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Declarations under Rule 4.17:

- as to the identity of the inventor (Rule 4.17(i))
- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))

[Continued on next page]

(54) Title: CROSSBAR ARRAYS WITH OPTICAL SELECTORS

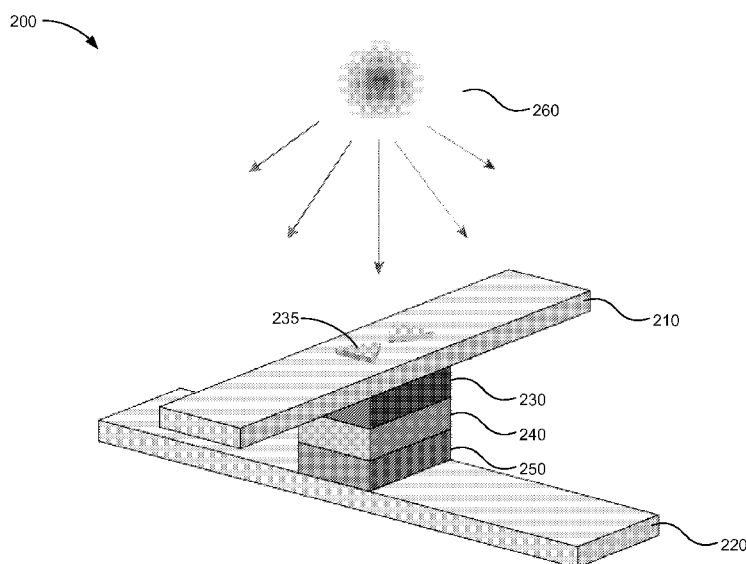


FIG. 2

(57) Abstract: A crossbar array with optical selectors includes a plurality of row lines, a plurality of column lines, and a plurality of junctions. Each junction is coupled between a unique combination of one row line and one column line. Each junction includes an optical selector.



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CROSSBAR ARRAYS WITH OPTICAL 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. Selectors may be combined with memristors to form crossbar arrays of memory devices. 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. 1 is a diagram of an example crossbar array;

[0004] FIG. 2 is a diagram of a radiation source and a junction of a crossbar array in a crossbar array system; and

[0005] FIG. 3 is a flowchart of an example method for selecting a portion of a crossbar array.

DETAILED DESCRIPTION

[0006] 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”.

[0007] 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.

[0008] 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.

[0009] Examples disclosed herein provide for crossbar arrays with optical selectors. In example implementations, crossbar arrays may include row lines, column lines, and junctions coupled between row lines and column lines. The junctions may include an optical selector. The optical selectors may have an electrical conductance that changes in response to exposure to an electromagnetic radiation (EMR), such as light. By using an optical 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.

[0010] Referring now to the drawings, FIG. 1 is a diagram of an example crossbar array 100. Crossbar array 100 may be a configuration of row lines 110 and column lines 120 with

junctions 130 coupled between lines at cross-points. In some examples, row lines 110 are in parallel with each other and perpendicular to column lines 120, which may in turn be in parallel to each other. Each junction 130 may be coupled between a unique combination of one row line 110 and one column line 120. In other words, no junctions share both a row line and a column line. As used herein, components may be coupled by forming an electrical connection between the components. For example, junctions 130 may be coupled to the lines by forming a direct, surface contact or other forms of connection. Crossbar array 100 may be used in a variety of applications, including in memristor technologies described herein.

[0011] Row lines 110 may be electrically conducting lines that carry current throughout crossbar array 100. Row lines 110 may be in parallel to each other, generally with equal spacing. Row lines 110 may sometimes be referred to as bit lines. Depending on orientation, row lines 110 may alternatively be referred to as word lines. Similarly, column lines 120 may be conducting lines that run perpendicular to row lines 110. Column lines 120 may be referred to as word lines in some conventions. In other orientations, column lines 120 may refer to bit lines. Row lines 110 and column lines 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_5Si_3 , TaSi_2 , WSi_2 , NbSi_2 , V_3Si , electrically doped polycrystalline Si, electrically doped polycrystalline Ge, and combinations thereof. Row lines 110 and column lines 120 may serve as electrodes that deliver voltage and current throughout crossbar array 100.

[0012] Junctions 130 may form the connections between row lines 110 and column lines 120. Each junction 130 may include an optical selector. An optical selector may be an electrical device that is used to provide desirable electrical properties. For example, an optical selector may be a 2-terminal device or circuit element that has an adjustable resistance. In some examples as described herein, optical selectors may be coupled with other components at junctions 130, such as memory cells and other selectors.

[0013] Optical selectors may have an electrical conductance that changes in response to exposure to an electromagnetic radiation. For example, optical selectors may include a

semiconductor material with a bandgap that may be overcome when the material is exposed to certain EMR. In some examples, optical selectors may have a wide bandgap semiconductor, such as Ga-doped ZnO, Al-doped ZnO, GaN, AlN, SnO₂, and In₂O₃. Other suitable materials may include other semiconductors such as GaAs, InP, InGaAs, and HgCdTe, and other photoresistive materials such as CdS, 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 optical 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 or enhance the temperature or field-enhance switching of memristors.

[0014] In this manner, optical selectors may, in some examples, have at least two resistance states. For example, an optical selector may have one default state, and another resistance state when it is exposed to a certain EMR or EMR range. In some examples, an optical selector may have more than two resistance states. In such instances, the optical 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 an optical selector to be in a first resistance state, a second EMR range may cause the optical selector to be in a second resistance state, and so forth.

[0015] In some examples, optical selectors of junctions 130 may include nanoplasmonic antennas. 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 optical selector. In some examples, nanoplasmonic antennas may lower the minimum EMR intensity for inducing effects on the optical selector. More details of nanoplasmonic antennas are described below in reference to FIG. 2.

[0016] Furthermore, in some examples, junctions 130 may include additional components, such as memory cells coupled in electrical series with the optical selectors. 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.

[0017] 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. 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.

[0018] In further examples, memory cells of junction 130 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.

[0019] 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.

[0020] 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.

[0021] FIG. 2 is a diagram of a radiation source 260 and a junction of a crossbar array in a crossbar array system 200. The junction of the array may include a row line 210, a column line 220, and a junction that includes an optical selector 230, a memristor 240, and a nonlinear selector 250. Optical selector 230 may include a nanoplasmonic antenna 235 to enhance photon sensitivity of the optical selector 230.

[0022] The crossbar array may be analogous to portions of crossbar array 100 of FIG. 1. For example, row line 210 may be analogous to one of the row lines 110, and column line 220 may be analogous to one of the column lines 120. Row line 210 and column line 220 may be electrically conducting and may conduct current to the junction. Row line 210 and column line 220 may connect the junction with a crossbar array, such as one illustrated in FIG. 1. Example materials for the lines may include conducting materials such as Pt, Ta, Hf, Zr, Al, Co, Ni, Fe, Nb, Mo, W, Cu, Ti, TiN, TaN, Ta₂N, WN₂, NbN, MoN, TiSi₂, TiSi, Ti₅Si₃, TaSi₂, WSi₂, NbSi₂, V₃Si, electrically doped polycrystalline Si, electrically doped polycrystalline Ge, and combinations thereof. In some examples, row line 210 and column line 220 may include transparent or semi-transparent materials that allow the transmission of EMRs, such as, for example, indium tin oxide.

[0023] Optical selector 230 may be analogous to the optical selector of junction 130 of FIG. 1. Optical 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. Each optical selector 230 may include a nanoplasmonic antenna 235.

[0024] Nanoplasmonic antennas 235 may be tuned to be sensitive to certain EMR ranges. For example, a nanoplasmonic antenna 235 may enhance EMR of a certain wavelength range. Another nanoplasmonic antenna 235 may enhance EMR of a different

wavelength range. Accordingly, the nanoplasmonic antennas may be selectively targeted by illuminating EMR of varying wavelength ranges. In a detailed example, a simple 2x2 crossbar array may contain four junctions with four different nanoplasmonic antennas, where each nanoplasmonic antenna is sensitive to a different wavelength range. To target a particular junction of the example array, an EMR in the wavelength range associated with the nanoplasmonic antenna associated with the particular junction can be used.

[0025] Nanoplasmonic antenna 235 may be an element on top of the line connected to the junction. In such examples, row line 210 or column line 220 may have a transparent material. Alternatively, nanoplasmonic antenna 235 may be created by milling into row line 210 or column 220 to create a nanoplasmonic structure.

[0026] In another example, an optical selector 230 may include multiple nanoplasmonic antenna. For example, each nanoplasmonic antenna may be tuned to be sensitive to a different EMR range to allow the optical selector 230 to be in a plurality of states or resistance levels. When combined with the appropriate components, such as certain memristors, such examples may allow crossbar array system 200 to be used in different applications, such as for analog computing and computing accelerators.

[0027] Memristor 240 may behave similar to the memory cells 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.

[0028] Nonlinear selector 250 may be analogous to the nonlinear selectors described in relation to FIG. 1. 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.

[0029] Radiation source 260 may selectively illuminate the crossbar array with an electromagnetic radiation. In some examples, radiation source 260 may illuminate a portion of the crossbar array, where the portion may cover multiple junctions. Alternatively, radiation source 260 may illuminate individual junctions.

[0030] 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.

[0031] FIG. 3 is a flowchart of an example method 300 for selecting a portion of a crossbar array. Method 300 may include operation 310 for providing a crossbar array with optical selectors, and operation 320 for selectively illuminating a portion of the crossbar array with an electromagnetic radiation. Although execution of method 300 is herein described in reference to crossbar array system 200 of FIG. 2, other suitable examples of method 300 should be apparent, including the example provided in FIG. 1.

[0032] In an operation 310, the crossbar array of crossbar array system 200 may be provided. The crossbar array may include a plurality of row lines 210, a plurality of column lines 220, and a plurality of junctions coupled between the row lines and column lines. Each junction may include an optical selector 230, which has an electrical conductance that changes in response to exposure to an electromagnetic radiation. As illustrated in FIG. 2, each junction may also include a memristor 240 and a nonlinear selector 250. Optical selector 230 may have a nanoplasmonic antenna to enhance the sensitivity of optical selector 230 to EMR.

[0033] After providing the crossbar array, in an operation 320, the portion of the crossbar array may be selectively illuminated with an EMR to change the electrical conductance of an optical selector 230 in the portion of the crossbar array being illuminated. For example, radiation source 260 may selectively direct EMR towards the portion of the crossbar array containing the junction or junctions to be selected. For example, radiation source may direct a portion of an LED array to emit EMR towards the respective portion of the crossbar array. Accordingly, the sneak current issue may be limited to the portion of the crossbar array that is illuminated with the EMR.

[0034] Alternatively, in some examples, a particular junction may be selectively illuminated with the EMR to change the conductance of the optical selector 230 at the

particular junction. In such examples, radiation source 260 may be finely tuned to the scale of the crossbar array.

[0035] The foregoing describes a number of examples for superlinear selectors and their applications. It should be understood that the superlinear selectors 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 superlinear selectors or their applications. 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.

[0036] It should 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.

CLAIMS

What is claimed is:

1. A crossbar array, including:
a plurality of row lines;
a plurality of column lines; and
a plurality of junctions coupled between a unique combination of one row line and one column line, wherein each junction includes an optical selector.
2. The crossbar array of claim 1, wherein the optical selector has an electrical conductance that changes in response to exposure to an electromagnetic radiation.
3. The crossbar array of claim 1, wherein the optical selector includes a nanoplasmonic antenna.
4. The crossbar array of claim 1, wherein the optical selector comprises a wide bandgap semiconductor.
5. The crossbar array of claim 1, wherein each junction comprises a memory cell coupled in electrical series with the optical selector.
6. The crossbar array of claim 5, wherein the memory cell includes a memristor.
7. The crossbar array of claim 5, wherein the memory cell includes a nonlinear selector.
8. A crossbar array system, including:
a crossbar array, comprising:
a plurality of row lines;

a plurality of column lines; and

a plurality of junctions coupled between a unique combination of one row line and one column line, wherein each junction includes an optical selector, wherein the optical selector has an electrical conductance that changes in response to exposure to an electromagnetic radiation; and

a radiation source to selectively expose portions of the crossbar array to the electromagnetic radiation.

9. The crossbar array system of claim 8, wherein the radiation source comprises an array of light emitting diodes.

10. The crossbar array system of claim 8, wherein the radiation source comprises a grating delivery system coupled with imprinted waveguides.

11. The crossbar array system of claim 8, wherein the optical selector includes a nanoplasmonic antenna.

12. The crossbar array system of claim 8, wherein each junction comprises a memory cell coupled in electrical series with the optical selector.

13. The crossbar array system of claim 12, wherein the memory cell includes a memristor.

14. A method for selecting a portion of a crossbar array, including:

providing the crossbar array, wherein the crossbar array comprises a plurality of row lines, a plurality of column lines, and a plurality of junctions coupled between a unique combination of one row line and one column line, wherein each junction includes an optical selector, wherein the optical selector has an electrical conductance that changes in response to exposure to an electromagnetic radiation; and

selectively illuminating the portion of the crossbar array with an electromagnetic radiation to change the electrical conductance of an optical selector in the portion of the

crossbar array.

15. The method of claim 14, comprising selectively illuminating a particular junction of the crossbar array to change the conductance of the optical selector at the particular junction.

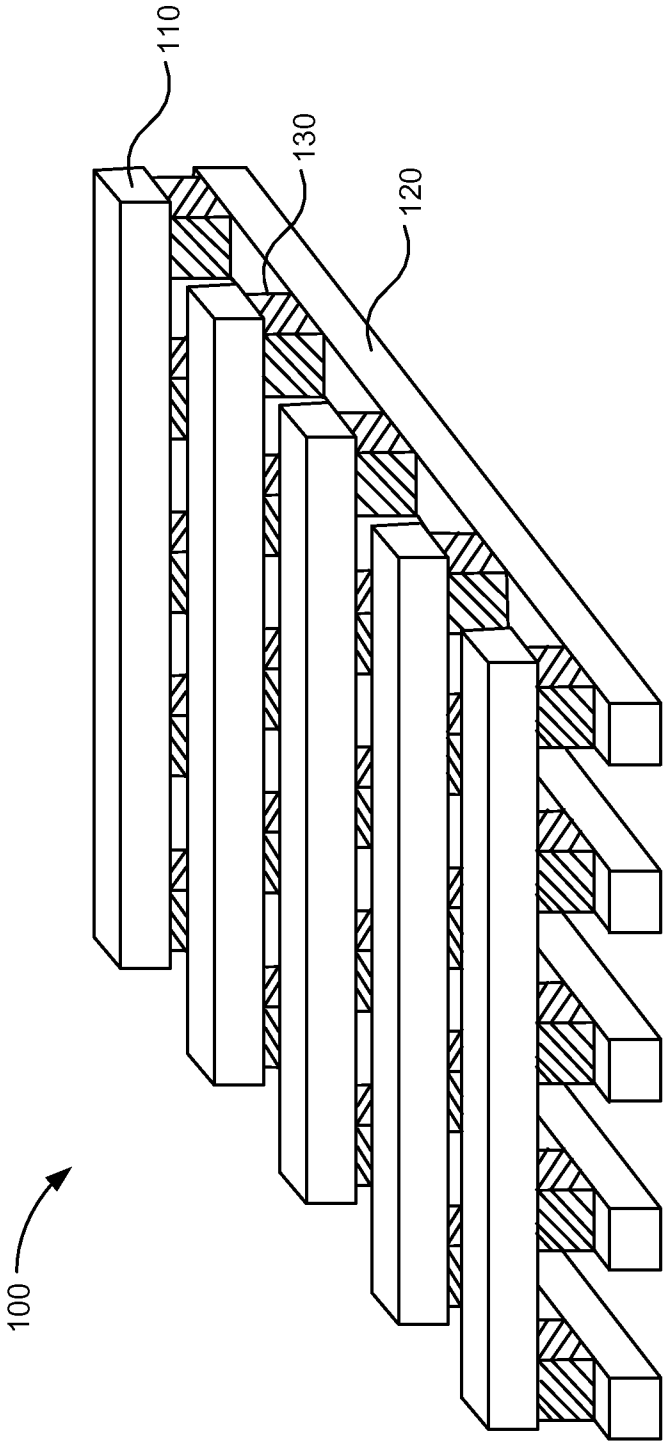


FIG. 1

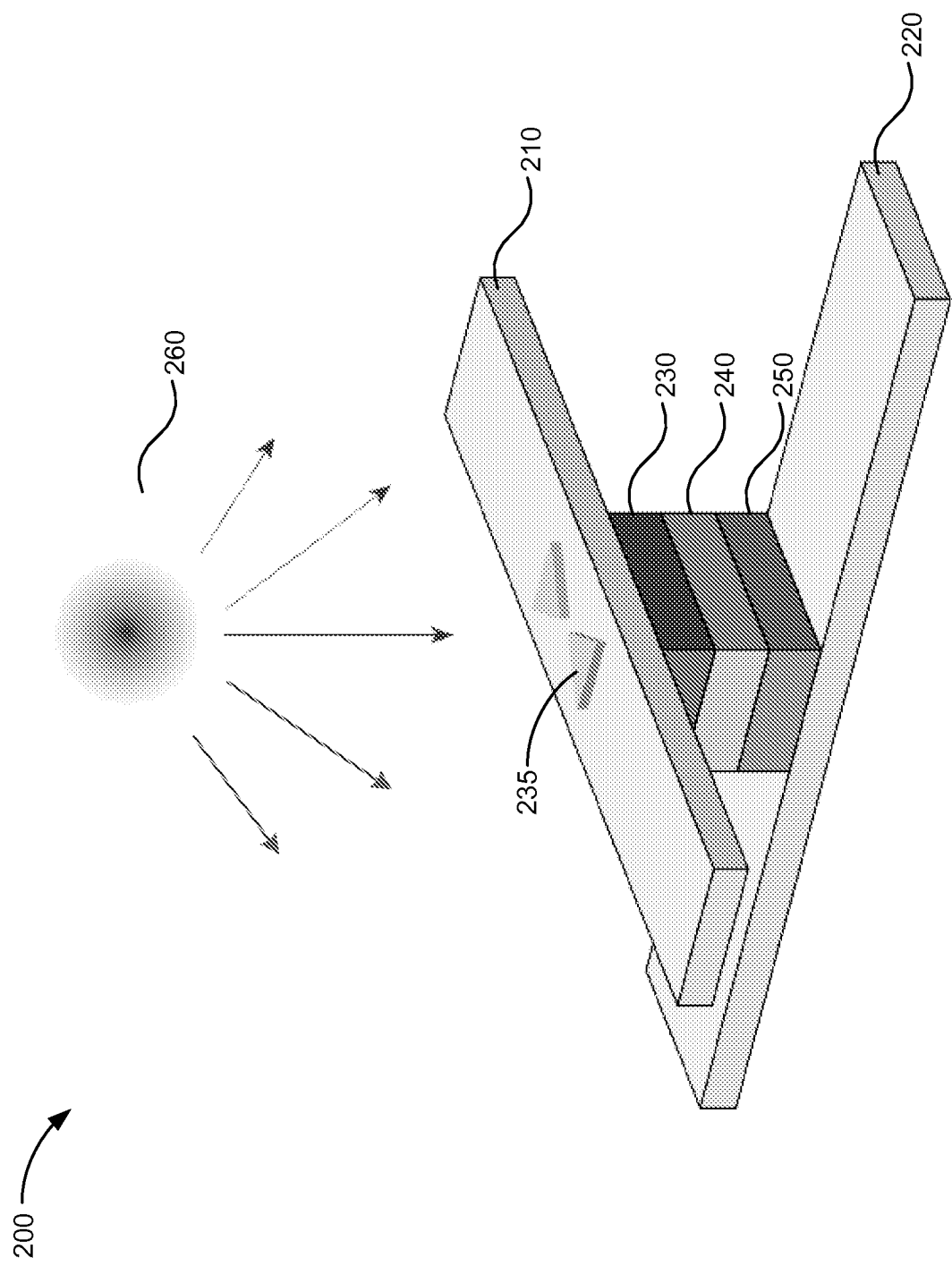
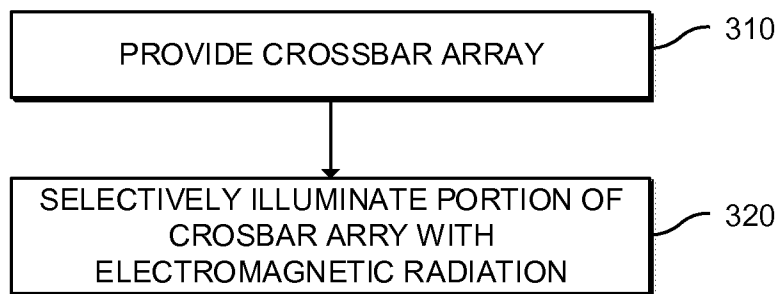


FIG. 2

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300
↘**FIG. 3**

A. CLASSIFICATION OF SUBJECT MATTER**H01L 27/115(2006.01)i**

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

B. FIELDS SEARCHEDMinimum documentation searched (classification system followed by classification symbols)
H01L 27/115; H01L 51/05; H01L 45/00; G02F 3/00; G02F 1/01; G11C 11/42; G11C 13/00Documentation 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 modelsElectronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: crossbar, optical selector, conductance, radiation**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2005-175202 A (NIPPON TELEGR & TELEPH CORP.) 30 June 2005 See abstract, paragraphs [0018]-[0040] and figures 1-2.	1-2, 4-5, 8-10, 12, 14-15
Y		3, 6-7, 11, 13
Y	WO 2015-028912 A1 (INTERNATIONAL BUSINESS MACHINES CORPORATION et al.) 05 March 2015 See abstract, page 14, line 23 - page 15, line 13 and figures 5-6.	3, 11
Y	US 2013-0128654 A1 (SHINICHI YONEDA et al.) 23 May 2013 See abstract, paragraphs [0136]-[0152] and figure 7A-7B.	6-7, 13
A	JP 2008-210441 A (MATSUSHITA ELECTRIC IND. CO., LTD.) 11 September 2008 See abstract, paragraphs [0053]-[0080] and figures 1-10.	1-15
A	JP 2009-043792 A (NATIONAL INSTITUTE FOR MATERIALS SCIENCE et al.) 26 February 2009 See abstract, paragraphs [0012]-[0032] and figures 1-4.	1-15



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

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