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(54) Title: CROSSBAR ARRAYS WITH PHOTOSENSITIVE SELECTORS

FIG. 1A

(57) Abstract: Example embodiments relate to crossbar arrays with photosensitive selectors. An example crossbar array disclosed
herein includes a top electrode, a bottom electrode, and a junction. The top electrode is coupled to a photosensitive selector that has
an electrical conductivity that changes in response to exposure to an electromagnetic radiation. The junction is coupled between the
top electrode and the bottom electrode.

1

CROSSBAR ARRAYS WITH PHOTOSENSITIVE SELECTORS

BACKGROUND

[0001]   Selectors are passive two terminal devices that may control the electrical properties, such as the conductance, of electronic devices containing the selectors. Memristors are passive two terminal devices that can be programmed to different resistive states by applying a programming energy, such as a voltage. Large crossbar arrays of memory devices can be used in a variety of applications, including random access memory, non-volatile solid state memory, programmable logic, signal processing control systems, pattern recognition, and other applications.

BRIEF DESCRIPTION OF THE DRAWINGS

[0002]   The following detailed description references the drawings, wherein:

[0003]   FIG. 1A is a diagram of an example crossbar array with a photosensitive selector;

[0004]   FIG. 1B is a diagram of an example crossbar array with multiple photosensitive selectors;

[0005]   FIG. 2 is a diagram of an example radiation source and a junction of a crossbar array; and

[0006]   FIG. 3 is a flowchart of an example method for selecting an electrode of a crossbar array.

2

DETAILED DESCRIPTION

[0007]   Memristors are devices that may be used as components in a wide range of electronic circuits, such as memories, switches, radio frequency circuits, and logic circuits and systems. In a memory structure, a crossbar array of memory devices having memristors may be used. When used as a basis for memory devices, memristors may be used to store bits of information, 1 or 0. The resistance of a memristor may be changed by applying an electrical stimulus, such as a voltage or a current, through the memristor. Generally, at least one channel may be formed that is capable of being switched between two states—one in which the channel forms an electrically conductive path ("ON") and one in which the channel forms a less conductive path ("OFF"). In some other cases, conductive paths represent "OFF" and less conductive paths represent "ON".

[0008]   Using memristors in crossbar arrays may lead to read or write failure due to sneak currents leaking through the memory cells that are not targeted—for example, cells on the same row or column as a targeted cell. Failure may arise when the total current through the circuit from an applied voltage is higher than the current through the targeted memristor due to current sneaking through untargeted neighboring cells. As a result, effort has been spent to investigate using a nonlinear selector coupled in series with each memristor in order to increase the current–voltage (I-V) nonlinearity of each memory cell of a crossbar array.

[0009]   Selectors may increase the nonlinearity of the memory device which may help mitigate sneak currents in the crossbar array. However, many proposed selector solutions are triggered electronically. For example, these selectors may use an applied electrical stimulus, such as a voltage, to be activated. Because memristors typically also use voltages or currents for reading and writing, it may be challenging to optimize the addressing voltages or currents.

[0010]   Examples disclosed herein provide for crossbar arrays with photosensitive selectors. In example implementations, a crossbar array may include a top electrode coupled to a photosensitive selector, a bottom electrode, and a junction coupled between the top electrode and the bottom electrode. The photosensitive selector may have an electrical conductivity that changes in response to exposure to an electromagnetic radiation

(EMR), such as light. By using a photosensitive selector, junctions or groups of junctions may be activated by selective illumination of the EMR. Accordingly, the selection mechanism of the junctions via EMR may be separated from the electrical operations of the crossbar array. In this manner, example crossbar arrays may provide for reduced leakage currents, which may promote the effective use of large crossbar arrays in such applications as memory, complex computations, accelerators, and many others.

[0011]   Referring now to the drawings, FIG. 1A is a diagram of an example crossbar array 100 with a photosensitive selector 130. Crossbar array 100 may be a configuration of top electrodes 110 and bottom electrodes 120 with a junctions 140 coupled between the electrodes at a cross-point. Photosensitive selector 130 may be coupled to top electrode 110, and may control the electrical conductance of the top electrode.

[0012]   Top electrode 110 may be an electrically conducting line that carries current or other electrical stimuli to junction 140. Top electrode 110 may sometimes be referred to as a bit line. Depending on orientation, top electrode 110 may alternatively be referred to as a word line. Similarly, bottom electrode 120 may be a conducting line that connects an opposite end of junction 140. Bottom electrode 120 may be referred to as a word line in some conventions. It should be noted that the terms top and bottom are merely for purposes of clear description, and examples herein are not limited by such orientation.

[0013]   In some examples, top electrode 110 and Bottom electrode 120 may be made of conducting materials, such as platinum (Pt), tantalum (Ta), hafnium (Hf), zirconium (Zr), aluminum (Al), cobalt (Co), nickel (Ni), iron (Fe), niobium (Nb), molybdenum (Mo), tungsten (W), copper (Cu), titanium (Ti), tantalum nitrides (TaN$_x$), titanium nitrides (TiN$_x$), WN$_2$, NbN, MoN, TiSi$_2$, TiSi, Ti$_5$Si$_3$, TaSi$_2$, WSi$_2$, NbSi$_2$, V$_3$Si, electrically doped polycrystalline Si, electrically doped polycrystalline Ge, and combinations thereof. Top electrode 110 and bottom electrode 120 may deliver voltage and current throughout crossbar array 100.

[0014]   As illustrated in the example of FIG. 1A, top electrode 110 may comprise a photosensitive selector 130. Photosensitive selector 130 may be an electrical device that is used to provide photosensitive properties for top electrode 110. For example, photosensitive selector 130 may be a 2-terminal device or circuit element that has an adjustable resistance.

4

[0015]   Photosensitive selector 130 may have an electrical conductance that changes in response to exposure to an electromagnetic radiation (EMR). For example, photosensitive selector 130 may include a semiconductor material with a bandgap that may be overcome when the material is exposed to certain EMR. In some examples, photosensitive selector 130 may have a photosensitive material, such as CdS, PbS, GaN, GaAs, and SiC. Other suitable materials may include wide bandgap semiconductors such as Ga-doped ZnO, Al-doped ZnO, AlN, SnO_2, In_2O_3, GaAs, InP, InGaAs, and HgCdTe, and other photoresistive materials such as CdSe, and ZnSe. When EMR of a certain wavelength or range of wavelengths and of a certain intensity or range of intensities is illuminated on the photosensitive selector, the semiconductor material may increase or decrease in electrical conductance. In some examples, the EMR may induce localized heating or enhanced electrical fields that increase the electrical conductance.

[0016]   In this manner, photosensitive selector 130 may, in some examples, have at least two resistance states. For example, photosensitive selector 130 may have one default state, and another resistance state when it is exposed to a certain EMR or EMR range. In some examples, a photosensitive selector may have more than two resistance states. In such instances, the photosensitive selector may reach each resistance by the wavelength of the EMR to which it is being exposed, the intensity of the EMR, or both. For example, a first EMR range may cause a photosensitive selector to be in a first resistance state, a second EMR range may cause the photosensitive selector to be in a second resistance state, and so forth.

[0017]   In some examples, photosensitive selector 130 may be coupled to a nanoplasmonic antenna. Nanoplasmonic antennas may be devices that enhance photon intensity at a particular area. Nanoplasmonic may mean plasmonic behavior on a nanoscale. For example, a nanoplasmonic antenna may focus the EMR on a particular area in order to direct the EMR onto the photosensitive selector. In some examples, nanoplasmonic antennas may lower the minimum EMR intensity for inducing effects on the photosensitive selector 130. More details of nanoplasmonic antennas are described below in reference to FIG. 2.

5

[0018]   In some examples, photosensitive selector 130 may be coupled in series with top electrode 110 such that photosensitive selector 130 may interrupt top electrode 110 so that photosensitive selector 130 controls the electrical conductivity of top electrode 110. For example, a less-conductive state of photosensitive selector 130 may be less conductive than top electrode 110 so that the photosensitive selector 130 may inhibit an electrical path through the corresponding top electrode 110. When an appropriate EMR is illuminated, photosensitive selector 130 may switch to a more conductive state, therefore facilitating an electrical path through the top electrode 110.

[0019]   Alternatively or in addition, bottom electrode 120 may have a photosensitive selector 130 with an electrical conductivity that changes in response to exposure to the EMR. In such examples, photosensitive selectors on the top electrodes and on the bottom electrodes may be operated together to precisely select junction 140 in the crossbar array.

[0020]   In some examples as described herein, junction 140 may form the connection between top electrode 110 and bottom electrode 120. Junction 140 may include a memory cell. A memory cell may be any device or element that stores digital data. For example, memory cell may be volatile or nonvolatile memory. In some examples, a memory cell may have a resistance that changes with an applied voltage or current. Furthermore, a memory cell may "memorize" its last resistance. In this manner, a memory cell may be set to at least two states. Such an array of a plurality of memory cells may, for example, be utilized in nonvolatile resistive memory, such as random access memory (RRAM), or other applications as described herein.

[0021]   In some examples, memory cells may include memristors. Memristors may provide the memory cells with the memristive properties described above. Memristors may be based on a variety of materials. Memristors may be oxide-based, meaning that at least a portion of the memristor is formed from an oxide-containing material. Memristors may also be nitride-based, meaning that at least a portion of the memristor is formed from a nitride-containing composition. Furthermore, memristors may be oxy-nitride based, meaning that a portion of the memristor is formed from an oxide-containing material and that a portion of the memristor is formed from a nitride-containing material. In some examples, memristors may be formed based on tantalum oxide (TaO_x) or hafnium oxide (HfO_x) compositions.

6

Other example materials of memristors may include titanium oxide, yttrium oxide, niobium oxide, zirconium oxide, aluminum oxide, calcium oxide, magnesium oxide, dysprosium oxide, lanthanum oxide, silicon dioxide, or other like oxides. Further examples include nitrides, such as aluminum nitride, gallium nitride, tantalum nitride, and silicon nitride. In addition, other functioning materials may be employed in the practice of the teachings herein. For example, memristors may have multiple layers that include electrodes and dielectric materials.

[0022]   In further examples, a memory cell of junction 140 may include a nonlinear selector. A nonlinear selector may be a 2-terminal device or circuit element that admits current in an amount that depends non-linearly on the voltage applied across the terminals.

[0023]   Nonlinear may describe a function that grows faster than a linear function. For example, this may mean that current flowing through a nonlinear selector increases faster than linear growth with relation to applied voltage. For example, typical materials may follow Ohm's law, where the current through them is proportional to the voltage. For a nonlinear selector, as the voltage is increased, the current flowing through the selector may disproportionately increase. As a result, the I-V behavior in this voltage range may be highly nonlinear.

[0024]   In some implementations, a nonlinear selector may exhibit negative differential resistance (NDR), which further adds to the nonlinearity. Negative differential resistance is a property in which an increase in applied current may cause a decrease in voltage across the terminals, in certain current ranges. In some examples, negative differential resistance may be a result of heating effects on certain selectors. In some examples, NDR effect may further contribute to the nonlinearity of nonlinear selectors.

[0025]   FIG. 1B is a diagram of an example crossbar array 150 with multiple photosensitive selectors. Crossbar array 150 may be a configuration of top electrodes 110 and bottom electrodes 120 with junctions 140 coupled between the electrodes at cross-points. In some examples, top electrodes 110 are in parallel with each other and perpendicular to bottom electrodes 120, which may in turn be in parallel to each other. For example, each top electrode 110 may be a row line, and each bottom electrode 120 may be a column line.

[0026]   A junction 140 may be coupled between each unique combination of one top electrode 110 and one bottom electrode 120. In other words, no junctions share both a top electrode and a bottom electrode. As used herein, components may be coupled by forming an electrical connection between the components. For example, junctions 140 may be coupled to the electrodes by forming a direct, surface contact or other forms of connection. Crossbar array 150 may be used in a variety of applications, including in memristor technologies described herein.

[0027]   Top electrodes 110 may be electrically conducting lines that carry current throughout crossbar array 150. Top electrodes 110 may be in parallel to each other, generally with equal spacing. Similarly, bottom electrodes 120 may be conducting lines that run perpendicular to top electrodes 110.

[0028]   Each top electrode 110 may be coupled to a plurality of photosensitive selectors, such as illustrated 130A and 130B. In the example illustrated in FIG. 1B, each top electrode 110 may be coupled to a first photosensitive selectors 130And a second photosensitive selector 130B placed along the top electrode to divide the top electrode 110 into selectively accessible portions. For example, illustrated in FIG. 1B, to access the two junctions 140A towards the left side of a top electrode 110, an electromagnetic radiation (EMR) may activate the left most photosensitive selector 130A. Alternatively, to access the two junctions 140B towards the right side of the top electrode 110, the EMR may activate both photosensitive selector 130A and 130B of the top electrode if, for example, an electrical signal is driven the left end of the top electrode 110. The two portions of the top electrode 110 may, for example, be referred to as a first top electrode and a second top electrode.

[0029]   Photosensitive selector 130 may be a 2-terminal device or circuit element that has an adjustable resistance. Photosensitive selector 130 may have an electrical conductance that changes in response to exposure to the EMR. For example, photosensitive selectors 130 may include a semiconductor material with a bandgap that may be overcome when the material is exposed to certain EMR. When EMR of a certain wavelength or range of wavelengths and of a certain intensity or range of intensities is illuminated on the photosensitive selector, the semiconductor material may increase or

8

decrease in electrical conductance. In some examples, the EMR may also induce localized heating or enhanced electrical fields that increase the electrical conductance.

[0030]   As explained previously in relation to FIG. 1A, photosensitive selector 130 may, in some examples, have at least two resistance states. For example, photosensitive selector 130 may have one default state, and another resistance state when it is exposed to a certain EMR or EMR range. In some examples, a photosensitive selector may have more than two resistance states. In such instances, the photosensitive selector may reach each resistance by the wavelength of the EMR to which it is being exposed, the intensity of the EMR, or both. For example, a first EMR range may cause a photosensitive selector to be in a first resistance state, a second EMR range may cause the photosensitive selector to be in a second resistance state, and so forth.

[0031]   In some examples, photosensitive selectors 130 may include nanoplasmonic antennas. For example, a nanoplasmonic antenna may focus the EMR on a particular area in order to direct the EMR onto the photosensitive selector. In some examples, nanoplasmonic antennas may lower the minimum EMR intensity for inducing effects on the photosensitive selector 130.

[0032]   In some examples, photosensitive selectors 130 may be coupled to top electrodes 110 such that each photosensitive selector 130 may interrupt a corresponding top electrode 110 so that photosensitive selector 130 controls the electrical conductivity of the top electrode 110. For example, a less-conductive state of photosensitive selector 130 may be less conductive than top electrode 110 so that the photosensitive selector 130 may inhibit an electrical path through the corresponding top electrode 110. When an appropriate EMR is illuminated, photosensitive selector 130 may switch to a more conductive state, therefore facilitating an electrical path through the corresponding top electrode 110.

[0033]   As a result, access to particular junctions 140 may be controlled by selectively illuminating particular photosensitive selectors 130A and 130B. For example, illuminating the left-most photosensitive selector 130A on a top electrode 110 raises the conductivity of the left-most photosensitive selector 130A so a current or other electrical stimulus may access junctions 140A coupled to the top electrode 110. However, because the right-most photosensitive selector 130B is not activated, its high resistance prevents electrical access

9

to the right-most two junctions 140B. As a result, the structure of crossbar array 150 and the placement of photosensitive selectors 130A and 130B may aid in precise targeting of particular junctions or mitigating such issues as sneak current.

[0034]   Furthermore, as an alternative or addition, bottom electrodes 120 may also have photosensitive selectors 130 to have an electrical conductivity that changes in response to exposure to the EMR. In such examples, photosensitive selectors on the top electrodes and on the bottom electrodes may be operated together to precisely select a particular junction in the crossbar array.

[0035]   In some examples as described herein, each junction 140 may include a memory cell. Memory cells may include memristors or other memory devices. In further examples, memory cells of junction 140 may include a nonlinear selector. A nonlinear selector may be a 2-terminal device or circuit element that admits current in an amount that depends non-linearly on the voltage applied across the terminals.

[0036]   FIG. 2 is a diagram of a radiation source 260 and a portion 200 of a crossbar array. The junction of the array may include a top electrode 210 with a photosensitive selector 230, a bottom electrode, and a junction that includes a memristor 240 and a nonlinear selector 250. Photosensitive selector 230 may include a nanoplasmonic antenna 235 to enhance the intensity of an electromagnetic radiation illuminating photosensitive selector 230.

[0037]   The crossbar array may be analogous to portions of crossbar array 100 of FIG. 1A and of crossbar array 150 of FIG. 1B. For example, top electrode 210 may be analogous to top electrode 110, and bottom electrode 220 may be analogous to bottom electrode 120. Top electrode 210 and bottom electrode 220 may be electrically conducting and may conduct current to the junction.

[0038]   Photosensitive selector 230 may be analogous to the photosensitive selectors 130 of FIG. 1A and 1B. Photosensitive selector 230 may have an electrical conductance that changes in response to exposure to an electromagnetic radiation, and may include a wide bandgap semiconductor material. Photosensitive selector 230 may include a nanoplasmonic antenna 235.

10

[0039]   Nanoplasmonic antennas 235 may be tuned to be sensitive to certain EMR ranges. For example, a nanoplasmonic antenna 235 may enhance the intensity of EMR of a certain wavelength range. Another nanoplasmonic antenna 235 may enhance the intensity of EMR of a different wavelength range. Accordingly, the nanoplasmonic antennas, and their corresponding photosensitive selectors, may be selectively targeted by illuminating EMR of varying wavelength ranges.

[0040]   In a detailed example, a simple 2x2 crossbar array may contain two top electrodes 210, where each top electrode has a photosensitive selector 230 with a nanoplasmonic antenna 235 that is sensitive to a different wavelength range. To target the junctions of a particular top electrode 210 of the example array, an EMR in the wavelength range associated with the nanoplasmonic antenna associated with the particular top electrode 210 can be used.

[0041]   In another example, a photosensitive selector 210 may include multiple nanoplasmonic antennae. For example, each nanoplasmonic antenna may be tuned to be sensitive to a different EMR range to allow the photosensitive selector 230 to be in a plurality of states or resistance levels. When combined with the appropriate components, such as certain memory cells, such examples may allow such crossbar array systems to be used in different applications, such as for analog computing and computing accelerators.

[0042]   Memristor 240 may behave similar to the memory cells and memristors described in relation to FIG. 1. Memristor 240 may have a resistance that changes with an applied voltage or current. Furthermore, a memory cell may "memorize" its last resistance. In some examples, as described previously, memristor 240 may be changeable to a plurality of states.

[0043]   Nonlinear selector 250 may be analogous to the nonlinear selectors described in relation to FIG. 1A and 1B. Nonlinear selector 250 may increase the nonlinearity of the junction, further aiding in the selection of particular junctions. Examples of nonlinear selectors include insulator-to-metal transition selectors and tunneling selectors.

[0044]   Radiation source 260 may selectively illuminate the crossbar array with the electromagnetic radiation. In some examples, radiation source 260 may illuminate a portion

11

of the crossbar array, where the portion may cover multiple top electrodes 210 with photosensitive selectors 230. Alternatively, radiation source 260 may illuminate individual photosensitive selectors 230.

[0045]   Radiation source 260 may be a variety of components, devices, or systems. For example, radiation source 260 may include an array of light emitting diodes. Alternatively for example, radiation source 260 may include a grating delivery system coupled with imprinted waveguides. In some examples, radiation source 260 may provide a plurality of EMR ranges, including infrared, visible light, ultraviolet, etc. Furthermore, in some examples, radiation source 260 may provide laser beams.

[0046]   In some examples, as explained in relation to FIG. 1A and 1B, bottom electrodes 220 may, as an alternative or addition, have photosensitive selectors. In such examples, there may be an additional radiation source for illuminating the photosensitive selectors of the bottom electrodes 220. Alternatively, the crossbar array may be designed so that radiation source 260 may be exploited for either or both of the photosensitive selectors of the top electrodes and the photosensitive selectors of the bottom electrodes.

[0047]   FIG. 3 is a flowchart of an example method 300 for selecting an electrode of a crossbar array. Method 300 may include operation 310 for providing a crossbar array with photosensitive selectors, and operation 320 for selectively illuminating a photosensitive selector of the crossbar array with an electromagnetic radiation. Although execution of method 300 is herein described in reference to crossbar array 200 of FIG. 2, other suitable examples of method 300 should be apparent, including the examples provided in FIG. 1A and 1B.

[0048]   In an operation 310, the crossbar array of crossbar array 200 may be provided. The crossbar array 200 may include a plurality of top electrodes 210, a plurality of bottom electrodes 220, and a plurality of junctions coupled between the top electrodes 210 and bottom electrodes 220. Each top electrode 210 may include an optical selector 230, which has an electrical conductance that changes in response to exposure to an electromagnetic radiation (EMR). As illustrated in FIG. 2, each junction may include a memristor 240 and a nonlinear selector 250. Photosensitive selector 230 may have a nanoplasmonic antenna

12

235 to enhance the intensity of an electromagnetic radiation illuminating photosensitive selector 230.

[0049]   After providing the crossbar array, in an operation 320, a photosensitive selector 230 of the crossbar array may be selectively illuminated with the EMR to change the electrical conductance of the photosensitive selector 230 in the top electrode 210 of the crossbar array being selected. For example, radiation source 260 may selectively direct a portion of an LED array to emit EMR towards the photosensitive selector 230. Accordingly, the sneak current issue may be limited to the portion of the crossbar array that is connected to the top electrode 210 having the photosensitive selector 230 illuminated with the EMR. Alternatively, in some examples, a group of photosensitive selectors 230 may be selectively illuminated with the EMR to change the conductance of the photosensitive selector 230 at the particular electrodes targeted. Such instances may be determined by the resolution of the radiation source.

[0050]   The foregoing describes a number of examples of crossbar arrays with photosensitive selectors and their applications. It should be understood that the crossbar arrays described herein may include additional components and that some of the components described herein may be removed or modified without departing from the scope of the crossbar arrays or their applications.

[0051]   It should also be understood that the components depicted in the figures are not drawn to scale, and thus, the components may have different relative sizes with respect to each other than as shown in the figures. For purposes of explanation, certain examples are described with reference to the components illustrated in FIGS. 1-3. All or part of the functionality of illustrated elements may co-exist or be distributed among several geographically dispersed locations. Moreover, the disclosed examples may be implemented in various environments and are not limited to the illustrated implementations.

[0052]   Further, the sequence of operations described in connection with FIGS. 1-3 are examples and are not intended to be limiting. Additional or fewer operations or combinations of operations may be used or may vary without departing from the scope of the disclosed examples. Furthermore, implementations consistent with the disclosed examples need not perform the sequence of operations in any particular order. Thus, the present disclosure

13

merely sets forth possible examples of implementations, and many variations and modifications may be made to the described examples. All such modifications and variations are intended to be included within the scope of this disclosure and protected by the following claims.

[0053] It should further be noted that, as used in this application and the appended claims, the singular forms "a," "an," and "the" include plural elements unless the context clearly dictates otherwise.

14

CLAIMS

What is claimed is:

1.   A crossbar array, comprising:
         a top electrode coupled to a photosensitive selector, wherein the photosensitive selector has an electrical conductivity that changes in response to exposure to an electromagnetic radiation;
         a bottom electrode; and
         a junction coupled between the top electrode and the bottom electrode.

2.   The crossbar array of claim 1, wherein the photosensitive selector is electrically insulating when the photosensitive selector is not exposed to the electromagnetic radiation, and the photosensitive selector is electrically conducting when the photosensitive selector is exposed to the electromagnetic radiation.

3.   The crossbar array of claim 2, further comprising a second photosensitive selector coupled to the top electrode, a second top electrode coupled to the second photosensitive selector, a second bottom electrode, and a second junction coupled between the second top electrode and the second bottom electrode, wherein:
         selectively exposing the photosensitive selector to electromagnetic radiation forms an electrical path to the junction; and
         selectively exposing the photosensitive selector and the second photosensitive selector to the electromagnetic radiation forms an electrical path to the second junction.

4.   The crossbar array of claim 1, further comprising a nanoplasmonic antenna coupled to the photosensitive selector.

5.   The crossbar array of claim 1, wherein each junction comprises a memory cell.

6.   The crossbar array of claim 5, wherein the memory cell comprises a nonlinear

selector coupled in series with a memristor.

7.   A crossbar memory array, comprising:

a plurality of top electrodes, wherein each top electrode is coupled to at least one photosensitive selector, wherein the photosensitive selector is electrically insulating when the photosensitive selector is not exposed to an electromagnetic radiation, and the photosensitive selector is electrically conducting when the photosensitive selector is exposed to the electromagnetic radiation;

a plurality of bottom electrodes;

a junction coupled between each unique combination of one top electrode and one bottom electrode, wherein each junction comprises a memory cell; and

a radiation source to selectively expose the photosensitive selectors to the electromagnetic radiation.

8.   The crossbar array of claim 7, wherein each bottom electrode comprises at least one second photosensitive selector coupled with the bottom electrode, wherein the second photosensitive selector is electrically insulating when the second photosensitive selector is not exposed to the electromagnetic radiation, and the second photosensitive selector is electrically conducting when the second photosensitive selector is exposed to the electromagnetic radiation.

9.   The crossbar array of claim 7, further comprising a nanoplasmonic antenna coupled to each photosensitive selector.

10.   The crossbar array of claim 7, wherein at least one of the plurality of top electrodes is coupled to at least two photosensitive selectors, wherein the at least two photosensitive selectors are coupled along the top electrode to divide the top electrode into selectively accessible portions.

11.   The crossbar array of claim 10, wherein the at least two photosensitive selectors coupled to the top electrode are photosensitive to different ranges in an electromagnetic

16

spectrum.

12.　　The crossbar array of claim 7, wherein the memory cell comprises a nonlinear selector coupled in series with a memristor.
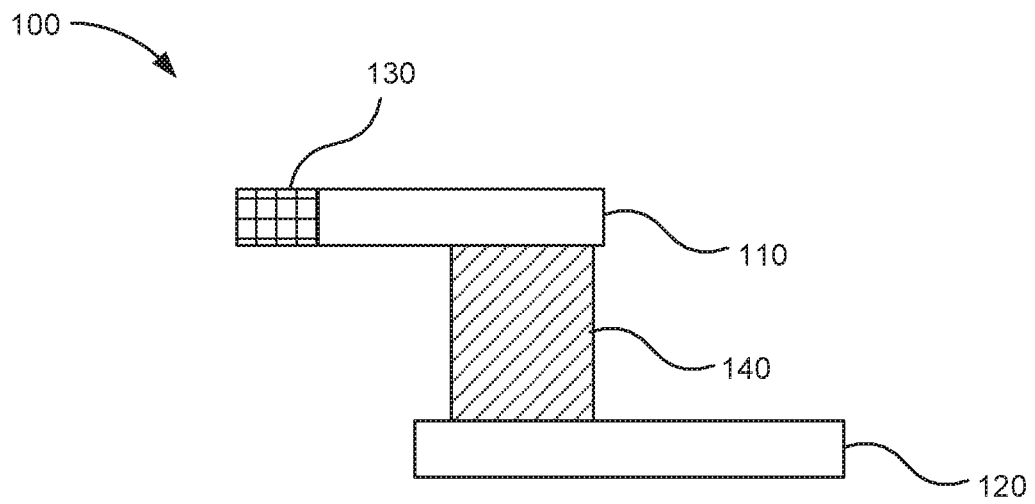
13.　　A method, comprising:

providing the crossbar array, wherein the crossbar array comprises a plurality of top electrodes, a plurality of bottom electrodes, and a plurality of junctions, each junction coupled between a unique combination of one top electrode and one bottom electrode, wherein each top electrode is coupled to at least one photosensitive selector, wherein the photosensitive selector has an electrical conductivity that changes in response to exposure to an electromagnetic radiation; and

selectively illuminating the photosensitive selectors with the electromagnetic radiation to change the electrical conductivity of the photosensitive selectors.
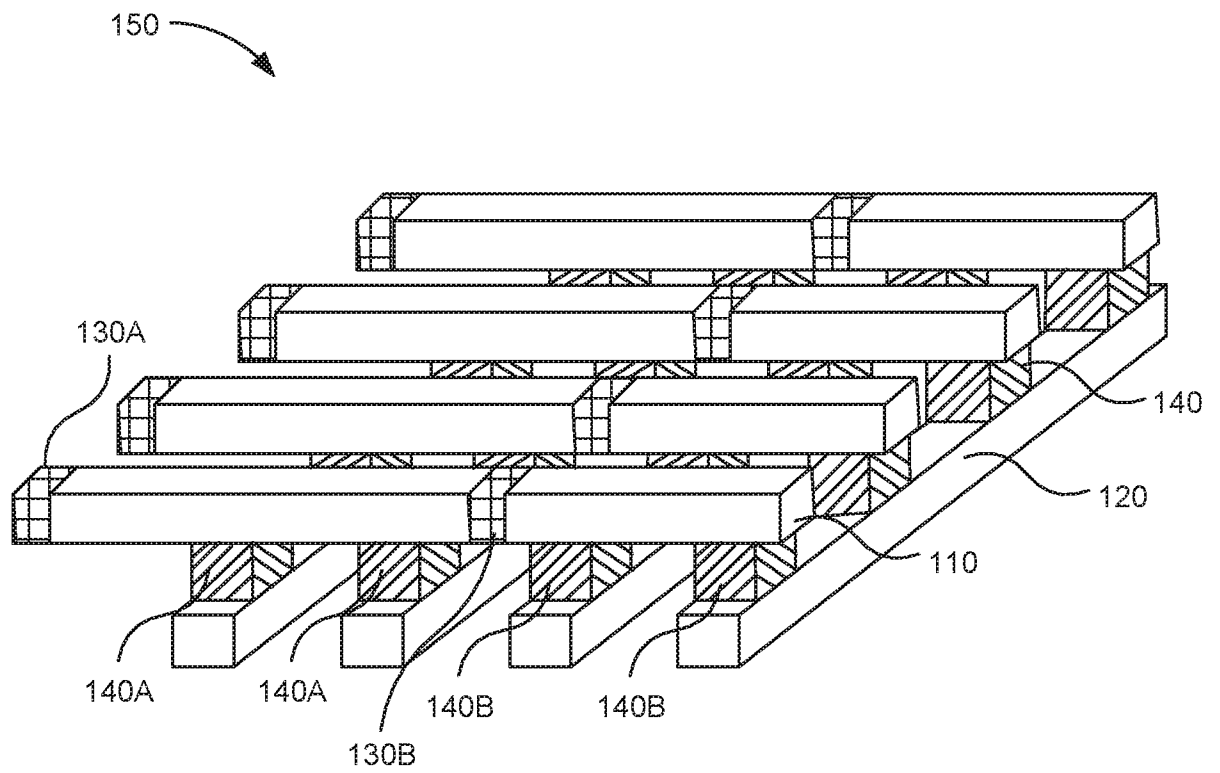
14.　　The method of claim 13, wherein at least one of the plurality of top electrodes is coupled to at least two photosensitive selectors, wherein the at least two photosensitive selectors are coupled along the top electrode to divide the top electrode into selectively accessible portions, and wherein the at least two photosensitive selectors coupled to the top electrode are photosensitive to different ranges in an electromagnetic spectrum.

15.　　The method of claim 13, wherein each photosensitive selector is coupled to a nanoplasmonic antenna.

100

130

110

140

120

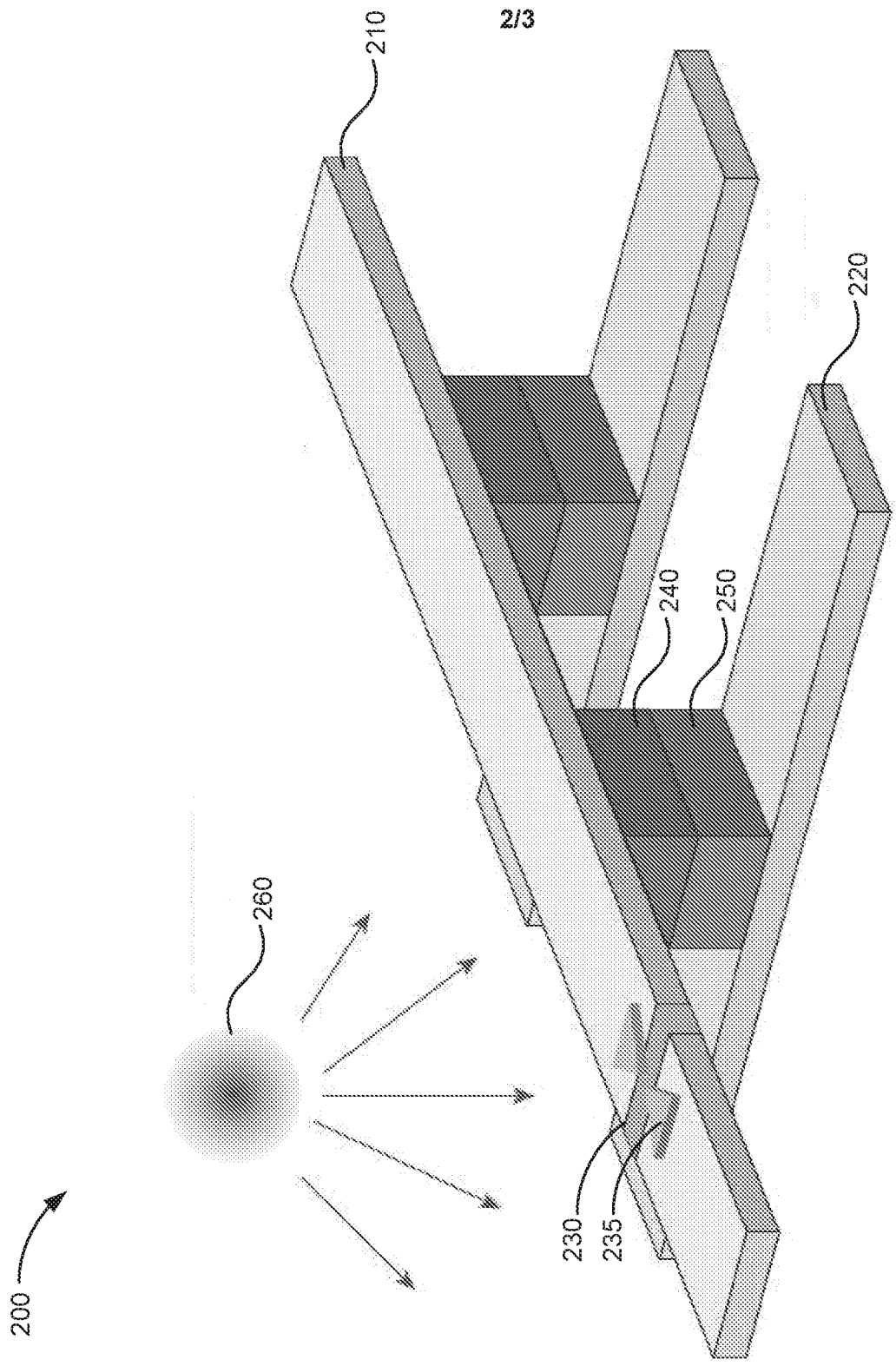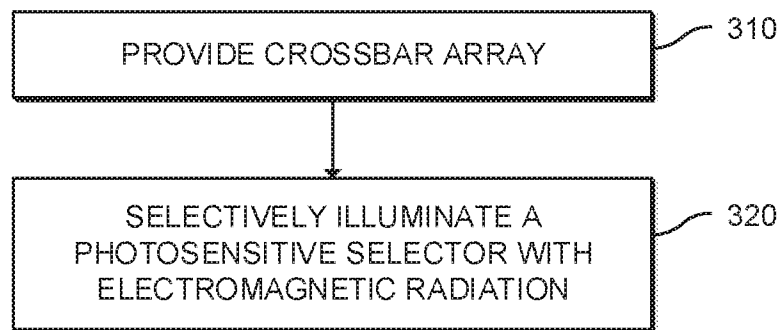**FIG. 1A**

150

130A

140

120

110

140A   140A   140B   140B

130B

FIG. 1B

FIG. 2

300

| PROVIDE CROSSBAR ARRAY | 310 |

| SELECTIVELY ILLUMINATE A PHOTOSENSITIVE SELECTOR WITH ELECTROMAGNETIC RADIATION | 320 |

FIG. 3

A.   CLASSIFICATION OF SUBJECT MATTER

G11C 11/16(2006.01)i, G11C 13/00(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)
 G11C 11/16; G11C 11/21; G11C 13/00; G11C 11/00

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: crossbar, array, top, bottom, electode, junction, photosensitive, selector, electromagnetic, radiation, memristor

C.   DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2014-0211535 A1 (JANICE H. NICKEL) 31 July 2014 See paragraphs [0026]-[0027]; and figure 2.	1-15
A	US 2014-0211536 A1 (ERICK ORDENTLICH et al.) 31 July 2014 See paragraph [0019]; and figure 1.	1-15
A	US 2008-0089110 A1 (WARREN ROBINETT et al.) 17 April 2008 See paragraph [0058]; and figure 9.	1-15
A	US 2013-0010521 A1 (RICHARD CARTER) 10 January 2013 See paragraphs [0016]-[0018]; and figure 1.	1-15
A	US 2011-0141801 A1 (KAILASH GOPALAKRISHNAN) 16 June 2011 See paragraphs [0068]-[0079]; and figure 2.	1-15

☐ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed	"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 "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 October 2016 (18.10.2016)	**18 October 2016 (18.10.2016)**

Name and mailing address of the ISA/KR	Authorized officer
International Application Division Korean Intellectual Property Office 189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea	BYUN, Sung Cheal
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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