

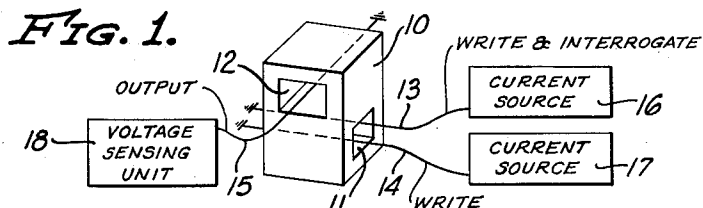
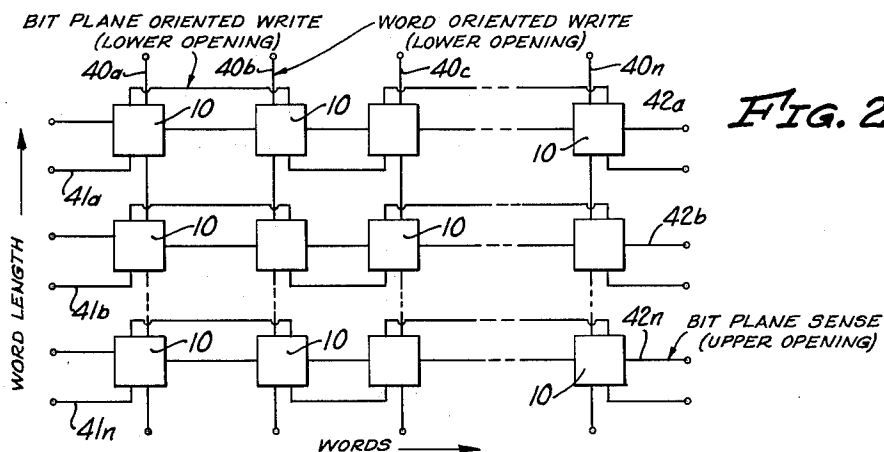
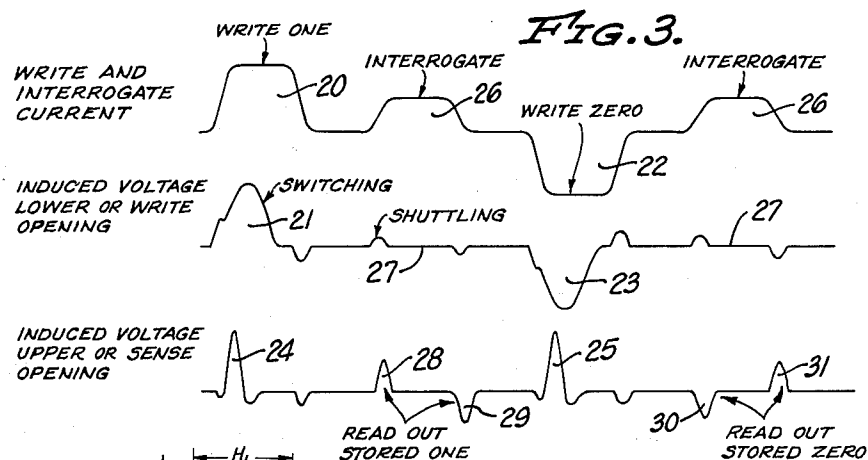
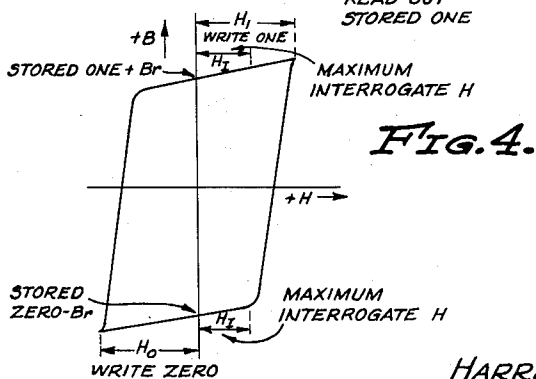
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WRITE-INTERROGATE MEMORY SYSTEM

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3,126,532

WRITE-INTERROGATE MEMORY SYSTEM

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This invention relates to magnetic memory devices and, in particular, to memory devices which are especially suitable for use in memory arrays.

It is an object of the invention to provide a memory device in which the peripheral equipment and the wiring for writing, interrogation and sensing are simplified, permitting assembly of large numbers of the devices in memory systems with a minimum of complexity. A further object of the invention is to provide such a memory device including a block of magnetic material with two perpendicular current axes therethrough with writing and interrogation being carried out along one axis and with the sense or output information being provided along the other axis. Another object is to provide such a structure which includes one conductor positioned along the output axis for the output signal and one or more conductors positioned along the other axis for writing and interrogation.

It is an object of the invention to provide a magnetic memory device including a block of magnetic material having two perpendicular current axes therethrough and means for generating a current along one axis of a magnitude and duration to produce a magnetizing force sufficient to cause flux switching about the axis for writing or storing information in the device. A further object is to provide such a structure including means for generating a current along the axis of a magnitude and duration to produce a magnetizing force only sufficient to provide shuttling (reversible flux changes) in the region of the residual flux density without producing flux switching (irreversible flux changes). A further object is to provide such a structure wherein the flux switching current and flux shuttling current can be achieved with various combinations of conductors and current sources.

It is an object of the invention to provide a magnetic memory device of the type referred to above which provides a bipolar output and which may be nondestructively interrogated without requiring rewriting or other setting current. A further object is to provide a magnetic memory device including a block of magnetic material having two residual flux states and first and second current axes therethrough perpendicular to each other, means for generating a current along the first axis of either polarity and of a magnitude and duration to produce a magnetizing force sufficient to switch the residual flux about the first axis from one of the residual magnetic states to the other, and for generating a current along the first axis of a magnitude and duration to produce a magnetizing force only sufficient to shuttle the residual flux about the first axis without switching the residual flux state, and output means for determining flux changes occurring about the second axis during the flux shuttling. Another object is to provide such a device including openings through the block along the current axes, conductors positioned in the openings, and current sources connected to the conductors for developing the desired magnetizing forces.

It is an object of the invention to provide a memory array formed of a plurality of the memory devices arranged in rows and columns with a set of write conductors directed along the write axis of each block of a column and a set of write conductors directed along the write axis of each block of a row to provide for coincident current writing in each block of the array, and a set of sense conductors running along the output axis of

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each block of a row, with the write conductors of each column also serving as the interrogate conductors.

Other objects, advantages, features and results of the invention will more fully appear in the course of the following description. The drawing merely shows and the description merely describes preferred embodiments of the present invention which are given by way of illustration or example.

In the drawing:

FIG. 1 is an isometric view of a preferred form of memory device;

FIG. 2 is a diagram showing a plurality of the memory devices connected in an array;

FIG. 3 is a plot of waveforms showing the basic operation of the memory device; and

FIG. 4 is a magnetic hysteresis loop illustrating the operation of the memory device.

In FIG. 1, a block 10 of magnetic material has openings 11, 12 passing therethrough perpendicular to each other. Conductors 13, 14 are positioned in the opening 11 and a conductor 15 is positioned in the opening 12. A current source 16 is connected to the conductor 13 and a current source 17 is connected to the conductor 14. A voltage sensing unit 18 is connected to the conductor 15. As illustrated, each conductor comprises a single turn winding. Of course, multiturn windings can be used, resulting in a reduction in current requirements but an increase in bulk and manufacturing time and a decrease in operating speed. In the preferred form, some magnetic material is provided between the openings 11, 12 but such structure is not essential to the operation of the device.

The selection of the magnetic material for the block 10 is not critical but the hysteresis loop of the material should have sufficient squareness to provide two residual flux states and a reasonable writing characteristic. A typical hysteresis loop is shown in FIG. 4 with the residual flux states indicated at $+Br$ and $-Br$.

In order to switch the residual flux from $+Br$ to $-Br$, a magnetizing force equal to or greater than H_0 must be provided. Similarly, in order to fully switch the stored flux from $-Br$ to $+Br$, a magnetizing force equal to or greater than H_1 must be provided. A lesser magnetizing force such as indicated at H_2 , will not produce flux switching but merely a temporary change with a return to the same residual state. This action is sometimes referred to as flux shuttling or reversible domain rotation.

Writing can be carried out in the device of FIG. 1 by providing coincident current pulses in the conductors 13, 14 with each current pulse being of a magnitude and duration to produce a magnetizing force only sufficient to provide flux shuttling while the combination of the coincident pulses produces a magnetizing force sufficient to cause flux switching. This mode of operation is illustrated in FIG. 3.

The positive current pulse 20 results from the combination of the coincident current pulses on the conductors 13, 14. This current pulse produces flux switching about the lower opening as indicated by the voltage pulse 21 which would be induced on a conductor positioned in the lower opening. For purposes of this discussion, the positive current pulse 20 is defined as writing a binary one and producing a positive residual flux. The negative current pulse 22 will produce flux switching about the lower opening in the opposite direction as indicated by the induced voltage pulse 23, providing for writing a binary zero into the memory. The magnetic material about the upper or sense opening 12 is initially set at one of the residual states, the choice being arbitrary. The output polarity of both pulses depends on which re-

sidual state the upper hole is in, i.e., output represents a decrease in flux density when interrogate current is increasing in direction of further saturation of the lower opening. Flux switching occurring about the lower opening produces a temporary flux change about the upper opening as indicated by the induced voltage pulses 24, 25. The flux switching about the lower opening produces a temporary decrease in flux about the upper opening. This flux decrease always starts from the same residual value and returns thereto regardless of the direction of flux switching about the lower opening, hence the polarity of the output pulses 24, 25 is the same.

Information is read from the memory by means of the interrogate current pulse 26. In the embodiment of FIG. 1, the interrogate current is applied to the conductor 13 from the current source 16 and is the same pulse which is applied to this conductor for writing a one. There is no coincident current on the conductor 14. The current pulse 26 is of a magnitude and duration to produce the magnetizing force H_I , resulting in merely shuttling the flux about the lower opening as indicated at 27 in FIG. 3. If the residual flux about the lower opening is in the positive state, i.e., a one is stored, the flux shuttling will produce a positive voltage pulse 28 followed by a negative voltage pulse 29 on the conductor 15 in the upper opening. If a zero is stored, i.e., the residual state is negative, the flux shuttling produces a negative pulse 30 followed by a positive pulse 31 on the output conductor. When interrogated to produce only flux shuttling, the polarity of the output signal on the conductor in the upper opening is a function only of the polarity of the residual flux about the lower opening when the polarity of the interrogate current and the polarity of the residual flux about the upper opening are fixed. Some of the magnetic material of the block 10 is shared by the flux paths about the upper and lower openings. It appears that the flux shuttling produces temporary magnetic domain rotation in this shared magnetic material with the polarity of flux change in the upper path being a function of the residual orientation of the flux around both holes and dependent on the direction of domain rotation.

The necessary magnetizing forces for switching and shuttling may be obtained by various combinations of conductors and current pulses. The structure of FIG. 1 is preferred as it provides for coincident current writing of ones and zeros and permits interrogation on one of the write conductors using the write current pulse. As an alternative, a single conductor can be positioned in the lower opening with the current source supplying a relatively large pulse thereto for flux switching and a relatively small pulse for flux shuttling. Another alternative may utilize two conductors in the lower opening 11 with the write current pulses connected to one of the conductors and the interrogate current pulses connected to the other conductor.

A word oriented linear select array utilizing a plurality of the memory devices of FIG. 1 is illustrated in FIG. 2. A plurality of the blocks 10 is shown arranged in columns and rows with each vertical column comprising a word and each horizontal row a bit plane. A conductor 40a is passed through the write or lower opening 11 of each block in the left column. Similar conductors 40b, 40c . . . 40n are provided for each succeeding column of blocks. A conductor 41a is passed through the lower or write opening 11 of each block of the upper row. Similar conductors 41b . . . 41n are passed through the lower openings of the succeeding rows. A conductor 42a is passed through the upper or output opening 12 of each block of the upper row. Similar conductors 42b . . . 42n are passed through the upper openings of each succeeding row.

In operation of the array, information is written into a particular block by providing coincident current pulses

on the particular 40 conductor and 41 conductor which pass through the selected block. Since the pulses on each of these conductors is insufficient to produce flux switching by itself, there will be no change in any of the remaining blocks. A complete word can be read from the array at one time by applying an interrogate pulse to one of the 40 conductors resulting in output voltages on each of the 42 conductors corresponding to the stored information in each of the blocks threaded by the particular 40 conductor energized. While the array is described herein in terms of vertical columns and horizontal rows, it should be noted that the actual physical arrangement of the blocks may take various forms and the expressions "row" and "column" actually refer to the threading of the conductors rather than the physical layout of the blocks.

A word oriented memory using a buffer diode matrix for current steering with row drivers and column switches can use the array of FIG. 2 with the same diode matrix and column switches and separate row drivers for write and interrogate. The drivers could be used with the same word oriented conductor resulting in a very significant saving of equipment.

The memory device of the present invention provides for the write and interrogate currents along the same axis, permitting use of a single word oriented conductor with a common current steering matrix. The output is bipolar in nature and the polarity for ones and zeros can be selected as desired by choosing an appropriate polarity for the interrogate pulse or the initial set of the sense hole. The interrogation operation is nondestructive in nature permitting the memory to be interrogated any number of times between writing operations.

Although exemplary embodiments of the invention have been disclosed and discussed, it will be understood that other applications of the invention are possible and that the embodiments disclosed may be subjected to various changes, modifications and substitutions without necessarily departing from the spirit of the invention.

I claim as my invention:

1. In a magnetic memory device, the combination of: a block of magnetic material having two residual flux states and first and second openings therethrough perpendicular to each other, with a first flux path about said first opening and a second flux path about said second opening intersecting and perpendicular to said first flux path in a zone of said block between said openings; means for generating a current in said first opening of either polarity and of a magnitude and duration to produce a magnetizing force sufficient to switch the residual flux about said first opening from one of said states to the other, and for generating a current in said first opening of a magnitude and duration to produce a magnetizing force only sufficient to shuttle the residual flux about said first opening without switching the residual flux state; and output means for determining flux changes occurring about said second opening during said flux shuttling with flux shuttling from either residual flux state in said first path providing an output pulse in said output means and with the polarity of said output pulse being a function of the polarity of the residual flux state in said first path.

2. In a magnetic memory device, the combination of: a block of magnetic material having two residual flux states and first and second openings therethrough perpendicular to each other, with a first flux path about said first opening and a second flux path about said second opening intersecting and perpendicular to said first flux path in a zone of said block between said openings; first and second write conductors positioned in said first opening; an output conductor positioned in said second opening; a first current source connected to said first write conductor for generating a current therein of either polarity and of a magnitude and duration to produce a

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magnetizing force only sufficient to shuttle the residual flux about said first opening without switching the residual flux state; a second current source connected to said second write conductor for generating a current therein of either polarity and of a magnitude and duration to produce a magnetizing force which when combined with the magnetizing force of said first write conductor is sufficient to switch the residual flux about said first opening from one of said states to the other; and output means connected to said output conductor for determining voltage signals generated thereon by said flux shuttling with flux shuttling from either residual flux state in said first path providing an output pulse in said output means and with the polarity of said output pulse being a function of the polarity of the residual flux state in said first path.

3. A memory array comprising: a plurality of blocks of magnetic material having two residual flux states, with each block having first and second openings therethrough perpendicular to each other, with a first flux path about said first opening and a second flux path about said second opening intersecting and perpendicular to said first flux path in a zone of said block between said openings, and with said plurality of blocks electrically arranged in rows and columns; a plurality of first write conductors, with each first write conductor passing through the first opening of all the blocks of a column respectively; a plurality of second write conductors, with each second write conductor passing through the first opening of all the blocks of a row respectively; a plurality of sense conductors, with each sense conductor passing through the second opening of all the blocks of a row respectively; a plurality of first means for generating currents in each of said write conductors, respectively, each of said first means generating a current of either polarity and of a magnitude and duration to produce a magnetizing force only sufficient to shuttle the residual flux about the first opening without switching the residual flux state; and a plurality of second means for generating currents in each of said second write conductors, respectively, each of said second means generating a current of either polarity and of a magnitude and duration to produce a magnetizing force only sufficient to shuttle the residual flux about the first opening without switching the residual flux state, with the magnetizing force resulting from coincidence of current in both write conductors of a particular block sufficient to switch the residual flux about the first opening from one of said states to the other, with flux shuttling from either residual flux state in said first path providing an output pulse in said output means and with the polarity of said output pulse being a function of the polarity of the residual flux state in said first path.

4. In a magnetic memory device, the combination of: a block of magnetic material having two residual flux states and first and second openings therethrough perpendicular to each other, with a first flux path about said first opening and a second flux path about said second opening;

means for generating a current in said first opening of either polarity and of a magnitude and duration to produce a magnetizing force sufficient to switch the residual flux in said first flux path from one of said states to the other, and for generating a current in said first opening of a magnitude and duration to produce a magnetizing force only sufficient to shuttle the residual flux in said first flux path without switching the residual flux state, with flux shuttling occurring for either residual flux state in said first path and with the polarity of the flux shuttling being a function of the polarity of the residual flux state in said first path;

and output means for determining flux changes occurring in said second flux path during said flux shuttling with the polarity of output pulses in said out-

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put means resulting from said flux shuttling being dependent on the residual flux state in said first path.

5. In a magnetic memory device, the combination of: a block of magnetic material having two residual flux states and first and second openings therethrough perpendicular to each other, with a first flux path about said first opening and a second flux path about said second opening;

at least one write conductor positioned in said first opening;

an output conductor positioned in said second opening; means for generating a current in the write conductor of either polarity and of a magnitude and duration to produce a magnetizing force sufficient to switch the residual flux in said first flux path from one of said states to the other, and for generating a current therein of a magnitude and duration to produce a magnetizing force only sufficient to shuttle the residual flux in said first flux path without switching the residual flux state, with flux shuttling occurring for either residual flux state in said first path and with the polarity of the flux shuttling being a function of the polarity of the residual flux state in said first path;

and output means connected to said output conductor for determining voltage signals generated thereon by said flux shuttling, with the polarity of the voltage signals resulting from flux shuttling being dependent on the residual flux state in said first path.

6. In a magnetic memory device, the combination of: a block of magnetic material having two residual flux states and first and second openings therethrough perpendicular to each other;

first and second write conductors positioned in said first opening;

an output conductor positioned in said second opening;

first means for generating a current in said first write conductor of either polarity and of a magnitude and duration to produce a magnetizing force only sufficient to shuttle the residual flux in said first path without switching the residual flux state;

second means for generating a current in said second write conductor of either polarity and of a magnitude and duration to produce a magnetizing force which when combined with the magnetizing force of said first means is sufficient to switch the residual flux in said first flux path from one of said states to the other, with flux shuttling occurring for either residual flux state in said first path and with the polarity of the flux shuttling being a function of the polarity of the residual flux state in said first path;

and output means connected to said output conductor for determining voltage signals generated thereon by said flux shuttling with the polarity of the voltage signals resulting from flux shuttling being dependent on the residual flux state in said first path.

7. A memory array comprising:

a plurality of blocks of magnetic material having two residual flux states, with each block having first and second openings therethrough perpendicular to each other with a first flux path about said first opening and a second flux path about said second opening, and with said plurality of blocks electrically arranged in rows and columns;

a plurality of first means for generating a current in the first opening of the blocks of each of the columns respectively, of either polarity and of a magnitude and duration to produce a magnetizing force only sufficient to shuttle the residual flux in the first flux path without switching the residual flux state;

a plurality of second means for generating a current in the first opening of the blocks of each of the rows respectively, of either polarity and of a magnitude and duration to produce a magnetizing force

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only sufficient to shuttle the residual flux in said first flux path without switching the residual flux state, with the magnetizing force resulting from coincidence of currents of said first and second means in a particular block being of a magnitude to produce a magnetizing force sufficient to switch the residual flux in the first flux path thereof from one of said states to the other, with flux shuttling occurring for either residual flux state in the first path and with the polarity of the flux shuttling being a function of the polarity of the residual flux state in the first path;

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and a plurality of output means for determining flux changes occurring in the second flux path of the block of each of the rows respectively, during flux shuttling produced by one of said first means.

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