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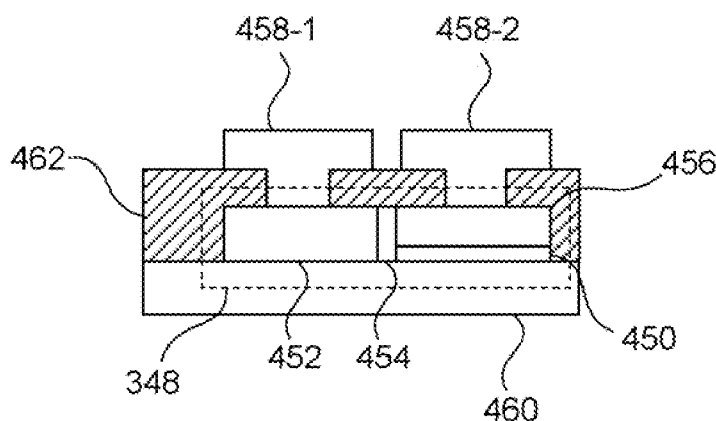
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[Continued on next page]

(54) **Title:** PRINthead WITH A NUMBER OF VERTICAL OXIDE MEMRISTORS HAVING A SACRIFICIAL DIELECTRIC LAYER

**Fig. 4A**

(57) **Abstract:** A printhead with a number of vertical oxide memristors having a sacrificial dielectric layer is described. The printhead includes a number of nozzles to deposit an amount of fluid onto a print medium. Each nozzle includes a firing chamber to hold the amount of fluid, an opening to dispense the amount of fluid onto the print medium, and an ejector to eject the amount of fluid through the opening. The printhead also includes a memristor array comprising a number of memristors. Each memristor includes a bottom electrode disposed on a substrate, a vertical switching oxide abutting the bottom electrode and disposed on the substrate, a sacrificial dielectric layer abutting the vertical switching oxide and disposed on the substrate, and a top electrode abutting the vertical switching oxide and disposed on the sacrificial dielectric layer.



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PRINthead WITH A NUMBER OF VERTICAL OXIDE MEMRISTORS HAVING A SACRIFICIAL DIELECTRIC LAYER

BACKGROUND

[0001] A memory system may be used to store data. In some examples, imaging devices, such as printheads may include memory to store information relating to printer cartridge identification, security information, and authentication information, among other types of information.

BRIEF DESCRIPTION OF THE DRAWINGS

[0002] The accompanying drawings illustrate various examples of the principles described herein and are a part of the specification. The illustrated examples do not limit the scope of the claims.

[0003] Fig. 1 is a diagram of a printing system according to one example of the principles described herein.

[0004] Fig. 2A is a diagram of a printer cartridge with a number of vertical oxide memristors having a sacrificial dielectric layer according to one example of the principles described herein.

[0005] Fig. 2B is a cross sectional diagram of a printer cartridge with a number of vertical oxide memristors having a sacrificial dielectric layer according to one example of the principles described herein.

[0006] Fig. 3 is a block diagram of a printer cartridge that uses a printhead with a number of vertical oxide memristors having a sacrificial dielectric layer according to one example of the principles described herein.

[0007] Figs. 4A and 4B are views of a vertical oxide memristor having a sacrificial dielectric layer according to one example of the principles described herein.

[0008] Fig. 5 is a flowchart of a method for forming a vertical oxide memristor having a sacrificial dielectric layer according to one example of the principles described herein.

[0009] Figs. 6A-6K are diagrams illustrating the formation of a vertical oxide memristor having a sacrificial dielectric layer according to one example of the principles described herein.

[0010] Throughout the drawings, identical reference numbers designate similar, but not necessarily identical, elements.

DETAILED DESCRIPTION

[0011] Memory devices are used to store information for a printer cartridge. Printer cartridges include memory to store information related to the operation of the printhead. For example, a printhead may include memory to store information related 1) to the printhead; 2) to fluid, such as ink, used by the printhead; or 3) to the use and maintenance of the printhead. Other examples of information that may be stored on a printhead include information relating to 1) a fluid supply, 2) fluid identification information, 3) fluid characterization information, and 4) fluid usage data, among other types of fluid or imaging device related data. More examples of information that may be stored include identification information, serial numbers, security information, feature information, Anti-Counterfeiting (ACF) information, among other types of information. While memory usage on printheads is desirable, changing circumstances may reduce their efficacy in storing information.

[0012] For example, an increasing trend in counterfeiting may lead to current memory devices being too small to contain sufficient anti-counterfeiting information and security and authentication information. Additionally, with loyalty customer reward programs, new business models and other customer relation management programs through cloud-printing and other printing

architectures, additional market data, customer appreciation value information, encryption information, and other types of information on the rise, a manufacturer may desire to store more information on a memory device.

[0013] Moreover, as new technologies develop, circuit space is at a premium. Accordingly, it may be desirable for the greater amounts of data storage to occupy less space within a device. Memristors may be used due to their non-volatility, low operational power consumption characteristics, and their compact size. A memristor selectively stores data based on a resistance state of the memristor. For example, a memristor may be in a low resistance state indicated by a "1," or a high resistance state indicated by a "0." Memristors may form a string of ones and zeroes that will store the aforementioned data. If an analog memristor is used, there may be many different resistance states.

[0014] A memristor may switch between a low resistance state and a high resistance state during a switching event in which a voltage is passed to the memristor. Each memristor has a switching voltage that refers to a voltage used to switch the state of the memristors. When the supplied voltage is greater than the memristors switching voltage, the memristors switches state. The switching voltage is largely based on the size of the memristor. For example, a larger memristor may use a larger voltage to execute a switching event. While memristors may be beneficial as memory storage devices, their use presents a number of complications.

[0015] For example, a smaller memristor may lead to a lower switching current and takes up less space on an integrated circuit. Moreover, space on a computing device may be at a premium and it may therefore be desirable to reduce the size of memristor elements. However, the ability to reduce the size of the memristor may be constrained by the width of the wire electrodes coupled to the memristor. More specifically, the lithographic and etching processes may connote a dimension that represents a smallest feature size that may be achieved for the memristor device. Any reduction in size past this dimension would result in a large capital investment as well as new complex lithographic and etching processes.

[0016] Accordingly, the present specification describes a memristor that alleviates these, and other, complications. More specifically a memristor according to the present specification uses a sacrificial dielectric layer to form a vertical switching oxide. Doing so removes the lithographic and etching processes and allows for a smaller memristor to be formed.

[0017] The present disclosure describes a printhead with a number of vertical oxide memristors having a sacrificial dielectric layer. The printhead includes a number of nozzles to deposit an amount of fluid onto a print medium. Each nozzle includes a firing chamber to hold the amount of fluid, an opening to dispense the amount of fluid onto the print medium, and an ejector to eject the amount of fluid through the opening. The printhead also includes a memristor array having a number of memristors. Each memristor includes a bottom electrode disposed on top of a substrate, a vertical switching oxide abutting the bottom electrode and disposed on top of the substrate, a sacrificial dielectric layer abutting the vertical switching oxide and disposed on top of the substrate, and a top electrode abutting the vertical switching oxide and disposed on top of the sacrificial dielectric layer.

[0018] The present disclosure describes a printer cartridge with a number of vertical oxide memristors having a sacrificially-formed dielectric layer. The cartridge includes a fluid supply and a printhead to deposit fluid from the fluid supply onto a print medium. The printhead includes a memristor array with a number of memristors. Each memristor includes a bottom electrode disposed on top of a substrate, a vertical switching oxide abutting the bottom electrode and disposed on top of the substrate, a sacrificially-formed dielectric layer abutting the vertical switching oxide and disposed on top of the substrate, and a top electrode abutting the vertical switching oxide and disposed on top of the sacrificially-formed dielectric layer.

[0019] More specifically, the present specification describes a method for forming a vertical oxide memristor having a sacrificial dielectric layer. The method includes forming a bottom electrode disposed on a top surface of a substrate, depositing a sacrificial dielectric layer on the bottom electrode and a top surface of the substrate, and forming a top electrode on a top surface of the

sacrificial dielectric layer. The top electrode is in planar orientation relative to the bottom electrode. The method also includes removing a portion of the sacrificial dielectric layer to maintain a portion of the sacrificial dielectric layer underneath the top electrode and forming a vertical switching oxide between the bottom electrode and the top electrode.

[0020] A printer cartridge and a printhead that utilize a vertical oxide memristor having a sacrificial dielectric layer may be beneficial by providing a simplified and cost-effective manufacturing process to produce a memristor that is not constrained by lithographic and etching process restrictions.

[0021] As used in the present specification and in the appended claims, the term "printer cartridge" may refer to a device used in the ejection of ink, or other fluid, onto a print medium. In general, a printer cartridge may be a fluidic ejection device that dispenses fluid such as ink, wax, polymers or other fluids. A printer cartridge may include a printhead. In some examples, a printhead may be used in printers, graphic plotters, copiers and facsimile machines. In these examples, a printhead may eject ink, or another fluid, onto a medium such as paper to form a desired image or a desired three-dimensional geometry.

[0022] Accordingly, as used in the present specification and in the appended claims, the term "printer" is meant to be understood broadly as any device capable of selectively placing a fluid onto a print medium. In one example the printer is an inkjet printer. In another example, the printer is a three-dimensional printer. In yet another example, the printer is a digital titration device.

[0023] Still further, as used in the present specification and in the appended claims, the term "fluid" is meant to be understood broadly as any substance that continually deforms under an applied shear stress. In one example, a fluid may be a pharmaceutical. In another example, the fluid may be an ink. In another example, the fluid may be a liquid.

[0024] Still further, as used in the present specification and in the appended claims, the term "print medium" is meant to be understood broadly as any surface onto which a fluid ejected from a nozzle of a printer cartridge may

be deposited. In one example, the print medium may be paper. In another example, the print medium may be an edible substrate. In yet one more example, the print medium may be a medicinal pill.

[0025] Further, as used in the present specification and in the appended claims, the term “memristor” may refer to a passive two-terminal circuit element that maintains a functional relationship between the time integral of current, and the time integral of voltage. More specifically, a “vertical oxide memristor” is a memristor in which the top electrode and bottom electrode are aligned horizontally with a vertically-oriented switching oxide disposed between the bottom electrode and the top electrode.

[0026] Still further, as used in the present specification and in the appended claims, the term “a number of” or similar language may include any positive number including 1 to infinity; zero not being a number, but the absence of a number.

[0027] In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present systems and methods. It will be apparent, however, to one skilled in the art that the present apparatus, systems, and methods may be practiced without these specific details. Reference in the specification to “an example” or similar language means that a particular feature, structure, or characteristic described is included in at least that one example, but not necessarily in other examples.

[0028] Turning now to the figures, Fig. 1 is a diagram of a printing system (100) according to one example of the principles described herein. The printing system (100) includes a printer (104). The printer (104) includes an interface with a computing device (102). The interface enables the printer (104) and specifically the processor (108) to interface with various hardware elements, such as the computing device (102), external and internal to the printer (104). Other examples of external devices include external storage devices, network devices such as servers, switches, routers, and client devices among other types of external devices.

[0029] In general, the computing device (102) may be any source from which the printer (104) may receive data describing a print job to be executed by the controller (106) of the printer (104) in order to print an image onto the print medium (126). For example, via the interface, the controller (106) receives data from the computing device (102) and temporarily stores the data in the data storage device (110). Data may be sent to the printer (104) along an electronic, infrared, optical, or other information transfer path. The data may represent a document and/or file to be printed. As such, data forms a print job for the printer (104) and includes print job commands and/or command parameters.

[0030] A controller (106) of the printer (104) includes a processor (108), a data storage device (110), and other electronics for communicating with and controlling the printhead (116), mounting assembly (118), and media transport assembly (120). The controller (106) receives data from the computing device (102) and temporarily stores data in the data storage device (110).

[0031] The controller (106) controls the printhead (116) in ejecting fluid from the nozzles (124). For example, the controller (106) defines a pattern of ejected fluid drops that form characters, symbols, and/or other graphics or images on the print medium (126). The pattern of ejected fluid drops is determined by the print job commands and/or command parameters received from the computing device (102). The controller (106) may be an application specific integrated circuit (ASIC) stored on the printer (104) to determine the level of fluid in the printhead (116) based on resistance values of memristors integrated on the printhead (116). The printer ASIC may include a current source and an analog to digital converter (ADC). The ASIC converts a voltage present at the current source to determine a resistance of a memristor, and then determine a corresponding digital resistance value through the ADC. Computer readable program code, executed through executable instructions enables the resistance determination and the subsequent digital conversion through the ADC.

[0032] The processor (108) may include the hardware architecture to retrieve executable code from the data storage device (110) and execute the executable code. The executable code may, when executed by the processor (108), cause the processor (108) to implement at least the functionality of printing on the print medium (126), and actuating the mounting assembly (118) and the media transport assembly (120) according to the present specification. The executable code may, when executed by the processor (108), cause the processor (108) to implement the functionality of providing instructions to the power supply (130) such that the power supply (130) provides power to the components of the printer (104).

[0033] The data storage device (110) may store data such as executable program code that is executed by the processor (108) or other processing device. The data storage device (110) may specifically store computer code representing a number of applications that the processor (108) executes to implement at least the functionality described herein.

[0034] The data storage device (110) may include various types of memory modules, including volatile and nonvolatile memory. For example, the data storage device (110) of the present example includes Random Access Memory (RAM), Read Only Memory (ROM), and Hard Disk Drive (HDD) memory. Many other types of memory may also be utilized, and the present specification contemplates the use of many varying type(s) of memory in the data storage device (110) as may suit a particular application of the principles described herein. In certain examples, different types of memory in the data storage device (110) may be used for different data storage needs. For example, in certain examples the processor (108) may boot from Read Only Memory (ROM), maintain nonvolatile storage in the Hard Disk Drive (HDD) memory, and execute program code stored in Random Access Memory (RAM).

[0035] Generally, the data storage device (110) may include a computer readable medium, a computer readable storage medium, or a non-transitory computer readable medium, among others. For example, the data storage device (110) may be, but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, or device, or

any suitable combination of the foregoing. More specific examples of the computer readable storage medium may include, for example, the following: an electrical connection having a number of wires, a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), a portable compact disc read-only memory (CD-ROM), an optical storage device, a magnetic storage device, or any suitable combination of the foregoing. In the context of this document, a computer readable storage medium may be any tangible medium that can contain, or store computer usable program code for use by or in connection with an instruction execution system, apparatus, or device. In another example, a computer readable storage medium may be any non-transitory medium that can contain, or store a program for use by or in connection with an instruction execution system, apparatus, or device.

[0036] The printing system (100) includes a printer cartridge (114) that includes a printhead (116), a reservoir (112), and a conditioning assembly (132). The printer cartridge (114) may be removable from the printer (104) for example, as a replaceable printer cartridge (114).

[0037] The printer cartridge (114) includes a printhead (116) that ejects drops of fluid through a plurality of nozzles (124) towards a print medium (126). The print medium (126) may be any type of suitable sheet or roll material, such as paper, card stock, transparencies, polyester, plywood, foam board, fabric, canvas, and the like. In another example, the print medium (126) may be an edible substrate. In yet one more example, the print medium (126) may be a medicinal pill.

[0038] Nozzles (124) may be arranged in columns or arrays such that properly sequenced ejection of fluid from the nozzles (124) causes characters, symbols, and/or other graphics or images to be printed on the print medium (126) as the printhead (116) and print medium (126) are moved relative to each other. In one example, the number of nozzles (124) fired may be a number less than the total number of nozzles (124) available and defined on the printhead (116).

[0039] The printer cartridge (114) also includes a fluid reservoir (112) to supply an amount of fluid to the printhead (116). In general, fluid flows from the reservoir (112) to the printhead (116), and the reservoir (112) and the printhead (116) form a one-way fluid delivery system or a recirculating fluid delivery system. In a one-way fluid delivery system, fluid supplied to the printhead (116) is consumed during printing. In a recirculating fluid delivery system, however, a portion of the fluid supplied to printhead (116) is consumed during printing. Fluid not consumed during printing is returned to the reservoir (112).

[0040] The reservoir (112) may supply fluid under positive pressure through a conditioning assembly (132) to the printhead (116) via an interface connection, such as a supply tube. The reservoir (112) may include pumps and pressure regulators. Conditioning in the conditioning assembly (132) may include filtering, pre-heating, pressure surge absorption, and degassing. Fluid is drawn under negative pressure from the printhead (116) to the reservoir (112). The pressure difference between the inlet and outlet to the printhead (116) is selected to achieve the correct backpressure at the nozzles (124).

[0041] A mounting assembly (118) positions the printhead (116) relative to media transport assembly (120), and media transport assembly (120) positioning the print medium (126) relative to printhead (116). Thus, a print zone (128), indicated by the dashed box, is defined adjacent to the nozzles (124) in an area between the printhead (116) and the print medium (126). In one example, the printhead (116) is a scanning type printhead (116). As such, the mounting assembly (118) includes a carriage for moving the printhead (116) relative to the media transport assembly (120) to scan the print medium (126). In another example, the printhead (116) is a non-scanning type printhead (116). As such, the mounting assembly (118) fixes the printhead (116) at a prescribed position relative to the media transport assembly (120). Thus, the media transport assembly (120) positions the print medium (126) relative to the printhead (116).

[0042] Fig. 2A is a diagram of a printer cartridge (114) and printhead (116) with a number of vertical oxide memristors having a sacrificial dielectric

layer according to one example of the principles described herein. As discussed above, the printhead (116) may comprise a number of nozzles (124). In some examples, the printhead (116) may be broken up into a number of print dies with each die having a number of nozzles (124). The printhead (116) may be any type of printhead (116) including, for example, a printhead (116) as described in Figs. 2A and 2B. The examples shown in Figs. 2A and 2B are not meant to limit the present description. Instead, various types of printheads (116) may be used in conjunction with the principles described herein.

[0043] The printer cartridge (114) also includes a fluid reservoir (112), a flexible cable (236), conductive pads (238), and a memristor array (240). The flexible cable (236) is adhered to two sides of the printer cartridge (114) and contains traces that electrically connect the memristor array (240) and printhead (116) with the conductive pads (238).

[0044] The printer cartridge (114) may be installed into a cradle that is integral to the carriage of a printer (Fig. 1, 104). When the printer cartridge (114) is correctly installed, the conductive pads (238) are pressed against corresponding electrical contacts in the cradle, allowing the printer (Fig. 1, 104) to communicate with, and control the electrical functions of, the printer cartridge (114). For example, the conductive pads (238) allow the printer (Fig. 1, 104) to access and write to the memristor array (240).

[0045] The memristor array (240) may contain a variety of information including the type of printer cartridge (114), the kind of fluid contained in the printer cartridge (114), an estimate of the amount of fluid remaining in the fluid reservoir (112), calibration data, error information, and other data. In one example, the memristor array (240) may include information regarding when the printer cartridge (114) should be maintained. The memristor array (240) may include other information as described below in connection with Fig. 3.

[0046] To create an image, the printer (Fig. 1, 104) moves the carriage containing the printer cartridge (114) over a print medium (Fig. 1, 126). At appropriate times, the printer (Fig. 1, 104) sends electrical signals to the printer cartridge (114) via the electrical contacts in the cradle. The electrical signals pass through the conductive pads (238) and are routed through the

flexible cable (236) to the printhead (116). The printhead (116) then ejects a small droplet of fluid from the reservoir (112) onto the surface of the print medium (Fig. 1, 126). These droplets combine to form an image on the surface of the print medium (Fig. 1, 126).

[0047] The printhead (116) may include any number of nozzles (124). In an example where the fluid is an ink, a first subset of nozzles (124) may eject a first color of ink while a second subset of nozzles (124) may eject a second color of ink. Additional groups of nozzles (124) may be reserved for additional colors of ink.

[0048] Fig. 2B is a cross sectional diagram of a printer cartridge (114) and printhead (116) with a number of vertical oxide memristors having a sacrificial dielectric layer according to one example of the principles described herein. The printer cartridge (114) may include a fluid supply (112) that supplies the fluid to the printhead (116) for deposition onto a print medium. In some examples, the fluid may be ink. For example, the printer cartridge (114) may be an inkjet printer cartridge, the printhead (116) may be an inkjet printhead, and the ink may be inkjet ink.

[0049] The printer cartridge (114) may include a printhead (116) to carry out at least a part of the functionality of depositing fluid onto a print medium. The printhead (116) may include a number of components for depositing a fluid onto a surface. For example, the printhead (116) may include a number of nozzles (124). For simplicity, Fig. 2B indicates a single nozzle (124), however a number of nozzles (124) are present on the printhead (116). A nozzle (124) may include an ejector (242), a firing chamber (244), and an opening (246). The opening (246) may allow fluid, such as ink, to be deposited onto a surface, such as a print medium (Fig. 1, 126). The firing chamber (244) may include a small amount of fluid. The ejector (242) may be a mechanism for ejecting fluid through the opening (246) from a firing chamber (244), where the ejector (242) may include a firing resistor or other thermal device, a piezoelectric element, or other mechanism for ejecting fluid from the firing chamber (244).

[0050] For example, the ejector (242) may be a firing resistor. The firing resistor heats up in response to an applied voltage. As the firing resistor heats up, a portion of the fluid in the firing chamber (244) vaporizes to form a bubble. This bubble pushes liquid fluid out the opening (246) and onto the print medium (Fig. 1, 126). As the vaporized fluid bubble pops, a vacuum pressure within the firing chamber (244) draws fluid into the firing chamber (244) from the fluid supply (112), and the process repeats. In this example, the printhead (116) may be a thermal inkjet printhead.

[0051] In another example, the ejector (242) may be a piezoelectric device. As a voltage is applied, the piezoelectric device changes shape which generates a pressure pulse in the firing chamber (244) that pushes a fluid out the opening (246) and onto the print medium (Fig. 1, 126). In this example, the printhead (116) may be a piezoelectric inkjet printhead.

[0052] The printhead (116) and printer cartridge (114) may also include other components to carry out various functions related to printing. For simplicity, in Figs. 2A and 2B, a number of these components and circuitry included in the printhead (116) and printer cartridge (114) are not indicated; however such components may be present in the printhead (116) and printer cartridge (114). In some examples, the printer cartridge (114) is removable from a printing system for example, as a disposable printer cartridge.

[0053] Fig. 3 is a block diagram of a printer cartridge (114) that uses a printhead (116) with a number of vertical oxide memristors having a sacrificial dielectric layer according to one example of the principles described herein. In some examples, the printer cartridge (114) includes a printhead (116) that carries out at least a part of the functionality of the printer cartridge (114). For example, the printhead (116) may include a number of nozzles (Fig. 1, 124). The printhead (116) ejects drops of fluid from the nozzles (Fig. 1, 124) onto a print medium (Fig. 1, 126) in accordance with a received print job. The printhead (116) may also include other circuitry to carry out various functions related to printing. In some examples, the printhead (116) is part of a larger system such as an integrated printhead (IPH). The printhead (116) may be of varying types. For example, the printhead (116) may be a thermal inkjet (TIJ)

printhead or a piezoelectric inkjet (PIJ) printhead, among other types of printhead (116).

[0054] The printhead (116) includes a memristor array (240) to store information relating to at least one of the printer cartridge (114) and the printhead (116). In some examples, the memristor array (240) includes a number of memristor cells (348) formed in the printhead (116). To store information, a memristor within each memristor cell (348) may be set to a particular resistance state. As memristors are non-volatile, this resistance state is retained even when power is removed from the printhead (116).

[0055] A memristor has a metal-insulator-metal layered structure. More specifically, the memristor may include a bottom electrode (metal), a switching oxide (insulator), and a top electrode (metal). A memristor may be classified as an anion device which includes an oxide insulator. Examples of such oxide insulators include transition metal oxides, complex oxides, and large band gap dielectrics in addition to other non-oxide materials. In this example, an aluminum-copper-silicon alloy oxide or tantalum oxide may be an example of a switching oxide in an anion device. In an anionic device, the switching mechanism is the oxygen vacancies in the oxide that are positively charged. By comparison, in a cation device the electrodes (i.e., the bottom electrode, the top electrode, or combinations thereof) are formed from an electrochemically active metal such as copper or silver.

[0056] The number of memristor cells (348) are grouped together into a memristor array (240). In some examples, the memristor array (240) may be a cross bar array. In this example, each memristor may be formed at an intersection of a first set of elements and a second number of elements, the elements forming a grid of intersecting nodes, each node defining a memristor. In another example, the memristor array (240) may include a number of memristor cells (348) that form a one-to-one structure with a number of transistors. For example, an integrated circuit may include a number of addressing units. Each addressing unit may include a number of components that allow for multiplexing and logic operations. The memristor cell (348) may be designed to be individually addressed by a distinct addressing unit. In some

examples, the addressing units may be transistors. In this example, the memristor cell (348) may share a one transistor-one memristor (1T1M) addressing structure with the addressing units of the integrated circuit.

[0057] The memristor array (240) may be used to store any type of data. Examples of data that may be stored in the memristor array (240) include fluid supply specific data and/or fluid identification data, fluid characterization data, fluid usage data, printhead (116) specific data, printhead (116) identification data, warranty data, printhead (116) characterization data, printhead (116) usage data, authentication data, security data, Anti-Counterfeiting data (ACF), ink drop weight, firing frequency, initial printing position, acceleration information, and gyro information, among other forms of data. In a number of examples, the memristor array (240) is written at the time of manufacturing and/or during the operation of the printer cartridge (114).

[0058] In some examples, the printer cartridge (114) may be coupled to a controller (106) that is disposed within the printer (Fig. 1, 104). The controller (106) receives a control signal from an external computing device (Fig. 1, 102). The controller (106) may be an Application-Specific Integrated Circuit (ASIC) found on the printer (Fig. 1, 104). A computing device (Fig. 1, 102) may send a print job to the printer cartridge (114), the print job being made up of text, images, or combinations thereof to be printed. The controller (106) may facilitate storing information to the memristor array (240). Specifically, the controller (106) may pass at least one control signal to the number of memristor cells (348). For example, the controller (106) may be coupled to the printhead (116), via a control line such as an identification line. Via the identification line, the controller (106) may change the resistance state of a number of memristors in the memristor array (240) to effectively store information to a memristor array (240). For example, the controller (106) may send data such as authentication data, security data, and print job data, in addition to other types of data to the printhead (116) to be stored on the memristor array (240).

[0059] While specific reference is made to an identification line, the controller (106) may share a number of lines of communication with the

printhead (116), such as data lines, clock lines, and fire lines. For simplicity, in Fig. 3 the different communication lines are indicated by a single arrow.

[0060] Figs. 4A and 4B are views of a vertical oxide memristor (348) having a sacrificial dielectric layer (450) according to one example of the principles described herein. Specifically, Fig. 4A is a cross-sectional view of the vertical oxide memristor (348) and Fig. 4B is a top view of the vertical oxide memristor (348).

[0061] The memristor (348), indicated in Fig. 4A by the dashed box, may have a metal-insulator-metal layered structure. More specifically, the memristor (348) may include a bottom electrode (452), a vertical switching oxide (454), and a top electrode (456).

[0062] The bottom electrode (452) may be an electrical connection between the memristor (348) and other components. As will be described below, the top electrode (456) may also be an electrical connection between the memristor (348) and other components. For example, a surface of the bottom electrode (452) may be coupled to a first routing element (458-1). The routing element (458-1) may be an electrical communication component that passes a control signal to the memristor (348). For example, the controller (Fig. 1, 106) may pass a control signal through the routing element (458-1) to change the state of the memristor (348) such that the memristor (348) may store information for the printer cartridge (Fig. 1, 114). Other examples of components that may attach to the bottom electrode (452) include a ground connection, a number of connection pads, a current regulator, a capacitor, a resistor, and metal traces, among other memristor array (Fig. 2, 240) components.

[0063] The bottom electrode (452) may be formed of a number of metallic materials, or any other material that conducts electricity. Examples of such mechanical materials include titanium nitride, tantalum, tantalum nitride, platinum, aluminum, copper, an aluminum-copper alloy, and an aluminum-copper-silicon alloy among other metallic materials. In some examples, the bottom electrode (452) may be of varying thicknesses such as between 4,000 and 8,000 angstroms (Å) thick. The bottom electrode (452) may be disposed on

a substrate (460). The substrate (460) may be any material that provides mechanical rigidity to the memristor (348). For example, the substrate (460) may be formed of a dielectric material, such as silicon oxide, that may be formed on top of a silicon wafer. Other examples of dielectric materials that may form a portion of the substrate (460) include un-doped silicon glass (USG), borophosphosilicate glass (BPSG), tetraethyl orthosilicate (TEOS), and combinations thereof, among other dielectric materials.

[0064] The memristor (348) also includes a vertical switching oxide (454) that abuts the bottom electrode (452) and is also disposed on top of the substrate (460). For example, the vertical switching oxide (454) may abut a side surface of the bottom electrode (452) and may be disposed on a top surface of the substrate (460). The vertical switching oxide (454) may be an insulator between the bottom electrode (452) and the top electrode (456). For example, in a first state, the vertical switching oxide (454) may be insulating such that current does not readily pass from the bottom electrode (452) to the top electrode (456). Then, during a switching event, the vertical switching oxide (454) may switch to a second state, becoming conductive. In a conductive state, the vertical switching oxide (454) allows a memristor (348) to store information by changing the memristor state. In some examples, the vertical switching oxide (454) may be less than 1.2 micrometers thick.

[0065] As will be described in more detail in connection with Figs. 6E-6H, the vertical switching oxide (454) may be formed using a sacrificial dielectric layer (450). Using a sacrificial dielectric layer (450) in this fashion may be advantageous in that size-limiting processes such as lithography and etching may not have a restricting impact on the size of the vertical switching oxide (454).

[0066] In some examples, the vertical switching oxide (454) may be made of a metal oxide or nitride-based dielectric material. Specific examples of vertical switching oxide (454) materials include magnesium oxide, titanium oxide, zirconium oxide, hafnium oxide, vanadium oxide, niobium oxide, tantalum oxide, chromium oxide, molybdenum oxide, tungsten oxide, manganese oxide, iron oxide, cobalt oxide, copper oxide, zinc oxide, aluminum oxide, gallium

oxide, silicon oxide, germanium oxide, tin dioxide, bismuth oxide, nickel oxide, yttrium oxide, gadolinium oxide, and rhenium oxide, among other oxides. In addition to the binary oxides presented, the vertical switching oxide (454) may be ternary and complex oxides such as silicon oxynitride. The oxides presented may be formed using a number of different processes such as sputtering from an oxide target or oxidizing a deposited metal or alloy layer.

[0067] The memristor (348) also includes a sacrificial dielectric layer (450) that abuts the vertical switching oxide (454) and is disposed on top of the substrate (460). For example, the sacrificial dielectric layer (450) may abut a side surface of the vertical switching oxide (454) and may be disposed on a top surface of the substrate (460). As will be described in connection with Figs. 5 and 6A-6K, a portion of the sacrificial dielectric layer (450) that is beneath the top electrode (456) remains after an etching process. The sacrificial dielectric layer (450) may be oriented planar relative to the bottom electrode (452) and the top electrode (456). As will be described in Figs. 5 and 6A-6K, the use of a sacrificial dielectric layer (450) is beneficial by offering a simplified manufacturing process of a vertical memristor (348) that avoids complex and expensive operations.

[0068] The memristor (348) also includes a top electrode (456) that abuts the vertical switching oxide (454) and is disposed on top of the sacrificial dielectric layer (450). For example, the top electrode (456) abuts a side surface of the vertical switching oxide (454) and is disposed on a top surface of the sacrificial dielectric layer (450). In other words, the top electrode (456) may be vertically-positioned relative to the sacrificial dielectric layer (450) and may be horizontally-positioned relative to the vertical switching oxide (454) and the bottom electrode (452).

[0069] As with the bottom electrode (452), the top electrode (456) may be an electrical connection between the memristor (348) and other components. Via a top surface, the top electrode (456) may be coupled to a second routing element (458-2) such as a data line. Other examples of components that may attach to the top electrode (456) include a ground connection, a number of connection pads, a current regulator, a capacitor, a

resistor, and metal traces, among other memristor array (Fig. 2, 240) components.

[0070] In some examples, the top electrode (456) may be formed from a metallic material such as tantalum or a tantalum-aluminum alloy, or other conducting material such as titanium, titanium nitride, copper, aluminum, platinum, and gold among other metallic materials. The top electrode (456) may be of varying thickness. For example, the top electrode (456) may be between 4,000 and 8,000 angstroms (Å) thick.

[0071] The memristor (348) may also include a dielectric layer (462) to electrically isolate the memristor (348) from other memristors (348) in an array (Fig. 2, 240) as well as to electrically isolate the components within a memristor (348).

[0072] In some examples, the memristor array (Fig. 2, 240) may be a cross bar array. In this example, each memristor (348) may be formed at an intersection of a first set of elements and a second number of elements, the elements forming a grid of intersecting nodes, each node defining a memristor (348). In another example, the memristor array (Fig. 2, 240) may include a number of memristors (348) that form a one-to-one structure with a number of transistors. For example, an integrated circuit may include a number of addressing units. Each addressing unit may include a number of components that allow for multiplexing and logic operations. The memristor (348) may be designed to be individually addressed by a distinct addressing unit. In some examples, the addressing units may be transistors. In this example, the memristor (348) may share a one transistor-one memristor (1T1M) addressing structure with the addressing units of the integrated circuit.

[0073] Fig. 5 is a flowchart of a method (500) for forming a vertical oxide memristor (Fig. 3, 348) having a sacrificial dielectric layer (Fig. 4, 450) according to one example of the principles described herein. The method (500) includes forming (block 501) a bottom electrode (Fig. 4, 452) on a top surface of the substrate (Fig. 4, 460). As described above, the substrate (Fig. 4, 460) may be any material that provides mechanical rigidity to the memristor (Fig. 3, 348), such as silicon for example. The bottom electrode (Fig. 4, 452) may be formed

by a number of formation processes such as physical vapor deposition (PVD), metal sputtering, metal alloy sputtering, and evaporation, among other types of formation processes. In some examples, forming (block 501) the bottom electrode (Fig. 4, 452) may include deposition of a metallic substance on a top surface of the substrate (Fig. 4, 460) and etching the substance to generate a geometry defined as the bottom electrode (Fig. 4, 452). The formation (block 501) of the bottom electrode (Fig. 4, 452) is depicted in Fig. 6A.

[0074] The method (500) also includes depositing (block 502) a sacrificial dielectric layer (Fig. 4, 450) on the substrate (Fig. 4, 460) and the bottom electrode (Fig. 4, 452). For example, the sacrificial dielectric layer (Fig. 4, 450) may be blanket deposited on the bottom electrode (Fig. 4, 452) and a top surface of the substrate (Fig. 4, 460). The portion of the sacrificial dielectric (Fig. 4, 450) deposited on the side surface of the bottom electrode (Fig. 4, 452) may be adjacent to a portion of the sacrificial dielectric (Fig. 4, 450) that is deposited on a top surface of the substrate (Fig. 4, 460) as depicted in Fig. 6B.

[0075] As depicted in Fig. 6D, the portion of the sacrificial dielectric layer (Fig. 4, 450) that is adjacent to the side surface of the bottom electrode (Fig. 4, 452) may be etched away such that a space is created between the bottom electrode (Fig. 4, 452) and the top electrode (Fig. 4, 456). This space is subsequently filled with an oxide material to form the vertical switching oxide (Fig. 4, 454). A first portion of the sacrificial dielectric layer (Fig. 4, 450) that is disposed on a top surface of the substrate (Fig. 4, 460) will similarly be etched away, while a second portion of the sacrificial dielectric layer (Fig. 4, 450), specifically a portion underneath the top electrode (Fig. 4, 456) may remain.

[0076] The method (500) also includes forming (block 503) a top electrode (Fig. 4, 456) on the sacrificial dielectric layer (Fig. 4, 450). More specifically, the top electrode (Fig. 4, 456) may abut a portion of the sacrificial dielectric layer (Fig. 4, 450) that is disposed on the side surface of the bottom electrode (Fig. 4, 452) as depicted in Fig. 6C. In this example, the top electrode (Fig. 4, 456) is planarly-oriented relative to the bottom electrode (Fig. 4, 452).

[0077] The top electrode (Fig. 4, 456) may be formed (block 503) by a number of formation processes such as physical vapor deposition (PVD). In

some examples, forming (block 503) the top electrode (Fig. 4, 456) may include deposition of a metallic substance and etching of the substance to generate a geometry defined as the top electrode (Fig. 4, 456). The formation (block 503) of the top electrode (Fig. 4, 456) is depicted in Fig. 6C.

[0078] A portion of the sacrificial dielectric layer (Fig. 4, 450) may then be removed (block 504). Specifically, a portion of the sacrificial dielectric layer (Fig. 4, 450) may be removed such that a portion of the sacrificial dielectric layer (Fig. 4, 450) that is underneath the top electrode (Fig. 4, 456) may remain intact. As described above, a vertical switching oxide (Fig. 4, 454) may then be formed (block 505) between the bottom electrode (Fig. 4, 452) and the top electrode (Fig. 4, 456). More specifically, the vertical switching oxide (Fig. 4, 454) may be formed in a cavity that was previously occupied by a removed portion of the sacrificial dielectric layer (Fig. 4, 450) that was disposed between the bottom electrode (Fig. 4, 452) and the top electrode (Fig. 4, 456) as indicated below in Figs. 6E-6H. Forming (block 505) the vertical switching oxide (Fig. 4, 454) may include depositing a switching oxide material and etching a portion of the switching oxide material away. For example, the switching oxide material may be deposited across an entire surface of the memristor (Fig. 3, 348) as indicated in Figs. 6E and 6F and then etching away a portion of the switching oxide to retain a vertical portion, which vertical portion is disposed between the bottom electrode (Fig. 4, 452) and the top electrode (Fig. 4, 456) as indicated in Figs. 6G and 6H.

[0079] In one example, the vertical switching oxide (Fig. 4, 454) may be formed (block 505) by a deposition process such as physical vapor deposition wherein atoms or molecules may be ejected from a target material onto the bottom electrode (Fig. 4, 452), the top electrode (Fig. 4, 456), the substrate (Fig. 4, 460) or combinations thereof. For example, a target material is bombarded with energetic particles. In response, atoms or molecules of the target material are dislodged and built up to form the vertical switching oxide (Fig. 4, 454). A deposition process is illustrated in Figs. 6E and 6G.

[0080] In another example, the vertical switching oxide (Fig. 4, 454) may be formed by a metal oxidation process. For example, the vertical

switching oxide (Fig. 4, 454) may be formed by thermal oxidation, a process which exposes the bottom electrode (Fig. 4, 452) and top electrode (Fig. 4, 456) to oxidizing agents at elevated temperatures. Specific examples of thermal oxidation processes that may be used include a furnace oxidation process, a rapid thermal process, a rapid thermal oxidation, and a rapid thermal annealing, among other oxidation processes. In some examples, the vertical switching oxide (Fig. 4, 454) is formed by performing plasma oxidation, which exposes the bottom electrode (Fig. 4, 452) and top electrode (Fig. 4, 456) to oxygen plasma at controlled temperatures. In some examples, a bi-metal vertical switching oxide (Fig. 4, 454) may be formed. A bi-metal vertical switching oxide (Fig. 4, 454) may indicate that a number of materials make up the switching oxide. A bi-metal switching oxide may be formed by forming the bottom electrode (Fig. 4, 452) and the top electrode (Fig. 4, 456) out of different materials. For example, the bi-metal switching oxide may be formed at the surfaces of the bottom electrode (Fig. 4, 452) and the top electrode (Fig. 4, 456). Then through an oxidation process distinct switching oxide materials may form on each electrode to form a bi-metal vertical switching oxide (Fig. 4, 454). While specific examples of vertical switching oxide (Fig. 4, 454) formation processes have been given, other oxide forming processes are also contemplated by the present specification.

[0081] The method (500) may include other operations such as depositing at least one dielectric layer (Fig. 4, 462) and forming routing elements (Fig. 4, 458-1, 458-2) within the dielectric layers (Fig. 4, 462). The routing elements (Fig. 4, 458-1, 458-2) being in electrical communication with the bottom electrode (Fig. 4, 452), the top electrode (Fig. 4, 456), or combinations thereof as will be depicted below in connection with Figs. 6A-6K.

[0082] Figs. 6A-6K are diagrams illustrating the formation of a vertical oxide memristor (Fig. 3, 348) having a sacrificial dielectric layer (Fig. 4, 450) according to one example of the principles described herein. Specifically, Fig. 6A depicts a bottom electrode (452) being formed on a substrate (460). As described above, the bottom electrode (452) may be a metallic substance made of titanium, tantalum, copper, aluminum, platinum, and alloys thereof, among

other metallic substances. The metallic substance may be deposited on the substrate (460) and etched to form a geometry referred to as the bottom electrode (452).

[0083] In some examples, the substrate (460) may include a first dielectric layer that is deposited on a top surface of a silicon wafer. The dielectric layer may be USG, BPSG, silicon nitride, tetraethyl orthosilicate, and combinations thereof, among other dielectrics. The first dielectric layer may electrically isolate the memristor (Fig. 3, 348) from other memristors (Fig. 3, 348) and may electrically isolate the individual components of the memristor (Fig. 3, 348).

[0084] In Fig. 6B, the sacrificial dielectric (Fig. 4, 450) is deposited on top of the bottom electrode (452) and the substrate (460). More specifically, a sacrificial dielectric material (450-1) is deposited such that it abuts a side surface of the bottom electrode (452) and is disposed on a top surface of the substrate (460).

[0085] In Fig. 6C, the top electrode (456) is formed on top of the sacrificial dielectric material (450-1). More specifically, the top electrode (456) is formed on a top surface of the sacrificial dielectric material (450-1) such that it is adjacent to a portion of the sacrificial dielectric material (450-1) that abuts the side surface of the bottom electrode (452). In other words, a portion of the sacrificial dielectric material (450-1) is positioned between the vertical walls of the bottom electrode (452) and the top electrode (456). As with the bottom electrode (452), formation of the top electrode (456) may include deposition of a metallic substance and the metallic substance may be etched to form a geometry referred to as the top electrode (456).

[0086] A portion of the sacrificial dielectric material (450-1) may then be etched away as depicted in Fig. 6D to form the sacrificial dielectric layer (450). Specifically, a portion of the sacrificial dielectric material (450-1) that is not underneath the top electrode (456) may be etched away. Doing so may leave a portion of the sacrificial dielectric material (450-1) underneath the top electrode (456) intact as the sacrificial dielectric layer (450). The etching away also removes a portion of the sacrificial dielectric material (450-1) that is

disposed between the bottom electrode (452) and the top electrode (456) that will be filled by the vertical switching oxide (Fig. 4, 454).

[0087] As described above, the vertical switching oxide (Fig. 4, 454) may be formed in a number of ways. In a first example, as depicted in Figs. 6E and 6G, a switching oxide material (454-1) may be deposited on top of the bottom electrode (452), the top electrode (456) and the substrate (460). The switching oxide material (454-1) may then be etched away as indicated in Fig. 6G to form the vertical switching oxide (454) between the bottom electrode (452) and the top electrode (456).

[0088] In another example, as depicted in Figs. 6F and 6H, each of the bottom electrode (452) and the top electrode (456) may be oxidized such that two separate switching oxide materials (454-1, 454-2) are formed on the bottom electrode (452) and the top electrode (456) respectively. The switching oxide materials (454-1, 454-2) may then be etched away as indicated in Fig. 6H to form a bi-metal switching oxide (454) between the bottom electrode (452) and the top electrode (456).

[0089] As described above, the method (Fig. 5, 500) may include deposition of another dielectric layer (462). Fig. 6I depicts the deposition of a dielectric material (462-1) to electrically isolate the components within a memristor (Fig. 3, 348) as well as to electrically isolate the memristor (Fig. 3, 348) from other memristors (Fig. 3, 348).

[0090] Fig. 6J depicts a portion of the dielectric material (462-1) being etched to make the dielectric layer (462) which houses the routing elements (458) that electrically couple the bottom electrode (452) and the top electrode (456) to other components such as the controller (Fig. 1, 106) and other control lines.

[0091] Fig. 6K depicts the deposition and etching of a metallic substance to form the routing elements (458-1, 458-2) used to couple the memristor (Fig. 3, 348) to other components.

[0092] The method (500) and operations depicted in Figs. 5 and 6A-6K may be beneficial in that a memristor (Fig. 3, 348) on a printhead (Fig. 1, 116) may be reduced to a smaller size and may not be constrained to the lithography

and etch process constraints. Moreover, the memristor (Fig. 3, 348) described herein may be robust in that it is positioned on a thick substrate (Fig. 4, 460) and is not as susceptible to breakdown.

[0093] A printer cartridge (Fig. 1, 114) and printhead (Fig. 1, 116) with a number of vertical oxide memristors (Fig. 3, 348) having a sacrificial dielectric layer (Fig. 4, 450) may have a number of advantages, including: (1) reducing the size of the memristor (Fig. 3, 348) smaller than allowed by lithographic techniques; (2) reducing a manufacturing cost of the memristor (Fig. 3, 348); (3) providing a simple, cost-effective bi-metal memristor (Fig. 3, 348); (4) improving printhead (Fig. 1, 116) memory performance; and (5) reducing cost of effective memristor (Fig. 3, 348) fabrication.

[0094] Aspects of the present system are described herein with reference to flowchart illustrations and/or block diagrams of methods, apparatus (systems) and computer program products according to examples of the principles described herein. Each block of the flowchart illustrations and block diagrams, and combinations of blocks in the flowchart illustrations and block diagrams, may be implemented by computer usable program code. The computer usable program code may be provided to a processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the computer usable program code, when executed via, for example, the processor (Fig. 1, 108) of the printer (Fig. 1, 104) or other programmable data processing apparatus, implement the functions or acts specified in the flowchart and/or block diagram block or blocks. In one example, the computer usable program code may be embodied within a computer readable storage medium; the computer readable storage medium being part of the computer program product. In one example, the computer readable storage medium is a non-transitory computer readable medium.

[0095] The preceding description has been presented to illustrate and describe examples of the principles described. This description is not intended to be exhaustive or to limit these principles to any precise form disclosed. Many modifications and variations are possible in light of the above teaching.

CLAIMS

WHAT IS CLAIMED IS:

1. A printhead with a number of vertical oxide memristors having a sacrificial dielectric layer, the printhead comprising:
 - a number of nozzles to deposit an amount of fluid onto a print medium, each nozzle comprising:
 - a firing chamber to hold the amount of fluid;
 - an opening to dispense the amount of fluid onto the print medium;
 - and
 - an ejector to eject the amount of fluid through the opening; and
 - a memristor array comprising a number of memristors, each memristor comprising:
 - a bottom electrode disposed on a substrate;
 - a vertical switching oxide abutting the bottom electrode and disposed on the substrate;
 - a sacrificial dielectric layer abutting the vertical switching oxide and disposed on the substrate; and
 - a top electrode abutting the vertical switching oxide and disposed on the sacrificial dielectric layer.
2. The printhead of claim 1, in which the fluid is inkjet ink.
3. The printhead of claim 1, in which the memristor array is a cross bar array.
4. The printhead of claim 1, in which the vertical switching oxide is less than 1.2 micrometers thick.
5. A printer cartridge with a number of vertical oxide memristors having a sacrificially-formed dielectric layer, the cartridge comprising:

a fluid supply; and
a printhead to deposit fluid from the fluid supply onto a print medium, the printhead comprising:

a memristor array comprising a number of memristors, each memristor comprising:

a bottom electrode disposed on a substrate;
a vertical switching oxide abutting the bottom electrode and disposed on the substrate;
a sacrificially-formed dielectric layer abutting the vertical switching oxide and disposed on the substrate; and
a top electrode abutting the vertical switching oxide and disposed on the sacrificial dielectric layer.

6. The cartridge of claim 5, in which:
the fluid is inkjet ink;
the printer cartridge is an inkjet printer cartridge; and
the printhead is an inkjet printhead.
7. The cartridge of claim 5, in which the cartridge passes at least one control signal from a controller to the memristor array.
8. The cartridge of claim 5, in which a number of memristors share a bottom electrode, a top electrode, or combinations thereof.
9. A method for forming a vertical oxide memristor having a sacrificial dielectric layer, the method comprising:
forming a bottom electrode disposed on a top surface of a substrate;
depositing a sacrificial dielectric layer on the bottom electrode and a top surface of the substrate;
forming a top electrode on a top surface of the sacrificial dielectric layer, in which the top electrode is in planar orientation relative to the bottom electrode;

removing a portion of the sacrificial dielectric layer to maintain a portion of the sacrificial dielectric layer underneath the top electrode; and
forming a vertical switching oxide between the bottom electrode and the top electrode.

10. The method of claim 9, in which a portion of the sacrificial dielectric layer is deposited on a side surface of the bottom electrode adjacent to a portion of the sacrificial dielectric layer deposited on a top surface of the substrate.

11. The method of claim 10, in which:
a side surface of the top electrode abuts the portion of the sacrificial layer deposited on a side surface of the bottom electrode; and
a bottom surface of the top electrode abuts the portion of the sacrificial layer deposited on a top surface of the substrate.

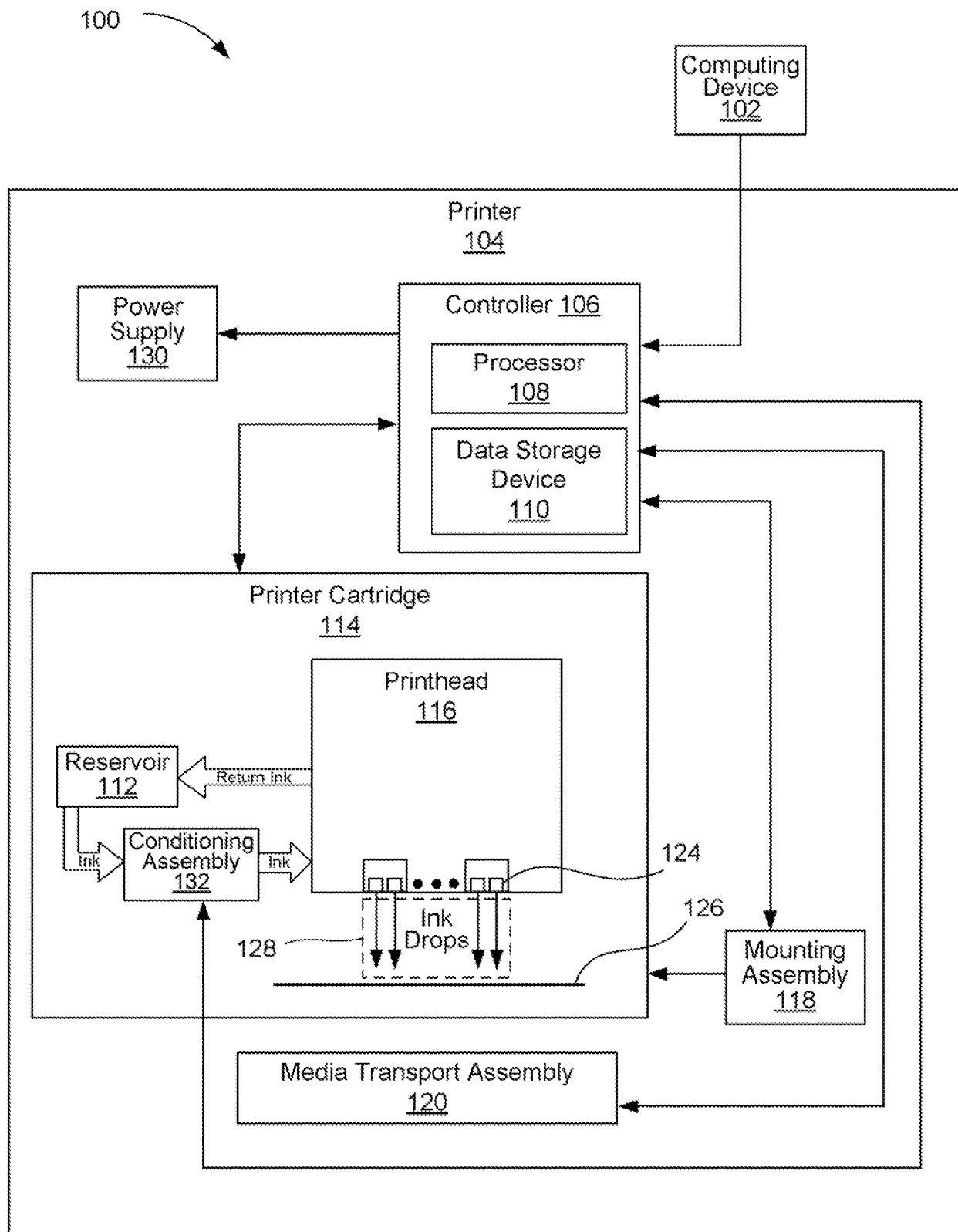
12. The method of claim 9, in which forming a vertical switching oxide comprises switching oxide deposition.

13. The method of claim 9, in which forming a vertical switching oxide comprises metal oxidation of the bottom electrode, the top electrode, or combinations thereof.

14. The method of claim 9, in which the vertical switching oxide is a bi-metal vertical switching oxide.

15. The method of claim 9, further comprising:
depositing at least one dielectric layer; and
forming routing elements in at least one of the dielectric layers, in which the routing elements are in electrical communication with the bottom electrode, the top electrode, or combinations thereof.

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**Fig. 1**

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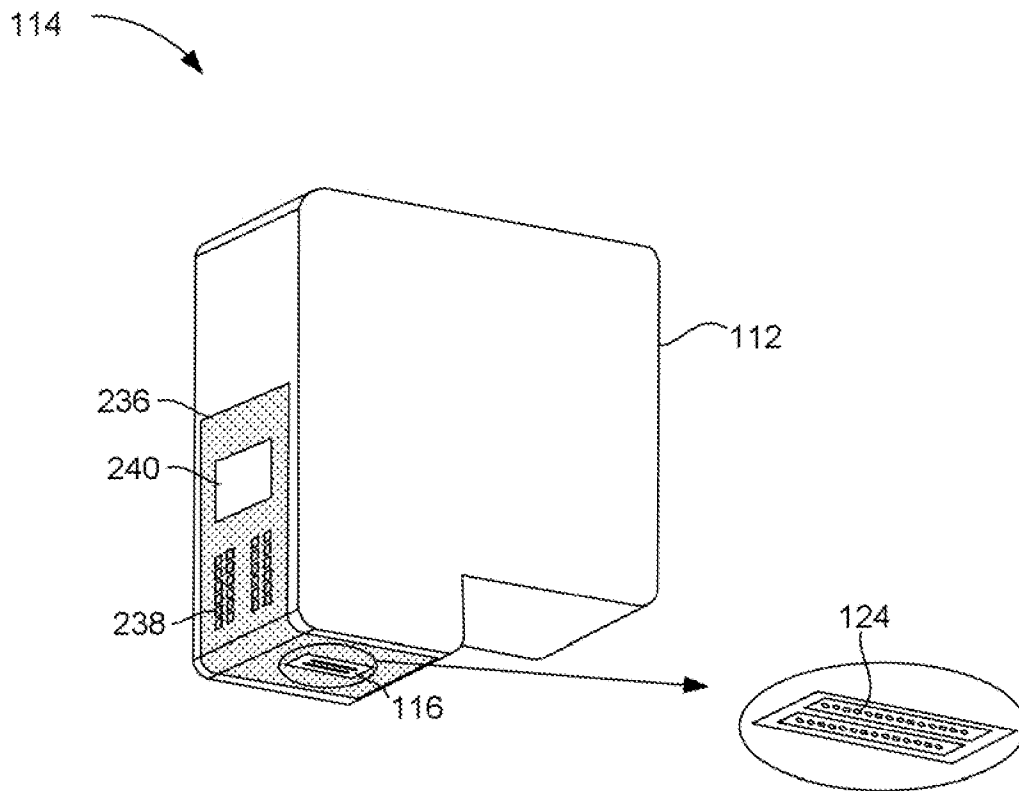


Fig. 2A

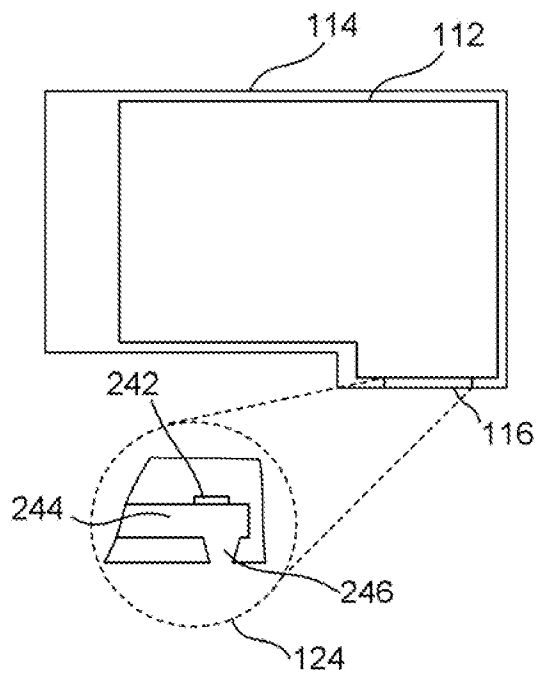
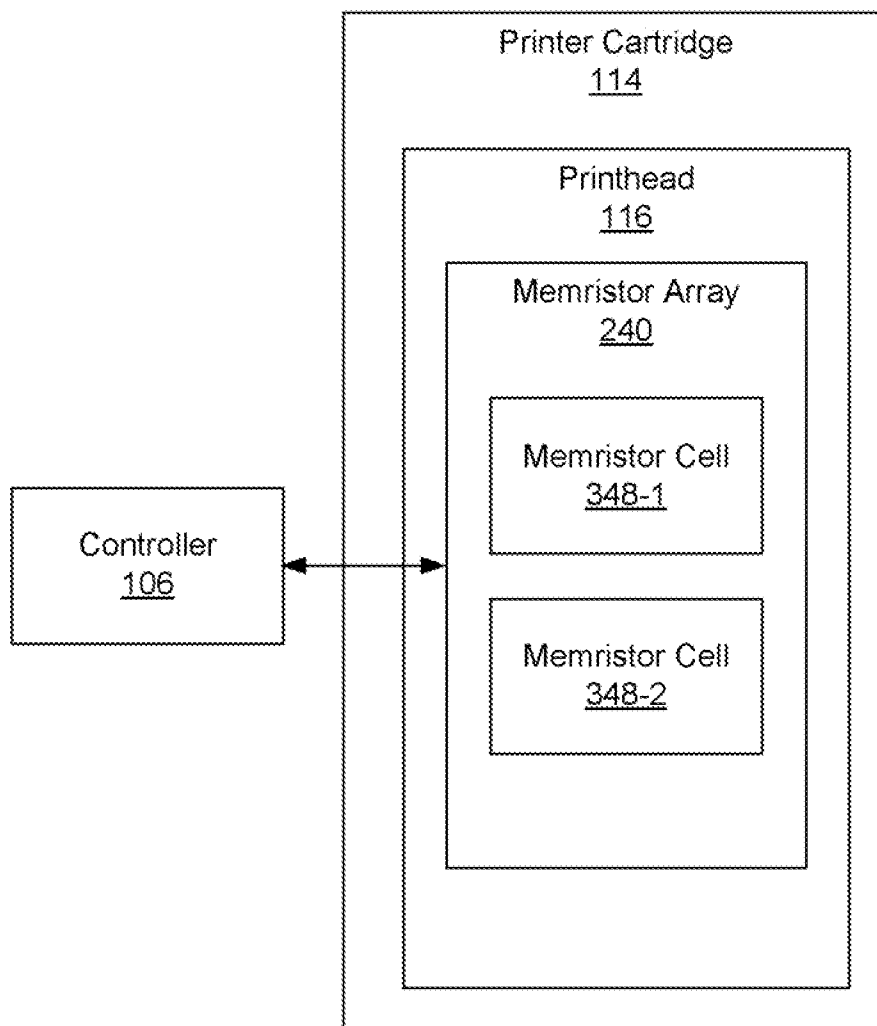


Fig. 2B

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**Fig. 3**

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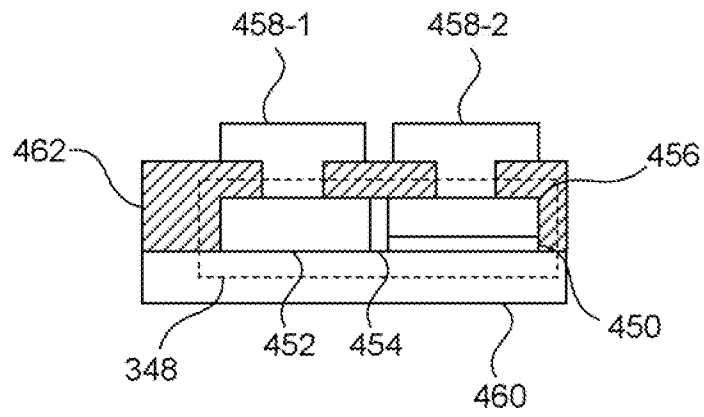


Fig. 4A

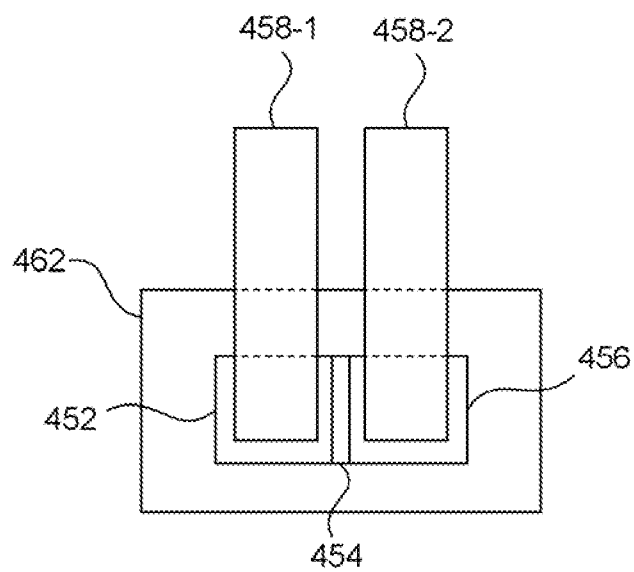
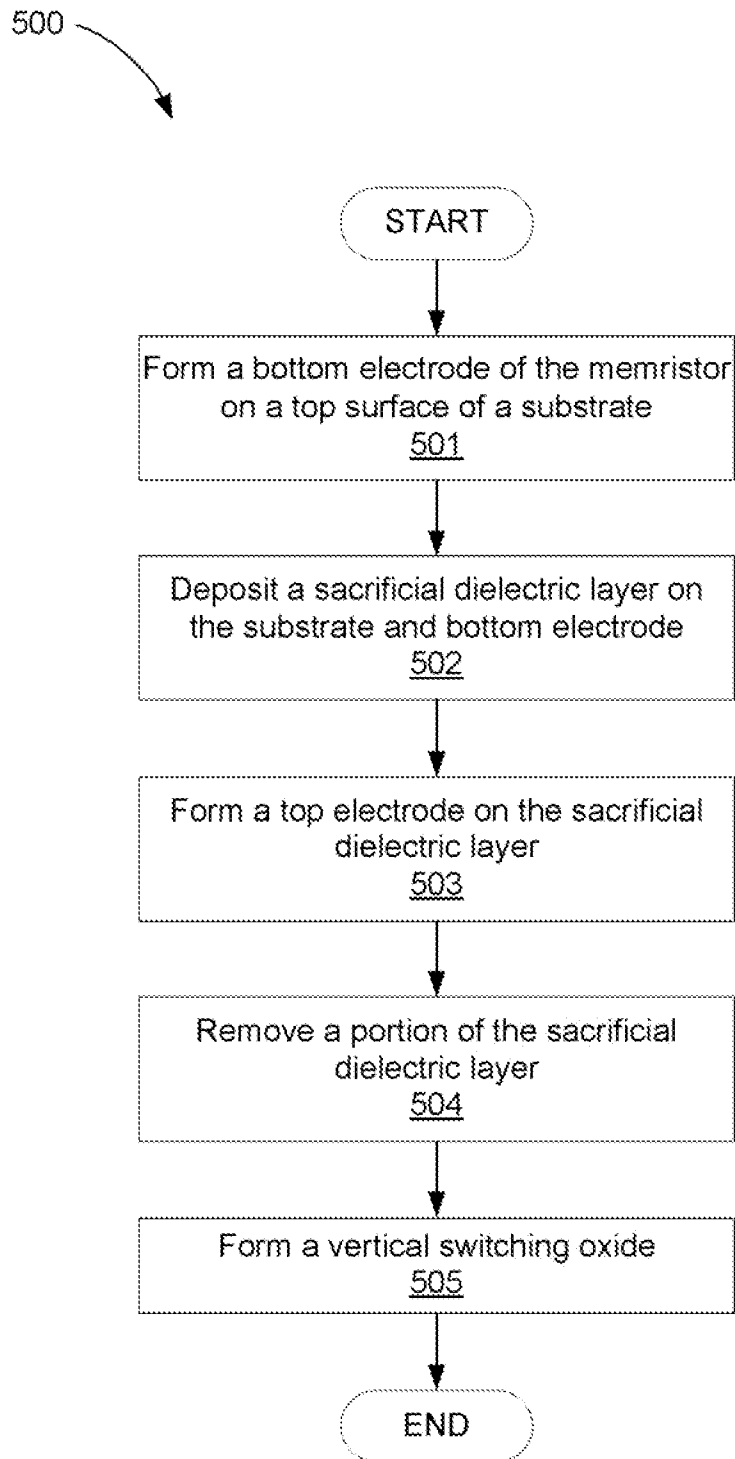


Fig. 4B

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**Fig. 5**

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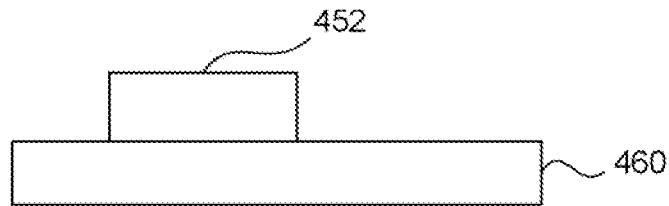


Fig. 6A

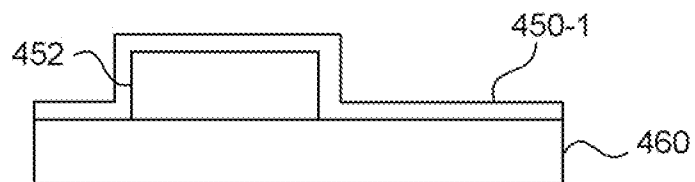


Fig. 6B

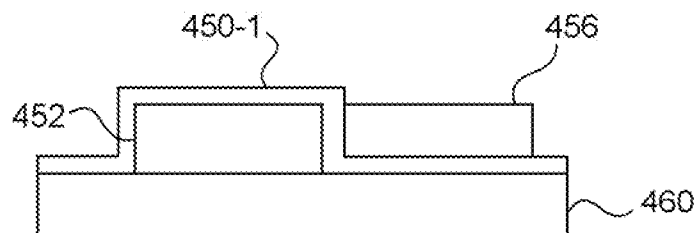
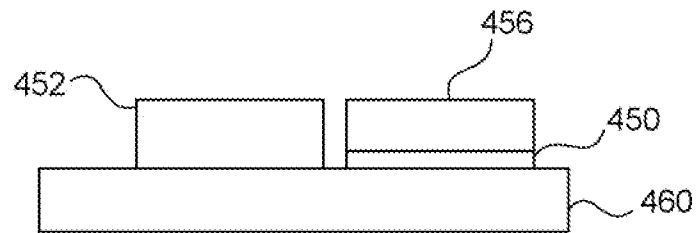
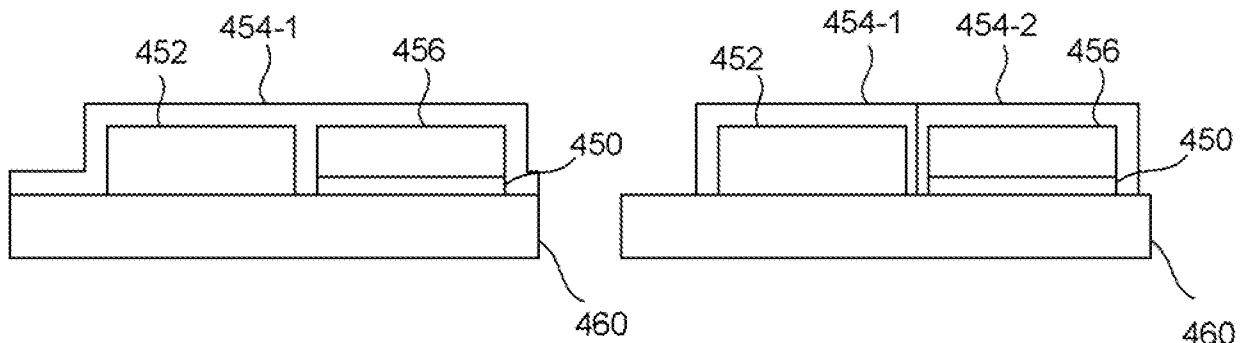
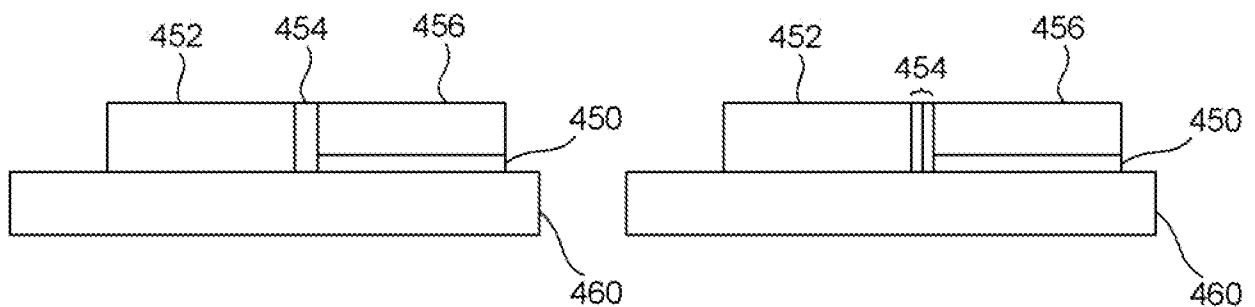
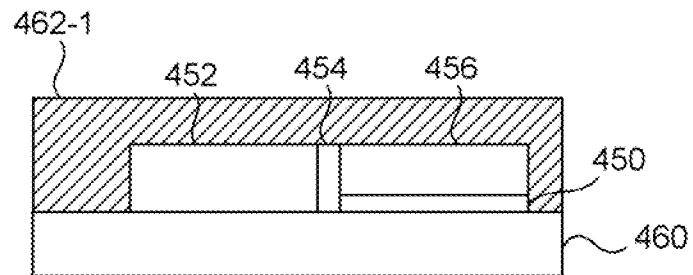
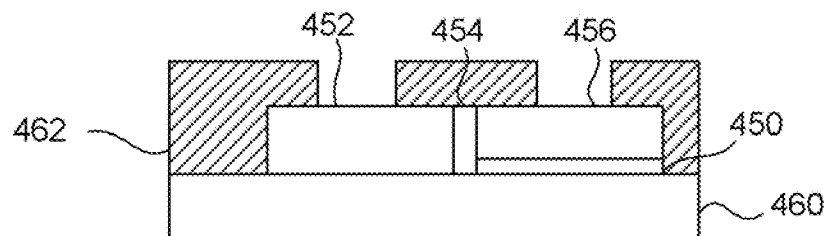
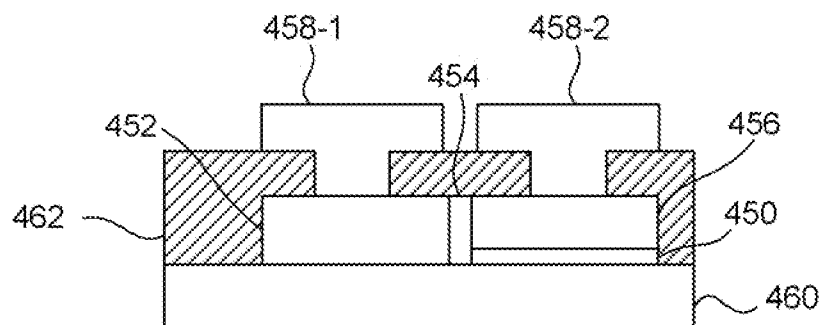


Fig. 6C

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**Fig. 6D****Fig. 6E****Fig. 6F****Fig. 6G****Fig. 6H**

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**Fig. 6I****Fig. 6J****Fig. 6K**

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/048272**A. CLASSIFICATION OF SUBJECT MATTER****B41J 2/175(2006.01)i, B41J 2/14(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B41J 2/175; G11C 11/34; H01L 21/336; B41J 2/04; B21D 53/76; B41J 2/07; H01L 21/335; H01L 29/76; B41J 29/38; B41J 2/14

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & keywords: memristor, nozzle, chamber, ejector, non-volatile, printhead, sacrificial dielectric layer, electrode, and oxide**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2013-0106930 A1 (LEA et al.) 02 May 2013 See abstract, paragraphs [0014]-[0016], [0023], and figures 1-3A.	1-15
A	US 2011-0310181 A1 (CURCIO et al.) 22 December 2011 See abstract, paragraphs [0023]-[0024], and figure 1.	1-15
A	US 2012-0120728 A1 (KIM et al.) 17 May 2012 See abstract, claims 16-19, and figure 6.	1-15
A	US 2009-0244132 A1 (BRUCE et al.) 01 October 2009 See abstract, paragraphs [0021]-[0029], and figures 1-2.	1-15
A	WO 2005-020312 A1 (INTEL CORPORATION) 03 March 2005 See abstract, paragraphs [0035]-[0036], and figures 4-5.	1-15



Further documents are listed in the continuation of Box C.



See patent family annex.

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search

15 April 2015 (15.04.2015)

Date of mailing of the international search report

15 April 2015 (15.04.2015)

Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2014/048272

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