

PATENT SPECIFICATION (11)

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(54) IMPROVEMENTS IN OR RELATING TO MAGNETIC DEVICES

(71) We, WESTERN ELECTRIC COMPANY, INCORPORATED, of 195, Broadway, New York City, New York State, United States of America, a Corporation organised and existing under the laws of the State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to magnetic devices and, more particularly, to such devices including a material in which single wall domains can be moved.

A single wall domain is a magnetic domain encompassed, in the plane of a material in which it can be moved, by a domain wall which closes on itself to form a stable entity free to move in the plane. A typical material is a rare earth orthoferrite or a garnet crystal having a preferred direction of magnetization along an axis out of the plane of movement, nominally normal to the plane. It is convenient to designate one direction along that axis (viz., the positive direction) as the direction of the magnetization of the domain, the remainder of the material having its magnetization in the negative direction. Such a convention permits a domain to be represented as an encircled plus sign in a field of negative signs or, most simply, as a circle. A single wall domain and an arrangement for manipulating such domains are disclosed in U.K. Patent No. 1,187,623.

Single wall domains in a sheet of material are constrained to a given diameter typically by a bias field of a polarity to constrict domains—a negative polarity according to the assumed convention. Domains are moved in the sheet by a field (viz., a field gradient) which is provided in positions consecutively offset from the position occupied by a domain.

Field gradients for moving domains are [Price 25p]

provided generally by pulses applied to an array of conductor loops adjacent the surface of the material in which the domains are moved. By pulsing a succession of conductors consecutively offset from the position occupied by a domain, consecutively offset gradients are established for causing domain displacement. In practice, the conductors are interconnected serially in three sets to provide a familiar three-phase shift register operation for domain patterns. A propagation arrangement of this type is disclosed in the above mentioned patent.

Generally, information is represented in a domain propagation path in binary form by having the presence of a domain at a particular position represent a "one" and the absence of a domain represent a "zero". In such an arrangement, it is possible for a domain to shift from one position into an adjacent empty position during propagation thus causing a double error in the stored information. Further, in order to change such stored information, it is necessary to create or annihilate domains. These operations require additional circuit elements and, in addition, input currents much larger than those needed for domain propagation. Moreover, because of the mutual repulsive force exhibited by domains on one another, the minimum spacing between domains is of the order of four domain diameters in material with low coercive force.

According to this invention there is provided a magnetic device comprising material in which single wall magnetic domains can be moved, means for propagating a single wall domain from stage to stage along a propagation channel in said material, and means for providing a first and a second stable location at each of said stages for a single wall domain, and means for moving a domain from a said location to the other location at a said stage, said means for providing a first and a second location and said means for propagating domains being ad-

apted to move a domain from a said location to a like location in a consecutive stage.

The propagation channel may have the form of a closed path.

5 The said means for providing a first and a second stable location may comprise magnetically soft material disposed along said propagation channel. The magnetically soft material may comprise permalloy strip extending between input and output positions on said channel.

10 The strip is preferably of reduced width at said output position. The said means for moving a domain from a said location to the other location at a said stage may serve to so move a domain at said input position. The step is preferably of increased width at said input position.

20 Means may be included for detecting a domain at said output position.

Instead of magnetically soft material the means for providing a first and a second stable location may comprise a groove in said material extending along said propagation channel.

25 One embodiment of this invention to be described in detail later includes a sheet of material in which magnetic domains can be moved and a strip of magnetically soft material adjacent the surface of the sheet and extending from an input to an output position. The strip has a thickness-to-width ratio which defines a stable location for a domain to either side of it. A pair of interleaved conductors crisscrosses the strip to define a sequence of stages or positions each including a pair of such locations. When the conductors are suitably pulsed, domains move to like locations of consecutive location pairs.

40 In an alternative embodiment, a single conductor is employed for moving domains. Permalloy dots or recesses are utilized to offset domains moved by that conductor thus functioning as would a second conductor.

45 The invention will now be described with reference to the accompanying drawing in which:

50 Fig. 1 is a schematic illustration of a magnetic device in accordance with the invention;

Figs. 2 and 3 are schematic illustrations of a portion of the device of Fig. 1 provided to illustrate and the operation thereof;

55 Fig. 4 is a cross-sectional view of the portion of the device shown in Fig. 3.

Referring now to Fig. 1. A magnetic device includes a slice or sheet 11 in which a representative channel for domain movement is defined. The channel comprises a magnetically soft strip 12 of, for example, low coercive force permalloy aligned with the axis of the channel represented by a broken line 13 and shown as a closed loop. Strip 65 for the recirculation of information. Strip

12 is criss-crossed by electrical conductors 14 and 15 offset with respect to one another and having, illustratively, a serpentine geometry. The conductors are conveniently deposited on opposite sides of a plastics substrate and juxtaposed with sheet 11.

70 The repeat patterns of the conductors define consecutive stages or positions along the channel for single wall domains as indicated by the domains D. Permalloy strip 12 defines a stable location for a domain to either side thereof for each position defined by the conductors. Thus locations below strip 12 as viewed in Fig. 1 may be taken to represent binary zero locations, 75 whereas locations above the strip may be taken as representing binary one locations. In operation, all the binary zero locations are occupied normally by domains for recirculation about closed loop 13 as conductors 14 80 and 15 are pulsed in the alternative, first with positive and then negative pulses. If a binary one is required in a particular stage or position, the domain occupying the zero location in that position is moved to the corresponding one location as shown for domain D in Fig. 2.

85 Movement of a domain from a zero to a one location is accomplished by an input conductor 20. Conductor 20 is connected between an input pulse source 21 of Fig. 1 and ground. When a pulse of a polarity to constrict domains is applied to conductor 20 by source 21, domain D of Fig. 2 is repelled to a one location. When a pulse of a polarity to attract domains is applied, domain D moves to the zero location, as shown in Fig. 3. Selective activation of conductor 20 introduces a pattern of domains in first and second locations for movement, by consecutively offset fields, as conductors 14 and 15 are pulsed, thus representing binary information in channel 13.

95 Information so formed and moved in the channel is detected at an output position indicated by an encircled X in Fig. 1. In practice, an electrical probe is coupled to indicate the passage of a domain in a one location at the output position. The probe may be a simple conductor loop or a Hall 100 probe, or detection may be accomplished by optical means utilizing the Faraday or Kerr effect. Such alternatives are well known and will not be discussed in detail. Any signal so generated is applied to a utilization circuit 24 of Fig. 1.

105 The diameter of a domain in the device of Fig. 1 is maintained at a nominal value by a bias field of a polarity to constrict domains. A source of such a field is represented by block 25. Sources 21 and 25 and circuit 24 are connected to a control circuit 26 for synchronization and control.

125 It is important to note that a propagation channel includes a plurality of consecutive 130

tive stages or positions for domains, each of which comprises first and second stable locations laterally displaced with respect to one another. The first and second location sets in a single propagation channel, in turn, define associated binary one and binary zero channels respectively.

A variety of advantages arise from such a device. Firstly, there is no need to generate or annihilate domains. Binary zeros can be recirculated and merely displaced to the associated one location for representing information. Secondly, relatively little current is necessary to so displace a domain. Thirdly, since lateral movement of domains is inhibited the mutual repulsion forces along the path are counterbalanced between preceding and subsequent domains, a relatively rigid force structure is formed which militates against information loss and leads to increased packing densities. Minimum domain spacings of two domain diameters are achieved as a result.

The realization of two stable locations at each bit position depends on the thickness-to-width ratio of the permalloy strip and the ratio of width of the permalloy strip to the diameter of the domain being moved. Unless the thickness-to-width ratio is less than the ratio of the domain magnetization to the permalloy magnetization, domains occupy positions directly below the permalloy strip rather than in first or second stable locations. The reason for this is that the internal demagnetizing fields in the permalloy strip, which are proportional to the product of permalloy magnetization and thickness of the strip divided by the width of the strip, must be smaller than the external demagnetizing field of the domain over most of the volume of the strip in order to avoid an energy minimum when a domain occupies a position directly under the strip.

Fig. 4 shows a cross section through sheet 11 and conductors 14 and 15 of Fig. 1 taken along line 4—4 as shown in Fig. 3. The two stable locations are indicated as the "1" and the "0" sides. The domain is shown on the "0" side with its wall under strip 12.

The lateral location of the domain is stable when the length of domain wall beneath the permalloy pattern is at a local maximum. For a single permalloy strip, there are two stable lateral locations only when the width of the strip is less than the domain diameter. The amount of force required to move a domain from the "zero" to "one" location is greatest when the strip width is about one-half the domain diameter so this width is optimum for regions of the path where only propagation takes place. A reduction in width of the strip to about 0.2 domain diameters is advantageous at the output position to increase the lateral separation between the "zero" and "one" location. An

increase to about 0.7 domain diameters in the width of the strip is advantageous at the input position to reduce the current needed to shift the lateral position of the domain.

In practice, sheet 11 can be notched (notch 30—Fig. 4) as a substitute for strip 12.

In an illustrative embodiment of this invention, domains having diameters of 100 micrometers were moved in a slice of thulium orthoferrite 50 micrometers thick, each domain having a magnetization of 0.01 weber per meter square. The propagation channel was defined by a permalloy strip having a magnetization of 0.8 weber per meter square and coercive force of 300 amperes per meter (less than four oersteds) and a width and thickness of 50 micrometers and 50 nanometers, respectively. A bias field of 2,000 amperes per meter maintained the domain diameter and currents of about 50 milliamperes caused domain movement. Domains were spaced about 200 micrometers apart during operation. Write currents of about 40 milliamperes were employed.

It is to be understood that the device described with reference to the drawing is not limiting for example, the wiring configuration for supplying drive fields as shown in Figs. 2 and 3 is merely illustrative and alternatives may be used. Moreover, only one-half (viz., a binary one channel) may be used to advantage.

WHAT WE CLAIM IS:—

1. A magnetic device comprising material in which single wall magnetic domains can be moved, means for propagating a single wall domain from stage to stage along a propagation channel in said material, means for providing a first and a second stable location at each of said stages for a single wall domain, and means for moving a domain from a said location to the other location at a said stage, said means for providing a first and a second location and said means for propagating domains being adapted to move a domain from a said location to a like location in a consecutive stage.
2. A device as claimed in claim 1 wherein the propagation channel has the form of a closed path.
3. A device as claimed in claim 1 or 2 wherein said means for providing comprises magnetically soft material disposed along said propagation channel.
4. A device as claimed in claim 3 wherein said magnetically soft material comprises a permalloy strip extending between input and output positions in said channel.
5. A device as claimed in claim 4 wherein the strip is of reduced width at said output position.
6. A device as claimed in claim 4 or 5, 130



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A variety of advantages arise from such a device. Firstly, there is no need to generate or annihilate domains. Binary zeros can be recirculated and merely displaced to the associated one location for representing information. Secondly, relatively little current is necessary to so displace a domain. Thirdly, since lateral movement of domains is inhibited the mutual repulsion forces along the path are counterbalanced between preceding and subsequent domains, a relatively rigid force structure is formed which militates against information loss and leads to increased packing densities. Minimum domain spacings of two domain diameters are achieved as a result.

The realization of two stable locations at each bit position depends on the thickness-to-width ratio of the permalloy strip and the ratio of width of the permalloy strip to the diameter of the domain being moved. Unless the thickness-to-width ratio is less than the ratio of the domain magnetization to the permalloy magnetization, domains occupy positions directly below the permalloy strip rather than in first or second stable locations. The reason for this is that the internal demagnetizing fields in the permalloy strip, which are proportional to the product of permalloy magnetization and thickness of the strip divided by the width of the strip, must be smaller than the external demagnetizing field of the domain over most of the volume of the strip in order to avoid an energy minimum when a domain occupies a position directly under the strip.

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1. A magnetic device comprising material in which single wall magnetic domains can be moved, means for propagating a single wall domain from stage to stage along a propagation channel in said material, means for providing a first and a second stable location at each of said stages for a single wall domain, and means for moving a domain from a said location to the other location at a said stage, said means for providing a first and a second location and said means for propagating domains being adapted to move a domain from a said location to a like location in a consecutive stage.

2. A device as claimed in claim 1 wherein the propagation channel has the form of a closed path.

3. A device as claimed in claim 1 or 2 wherein said means for providing comprises magnetically soft material disposed along said propagation channel.

4. A device as claimed in claim 3 wherein said magnetically soft material comprises a permalloy strip extending between input and output positions in said channel.

5. A device as claimed in claim 4 wherein the strip is of reduced width at said output position.

6. A device as claimed in claim 4 or 5,



wherein said means for moving a domain from a said location to the other location at a said stage serves to so move a domain at said input position.

5 7. A device as claimed in claim 6 wherein the strip is of increased width at said input position.

10 8. A device as claimed in any one of claims 4 to 7, comprising means for detecting a domain at said output position.

9. A device as claimed in claim 1 or 2 wherein said means for providing a first and a second stable location comprises a groove

in said material extending along said propagation channel.

10. A magnetic device arranged and adapted to operate substantially as herein described with reference to the accompanying drawing.

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