Provide Nozzle with Resistive Heater

Receive Ink at the Nozzle

Energize the Resistive Heater

Determine Heater Temperature

Control Ink Temperature

In an embodiment, the disclosure relates to a method and apparatus for fault monitoring and controlling operation of a discharge nozzle in a large array of discharge nozzles. An exemplary apparatus includes a thin, thermally conductive membrane, with an integrated thin-film electrical heater. When a fixed voltage is applied to the heater, and as the heater heats, the resistance of the heater will increase which will cause a concomitant decrease in the electrical current flowing through the heater. By measuring the resistance of the heater it can readily be determined whether the device is functioning properly.
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Figure 10
METHOD AND APPARATUS FOR CONTROLLING THE TEMPERATURE OF AN ELECTRICALLY-HEATED DISCHARGE NOZZLE

[0001] The instant application claims priority to Provisional Application No. 61/142,575, which was filed on Jan. 5, 2009, and to U.S. patent application Ser. No. 12/139,391, filed Jun. 13, 2008. The disclosures of both applications are incorporated herein in their entirety.

BACKGROUND

[0002] 1. Field of the Invention
[0003] The disclosure relates to a method and apparatus for sensing and controlling the temperature of an electrically resistive heater which may be integrated with a discharge nozzle of a print-head. More specifically, the disclosure relates to a novel controller for controlling temperature of a discharge nozzle. The discharge nozzle can be used for depositing substantially dry ink on a surface to be used for electronic applications.

[0004] 2. Description of Related Art
[0005] The manufacture of organic light emitting devices (OLEDs) requires depositing one or more organic films on a substrate and coupling the top and bottom of the film stack to electrodes. The film thickness is a prime consideration. The total layer stack thickness is about 100 nm and each layer is optimally deposited uniformly with an accuracy of better than +/-1 nm. Film purity is also important. Conventional apparatus forms the film stack using one of two methods: (1) thermal evaporation of organic material in a relative vacuum environment and subsequent condensation of the organic vapor on the substrate; or (2) dissolution of organic material into a solvent, coating the substrate with the resulting solution, and subsequent removal of the solvent.

[0006] Another consideration in depositing the organic thin films of an OLED is placing the films precisely at the desired location. There are two conventional technologies for performing this task, depending on the method of film deposition. For thermal evaporation, shadow masking is used to form OLED films of a desired configuration. Shadow masking techniques require placing a well-defined mask over a region of the substrate followed by depositing the film over the entire substrate area. Once deposition is complete, the shadow mask is removed. The regions exposed through the mask define the pattern of material deposited on the substrate. This process is inefficient, as the entire substrate must be coated, even though only the regions exposed through the shadow mask require a film. Furthermore, the shadow mask becomes increasingly coated with each use, and must eventually be discarded or cleaned. Finally, the use of shadow masks over large areas is made difficult by the need to use very thin masks (to achieve small feature sizes) that make said masks structurally unstable. However, the vapor deposition technique yields OLED films with high uniformity and purity and excellent thickness control.

[0007] For solvent deposition, ink jet printing can be used to deposit patterns of OLED films. Ink jet printing requires dissolving organic material into a solvent that yields a printable ink. Furthermore, ink jet printing is conventionally limited to the use of single layer OLED film stacks, which typically have lower performance as compared to multilayer stacks. The single-layer limitation arises because printing typically causes destructive dissolution of any underlying organic layers. The ink jet printing technique is capable of providing patterns of OLED films over very large areas with good material efficiency.

[0008] Large area printing capabilities of ink jet printing allow relatively high uniformity, purity, and thickness control for vapor deposition of organic thin films over a large surface area. Large area printing is enabled by arranging a multitude of discharge nozzles in an array formation over a substrate. Ink deposition from the array can be controlled by controlling ink metering discharge at each nozzle.

SUMMARY

[0010] The disclosure relates to a method and apparatus for fault monitoring and controlling operation of a discharge nozzle in a large array of discharge nozzles. In one embodiment, the apparatus comprises a thin, thermally conductive membrane, with an integrated thin-film electrical heater. The resistance of the heater and its temperature can have monotonic increasing relationship. When a fixed voltage is applied to the heater, as the heater heats, the resistance of the heater will increase, which will cause a concomitant decrease in the electrical current flowing through the heater. Alternatively, when a fixed electrical current is flown through the heater, the temperature of the heater will increase and so will the resistance of the heater. Thus, the voltage measured across the heater will increase.

[0011] In another embodiment, each discharge nozzle in an array of discharge nozzles is provided with a separate detection circuit for detecting failure mode at the discharge nozzle. Each discharge nozzle communicates with a controller for controlling the temperature of the discharge nozzle. The controller can be interposed between a power supply and the discharge nozzle. By controlling the power supplied to the discharge nozzle, the controller can increase or decrease the temperature of the discharge nozzle. The controller may optionally include a sensor for detecting the temperature of the nozzle either directly or indirectly. The sensor can also detect failure mode at the discharge nozzle. With each nozzle in the array having a sensor, the operator can readily identify a failing sensor in a large array of sensors.

[0012] In another embodiment, the disclosure relates to a method for controlling the temperature of a discharge nozzle. The method includes the steps of: providing a discharge nozzle for dispensing ink, the discharge nozzle having a thermally-conductive membrane with an integrated thin film electric heater and the thin film electric heater defining a resistance; receiving a quantity of ink in liquid-form at the discharge nozzle; energizing the thin-film heater by applying a substantially constant current to the thin-film heater; measuring a voltage across the heater and a current through the heater; and determining temperature of the heater as a function of the voltage and the current; and determining the temperature of the ink droplet as a function of the heater tempera-
ture. In one embodiment, the ink drop temperature is determined by measuring the voltage across the heater for a substantially constant current.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] These and other embodiments of the disclosure will be discussed with reference to the following exemplary and non-limiting illustrations, in which like elements are numbered similarly, and where:

[0014] FIG. 1 is a schematic representation of an exemplary print-head having a thermal ink depositing mechanism according to one embodiment of the disclosure;

[0015] FIG. 2 schematically illustrates a print-head apparatus having multiple discharge nozzles arranged in an array and using thermal ink dispensing elements;

[0016] FIG. 3 is a sideview representation of an embodiment of the invention;

[0017] FIG. 4 is a bottom view representation of an embodiment of the invention;

[0018] FIG. 5 is a circuit diagram for the heater and sensor combination according to one embodiment of the invention;

[0019] FIG. 6 is an exploded photograph of the physical representation of a resistive heater and a sensor;

[0020] FIG. 7 is a representative driving circuit according to one embodiment of the disclosure;

[0021] FIG. 8 shows a closed-loop temperature controller according to an embodiment of the disclosure;

[0022] FIG. 9 is an exemplary control system according to another embodiment of the disclosure; and

[0023] FIG. 10 is a flow-diagram for implementing a method according to one embodiment of the disclosure.

DETAILED DESCRIPTION

[0024] FIG. 1 is a schematic representation of an exemplary print-head having a thermal ink depositing mechanism according to one embodiment of the disclosure. The exemplary print-head of FIG. 1 includes chamber 130, orifice 170, nozzle 180, and micro-porous conduits 160. Chamber 130 receives ink in liquid form and communicates the ink from orifice 170 to discharge nozzle 180. The ink can comprise suspended or dissolved particles in a carrier liquid. These particles can comprise single molecules or atoms, or aggregations of molecules and/or atoms. The path between orifice 170 and discharge nozzle 180 defines a delivery path. In the embodiment of FIG. 1A, discharge nozzle 180 comprises conduits 160 separated by partitions 165. Conduits 160 may include micro-porous material therein. A surface of discharge nozzle 180 proximal to orifice 170 defines the inlet port to discharge nozzle 180 while the distal surface of discharge nozzle 180 defines the outlet port. A substrate (not shown) can be positioned proximal to the outlet port of discharge nozzle 180 for receiving ink deposited from the nozzle.

[0025] The thermal jet print-head of FIG. 1 further includes bottom structure 140, which receives discharge nozzle 180. Discharge nozzle 180 can be fabricated as part of the bottom structure 140. Alternatively, discharge nozzle 180 can be manufactured separately and later combined with bottom structure 140 to form an integrated structure. Top structure 142 receives chamber 130. Top structure 142 can be formed with appropriate cavities and conduits to form chamber 130. Top structure 142 and bottom structure 140 are coupled through bonds 120 to form a housing. The housing allows the thermal jet print-head to operate under pressure or in a vacuum. The housing may further comprise an inlet port (not shown) for accepting a transport gas for carrying the material from the discharge nozzle to the substrate (not shown).

[0026] Alternatively, a port (not shown) can be integrated into top structure 142 to receive transport gases. The port can include a flange adapted to receive a transport gas, which according to one embodiment comprises a substantially inert mixture of one or more gases. The mixture can include gases which are substantially non-reactive with the materials being deposited by the apparatus, such as nitrogen or argon when used with typical organic materials. The transport gas can transport particles from discharge nozzle 180 by flowing through micro-pores 160.

[0027] Heater 110 can be optionally added to chamber 130 for heating and/or dispensing the ink. In FIG. 1, heater 110 is positioned inside chamber 130. Heater 110 can be any thermal energy source coupled to chamber 130 for providing pulsating energy to the liquid ink and thereby discharging a droplet of the liquid ink through orifice 170. In one embodiment, heater 110 delivers heat in pulses having a duration of one second or less. For instance, the heater can be energized with square pulses having a variable duty cycle and a cycle frequency of 1 kHz. Thus, the heater energy can be used to meter the quantity of ink delivered from chamber 130 to discharge nozzle 180. Chamber 130 may also contain material, other than ink, required for forming a film used in the fabrication of an OLED or transistor. Orifice 170 can be configured such that surface tension of the liquid in chamber 130 prevents discharge of the liquid prior to activation of the mechanism for dispensing the ink.

[0028] In the embodiment of FIG. 1, discharge nozzle 180 includes partitions (or rigid portions) 165 separated by conduits 160. Conduits 160 and rigid portions 165 can collectively define a micro-porous environment. The micro-porous environment can be composed of a variety of materials, including micro-porous alumina or solid membranes of silicon or silicon carbide and having micro-fabricated pores. Micro-pores 160 prevent the material dissolved or suspended in the liquid from escaping through discharge nozzle 180 until the medium is appropriately activated.

[0029] When the discharged droplet of liquid encounters discharge nozzle 180, the liquid is drawn into micro-pores 160 with assistance from capillary action. The liquid in the ink may evaporate prior to activation of discharge nozzle 180, leaving behind a coating of the suspended or dissolved particles on the micro-pore walls. The liquid in the ink may comprise one or more solvents with a relatively-low vapor pressure. The liquid in the ink may also comprise one or more solvents with a relatively-high vapor pressure.

[0030] The evaporation of the liquid in the ink may be accelerated by heating the discharge nozzle. The evaporated liquid can be removed from the chamber and subsequently collected (not shown), for instance, by flowing gas over one or more of the discharge nozzle faces. Depending on the desired application, micro-pores 160 can provide conduits (or passages) having a maximum linear cross-sectional distance W of a few nanometers to hundreds of microns. The micro-porous region comprising discharge nozzle 180 will take a different a shape and cover a different area depending on the desired application, with a typical maximum linear cross-sectional dimension D ranging from a few hundred nanometers to tens of millimeters. In one embodiment, the ratio of W/D is in a range of about 1/10 to about 1/1000.
Discharge nozzle 180 can be actuated by nozzle heater 150. Nozzle heater 150 may be proximal to discharge nozzle 180. Nozzle heater 150 may comprise a thin metal film. The thin metal film can be comprised of, for example, platinum. When activated, nozzle heater 150 provides pulsing thermal energy to discharge nozzle 180, which acts to dislodge the material contained within micro-pores or conduits 160, which can subsequently flow out from the discharge nozzle. In one embodiment, the pulsations can be variable on a time scale of one minute or less.

Dislodging the ink particles may include vaporization, either through sublimation or melting and subsequent boiling. It should be noted again that the term particles is used generally, and includes anything from a single molecule to a cluster of molecules or atoms. In general, one can employ any energy source coupled to the discharge nozzle that is capable of energizing discharge nozzle 180 and thereby discharging the material from micro-pores 160; for instance, mechanical (e.g., vibrational). In one embodiment of the disclosure, a piezoelectric material is used instead of, or in addition to, nozzle heaters 150.

FIG. 2 schematically illustrates a print-head apparatus having multiple discharge nozzles arranged in an array and using thermal ink dispensing elements. The apparatus of FIG. 2 includes chamber 230 for housing liquid 201. Liquid 201 can comprise dissolved or suspended particles for deposition on a substrate. Chamber 230 also includes a plurality of chamber orifices 270. The embodiment of FIG. 2 comprises ink dispensing heaters 210 for pulsating metering liquid ink through each chamber orifice 270 and towards discharge nozzles 280. Discharge nozzles 280 are arranged in an array such that each discharge nozzle 280 communicates with a corresponding chamber orifice 270. Nozzle heaters 250 are positioned near discharge nozzles 280 to evaporate substantially all of the carrier liquid and to allow solid particles to be deposited by the discharge nozzle array.

The array 200 of FIG. 2 includes a number of independent discharge nozzle 280 arranged in one row. A typical array includes several rows of independent discharge nozzles. As shown each nozzle is in thermal communication with at least one heater 250. In the event that any one heater element should fail, the ink deposit process will be affected. Consequently, the deposited pixel will be faulty. The problem of faulty pixel is significant because it often goes undetected until late in the manufacturing process after much labor and cost have been spent.

To address this and other problems, an embodiment of the invention relates to a thin-film heater and a thin-film temperature sensor in communication with the thin-film heater. The thin-film heater and the temperature sensor can be integrated. The sensor enables immediate detection of the heater temperature. Moreover, because each heater will have a separate sensor, failure detection can be pinpointed immediately.

FIG. 3 is a side view representation of an embodiment of the invention. Device 300 of FIG. 3 includes print-head chip 310 and a thin-film heater and temperature sensor 320. The thin-film heater is mounted to a side of the print-head chip proximal to the substrate surface (not shown). Thin-film heater 310 can be integrated with a temperature sensor to form a single device for easier manufacturing and assembly.

FIG. 4 is a bottom view representation of an embodiment of the invention. In FIG. 4, the thin-film heater 420 has segments A, B, C and D. Each segment represents a node of the sensor. Print-head chip 410 is shown in the dark shade area, overlapping the sensor. It should be noted that the bottom-view shown in FIG. 4 is the face closest to the substrate (not shown).

FIG. 5 is a circuit diagram for the heater and sensor combination according to one embodiment of the invention. Circuit 500 of FIG. 5 comprises heater 530 connected to current source 510 and voltmeter 520. Current source 510 is connected to resistive heater 530 through nodes A and B. Voltmeter 520 is connected to resistive heater 530 through nodes C and D. Nodes A, B, C and D are schematically represented in FIG. 4.

FIG. 6 is an exploded photograph of the physical representation of a resistive heater and a sensor. FIG. 6 is a 100× magnification of an exemplary heater. Resistive heater 630 is shown at the center of FIG. 6. Regions A, B, C and D are also identified as corresponding to nodes A, B, C and D. Shaded portions 640, 650, 660 and 670 are the bottom portions of the printer-head discharge nozzle. In one embodiment, platinum was used for nodes A, B, C and D. In another embodiment, a combination of titanium and platinum was used for the nodes. The nodes can also be prepared as a multilayer device having an adhesive layer connecting a heater layer to a pad (substrate) layer.

A number of different circuits can be used to sense the voltage across the heater. The voltage may be sensed directly as a DC voltage or it may be sensed using one or more operational amplifiers ("op-amp") which are used to drive the current of the heater while having a high-pass filter let through a high frequency current. The high frequency current can be taken by another op-amp to provide an open loop signal to a controller. Thus, in FIGS. 4, 5 and 6, the current I_{heater} is supplied by the current source I and the voltage V_{heater} is measured across the heater and directly proportional to the temperature of the heater.

FIG. 7 is a representative driving circuit according to one embodiment of the disclosure. The circuit of FIG. 7 can define a constant-current driving circuit. Circuit 700 receives driving signal 705 at operational amplifier 730. Operational amplifier 730 drives heater 710 which drives the resistive heater and the thermal sensor circuits. Heater 710 can be co-located with the discharge nozzle (not shown) and can comprise a platinum heater. Resistor 720 is the circuit sensing device connected to the ground. The circuit sensing device provides voltage-proportional to heater current feedback to operational amplifier 730 and can define a 1 Ohm resistor. As shown in FIG. 7, the driving circuit can receive, for example, voltage as feedback. The voltage can define the instantaneous temperature of the heater.

FIG. 8 shows a circuit for a closed-loop temperature controller according to another embodiment of the disclosure. The circuit of FIG. 8 includes microprocessor 800, I/O device 815 and resistance measuring circuit 820. The desired temperature is entered to controller 800. Controller 800 correlates the temperature value to a corresponding resistance value. The resistance value for the heater can be stored in a memory circuit associated with the controller. A software algorithm can correlate the resistance value and the temperature. If the desired temperature is less than the measured value, controller 800 can reduce the current supplied to heater 810 in order to heat the discharge nozzle. On the other hand, if the heater temperature is lower than the desired value, the current supplied to the heater can be increased to raise the
temperature. Operational amplifier 830 drives heater 810. In this manner, controller 800 provides a constant temperature control and feedback. Temperature feedback is provided through amplifier 840 to I/O device 815, which in turn, communicates with controller 800.

[0043] In FIGS. 7 and 8, the controlling circuits can be can be devised independently for each printer-head and can be controlled and monitored from a remote location. Thus, in an array of 50 printer-heads arranged in five columns of ten print-heads, each print-head can have an independent control circuit. The independent control circuits can communicate with a master controller (not shown) and ultimately with the technician through a graphic user interface.

[0044] According to the principles disclosed herein a driving circuit, such as those represented in FIG. 5, 6 or 7, can be used with each discharge nozzle in an array of print-heads. The driving circuit can be integrated with the heater or it may define a separate module. In one embodiment of the invention, the driving circuit is interposed between the heater and a power supply.

[0045] The power supply can define an AC or a DC source sufficiently seized to energize the resistive heater. The driving circuit may provide constant current with variable voltage to the resistive heater. Alternatively, the power supply may provide a constant AC voltage with variable pulse width. In such embodiment, the pulse height can define the voltage level and the pulse width can define the duration of voltage supplied to the heater. A feedback to the driving circuit can help adjust the input power by increasing or decreasing the power supplied (or its duration) to the resistive heater.

[0046] FIG. 9 is an exemplary control system according to one embodiment of the disclosure. The system of FIG. 9 comprises processor 910 in communication with memory 920. Memory 920 can contain data relating the resistance of the heater to its temperature. Memory 920 can store data relating the voltage to the temperature of resistive heater 920. Memory 920 may also contain data relating the current measured across heater 940 to its instantaneous temperature. It will be appreciated by one of ordinary skill in the art that such data is material-dependent and can vary widely from one resistive heater to another. Memory 920 and processor 910 can define a firmware.

[0047] Driving circuit 930 can be integrated with processor 910 or it can define a separate circuitry. In the embodiment of FIG. 9, driving circuit 930 is interposed between power supply 950 and heater 940. As discussed, power supply 950 can define an AC or a DC power supply. Driving circuit 930 can receive a driving signal from processor 910 and control the power supplied to heater 940. Driving circuit 930 also communicates with heater 930 as shown in FIGS. 5, 6 and 7 across nodes C and D. While the embodiment of FIG. 9 shows a single heater, the disclosed principles are not limited thereto. Processor 910 can control multiple driving circuits and heaters simultaneously.

[0048] In an alternative embodiment, the function of the driving and the processor can be combined into a controller as schematically represented by broken lines 960. The controller can define a single integrated circuit or it can define multiple circuit modules. The controller can receive feedback from heater 940 and determine the temperature of the heater as a function of resistance data stored in memory 920. The controller can also detect failure mode of the heater as a function of, for example, the voltage across heater 940. In the event of failure detection, the controller can communicate the failure to the operator. Control system 860 can be used to control a multitude of heaters 940 in a large array of print-heads and discharge nozzles (see FIG. 2).

[0049] FIG. 10 is a flow-diagram for implementing a method according to one embodiment of the disclosure. In step 1010 a discharge nozzle in communication with a resistive heating element is provided. The discharge nozzle can be integrated with the heater as one unit. Alternatively, the heater can be mounted or attached to the discharge nozzle. The nozzle may comprise one or more conduits between two surfaces thereof for heating the received ink. In step 1020, ink is received at the nozzle. The ink can be received at a surface of the nozzle or it can be received at the conduits of the discharge nozzle. In step 1030, the resistive heater is energized to thereby heat the ink received at the nozzle. The energizing step can comprise supplying AC, DC or voltage pulses to the heater. A control circuit (interchangeably, controller) in communication with the heater and the energy source can dictate the amount of energy supplied to the heater based on the desired ink temperature at deposition.

[0050] At the same time, a control circuit can monitor the instantaneous temperature of the heater by detecting the voltage across the resistive heater. If the resistance should exceed a predetermined threshold, the controller may interrupt or decrease the energy supplied to the heater. As stated, the controller may comprise a processor circuit in communication with a memory circuit. The memory circuit can contain data relating the temperature of the resistive heater to its voltage or current. In one embodiment, the memory circuit contains a data table correlating the instantaneous temperature of the heater to the voltage measure across the heater. Using such data, in step 1050, the processor circuit may increase, decrease or leave unchanged the energy supplied to the resistive heater. The processor circuit can communicate with the operator through a graphic user interface and a keyboard. The operator may dial in different temperatures depending on the type of ink, the resistive heater and the deposition parameters.

[0051] While the principles of the disclosure have been illustrated in relation to the exemplary embodiments shown herein, the principles of the disclosure are not limited thereto and include any modification, variation or permutation thereof.

What is claimed is:

1. A method for controlling the temperature of a discharge nozzle, the method comprising:
   - providing a discharge nozzle for dispensing ink, the discharge nozzle having a thermally-conductive membrane with an integrated thin film electric heater and the thin film electric heater defining a resistance;
   - receiving a quantity of ink in liquid-form at the discharge nozzle;
   - energizing the thin-film heater by applying a substantially constant current to the thin-film heater;
   - measuring a voltage across the heater and a current through the heater; and
   - determining the temperature of the heater as a function of the voltage and the current; and
   - determining the temperature of the ink droplet as a function of the heater temperature.

2. The method of claim 1, further comprising energizing the thin-film heater by supplying electric current and measuring the ink quantity by measuring a change in the heater temperature.
3. The method of claim 1, further comprising energizing the thin-film heater by applying a plurality of voltage pulses to the thin-film heater, each voltage pulse providing substantially identical voltage and having varying pulse width.

4. The method of claim 1, wherein the step of determining temperature of the heater further comprises determining the temperature as a function of the resistance from data specific to said resistor.

5. The method of claim 1, further comprising varying the voltage to increase the temperature of the heater.

6. A control system for controlling temperature of a discharge nozzle, the control system comprising:
   a discharge nozzle having a plurality of conduits for receiving a quantity of liquid ink, the discharge nozzle thermally communicating with a heater;
   a first metering device for measuring a voltage across the heater;
   a second metering device for measuring a current through the heater;
   a processor circuit for determining resistance of the heater as a function of the voltage and the current, the processor circuit controlling at least one of voltage or current input to the heater; and
   a memory circuit in communication with the processor circuit, the memory containing data associating resistance with the temperature of the conduits of the discharge nozzle;
   wherein the processor increases the voltage supplied to the heater to increase the temperature at the conduits of the discharge nozzle.

7. The control system of claim 6, wherein the discharge nozzle has a thermally-conductive membrane.

8. The control system of claim 6, further comprising a power supply in communication with the processor, the processor controlling at least one of voltage or current supplied to the heater.

9. The control system of claim 6, further comprising a power supply in communication with the processor, the power supply supplying voltage pulses to the heater, wherein the voltage pulses have substantially identical pulse height and varying pulse width.

10. The control system of claim 6, wherein the resistive heater is integrated with the discharge nozzle.

11. A discharge system for depositing ink on a substrate, the system comprising:
   a chamber having a quantity of ink, the ink defined by a plurality of suspended ink particles in a carrier liquid;
   a discharge nozzle for receiving a quantity of liquid ink from the chamber;
   a heater in thermal communication with the discharge nozzle, the heater evaporating the carrier liquid at the discharge nozzle to deposit a substantially solid quantity of ink particles from the discharge nozzle; and
   a controller in communication with the discharge nozzle, the controller maintaining the heater temperature by varying the voltage while maintaining substantially constant current supplied to the heater.

12. The system of claim 11, wherein the controller supplies a plurality of energy pulses to a heater, each of the plurality of pulses having a substantially constant pulse height and varying pulse width.

13. The system of claim 1, wherein the controller further comprises a processor circuit programmed with instructions to:
   (a) determine one of the amount or the duration of activation required to discharge the quantity of ink particles to the substrate;
   (b) energize the discharge nozzle consistent with the amount or duration determined in step (a); and
   (c) repeat steps (a) and (b) to discharge additional quantities of ink particles onto the substrate.

14. The system of claim 1, wherein the controller further comprises at least one processor circuit in communication with a memory for storing instructions.

15. The system of claim 1, wherein the controller tasks the dispenser to provide the metered quantity of ink by providing pulsating energy to the dispenser, the pulsating energy adapted to exact a metered quantity of ink to the discharge nozzle.

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