

PATENT SPECIFICATION

(11) 1387853

1387853

- (21) Application No. 20337/72 (22) Filed 2 May 1972
 (31) Convention Application No. 140894 (32) Filed 6 May 1971 in
 (33) United States of America (US)
 (44) Complete Specification published 19 March 1975
 (51) INT CL² G11C 19/02//11/14 7/02
 (52) Index at acceptance

H3B 201 202 203 204 230 231 236 237 245 247 250 253
 280 282 285 286 288 289 303 325 326 350 352 376
 383 388 390 471 496 520 BA DA



(72) Inventor ANDREW HENRY BOBECK

(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 organized 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 in which information can be represented as single wall domains.

The term "Single wall domain" refers to a magnetic domain which is movable in a layer of a suitable magnetic material and is encompassed by a domain wall which closes on itself in the plane of that layer.

Propagation arrangements for moving such a domain are designed to produce magnetic fields of a geometry determined by the layer in which a domain is moved. Most materials in which single wall domains are moved are characterized by a preferred magnetization direction, for all practical purposes, normal to the plane of the layer. The domain accordingly constitutes a reverse magnetized domain which may be thought of as a dipole oriented nominally normal to the plane of the layer. Accordingly, the movement of a domain is accomplished by the provision of an attracting magnetic field normal to the layer and at a localized position offset from the position occupied by the domain. A succession of such fields causes successive movements of a domain as is well known.

One propagation arrangement comprises a pattern of electrical conductors each designed to form conductor loops which generate the requisite fields when externally pulsed. The loops are interconnected and pulsed in a three phase manner to produce shift register operation.

An alternative propagation arrangement employs a repetitive pattern of soft magnetic elements adjacent (slightly spaced from) the surface of a layer in which single wall domains are moved. Alternatively, a pattern of grooves in the surface of the slice may be used. Changing pole patterns are generated in the elements in response to a magnetic field reorienting in the plane of the layer. The elements are arranged to displace domains along a selected path or channel in the layer as the in-plane field reorients. The familiar T-bar (or Y-bar) overlay pattern responds to a rotating in-plane field to so displace domains. Arrangements of this type are called "field access" arrangements.

The field access arrangement permits the realization of very large packing densities. For example, overlay patterns with periods of 0.8 mils are common; but patterns with periods of 0.3 mils have been made, and patterns with periods of 0.1 mils are possible. Certainly, packing densities of from 2 to 10 million bits per square inch are realizable. Unfortunately, the larger the packing density, the smaller the elements of the pattern and the smaller the domains moved thereby. The smaller the domains, the harder it is to detect them, particularly for domains moved at relatively high speeds. Moreover, turns in channels (or paths) defined by the overlay patterns are typically of a geometry which causes a reduction in the distance between adjacent domains leading to unwanted interactions. Consequently, turns typically exhibit lower operating margins than straight line sections of the channel.

A magnetic device in accordance with the invention comprises a layer of magnetic material in which single wall domains can be moved, and a pattern of elements defining a channel for moving domains in the material in response to a magnetic field reorienting in the plane of the layer, part of the pattern being operative such that a domain moving along the part of the channel defined by the said

part of the pattern is enlarged whilst remaining undivided thereby.

The said part of the pattern may be so disposed as to elongate said domain.

- 5 In one way of carrying out the invention, said part of the pattern may include a magnetically soft elongate member disposed along the channel.

The said elongate member may be curved.

- 10 The said part of the pattern may include a plurality of magnetically soft elements extending normally from the elongate member, and there may be provided detecting means electrically coupled to a pair of said plurality of elements for detecting the presence or absence of elongated domains. The thickness of the elongated member may be substantially less than the thickness of each of said plurality of elements.

- 20 In another way of carrying out the invention said part of the pattern may comprise a plurality of elements each having a long dimension substantially orthogonal to the direction of domain movement. Said plurality of elements may be disposed parallel to each other to define an extended diffuse pole when said field is substantially aligned with their long dimensions.

- 30 The said part of the pattern may comprise a plurality of stages of a multistage pattern formed by said pattern of elements.

- Alternatively the said part of the pattern may comprise a single stage of a multistage pattern formed by said pattern of elements.

- 35 When the said part of the pattern designed for enlarging a domain during propagation is employed for defining a turn in the propagation path, the resulting operating margins at the turn are comparable to those of straight line sections of the path because the turn is negotiated by a domain during a single cycle of the in-plane field in a manner which avoids domain interaction. A detector placed, for example, at the turn responds to relatively large domains to provide improved outputs.

- 45 Embodiments of the invention will now be described with reference to the accompanying drawings in which:—

- 50 Fig. 1 is a schematic illustration of a field access, domain propagation arrangement embodying the invention.

- Figs. 2, 3, 4 and 5 are schematic illustrations of portions of the arrangement of Fig. 1 and;

- 55 Figs. 6 and 7 are schematic illustrations of portions of alternative arrangements embodying the invention.

- Fig. 1 shows a domain propagation arrangement 10. The arrangement includes a slice of material 11 in which single wall domains can be moved. A representative channel 12 for circulating patterns of single wall domains is defined illustratively by a Y-bar pattern of elements 13.

- 65 The pattern is formed of magnetically soft

material which exhibits changing pole patterns in response to a magnetic field rotating clockwise in the plane of slice 11. The in-plane field is provided by a source represented by block 14 in Fig. 1. The pattern may be formed by photolithographic techniques on a glass substrate and abutted with the surface of slice 11. Alternatively, the pattern may be formed directly on slice 11 on a thin spacing layer of, for example, silicon dioxide in order to avoid exchange coupling between the elements and the slice. A typical spacing layer has a thickness of about one-eighth the diameter of a domain in the slice.

The channel can be seen in the figure to form a serpentine path of straight line sections and interconnecting turn sections defined by the overlay geometry. A representative turn is indicated at 17 in Fig. 1. The overlay geometry at the turn comprises a curved element 18 from which a pattern of elements 21 to 25 radiate. The radial elements are illustratively at consecutive 45° orientations with respect to one another.

As a domain moves from left to right along the top portion of channel 12 as viewed in Fig. 1, it arrives at the bottom of element 21 when the in-plane field is in a downward orientation as indicated by the arrow H in Fig. 1. At this juncture in the propagation operation, magnetic poles which are of a polarity to attract domains accumulate at the bottom of element 21 as viewed. As the in-plane field rotates next through 180 degrees, poles appear in quick succession at the ends of elements 21, 22, 23, 24, and 25 close to element 18, thus forming a diffuse pole for expanding a domain there. By the time the field is directed to the left and slightly upward as shown in Fig. 2, the domain D0 is expanded around the turn and the next following domain D1 (or absent domain) occupies the position in the next subsequent stage as shown in Fig. 2.

Fig. 3 shows the in-plane field (rotated 180 degrees) now directed upward as indicated by the arrow H. Domain D0, at this juncture has fully negotiated the turn.

Fig. 4 shows arrow H once again rotated almost into the orientation of the starting point in Fig. 1. At this juncture, domains D0 and D1 move to the positions shown. Domain D1 moves into the turn as the field next rotates to the downward orientation as was the case in connection with Fig. 1.

Fig. 5 shows the domain disposition when the field again reorients upward, as indicated by arrow H, in initiating the next cycle of operation. A next subsequent domain D2 advances to the position shown whereas domain D1 occupies the turn as shown.

Domain patterns, moved in the field access mode in channel 12 of Fig. 1, advance from an input position I past an output position O

at turn 17 to an annihilator designated 30 in Fig. 1.

A source of domains is provided at *I*. The source comprises, for example, a magnetically soft disc about the periphery of which a domain moves, following the changing pole patterns induced there, in response to the reorienting in-plane field. The domain divides into two when a conductor, indicated at 31 is pulsed as described in US Patent No. 3611331. Conductor 31 is connected to a source of input pulses 32 in Fig. 1.

Annihilator 30 similarly may comprise a disc of magnetically soft material about the periphery of which a domain also moves in response to the reorienting in-plane field. The domain in this instance is always in a position to coalesce with a domain moving along channel 12 at the position of the annihilator.

A detector is provided at output position *O* conveniently by forming electrical conductors 40 and 41 illustratively in contact with elements 23 and 25 respectively as shown in Fig. 1. The electrical conductors are connected to a utilization circuit 42. A dc source 43 applies a current (of typically one milliamp) through conductor 40, elements 23, 18, and 25, and conductor 41. The difference in (magneto) resistance of the path exhibited when a domain is present appears as a voltage change between conductors 40 and 41 and is applied to circuit 42. Conductors 40 and 41, of course, could similarly be connected to elements 21 and 25 of Fig. 1.

For domain expanders defined at turns as shown in Fig. 2, no penalty need be incurred as far as area occupied by the modified geometry. As shown, the turn occupies the length of $\pi/2$ stages (or periods λ) of the Y-bar pattern as is clear from Fig. 5. The turn may occupy a single stage or many stages however.

Fig. 6, on the other hand, shows an expander occupying a portion of a straight line section of channel 12. A series of domains moving along the channel is represented by domains D0, D1, D2, and D3, domain D1 shown expanded at the expander section. Consecutive domains in a channel are typically separated by a distance equal to three domain diameters ($3d$) to avoid domain interaction. But a domain (D1 of Fig. 6), when expanded, is disproportionately long and may occupy a space greater than three domain diameters. Consequently, the expander stage may have a length of many stages. The ends of the stages in such a case typically are three domain diameters from the adjacent stages as indicated in Fig. 6.

In nonexpander sections of the channel, a domain has a smaller prescribed diameter determined by a bias field in a well known manner. A source of such a bias field is represented by block 50 of Fig. 1.

Sources 14, 32, 43, and 50, and utilization

circuit 42 are connected to a control circuit 51 for synchronization. Any suitable circuits may be used for the purpose outlined.

Both Fig. 1 and Fig. 6 show a magnetoresistive detector connected to the expander section of the overlay to illustrate alternative positions for such a detector to properly respond to an enlarged domain. When a detector is connected to an expander, the expander includes the common element 18 of Fig. 1 disposed along the axis of domain movement in a propagation channel and the auxiliary elements radiating therefrom disposed to align with the in-plane field for different orientation thereof as already described. But the common element is relatively thin compared with the thickness of the radial and Y-bar elements in order to provide the high resistance necessary for satisfactory performance of the magnetoresistive detector in accordance with well-understood principles.

In instances where a magnetoresistive detector is not employed or where a detector is not coupled to an expander, a common element is unnecessary. Fig. 7, for example, shows a portion of a domain propagation channel defined by a Y-bar overlay pattern with an expander section including a number of magnetically soft elements in parallel and oriented orthogonally with respect to the axis of channel 12 in the absence of a common element. The expander section in Fig. 7 occupies a multistage portion of the propagation channel. Each element of the expander exhibits an attracting pole (not shown) at the bottom thereof as viewed when the in-plane field is directed downward as represented by the arrow *H* in the figure. Consequently, the domain in the expander (D1 of Fig. 7) occupies the entire (multistage) portion expanding to position 63. It is clear that an expander has additional uses as, for example, adjusting path lengths to allow domains to reach an interaction point simultaneously where space does not otherwise permit the formation of number of paths with like numbers of stages to ensure simultaneous arrival there of domains moving along the paths.

It should be clear also that an expander need not include a common element but advantageously employs such an element when utilized in conjunction with a magnetoresistive detector. For magnetoresistive detectors, the common element is relatively thin for peak performance. On the other hand, a common element can be used and its thickness may be equal to the remaining elements of the Y-bar pattern to simplify the process of depositing the pattern. In the last mentioned case, care should be taken to ensure that the common element has a geometry which permits a domain to exit from the expander section.

An arrangement of the type shown in Fig. 1 is defined in a slice of europium erbium gallium garnet about 4.5 microns thick formed

by liquid phase epitaxial deposition techniques on a substrate of gadolinium gallium garnet. Domains in the material are maintained at a nominal diameter of about 4 microns by a bias field of about 90 oersteds. A Y-bar overlay pattern of permalloy having a coercive force of 0.5 oersteds and a thickness of 3000 Å is deposited on a spacing layer of silicon dioxide on the surface of the slice. The pattern has a period of 0.6 mil. The common element 18 of Fig. 1 has a thickness of about 300 Å and a radius of 0.3 mil with the common element and the radial elements each having a width of .06 mil and spaced minimally .06 mil apart at 45° with respect to one another. The radial elements occupy a $(\pi/2)\lambda$ area.

An in-plane field of 20 oersteds rotating at a 100 khz rate generates a signal of 0.5 millivolts in a magnetoresistive detector disposed as shown in Fig. 1 and connected in a noise cancellation bridge arrangement with like detectors.

A 1 milliamp current is supplied by source 43 of Fig. 1. The expander enlarges a domain to a length equal to five times its normal diameter thus providing a signal five times that provided by an unexpanded domain in the absence of external amplification.

The permalloy common element may comprise a lamellate structure of 1500 Å permalloy, 200 Å chromium, and 1500 Å permalloy, which is operative to define a flux closure path for concentrating available flux for detection and the elements connected to conductors 40 and 41 of Fig. 1 are conveniently arranged at 90° to one another, as shown, to increase the output signal and reduce noise due to the in-plane field respectively.

WHAT WE CLAIM IS:—

1. A magnetic device comprising a layer of magnetic material in which single wall domains can be moved, and a pattern of elements defining a channel for moving domains in the material in response to a magnetic field reorienting in the plane of the layer, part of the pattern being operative such that a domain moving along the part of the channel defined by the said part of the pattern, is enlarged whilst remaining undivided thereby.

2. A device according to claim 1, wherein said part of the pattern is operative to elongate said domain.

3. A magnetic device according to claim 2, wherein said part of the pattern includes

a magnetically soft elongate member disposed along the channel.

4. A magnetic device according to claim 3, wherein the elongate member is curved.

5. A magnetic device according to claim 3 or 4, wherein the said part of the pattern includes a plurality of magnetically soft elements extending normally from the elongate member, and there is provided detecting means electrically coupled to a pair of said plurality of elements for detecting the presence or absence of elongated domains.

6. A magnetic device according to claim 5, wherein the thickness of the elongate member is substantially less than the thickness of each of said plurality of elements.

7. A magnetic device according to claim 2, wherein said part of the pattern comprises a plurality of elements each having a long dimension substantially orthogonal to the direction of domain movement.

8. A device according to claim 7, wherein said plurality of elements are disposed parallel to each other to define an extended diffuse pole when said field is substantially aligned with their long dimensions.

9. A magnetic device according to any preceding claim, including means for providing a bias field for controlling domain size.

10. A magnetic device according to any preceding claim, including means for providing the in-plane magnetic field.

11. A magnetic device according to any preceding claim, wherein the pattern of elements is a multistage pattern, and said part of the pattern comprises a plurality of the stages.

12. A magnetic device according to any preceding claim, wherein the pattern of elements is a multistage pattern, and said part of the pattern comprises a single stage of the pattern.

13. A magnetic device substantially as herein described with reference to Figs. 1 to 5, or to Fig. 6 or to Fig. 7, of the accompanying drawings.

14. A magnetic device arranged to operate substantially as herein described with reference to Figs. 1 to 5, or to Fig. 6 or to Fig. 7 of the accompanying drawings.

C. S. T. BUCKLEY,
Chartered Patent Agent,
5 Mornington Road,
Woodford Green,
Essex.

Agent for the Applicants.



by liquid phase epitaxial deposition techniques on a substrate of gadolinium gallium garnet. Domains in the material are maintained at a nominal diameter of about 4 microns by a bias field of about 90 oersteds. A Y-bar overlay pattern of permalloy having a coercive force of 0.5 oersteds and a thickness of 3000 Å is deposited on a spacing layer of silicon dioxide on the surface of the slice. The pattern has a period of 0.6 mil. The common element 18 of Fig. 1 has a thickness of about 300 Å and a radius of 0.3 mil with the common element and the radial elements each having a width of .06 mil and spaced minimally .06 mil apart at 45° with respect to one another. The radial elements occupy a $(\pi/2)\lambda$ area.

An in-plane field of 20 oersteds rotating at a 100 khz rate generates a signal of 0.5 millivolts in a magnetoresistive detector disposed as shown in Fig. 1 and connected in a noise cancellation bridge arrangement with like detectors.

A 1 milliamp current is supplied by source 43 of Fig. 1. The expander enlarges a domain to a length equal to five times its normal diameter thus providing a signal five times that provided by an unexpanded domain in the absence of external amplification.

The permalloy common element may comprise a lamellate structure of 1500 Å permalloy, 200 Å chromium, and 1500 Å permalloy, which is operative to define a flux closure path for concentrating available flux for detection and the elements connected to conductors 40 and 41 of Fig. 1 are conveniently arranged at 90° to one another, as shown, to increase the output signal and reduce noise due to the in-plane field respectively.

WHAT WE CLAIM IS:—

1. A magnetic device comprising a layer of magnetic material in which single wall domains can be moved, and a pattern of elements defining a channel for moving domains in the material in response to a magnetic field reorienting in the plane of the layer, part of the pattern being operative such that a domain moving along the part of the channel defined by the said part of the pattern, is enlarged whilst remaining undivided thereby.

2. A device according to claim 1, wherein said part of the pattern is operative to elongate said domain.

3. A magnetic device according to claim 2, wherein said part of the pattern includes

a magnetically soft elongate member disposed along the channel.

4. A magnetic device according to claim 3, wherein the elongate member is curved:

5. A magnetic device according to claim 3 or 4, wherein the said part of the pattern includes a plurality of magnetically soft elements extending normally from the elongate member, and there is provided detecting means electrically coupled to a pair of said plurality of elements for detecting the presence or absence of elongated domains.

6. A magnetic device according to claim 5, wherein the thickness of the elongate member is substantially less than the thickness of each of said plurality of elements.

7. A magnetic device according to claim 2, wherein said part of the pattern comprises a plurality of elements each having a long dimension substantially orthogonal to the direction of domain movement.

8. A device according to claim 7, wherein said plurality of elements are disposed parallel to each other to define an extended diffuse pole when said field is substantially aligned with their long dimensions.

9. A magnetic device according to any preceding claim, including means for providing a bias field for controlling domain size.

10. A magnetic device according to any preceding claim, including means for providing the in-plane magnetic field.

11. A magnetic device according to any preceding claim, wherein the pattern of elements is a multistage pattern, and said part of the pattern comprises a plurality of the stages.

12. A magnetic device according to any preceding claim, wherein the pattern of elements is a multistage pattern, and said part of the pattern comprises a single stage of the pattern.

13. A magnetic device substantially as herein described with reference to Figs. 1 to 5, or to Fig. 6 or to Fig. 7, of the accompanying drawings.

14. A magnetic device arranged to operate substantially as herein described with reference to Figs. 1 to 5, or to Fig. 6 or to Fig. 7 of the accompanying drawings.

C. S. T. BUCKLEY,
Chartered Patent Agent,
5 Mornington Road,
Woodford Green,
Essex.
Agent for the Applicants.