram of a preferred embodiment of the toner ejection printer 100 according to the preferred embodiment of the invention. The present invention includes a developer supply 102 providing electrostatically charged toner particles 104, a printhead structure 106 including a plurality of apertures 108, a back electrode 110 disposed in opposed relation with a surface 112 of the printhead structure 106, a control circuit 114 for applying controlled electric signals to the printhead structure 106, the developer supply 102, and the back electrode 110, the controlled electrical signals causing charged toner particles 104 to flow through selected apertures towards the back electrode 110. The electric signals include a signal 120 applied to the developer supply 102, a signal 122 applied to the back electrode 110, a signal 124 applied to a gate electrode 126 of the printhead, and a signal 128 applied to the shield electrode 130 where the signal 120 applied to the developer supply 102 and the signal 124 applied to the gate electrode 126 are synchronized.

Typically, the signal 124 is synchronized so that the signal 124 applied to the gate electrode 126 lags the signal 120 applied to the developer supply 102 by a predetermined time period 148. Preferably, the predetermined time period is approximately equal to the transit time for the highest electrostatically charged toner par-

ticle 104 capable of overcoming electrostatic adhesion to the DR from its initial position near the surface of the developer supply 102 to the printhead structure 106 in order to maximize the development time window of the TEP printer 100. More specifically, in the embodiment shown in Figure 1, where the shield electrode 130 faces and is in opposed relation to the developer supply 102, the predetermined time period is approximately equal to the transit of a toner particle 104 from the developer supply 102 to the shield electrode 130 of the printhead structure 106.

Toner 104 is supplied by a developer supply 102 spaced apart from the printhead 106 by approximately 50 to 150 μm preferably 75 to 100 μm . The toner 104 may be comprised of any suitable non-magnetic insulative toner combination. The toner 104 may be positively or negatively charged. For purposes of discussion in this application, the toner 104 is assumed to be negatively charged. (If magnetic insulative toner is used, the spacing is typically increased to between 125 to 350 μm , preferably 150 to 250 μm).

The toner charge-to-mass ratio (q/m) is known to vary widely even for a tight size distribution. After the developer roller pulse starts, toner proceeds towards the printhead 106. But toner arrival time can clearly have considerable spread. The highest charged toner capable of initially overcoming its electrostatic adhesion to the DR has the shortest transit time. Because adhesion is proportional to q^2 , q/m capable of jumping is typically limited to 10 to 20 $\mu\text{C/g}$ depending on the DR voltage conditions.

The printhead structure 106 is positioned in the toner ejection printer 100 such that the gate electrode 126 faces the back electrode 110 and the shield electrode 128 faces the developer supply means 102. The printhead structure 106 is comprised of an electrically insulative base member 132, a gate electrode 126, and a shield electrode 130. The electrically insulative base member 132 is typically made from polyimide film having a thickness in the range of 25 to 125 μm , preferably 50 to 100 μm , although other insulative materials and thicknesses may be used. A continuous conductive shield electrode 130 is formed on a first major surface 134 of the base member 106. The shield electrode 130 is typically comprised of Cr-Au having a total thickness of approximately 0.1 to 0.5 μm , preferably 0.2 to 0.5 μm thick. A segmented conductive gate electrode 126 is fabricated on the second major surface 112 of the base member 106 opposite to the first major surface 134. Similar to the conductive shield electrode 130, the gate electrode 126 is typically comprised of Cr-Au having a thickness of approximately 0.2 μm to 1 μm , preferably 0.3 to 0.6 μm thick.

A plurality of holes or apertures 108 are in the printhead structure 106, the apertures extending from the first major surface 138 of the printhead structure to the second major surface 140 of the printhead structure. The apertures 108 are typically cylindrical and approxi-

mately 100 to 180 μm preferably 120 to 160 μm in diameter. The apertures form an electrode array of individually addressable electrodes in a pattern suitable for use in recording information.

The back electrode 110 is disposed in opposed relation with the second major surface 140 of the printhead structure 106. In the preferred embodiment, the back electrode 110 is a rotatable conducting drum, having an outer surface. Typically a copy substrate 142 is positioned on the surface of the back electrode to record the toner pattern. Alternatively, toner can be directly deposited on the electrode surface and is subsequently transferred to the recording substrate at another location. If toner is first deposited on the back electrode, the electrode may further have a thin layer of a toner release promoting plastic such as silicone rubber or polyvinyl-fluoride, substantially covering the outer surface of the drum. For sake of simplicity, the toner release promoting plastic layer is not shown in Figure 1.

A control circuit 114 applies controlled electrical signals to the printhead structure 106, the developer roll 102 and the back electrode 110, causing electrostatically charged toner particles 104 to flow through selected apertures towards the back electrode 110. Addressing of the individual electrical electrodes is well known in the art and any number of addressing methods may be used to electronically select the desired printing element. The control circuit 114 applies an electrical signal 120 to the developer supply 102, an electrical signal 122 to the back electrode 110, an electrical signal 124 to the gate electrode 126, and an electrical signal 128 to the shield electrode 130.

In the preferred embodiment where the toner particles are negatively charged, the control circuit 114 electrically couples the shield electrode layer 130 to ground, the back electrode 110 to a high voltage source, and the gate electrode 126 and the developer supply 102 to a modulating signal source. The signal applied to the back electrode 110 is a high voltage source, typically in the range of 0.8 to 1.5 kvolts, preferably 1.0 to 1.3 kvolts so that streams of the charged toner particles flowing through the selected aperture are then electrostatically attracted to the back electrode 110 to deposit the charged toner particles 104 onto the drum surface of the back electrode 110 as the drum rotates or to the receiving substrate 142 in front of the back electrode 110.

Figure 2B is a representation of the waveform 124 applied to the gate electrode according to the preferred embodiment of the present invention. We have found a signal 124 modulating between -20 volts and -340 volts to be sufficient to open and close the gate. The gate electrode is open at the more positive voltage and closed at the more negative voltage. Preferably, for a negatively charged toner particle (the most positive portion of) the voltage waveform applied to the gate electrode is always negative whereas for a positively charged toner particle (the most negative portion of) the voltage waveform applied to the gate electrode is posi-

tive. This improves the quality of the output. In addition, preferably the signal 124 alternates between the two voltages -20 and -340 with no intermediate states. For a negatively charged toner particle, the signal 124 is held at its most negative voltage until the gate is opened.

Figure 2A is a representation of the waveform applied to the developer supply 102 of the toner ejection printer 100 according to the preferred embodiment of the present invention. The waveform shown in Figure 2A is comprised of a wavepacket 149 including a series of alternating voltages followed by a constant reverse voltage designed to pull toner back to the DR. The electrical signal 120 applied to the developer supply 104 typically includes both a DC and AC (modulating signal) components. Preferably, the signal 120 modulates between 340 and -260 volts. When the developer supply voltage 120 is negative, toner particles 104 are repelled from the surface of the developer supply 102. At the end of the wavepacket, the DR voltage reverts to the baseline high positive voltage to draw toner 104 back to the DR 102 from the shield electrode 130. In the preferred embodiment, the constant positive should occupy at least 10 to 20 % of the waveform in order to keep the shield electrode 130 clean of obstruction.

An alternative developer supply waveform is shown in Figure 2D. Referring to the waveform in Figure 2D, we found the following conditions give good print quality for the developer used in our toner ejection printer: +340 volts (except for the pulse train consisting of three 230 μ sec pulses), -600 volt pulses every 330 μ sec with 3 ms between gate triggers (1.2 cm/s process speed). Although the wavepacket 149 shown in Figure 2D alternates between voltages +340 (h1) and -600 (h2), alternatively the wavepacket voltages may alternate between intermediate voltages such as shown in Figure 2A. This is due to the rounding of the pulses from the capacitance between the DR and the shield electrode 130. Note in Figure 2D, the peak negative voltage is -260 volts, whose absolute value is less in magnitude than the 340 volt background voltage. For insulative negative toners, the average DR voltage within the wavepacket should be at least slightly positive to keep the shield electrode 130 clean, although the requirement can be slightly relaxed if the constant high positive voltage takes a sufficient fraction of the waveform.

In the preferred embodiment shown in Figure 2A, the period 150 of the signal 120 applied to the developer roll includes at least a first portion 152 having a negative slope, the first portion 152 defined by a height h1 and a height h2, where the height h2 is the most negative position on the developer roll waveform, and a second portion 154 having both a positive and negative slope, the second portion defined by a height h3, a height h4, and a height h5, wherein the height h4 is more positive than the heights h3 and h5 and the height h4 is less than the height h1. For the second portion 152 of the DR waveform, the height h5 is more positive than the height h4. The shape of the DR waveform applied to the developer

supply 102 is designed to take advantage of the toner adhesion characteristics. The energy to repel a toner particle from the developer supply 102 decreases as the number of toner particles decreases. Thus it is preferably to begin the DR waveform with a large pulse to break the toner adhesion to the chain (magnetic toner) or the developer roll (non-magnetic). The first portion 152 of the waveform accomplishes this goal. Next, we want to repel the toner particle without increasing toner particle acceleration so much as to give the toner particle sufficient acceleration to pass through the gate aperture when the gate aperture is closed. This is best accomplished by a series of alternating waveform, described as the second portion of the DR waveform.

The layer of toner particles 104 are spaced perhaps 100 μ m from the shield electrode. If sufficient voltage is applied to the DR for toner to overcome the electrostatic adhesion, toner can move from the DR toward the shield electrode. The transit time to reach the shield electrode depends on the toner charge, the applied voltage, and the spacing. At a typical toner charge of -7 μ C/g a fraction of the toner is charged at -10 μ C/g and above. The minimum transit time for a 100 μ m DR-shield electrode separation for a -10 μ C/g cutoff is around 100 μ s. Higher charged particles adhere too strongly to come off the developer roll while the transit time of lower charged particles is considerably longer. Because of charge distribution of typical toner particles, the average transit time can be much larger than the minimum transit time.

Consider a toner ejection printer having a 5 cm/s process speed where toner is deposited either directly on the back electrode or on the receiving substrate. Assume a trigger occurs every 0.85 ms. In the preferred embodiment of the present invention the voltage signal applied to the developer roll is synchronized to pulse at the trigger while the gate opens after the trigger. Thus in the preferred embodiment, the voltage signal applied to the gate electrode and the voltage signal applied to the DR are out of phase with the exact phase angle dependant on the TEP developer geometry and applied voltage conditions. Also important is the fixed time relationship between the DR waveform and the gate signal which promotes uniform printing.

The amount of toner passing through the aperture of the gate electrode is maximized if the gate remains open until just before the toner burst corresponding to the next pixel arrives. The minimum amount of toner passes through the gate electrode aperture if the gate electrode opens for a short duration compared to the maximum. Thus to provide gray scaling, the gate opening timing is varied dependent on the darkness of the pixel desired. For example, to obtain the darkest pixel available the gate remains open for the longest possible time. To provide a grey scale, the gate opening time is selected to decrease the amount of toner deposited. Each gate opening time corresponds to a gray scale level.

It is understood that the above description is intend-

ed to be illustrative and not restrictive. For example, the voltage magnitudes, exact waveform, and phase relationship clearly depend on the toner used. The scope of the invention should therefore not be determined with reference to the above description, but instead should be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.

Claims

1. An image recording apparatus, comprising:

a developer supply (102) for providing electrostatically charged toner particles (104);
a printhead structure (106) including a plurality of apertures (108), the printhead structure (106) having a first major surface and a second opposite major surface, wherein a shield electrode (130) is formed on the first major surface and a plurality of gate electrodes (126) is formed on the second major surface;
a back electrode (110) disposed in opposed relation with a surface (112) of the printhead structure (106); and
a control circuit (114) applying controlled electrical signals to the printhead structure (106), the developer supply (102), and the back electrode (110); the electrical signals causing charged toner particles (104) to flow through selected apertures (108) towards the back electrode (110), wherein the voltages applied to the developer supply and the gate electrode are synchronized such that the voltage applied to the gate electrode lags the developer supply by a predetermined time period, the predetermined time period corresponding to a specific gray scale level.

2. The image recording apparatus recited in claim 1 wherein the predetermined time period is approximately equal to the minimum transit of a toner particle from the developer supply to the printhead structure.

3. The image recording apparatus recited in claim 1 or 2 wherein the minimum transit time of a toner particle is approximately equal to the transit time of the highest charged toner particle capable of overcoming electrostatic adhesion to the developer supply from the developer supply to the printhead structure.

4. The image recording apparatus recited in claim 1, 2 or 3 wherein the developer supply voltage includes a wavepacket of alternating voltages followed by a reverse voltage to pull toner back to-

wards the developer supply.

5. The image recording apparatus recited in claim 4 wherein the wavepacket of the developer supply voltage includes at least a first portion, the first portion defined by a height h1 and a height h2, where the height h2 is the most negative position on the developer roll waveform, and a second portion, the second portion defined by a height h3, a height h4, and a height h5, wherein the height h4 is more positive than the heights h3 and h5 and the height h4 is less than the height h1.

6. The image recording apparatus recited in claim 5 wherein the height h5 is more positive than the height h4.

7. The image recording apparatus recited in claim 5 wherein for a positively or negatively charged toner particle, the first portion of the wavepacket has respectively a positive or negative slope, and the second portion of the wavepacket has both a positive and negative slope.

8. The image recording apparatus recited in claim 1 wherein for a positive or negative electrostatically charged toner particle, the most negative or positive portion of the voltage waveform applied to the gate electrode is positive or negative respectively.

9. A printing method comprising the steps of:

providing a toner of electrostatically charged particles from a developer supply, a printhead having a surface and apertures therein, and a back electrode disposed in opposed relation with a surface of said printhead, which is remote from said developer supply; and
applying controlled electrical signals to the printhead structure, the developer supply, and the back electrode, the electrical signals causing the charged toner particles to flow through selected apertures towards the back electrode, wherein the electrical signals applied to the gate electrode of the printhead structure and the developer supply are synchronized such that the voltage applied to the gate electrode lags the developer supply by a predetermined time period, the predetermined time period corresponding to a specific gray scale level.

10. The printing method recited in claim 9 wherein the predetermined time period approximately equal to the minimum transit time of a toner particle from the developer supply to the printhead structure establishes the darkest pixel.

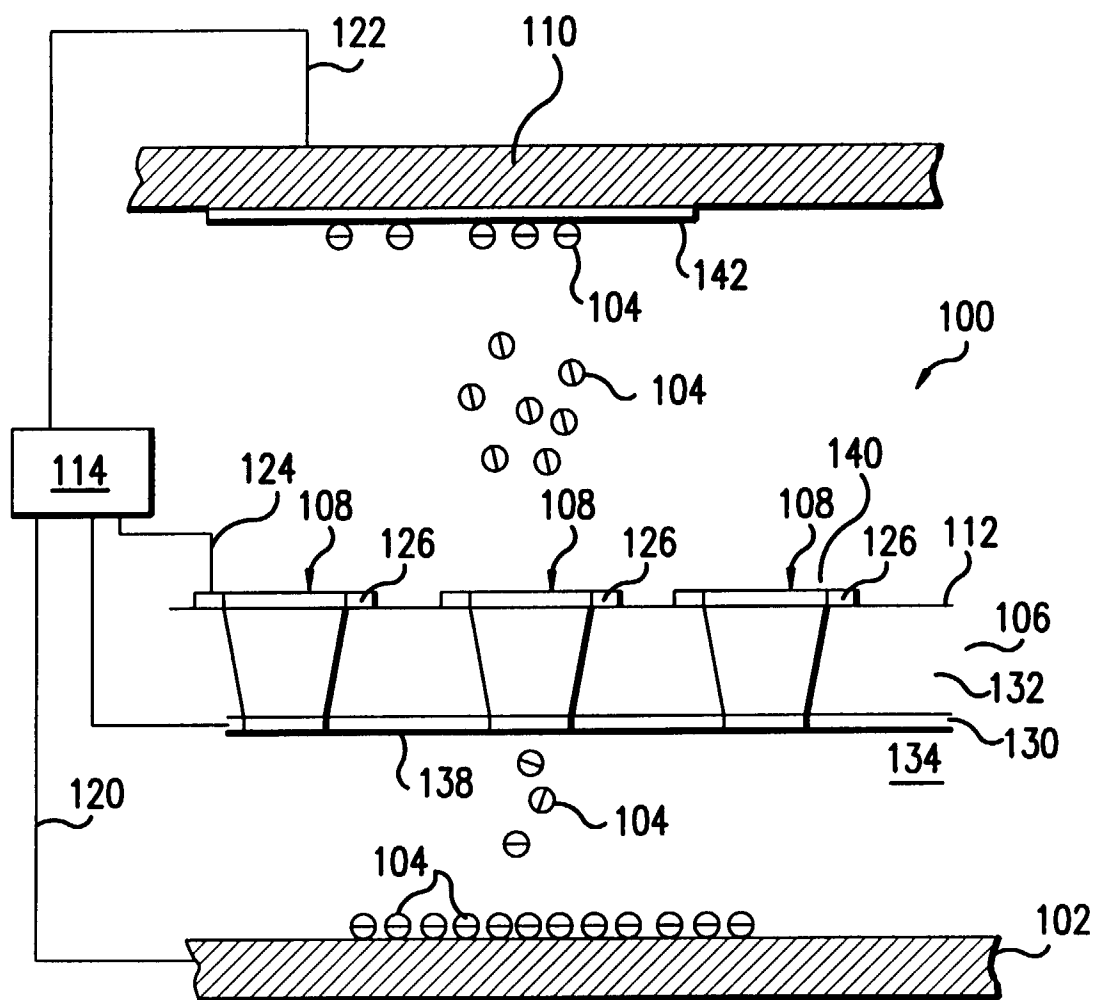


FIG.1

