

MULTIPLE DATA STATE MEMORY CELL

TECHNICAL FIELD

The invention relates to random access memories ("RAMs"), and more particularly to memory cells of a RAM capable of storing data in multiple data states.

5 BACKGROUND OF THE INVENTION

Random access memory devices are an integral part of any computing environment. Without these memory devices, processing data in a computing device would be nearly impossible. Consequently, there has been a great amount of research and development directed to the area of random access computer memory. The research and
10 development has been directed to different areas related to computer memory, for example, in increasing the speed at which data stored by the memory devices can be accessed, in designing memories with lower power consumption, and in engineering memory devices having greater data retention times. Additionally, one particular area to which a great amount of effort has been spent is in the areas of increasing memory density and data
15 capacity.

One conventional approach to increasing memory density has been to decrease the size of memory devices, and more particularly, decrease the size of memory cells. As a result, the size of memory cells have been reduced dramatically in the recent past. However, the size of memory cells have diminished to the point where the current
20 state of processing technology is being constantly challenged when manufacturing memory devices with these feature sizes. Another approach to the memory density and data capacity issue has been experiment with memory devices that are capable of storing data in more states than conventional binary memory. That is, conventional memory stores data in a binary format, where data is stored as either one of two different data states. With
25 multiple data state memory, data can be stored as one of many different states, where the number of different states is greater than two. As a result, with multiple data state memory,

store data in various states. Further described in the aforementioned patents are various structural embodiments of a PMC in different applications.

Although there has been development in the area of multiple data state and variable resistance memories, it will be appreciated that new and alternative approaches to this area is still possible. For example, further development in the area of multiple data state memory cells having true quantization of data states. Therefore, there is a need for alternative approaches to storing data in multiple data states.

SUMMARY OF THE INVENTION

The present invention is directed to a multiple data state memory cell. The memory cell includes a first electrode layer formed from a first conductive material, a second electrode layer formed from a second conductive material, and a first layer of a metal-doped chalcogenide material disposed between the first and second electrode layers, the first layer providing a medium in which a conductive growth can be formed to electrically couple together the first and second electrode layers. The memory cell further includes a third electrode layer formed from a third conductive material, and a second layer of a metal-doped chalcogenide material disposed between the second and third electrode layers, the second layer providing a medium in which a conductive growth can be formed to electrically couple together the second and third electrode layers.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a cross-sectional view of an embodiment of the invention.

Figures 2a-c are cross-sectional views of the embodiment of Figure 1 illustrating the operation thereof.

Figure 3 is a cross-sectional view of another embodiment of the invention.

Figure 4 is a block diagram of a typical memory device that includes one or more memory arrays of the present embodiment.

approximately the same, or the thickness t_2 may be less than t_1 . As will be explained in more detail below, the composition of the respective metal-doped chalcogenide layers 206 and 208 may need to be modified in order to accommodate layers 206 and 208 having various thicknesses. Formed on the metal-doped chalcogenide layer 208 is another metal electrode layer 210, which represents an anode of the multiple-state memory cell 200. The metal electrode layer 210 and the floating electrode layer 206 are typically formed from the same material. As illustrated in Figure 1, the cathode is formed below the anode, however, it will be appreciated that the arrangement of the two layers may be reversed as well without departing from the scope of the present invention. Moreover, the vertical orientation illustrated in Figure 1 can be changed such that the various layers are formed in a horizontal orientation between a cathode and an anode that are laterally spaced apart from one another.

It will be appreciated that many materials known by those of ordinary skill in the art may be used for the metal-doped chalcogenide layers. For example, compositions of germanium selenide, Ge_xSe_y , can be used. Exemplary ratios are in the range from $\text{Ge}_{20}\text{Se}_{80}$ to GeSe . Compositions of arsenic sulfide, germanium telluride, and germanium sulfide can also be used for the metal-doped chalcogenide layers. Similarly, materials that can be used for the electrode layers are also known, such as silver, compositions of silver selenide, copper, germanium selenide, and the like. It will be appreciated that later developed materials that display the same characteristics as known materials can also be used for the metal-doped chalcogenide and electrode layers without deviating from the scope of the present invention.

In operation, the multiple-state memory cell 200 illustrated in Figure 1 is capable of storing multiple states by altering or programming the total resistance between the anode and the cathode in a relatively digital fashion. The resistance of the memory cell 200 can then be measured or compared to determine the value of the data stored by the memory cell 200. As a result of the relatively discrete manner in which the resistance can be changed, multiple states can be stored by the memory cell 200.

metal electrode layer 202 is short circuited to the floating electrode layer 206 by the conductive growth 304. A reading circuit coupled to the memory cell 200 measures the resistance of the memory cell 200 in order to determine the data stored by the cell.

5 The growth of the conductive growths 304 and 308 is dependent on the orientation of the electrical field applied to the memory cell 200. That is, as discussed so far, a voltage applied to the metal electrode layer 210 (*i.e.*, the anode) is positive relative to the voltage applied to the metal electrode layer 202 (*i.e.*, the cathode), thus, the direction of growth is from the metal electrode layer 202 to the floating electrode layer 206. Similarly, a conductive growth will be formed extending from the floating electrode layer 206 to the
10 metal electrode layer 210. However, it will be appreciated that application of the voltage in an opposite polarity will reduce whatever conductive growth has been previously formed. Consequently, the memory cell 200 can be programmed to store a different data state by changing the polarity of the applied voltage to the memory cell 200 during a read or write operation to change the resistance of the memory cell 200.

15 It will be further appreciated that reading and writing circuitry for use with embodiments of the present invention is well known to those of ordinary skill in the art, and may be implemented using conventional circuitry and design. It will be further appreciated that the description provided herein is sufficient to enable one of ordinary skill in the art to practice the invention.

20 As illustrated in Figure 2b, application of a voltage to the anode induces the formation of not only conductive growth 304, but conductive growth 308 as well. However, because the thickness of the layer 208 is greater than the thickness of the layer 204, for a given applied voltage across the multiple state memory cell 200 the voltage across the layer 208 is greater than the voltage across the layer 204. Consequently, the
25 floating electrode 206 is short circuited to the anode before the cathode is short circuited to the floating electrode 206. With continued application of a voltage to the anode, the conductive growth 304 eventually creates a short circuit between the cathode and the floating electrode 206, thus reducing the resistance between the anode and the cathode to a

A memory device 500 that includes a memory array 502 having memory cells according to an embodiment of the invention is shown in Figure 4. The memory device 500 includes a command decoder 506 that receives memory command through a command bus 508 and generates corresponding control signals. A row or column address is applied to the memory device 500 through an address bus 520 and is decoded by a row address decoder 524 or a column address decoder 528, respectively. Memory array read/write circuitry 530 are coupled to the array 502 to provide read data to a data output buffer 534 via a input-output data bus 540. Write data are applied to the memory array through a data input buffer 544 and the memory array read/write circuitry 530.

From the foregoing it will be appreciated that, although specific embodiments of the invention have been described herein for purposes of illustration, various modifications may be made without deviating from the spirit and scope of the invention. Accordingly, the invention is not limited except as by the appended claims.

6. The memory cell of claim 1 wherein the thickness of the first layer of a metal-doped chalcogenide material is less than the thickness of the second layer of a metal-doped chalcogenide material.

7. The memory cell of claim 1 wherein the thickness of the second layer of a metal-doped chalcogenide material is less than the thickness of the first layer of a metal-doped chalcogenide material.

8. The memory cell of claim 1, further comprising:
a fourth electrode formed from a fourth conductive material; and
a third layer of a metal-doped chalcogenide material disposed between the third and fourth electrode layers, the third layer providing a medium in which a conductive growth can be formed to electrically couple together the third and fourth electrodes.

9. The memory cell of claim 1 wherein the metal-doped chalcogenide material of the first and second layers are the same.

10. The memory cell of claim 1 wherein the metal-doped chalcogenide material of the first and second layers comprise a silver glass material.

11. A multiple-state memory cell, comprising:
a first electrode coupled to a first voltage;
a second electrode coupled to a second voltage;
a multiple layer data state stack in which multiple data states are stored, the data-state stack including:
a first portion of a metal-doped chalcogenide material adjoining the first electrode, the first portion having a first thickness;
a third electrode of a conductive material adjoining the first portion; and

18. A multiple state memory cell, comprising:

a first electrode layer formed from a first conductive material;

a second electrode layer formed from a second conductive material;

a first layer of a metal-doped chalcogenide material disposed between and adjoining the first and second electrode layers, the first layer providing a medium in which a conductive growth can be formed to electrically couple together the first and second electrode layers;

a third electrode layer formed from a third conductive material;

a second layer of a metal-doped chalcogenide material disposed between and adjoining the second and third electrode layers, the second layer providing a medium in which a conductive growth can be formed to electrically couple together the second and third electrode layers;

a fourth electrode layer formed from a fourth conductive material; and

a third layer of a metal-doped chalcogenide material disposed between and adjoining the third and fourth electrode layers, the third layer providing a medium in which a conductive growth can be formed to electrically couple together the third and fourth electrode layers.

19. The memory cell of claim 18 wherein at least one of the first, second, third, and fourth electrode layers comprises a composition of a silver material.

20. The memory cell of claim 18 wherein the first, second, third, and fourth conductive material are the same.

21. The memory cell of claim 18 wherein the thickness of the first layer of a metal-doped chalcogenide material is less than the thickness of the second layer of a metal-doped chalcogenide material, and the thickness of the second layer of a metal-doped chalcogenide material is less than the thickness of the third layer of a metal-doped chalcogenide material.

conductive growth can be formed to electrically couple together the first and second electrode layers;

a third electrode layer formed from a third conductive material and coupled to a respective column; and

a second layer of a metal-doped chalcogenide material disposed between and adjoining the second and third electrode layers, the second layer providing a medium in which a conductive growth can be formed to electrically couple together the second and third electrode layers;

a row address decoder for selecting a row of memory cells corresponding to a row address;

a column address decoder for selecting a column of memory cells corresponding to a column address;

reading and writing circuitry coupled to the memory array to read data from and write data to the memory cells selected by the row and column address decoders;

a data path coupled between the reading and writing circuitry and an external data terminal of the memory device; and

a command decoder operable to generate control signals responsive to memory commands applied to the memory device.

28. The memory device of claim 27 wherein the first conductive layer of each memory cell is formed from a composition of a silver material.

29. The memory device of claim 27 wherein the conductive material of the first, second and third electrodes is the same.

30. The memory device of claim 27 wherein the thickness of the first layer of a metal-doped chalcogenide material is less than the thickness of the second layer of a metal-doped chalcogenide material.

a first layer of a metal-doped chalcogenide material adjoining the first electrode, the first layer having a first thickness;

a third electrode layer of a conductive material adjoining the first layer;

and

a second layer of a metal-doped chalcogenide material adjoining the third electrode layer, the second layer having a second thickness,

wherein application of a programming voltage to the first electrode induces the formation of a first conductive growth from the third electrode layer to the first electrode and a second conductive growth from the second electrode to the third electrode layer;

a row address decoder for selecting a row of memory cells corresponding to a row address;

a column address decoder for selecting a column of memory cells corresponding to a column address;

reading and writing circuitry coupled to the memory array to read data from and write data to the memory cells selected by the row and column address decoders;

a data path coupled between the reading and writing circuitry and an external data terminal of the memory device; and

a command decoder operable to generate control signals responsive to memory commands applied to the memory device.

37. The memory device of claim 36 wherein the first voltage is positive relative to the second voltage.

38. The memory device of claim 36 wherein the first portion is positioned below the third electrode, and the third electrode is positioned below the second portion.

44. The method of claim 43 wherein under the application of the programming voltage the first electrode is short circuited to the second electrode prior to the second electrode short circuiting to the third electrode.

45. The method of claim 42, further comprising to store a fourth data state, short circuiting the third electrode to a fourth electrode to change the second resistance to a third resistance.

46. A method for forming a multiple state memory cell, comprising:
forming a first electrode layer from a first conductive material;
forming a first layer from a metal-doped chalcogenide material on the first electrode layer,
forming a second electrode layer from a second conductive material on the first layer;
forming a second layer from a metal-doped chalcogenide material on the second electrode layer; and
forming a third electrode layer from a third conductive material on the second layer,
the first layer providing a medium in which a conductive growth can be formed to electrically couple together the first and second electrode layers and the second layer providing a medium in which a conductive growth can be formed to electrically couple together the second and third electrode layers.

47. The method of claim 46 wherein forming the first electrode layer comprises forming the first electrode layer from a composition of a silver material.

48. The method of claim 46 wherein forming the first and second electrode layers comprises forming the first and second electrodes from the same type of material.

55. The method of claim 46 wherein the first electrode is formed beneath the first layer, the first layer is formed beneath the second electrode, the second electrode is formed beneath the second layer, and the second layer is formed beneath the third electrode layer.

56. The method of claim 46 wherein the first electrode is formed adjacent the first layer, the first layer is formed adjacent the second electrode, the second electrode is formed adjacent the second layer, and the second layer is formed adjacent the third electrode layer.