

TITLE OF INVENTION
COMPLEMENTARY BIT PCRAM SENSE AMPLIFIER
AND METHOD OF OPERATION

FIELD OF THE INVENTION

[0001] The invention relates to a method and apparatus for sensing the resistance of a Programmable Conductor Random Access Memory (PCRAM) element.

BACKGROUND OF THE INVENTION

[0002] PCRAM devices store binary data as two different resistance values, one higher than the other. The resistance value represents a particular binary value of logic "0" or logic "1". When sensing the resistance value of a PCRAM device, it is common to compare the resistance of a memory cell undergoing a read operation with resistance of a reference cell to determine the resistance value of the cell being read and thus its logic state. Such an approach is disclosed in U.S. Patent No. 5,883,827. However, this approach has some limitations.

[0003] If the reference cell is defective and a column of memory cells within an array uses a same defective reference cell, the entire column of memory cells will have erroneous resistance readings. In addition, specialized circuitry is required to write a resistance value into the reference cell, and a sense amplifier circuit for such an arrangement tends to be complex and large.

[0004] Typically, sensing schemes for PCRAM devices also tend to have a unique architecture which is different from that normally employed in typical DRAM circuits. Although PCRAM's differ from DRAM's in that they store

binary values in resistive memory elements rather than as charges on capacitors, and although PCRAM's are non-volatile, where the capacitor structures employed in DRAM's are volatile, nevertheless it would be desirable if the read and write circuits for both devices were as similar as possible so that existing DRAM memory device architectures could be easily adapted to read and write PCRAM devices.

BRIEF SUMMARY OF THE INVENTION

[0005] The present invention provides a PCRAM memory device and its method of operation which utilizes a read architecture similar to that employed in some DRAM memory devices. A pair of complementary PCRAM memory cells comprising first and second programmable conductor memory elements are employed, each connected to respective access transistors. During a write operation, the first and second memory elements are written with complementary binary values, that is: if the first memory element is written to a high resistance state, then the second memory element is written to a low resistance state; whereas if the first memory element is written to a low resistance state, the second memory element is written to a higher resistance state.

[0006] During a read operation of, for example, the first memory element, a sense amplifier is connected so that its respective inputs are coupled to receive respective precharge voltages which discharge through the first and second memory elements. A sense amplifier reads the discharging voltages through the two memory elements to determine which is the larger voltage, thus determining

the resistance (high or low) and logic state (high or low) of the memory cell being read.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] These and other features and advantages of the invention will become more apparent from the following detailed description of exemplary embodiments of the invention which are provided in connection with the accompanying drawings in which:

[0008] Figure 1 shows an exemplary PCRAM device;

[0009] Figure 2 is a schematic diagram depicting one aspect of the invention;

[00010] Figure 3 is a schematic diagram depicting an additional aspect of the invention;

[00011] Figure 4 is a schematic diagram depicting an additional aspect of the invention;

[00012] Figure 5 shows the discharge rate characteristics of capacitors employed in the invention;

[00013] Figure 6 shows the invention utilized in a computer system.

DETAILED DESCRIPTION OF THE INVENTION

[00014] The present invention employs a sense amplifier architecture which is somewhat similar to that employed in some conventional DRAM devices to sense

the resistance states of PCRAM memory cells. In the invention, a binary value is stored as a resistance value in a first PCRAM cell while its complement resistance value is stored in a second PCRAM cell. During readout of the first PCRAM cell, both PCRAM cells are used to discharge a precharge voltage into respective inputs of a sense amplifier which reads the discharge voltages to determine the resistance and thus the binary value stored in the first PCRAM cell undergoing a read operation.

[00015] Figure 1 illustrates an exemplary cell arrangement provided within a portion of a PCRAM memory device constructed in accordance with the invention. A PCRAM memory element 102 is illustrated which has a chalcogenite glass body and lower 103 and upper 104 conductors. As is well known, a programmable conductor memory element has two stable resistance states: one high resistance and one low resistance. Normally, when at rest the memory has a high resistance state, but it can be programmed to a low resistance state by suitably applying bias voltages to the conductors 103 and 104. Typically, the low resistant state of a PCRAM memory element is characterized by a dendrite growth through the chalcogenite glass body or along the surface of the chalcogenite glass body between the conductors 103 and 104. A high resistant state is present when there is no such dendrite growth. The grown dendrite is relatively non-volatile in that it will remain in place for a relatively long time, e.g. days or weeks, after the bias voltage is removed.

[00016] As further shown in Figure 1, the PCRAM memory element 102 is coupled by a conductive plug 101 to an access transistor 207 which is driven by a word line 105 which forms the gate structure of transistor 207. The access transistor is coupled through conductive plug 101 to one of the conductors 103

of the PCRAM memory element. The other conductor 104 of the PCRAM element is connected by a common cell plate 109 to a bias voltage, which is common to other PCRAM memory elements provided in the memory device.

[00017] Figure 1 illustrates a common PCRAM architecture in which two adjacent memory cells 207, 211 are coupled to a common digit line 118. Thus, Figure 1 also shows another access transistor 211 driven by a word line 107 which is connected through conductive plug 99 to another PCRAM memory element 104, which in turn is also connected also to the common cell plate 109. Access transistor 211 also has one terminal connected to digit line 118.

[00018] Figure 2 shows an electrical schematic arrangement of a memory array employing the cell architecture illustrated in Figure 1. Thus, the top portion of Figure 2 illustrates the transistors 207 and 211 coupled to the respective PCRAM memory elements 102 and 106 with the access transistors 207 and 211 coupling the memory elements 102 and 106 to the digit line 118.

[00019] As also illustrated in Figure 2, a complementary digit line D1* 120 is also provided in the memory array, to which another set of access transistors is connected which are in turn connected to other PCRAM memory elements. To simplify discussion, a single complementary pair of PCRAM cells is illustrated as 300. It includes transistor 207 and associated PCRAM memory element 102, which is coupled to the digit line 118 (D1), and an access transistor 209 and associated PCRAM memory element 124, which are coupled to digit line 120 (D1*).

[00020] During a write operation, a row line 104, which is coupled to transistor 207 and a row line 113 which is coupled to transistor 209 are activated

such that if PCRAM memory element 102 is written to a high resistance state, PCRAM element 124 is written to a low resistance state, and vice versa. In this way, PCRAM memory elements 102 and 124 are accessed together and always store complementary resistance digit values. Thus assuming that PCRAM memory element 102 is the primary element which is being written to and read from, a sense amplifier 210 which is coupled to the digit lines 118 and 120 will read the value of PCRAM memory element 102 by comparing a discharging precharge voltage on digit line 118 to the discharging precharge voltage on digit line 120 during a memory read operation.

[00021] Thus, prior to a memory read, a precharge voltage is applied to complementary digit lines 118 and 120 by a precharge circuit 301. The precharge circuit is activated by a logic circuit on a precharge line which activates transistors 305 to supply a voltage, for example, $V_{cc}/2$, to both digit lines 118 and 120.

[00022] An equilibrate circuit 303 may also be provided which is activated by an equilibrate signal after the precharge circuit is activated to ensure that the voltages on lines 118 and 120 are the same. The voltages on lines 118 and 120 are held by a parasitic capacitance of the lines. After precharge and equilibrate (if present) circuits are activated, a read operation may be conducted on the complimentary cell pair 300. This read operation is illustrated in greater detail in Figure 3, which is a simplification of the sense amplifier 210 input path.

[00023] Parasitic capacitance for the complementary digit lines 118 and 120 are illustrated as $C1$ and $C1^*$. The respective access transistors 207 and 209 are illustrated as connected to their respective word lines 105 and 113. The

PCRAM memory elements 102 and 124 are also illustrated. As noted, a binary value is stored, for example, in memory PCRAM memory element 102 as a resistance value. It will be either a high resistance value or a low resistance value, and the complementary resistance value will be stored in PCRAM memory element 124.

[00024] During a read operation, the precharge voltage applied to the complementary digit lines 118 and 120 is allowed to discharge through the access transistors 207 and 209 and through the respective resistance values of the PCRAM memory elements 102 and 124. Because the resistance values will be different, one high and one low, the voltages on the digit lines D1 and D1* (118, 120) will begin to diverge during a read operation. Although the voltage initially applied to the complementary digit lines 118 and 120 is a voltage of $V_{cc}/2$, during a read operation this voltage actually is slightly higher by approximately .3mV due to the presence of the parasitic capacitance C1 and C1* on the digit lines 118 and 120, as well as gate-drain capacitance inherent within transistors 207 and 209.

[00025] Figure 5 illustrates the voltages on the complementary digit lines 118 and 120 during a read operation. The activation of the word lines 105 and 113 is illustrated as a pulse signal, and initially the voltage of $V_{cc}/2$ + approximately .3mV which exists on both digit lines D1 and D1* begins to decay. Because one PCRAM memory element, e.g. 102, has a higher resistance than the other, the voltage on the digit line associated with the lower resistance value, e.g. 124, will decay faster than the voltage on the digit line coupled to the higher resistance value, e.g. D1. This is illustrated in Figure 5.

[00026] The divergence of the two voltages on the lines D1 and D1* progressively increases. At a predetermined time after the word lines 105 and 113 are activated, the sense amplifier 210 is activated. The sense amplifier can have an architecture typically employed in a DRAM arrangement which is illustrated in Figure 4. Such a sense amplifier includes an Nsense amplifier latch 302 and a Psense amplifier latch 304. This structure is illustrated in Figure 4.

[00027] Reverting back to Figure 5, the N sense amplifier is fired first at a time t_1 . When the Nsense amplifier fires, the digit line which has the lower voltage, e.g. D1* in the example, is immediately pulled to ground. Thereafter, the Psense amplifier is fired at a time t_2 which drives the higher voltage line, e.g. D1, to Vcc. Accordingly at a time t_2 , the sense amplifier 210 outputs a value of Vcc indicating the high resistant state for the PCRAM memory element 102.

[00028] Although Figure 5 illustrates the signal timing which occurs when PCRAM memory element 102 has a higher resistance than memory element 104, obviously the signal levels are reversed if PCRAM memory element 102 has a low resistance state and PCRAM memory element 124 has a high resistance state. That is, the signal diagrams illustrated in the Figure 5 would have the digit line D1* going towards Vcc and the digit line D1 going towards ground.

[00029] Figure 5 also illustrates another aspect of the invention. As shown, the voltage for row lines 105, 113 increases from near ground level to a positive voltage near Vcc for a read operation. This voltage then returns to near ground level before the sense amplifier is enabled (before t_1). As a result, there is no rewriting of a read PCRAM memory element. If such rewriting of a PCRAM cell is desired, then the voltage on row line 105, 113 having a memory element

which is written to a low resistance state, may be at a voltage level near V_{cc} during operation of the sense amplifier 210, which will automatically rewrite (refresh) the read cell to the low resistance state.

[00030] Because programmable contact memory elements are resistive rather than capacitive memory elements, it is possible they will take longer to pull the digit lines up to V_{cc} and to ground than a typical capacitive memory element found within a DRAM. Supposing that to be true, older DRAM sense amplifier designs that run somewhat slower than the latest generation of DRAM sense amplifiers could also be used with PCRAM memory cells. The advantage of doing so would be that these older DRAM sense amplifiers have already been shown to perform effectively, and their test infrastructure is already confirmed. Consequently, a hybrid memory consisting of PCRAM memory elements using DRAM sense amplifiers can be produced having the advantages of PCRAM technology, yet being producible quickly and inexpensively.

[00031] Although Figure 2 shows the complementary programmable contact memory element 102 and 106 and associated access transistors and digit lines D and D* as being provided in the same memory array, the complementary memory elements, access transistors and digit lines may also be provided in respective different memory arrays.

[00032] Figure 6 is a block diagram of a processor-based system 400 utilizing a PCRAM memory device 200 constructed in accordance with one of the embodiments of the present invention. The processor-based system 400 may be a computer system, a process control system or any other system employing a processor and associated memory. The system 400 includes a central processing

unit (CPU) 402, e.g., a microprocessor, that communicates with the PCRAM memory device 408 and an I/O device 404 over a bus 420. It must be noted that the bus 420 may be a series of buses and bridges commonly used in a processor-based system, but for convenience purposes only, the bus 420 has been illustrated as a single bus. A second I/O device 406 is illustrated, but is not necessary to practice the invention. The processor-based system 400 also includes read-only memory (ROM) 410 and may include peripheral devices such as a floppy disk drive 412 and a compact disk (CD) ROM drive 414 that also communicates with the CPU 402 over the bus 420 as is well known in the art.

[00033] One or more memory devices 200 may be provided on a plug-in memory module 256, e.g. SIMM, DIMM or other plug-in memory module, for easy connection with or disconnection from the bus 420. While the invention has been described and illustrated with reference to specific exemplary embodiments, it should be understood that many modifications and substitutions can be made without departing from the spirit and scope of the invention. Accordingly, the invention is not to be considered as limited by the foregoing description but is only limited by the scope of the appended claims.

1. A method of operating a programmable conductor memory device comprising:

storing a binary value as respective resistance states in a first and second programmable conductor memory element wherein the resistance state stored in the first programmable conductor memory element is complementary to the resistance state concurrently stored in the second programmable conductor memory element:

determining a binary value stored in one of said programmable conductor memory elements by discharging respective voltages through said memory elements and comparing the discharging voltages; and

rewriting the binary value stored only in the one of said first and second programmable conductor memory elements which is storing a low resistance state.

2. A method as in claim 1 wherein said discharging comprises:
precharging complementary digit lines to a voltage value; and
respectively discharging the voltage value on each of said complementary digit lines through said first and second programmable conductor memory elements.

3. The method as in claim 2 wherein said precharged voltage value on said complementary digit lines is discharged through said respective first and second programmable conductor memory elements by enabling access transistors respectively associated with each of said first and second programmable conductor memory elements.

4. The method as in is claim 3 further comprising completing said precharge before enabling said access transistors.

5. The method as in claim 4 further comprising equilibrating said digit lines before enabling said access transistors.

6. The method as in claim 3 where said comparison comprises:
determining whether the discharging voltage associated with one memory element is the higher or lower of the two discharging voltages and outputting a first

binary value if the discharging voltage associated with the said one memory element is the higher voltage and outputting a second binary value if the discharging voltage associated with said one memory element is the lower voltage.

7. The method as in claim 6 further comprising setting a digit line having a higher discharge voltage to a first predetermined voltage state and setting a digit line having a lower discharging voltage to a second predetermined voltage state.

8. The method as in claim 7 wherein said first predetermined voltage is higher than said second predetermined voltage.

9. The method as in claim 8 wherein said second predetermined voltage is ground voltage.

10. The method as in claim 7 further comprising disabling said access transistors before said digit lines are set to said first and second voltage states.

11. The method as in claim 7 further comprising enabling at least one of said access transistors during a time when said digit lines are set to said first and second voltage states.

12. A programmable resistance memory device, comprising:
a first and second digit line;
first and second programmable resistance memory elements associated with a single memory cell for respectively storing complementary binary digit values of a data bit as different resistance values;
first and second access devices for respectively coupling said first and second memory elements to said first and second digit lines; and
a sense amplifier having inputs respectively coupled to said first and second digit lines for reading said data bit stored as a resistance value in one of said memory elements.

13. The device as in claim 12 further comprising a precharge circuit for precharging said digit lines to a common precharge voltage prior to a read operation.

14. The device as in claim 12 further comprising a pair of row lines respectively coupled to said first and second access devices; and
circuitry for simultaneously activating said first and second row lines and therefore activating said first and second access devices.

15. The device as in claim 14 wherein said first and second access devices are access transistors.

16. The device as in claim 14 wherein when said access devices are activated, said precharge voltage on said digit-lines discharges through a respective resistance of said first and second resistance-based memory elements, said sense amplifier determining whether said one of said memory elements is storing a high or low resistance state and outputting a binary value corresponding to the stored resistance state.

17. The device as in claim 13 wherein said digit lines have an associated parasitic capacitance which stores said precharge voltage.

18. The device as in claim 13 wherein said parasitic capacitance stores a voltage value which is larger than said precharge voltage.

19. The device as in claim 14 wherein said row lines are activated in a manner which prevents an automatic refresh of at least one of said memory elements during a read operation.

20. The device as in claim 12 wherein said first and second memory elements are in different memory arrays.

21. The device as in claim 13 further comprising an equilibrate circuit for

equilibrating the voltage on said digit lines.

22. A memory device comprising:

a plurality of pairs of first and second programmable resistance memory cells, each pair of memory cells comprising:

first and second programmable resistance memory elements associated with a single memory cell for respectively storing complementary binary digit values of a data bit as different resistance values;

first and second access devices for respectively coupling said first and second memory elements to first and second digit lines; and

a sense amplifier having inputs respectively coupled to said first and second digit lines for reading said data bit stored as a resistance value in one of said memory elements.

23. The device as in claim 22 further comprising a precharge circuit for precharging said digit lines to a common precharge voltage prior to a read operation.

24. The device as in claim 22 further comprising a pair of row lines respectively coupled to said first and second access devices; and

circuitry for simultaneously activating said first and second row lines and therefore activating said first and second access devices.

25. The device as in claim 24 wherein said first and second access devices are access transistors.

26. The device as in claim 24 wherein when said access devices are activated, said precharge voltage on said digit lines discharges through a respective resistance of said first and second programmable resistance memory elements, said sense amplifier determining whether said one of said memory elements is storing a high or low resistance state and outputting a binary value corresponding to the stored resistance state.

27. The device as in claim 26 wherein said digit lines have an associated parasitic capacitance which stores said precharge voltage.

28. The device as in claim 27 wherein said parasitic capacitance stores a voltage value which is larger than said precharge voltage.

29. The device as in claim 22 wherein said first and second memory elements are in a common memory array.

30. The device as in claim 22 wherein said first and second memory elements are in different memory arrays.

31. The device as in claim 23 further comprising an equilibrate circuit for equilibrating the precharge voltage on said digit lines.

32. The device as in claim 22 wherein said memory device is provided on a memory module.

33. The device as in claim 32 wherein said memory module is a plug-in memory module.

34. A computer system comprising:
a processor;
a memory system coupled to said processor, said memory system comprising:
a first and second digit line;
first and second programmable resistance memory elements associated with a single memory cell for respectively storing complementary binary digit values of a data bit as different resistance values;
first and second access devices for respectively coupling said first and second programmable resistance memory elements to said first and second digit lines; and
a sense amplifier having inputs respectively coupled to said first and second digit lines for reading said data bit stored as a resistance value in one of said memory

elements.

35. The system as in claim 34 further comprising a precharge circuit for precharging said digit lines to a common precharge voltage prior to a read operation.

36. The system as in claim 24 further comprising a pair of row lines respectively coupled to said first and second access devices; and
circuitry for simultaneously activating said first and second row lines and therefore activating said first and second access devices.

37. The system as in claim 36 wherein said first and second access devices are access transistors.

38. The system as in claim 36 wherein when said access devices are activated, said precharge voltage on said digit lines discharges through a respective resistance of said first and second memory elements, said sense amplifier determining whether said one of said memory elements is storing a high or low resistance state and outputting a binary value corresponding to the stored resistance state.

39. The system as in claim 35 wherein said digit lines have an associated parasitic capacitance which stores said precharge voltage.

40. The system as in claim 39 wherein said parasitic capacitance stores a voltage value which is larger than said precharge voltage.

41. The system as in claim 34 wherein said first and second memory elements are in a common memory array.

42. The system as in claim 34 wherein said first and second memory elements are in different memory arrays.

43. The system as in claim 34 further comprising an equilibrate circuit for

equilibrating the voltage on said digit lines.

44. The method as in claim 1, wherein said act of rewriting comprises:
increasing a voltage level of a rowline coupled to said one programmable conductor memory element from approximately ground level to approximately a system voltage level during operation of a sense amplifier circuit used in performing said act of determining.

45. A method of operating a programmable conductor memory device comprising:
storing a binary value as respective resistance states in a first and second programmable conductor memory element wherein the resistance state stored in the first programmable conductor memory element is complementary to the resistance state concurrently stored in the second programmable conductor memory element;
determining a binary value stored in one of said programmable conductor memory elements by discharging respective through said memory elements and comparing the discharging voltages; and
maintaining a voltage level of a wordline coupled to each of said first and second programmable conductor memory elements at approximately ground during activation of a sense amplifier used to perform said act of determining.

46. A method of operating a programmable resistance memory device comprising:
storing a binary value as respective different resistance states in a first and second programmable resistance memory element;
determining a binary value stored in one of said memory elements by discharging respective voltages through said memory elements and comparing the discharging voltages.

47. The method as in claim 46 wherein said discharging comprises:
precharging complementary digit lines, which are respectively switchably

coupled to said first and second programmable resistance memory elements, to a common voltage value; and

respectively discharging the common voltage value on each of said complementary digit lines through each of said first and second programmable resistance memory elements.

48. The method as in claim 47 wherein said precharged voltage value on said complementary digit lines is discharged through said respective programmable resistance memory elements by enabling access transistors respectively associated with each of said memory elements.

49. The method as in claim 48 further comprising completing said precharge before enabling said access transistors.

50. The method as in claim 49 further comprising equilibrating said digit lines before enabling said access transistors.

51. The method as in claim 48 wherein said comparison comprises: determining whether the discharging voltage associated with one memory element is the higher or lower of the two discharging voltages and outputting a first binary value if the discharging voltage associated with the said one memory element is the higher voltage and outputting a second binary value if the discharging voltage associated with said one memory element is the lower voltage.

52. The method as in claim 51 further comprising setting a digit line having a higher discharge voltage to a first predetermined voltage state and setting a digit line having a lower discharging voltage to a second predetermined voltage state.

53. The method as in claim 52 wherein said first predetermined voltage is higher than said second predetermined voltage.

54. The method as in claim 53 wherein said second predetermined voltage

is ground voltage.

55. The method as in claim 52 further comprising disabling said access transistors before said digit lines are set to said first and second voltage states.

56. The method as in claim 52 further comprising enabling at least one of said access transistors during a time when said digit lines are set to said first and second voltage states.

57. A method of producing a programmable resistance memory device, said method comprising:

forming first and second digit lines;

forming first and second programmable resistance memory elements;

forming first and second access transistors for respectively coupling said first and second memory elements to said first and second digit lines;

forming a precharge circuit for precharging said first and second digit lines to a first voltage;

forming respective row lines for operating said access transistors to couple said memory elements to respective digit lines; and

forming a sense amplifier which has inputs respectively coupled to said digit lines.

58. The method as in claim 57 further comprising forming a row decoder for decoding row address signals and selectively and simultaneously enabling said word lines.

59. The method as in claim 57 wherein said memory elements are fabricated in a common memory array.

60. The method as in claim 57 wherein said memory elements are fabricated in different memory arrays.

61. The method as in claim 57 further comprising forming an equilibrate circuit for equilibrating said digit lines.

62. A method of operating a programmable resistance memory device, the method comprising:

respectively storing complementary binary digit values of a data bit as different resistance values in first and second programmable resistance memory elements associated with a single memory cell; and

reading said data bit stored as a resistance value in one of said memory elements.

63. The method of claim 62 further comprising:

precharging respective digit lines switchably coupled to said first and second programmable resistance memory elements to a common precharge voltage prior to said act of reading.

64. The method of claim 63 further comprising:

discharging said precharge voltage on said digit lines through a respective resistance of said first and second programmable resistance memory elements;

determining whether said one of said memory elements is storing a high or low resistance state; and

outputting a binary value corresponding to the stored resistance state.

65. The method of claim 63, wherein said act of precharging further comprises:

storing said precharge voltage with a parasitic capacitance associated with said digit lines.

66. The method of claim 63 further comprising:

equilibrating said precharge voltage on said digit lines.

67. A method of forming a memory device, the method comprising:

forming an array of memory cells, wherein said act of forming further comprises:

forming first and second digit lines;

forming first and second programmable resistance memory elements;

forming first and second access transistors for respectively coupling said first and second memory elements to said first and second digit lines;

forming a precharge circuit for precharging said first and second digit lines to a first voltage;

forming respective row lines for operating said access transistors to couple said memory elements to respective digit lines; and

forming a sense amplifier which has inputs respectively coupled to said digit lines.

68. The method of claim 67, wherein said first act of forming further comprises forming a row decoder for decoding row address signals and selectively and simultaneously enabling said word lines.

69 The method of claim 67, wherein said first act of forming further comprises forming an equilibrate circuit for equilibrating said digit lines.