

PATENT SPECIFICATION

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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 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.

Single wall domains and the movement of such domains in a layer of magnetic material along channels defined by a pattern of magnetically soft elements coupled to the layer are described in GB Patent No. 1,241, 235. The movement of domains is in response to a uniform magnetic field reorienting, typically by rotation, in the plane of the layer in what has been termed a "field access" mode of operation.

A magnetoresistance detector for magnetic domains is disclosed in U.S. Patent No. 3,609,720. That detector is shown to be compatible with the above-mentioned rotating field and actually may employ a channel-defining element as the magnetoresistance element of the detector. But in practice a magnetoresistance element is made thinner than the channel-defining elements in order to reduce both the current applied to the magnetoresistance element and the disturbing effects of the fields and poles generated thereby. Optimum thicknesses for magnetoresistance elements are about 300 Angstrom units. The propagation elements on the other hand are generally considerably thicker, for example, 3000 Angstrom units. It would, of course, be a considerable processing advantage to form a magnetoresistance detector element and the channel-defining elements of the same thickness and in a single photoresist process.

It appears that changes in the cross section of the element accomplish little in the way of

improved output signal and changes in shape endanger propagation margins. A magnetoresistance detector element comprises typically a 300 Angstrom unit thick layer of permalloy. This material is characterized by a 3 percent magnetoresistance coefficient and a sheet resistance of 10 ohms per square. A "square" of a 300 Angstrom thick permalloy layer ideally gives an output signal of 300 microvolts per milliamper. Ion migration appears to limit the allowable current density in any such magnetoresistance element. Consequently, there appears to be an upper limit to the current density in such an element. Yet the output signal level provided by a magnetoresistance detector increases proportionally with increasing current density. If the absolute signal level is taken as the single most important detector criterion, an increase in the element cross section is to be accompanied by an increased current in order to avoid lowering the detector current density and thus lowering the signal level. The problem then is to obtain an increased output signal for a specified current density.

An increase in the length of the magnetoresistance element of, for example, a factor of three from about the size of a 6 micron domain to three times that size provides an increased output signal of from 100 to about 300 microvolts/milliamper. Moreover, the realization that the output signal is independent of Permalloy thickness suggests that the magnetoresistance element (viz: an elongated element) can be incorporated into the Permalloy propagation pattern and formed therewith in a single photoresist process. But the propagation pattern must not be adversely effected in its performance by the inclusion of the magnetoresistance element.

U.S. Patent Specification No. 3,723,716 describes channel-defining elements for field access, single wall domain arrangements as being fine-grained and permitting displacement of domains laterally from channel-to-channel. The pattern formed by the elements

is that of a chevron with elements laterally displaced from one another a distance of about the diameter of a domain in the adjacent layer.

5 This type of pattern has the advantage that domains of differing geometry are propagated along the channel simultaneously in response to the in-plane field and is particularly compatible with elongated magnetoresistance elements.

10 According to one aspect of the invention there is provided a magnetic device comprising a layer of material in which single wall domains can be moved, and an arrangement of elements defining stages, including an output stage, in a channel for moving a said domain therealong in response to a varying magnetic field, each of said stages being defined by a plurality of said elements, the arrangement being such as to provide an expanded said domain at said output stage.

20 According to another aspect of the invention there is provided a magnetic device comprising a layer of material in which single wall domains can be moved, and an arrangement of elements defining stages, including an output stage, in a channel for moving domains therealong in response to a varying magnetic field, and wherein the number of elements defining one of said stages is greater than the number of elements defining a stage adjacent said one stage.

35 The number of elements defining the stages may increase stage by stage in the direction of domain movement and may reach a maximum number at the output stage. The number of elements defining stages following the output stage may decrease stage by stage in the direction of domain movement.

40 The elements defining the output stage may comprise like elements and the output stage may further comprise an additional element interconnecting said like elements. The additional element may have the same thickness as the said like elements. The elements defining said stages may be arranged such that, in operation, a said domain moves along the channel when the magnetic field reorients in the plane of the layer. The width of the additional element may be substantially the same as the width of a said like element. The elements defining the output stage may be V-shaped and the additional element may connect the apices of the V-shaped elements. The elements defining a stage other than the output stage may comprise like elements and said other stage may further include a second additional element interconnecting the elements defining that stage. The device may include means electrically connecting the additional elements. The elements defining said other stage may comprise V-shaped elements and the second additional element may interconnect the apices of those V-shaped elements. The second additional element may

comprise magnetically soft material and the other stage may be defined by relatively few of the elements compared with the number of elements defining the output stage.

70 The additional element may comprise a magnetoresistance detector element and the device may comprise means for detecting changes in the resistance of the magnetoresistive material.

75 The channel defined by the elements may comprise a closed path. The additional element defines an elongated magnetoresistance detector which may be formed with the remaining elements in a single photo resist process.

80 In embodiments of the invention comprising an output stage including a magnetoresistance detector element, the detector element may be formed in a common photo resist process with the elements defining the stages of the channel.

85 The invention will now be described, by way of example, with reference to the accompanying drawing in which:—

90 Fig. 1 is a schematic representation of a fine-grained, field access, single wall domain arrangement; and,

95 Figs. 2 and 3 are schematic representations of possible alternative domain detector arrangements.

Fig. 1 shows a single wall domain arrangement 10 including a magnetoresistance detector. The arrangement comprises a layer 11 of material in which single wall domains can be moved. In practice, domains in layer 11 are maintained at a nominal diameter by a bias field of a polarity to contract domains and supplied by a bias field source represented by block 13 in Fig. 1.

100 The movement of domains in layer 11 is accomplished by the use of a magnetically soft, overlay pattern of elements 15 which are arranged to generate magnetic pole patterns in response to a magnetic field reorienting in the plane of layer 11. The elements shown in Fig. 1 are V-shaped and closely spaced laterally with respect to one another to form a chevron pattern for each of a sequence of stages. The chevron pattern repeats from left to right as viewed in the figure, a greater number of elements being present in consecutive stages from an input stage at 16 to an output or detection stage at 17. The number of elements in the consecutive stages to the right of output stage 120 17 diminishes similarly.

125 The term "closely spaced" when characterizing the distance between adjacent elements in a stage of a field access arrangement of the type shown in Fig. 1 indicates that the elements are spaced so that the poles generated on more than one element attract a given domain at the same time. Typically, such a spacing is about equal to the diameter of a domain. "Fine grained" also refers to a pat-

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tern in which the spacing between adjacent elements is about equal to the diameter of a domain. Patterns of this type define domain propagation channels in which domains of different lengths can be moved without, necessarily, an accompanying change in the bias field. Propagation of domains in the channels is in response to a clockwise rotating in-plane field supplied by a source represented by block 18 in Fig. 1.

The increasing number of laterally displaced elements in consecutive stages of Fig. 1 are operative in the presence of a specified bias field and in-plane field to elongate in the direction orthogonal to the direction of movement a domain moving from stage to stage as viewed in Fig. 1. For example, a six micron domain introduced at input 16 increases to about two hundred and forty microns by increasing the number of elements from three at input 16 to forty at the output stage 17.

An illustrative magnetoresistance element is shown at 20 in the output stage 17 of Fig. 1 and in Fig. 2. The element can be seen to extend vertically through the apices of all the elements 21 in that stage. The thickness of the magnetoresistance element is equal to that of an element 21 and accordingly may be produced by the same photoresist process which forms those elements. Also element 20 has a width illustratively equal to that of an element 21. The width of element 20 is chosen such that the element saturates magnetically when the in-plane field is aligned therewith. This ensures that the magnetic poles required at the apices of the elements during a portion of the propagation cycle will actually be present. This would not be the case if element 20 is relatively wide (viz: five times the chevron element width).

Element 20 is connected illustratively between a utilization circuit represented by block 22 in Fig. 1 and ground. Where the pattern of channel defining elements is formed in a closed loop geometry along broken line 40 of Fig. 1, it is particularly convenient that a return current path for element 20 be provided along a path 23 in Fig. 1. Each stage of a return portion of a closed loop path corresponding to line 40 could comprise two or three V-shaped elements. The current return path may be defined by an electrical conductor or, more conveniently, by magnetically soft permalloy deposited during the photoresist process which produces elements 15, 20, and 21 of Figs. 1 and 2. Fig. 3 shows the geometry for permalloy magnetoresistance element which interconnects chevron patterns 32 and 33 of two stages of a channel.

If a conductor-permalloy path is employed for detection, the organization of the return path through the symmetrical portion of the chevron pattern of the stage adjacent to 17 has an advantageous effect consistent with

normal domain propagation by a fine-grained pattern of elements. To be specific, element 20 is pulsed periodically (once each propagation cycle to interrogate or strobe the output signal) under the control of control circuit 35 of Fig. 1 by means of conductors connected to lands 36 and 37 of Fig. 3. The current so generated in the loop defined by the hairpin path generates a field (interrogation) to expand a domain encompassed by the hairpin and thus improves detection by aiding domain elongation. The use of a pulsed interrogation field will not impair normal propagation.

If the return path for common element 20 is also permalloy, then that path is through the symmetrical portion of a stage with fewer propagation elements, typically one-tenth the number in the stage coupled by element 20. This arrangement is to avoid combining signals from two stages.

In the absence of a closed loop path, domains are provided selectively at 16 illustratively by a method described in U.S. Patent No. 3,611,331 in response to an input pulse provided by a source represented in Fig. 1 by block 42.

Sources 13, 18, and 42 and circuit 22 are connected to control circuit 35 for synchronization and activation. The various sources and circuits may be any suitable elements capable of performing the operations described above.

An elongated magnetoresistance element is clearly compatible with the element geometry for normal operation of a fine-grained single wall domain propagation arrangement. The following example will now show the advantages in terms of enhanced output signal obtained as a result of such an arrangement: Assume a permissible current density of 10^6 amps/cm². The maximum detector signal is given by

$$(1) \quad v_{\text{signal}} = i \cdot \rho \cdot \left(\frac{\Delta \rho}{\rho} \right) \cdot l$$

where

i = allowable current density

ρ = permalloy resistivity

$\Delta \rho$ = change in resistivity due to magnetoresistance

l = detector length (active).

Using the parameters for permalloy, $v_{\text{signal}} = 0.06$ millivolts/micron .1 (microns). Experimental results show that the signal due to a domain is one-fifth to one-seventh of the voltage produced by the in-plane field. The final expression accordingly becomes

$$(3) \quad v_{\text{signal}} \approx 0.01 \text{ millivolts/micron .1 (microns).}$$

In other words, to produce a one millivolt signal, the detector is one hundred microns in length. On a permalloy pattern having a thickness of 0.3 microns and a stage-to-stage period of twenty microns for moving domains having nominal diameters of about six microns, adjacent elements in a stage are on about six-micron centers and are two microns wide. A stack of forty elements at the detector stage provides an output signal of 1.0 millivolt for a six-micron domain moved for example in an epitaxially grown film of YGdLaY₃ garnet, 6 microns thick. The detector is strobed with pulses of 6.5 milliampers of 2 microsecond duration. The in-plane field is 20 oersteds. Propagation operation in excess of one hundred kilohertz have been achieved in such arrangements. A bias field typically of 80 oersteds is employed.

For comparison, a magnetoresistance detector having a geometry to correspond to domains of six microns produces signals of 60 microvolts in a like environment.

The embodiments described are only illustrative and various other embodiments can be devised. For example, the magnetoresistance element need not correspond to the apices of the propagation pattern. The position of the element depends upon the designed orientation of the in-plane field when an output signal occurs (viz: when the interrogation pulse is applied). In the illustrative arrangement, the output signal occurs when the in-plane field is directed upward as indicated by arrow H in Fig. 1 at a time when a domain is moved to the apices of the chevron pattern. If an output signal is desired at a time when the in-plane field is directed to the right as viewed in Fig. 1, the magnetoresistance element would correspond to the right edges of the elements of the chevron rather than in the position shown in Fig. 1. Moreover, a common (magnetoresistance) element advantageously intersects each chevron element squarely in an output stage to maximize the output signal.

WHAT WE CLAIM IS:—

1. A magnetic device comprising a layer of material in which single wall domains can be moved, and an arrangement of elements defining stages, including an output stage, in a channel for moving a said domain therealong in response to a varying magnetic field, each of said stages being defined by a plurality of said elements, the arrangement being such as to provide an expanded said domain at said output stage.

2. A magnetic device comprising a layer of material in which single wall domains can be moved, and an arrangement of elements defining stages, including an output stage, in a channel for moving domains therealong in

response to a varying magnetic field, and wherein the number of elements defining one of said stages is greater than the number of elements defining a stage adjacent said one stage.

3. A device according to claim 1 or 2, wherein the number of elements defining said stages increase stage by stage in the direction of domain movement and reaches a maximum number at said output stage.

4. A device according to claim 3, wherein the number of elements defining stages following the output stage decreases stage by stage in said direction.

5. A device according to any one of claims 1 to 4, wherein the elements defining the output stage comprise like elements, and wherein the output stage further comprises an additional element interconnecting said like elements and having substantially the same thickness as said like elements.

6. A device according to claim 5, wherein the elements defining said stages are arranged such that, in operation, a said domain moves along the channel when said magnetic field reorients in the plane of the layer.

7. A device according to claim 6, wherein the width of said additional element is substantially the same as the width of a said like element.

8. A device according to claim 6 or 7, wherein said elements defining the output stage are V-shaped and wherein the additional element connects the apices of the V-shaped elements.

9. A device according to any one of claims 6, 7 or 8, wherein the elements defining a stage other than said output stage comprise like elements, said other stage further including a second additional element interconnecting the elements defining that stage, and wherein the device includes means electrically connecting said additional elements.

10. A device according to claim 9, wherein the elements defining said other stage comprise V-shaped elements and wherein the second additional element interconnects the apices of those V-shaped elements.

11. A device according to claim 9 or 10, wherein said second additional element comprises magnetically soft material and said other stage is defined by relatively few of the elements compared with the number of elements defining said output stage.

12. A device according to claim 9 or 10, wherein said other stage comprises a stage adjacent to said output stage.

13. A device according to any one of claims 6 to 12, wherein said additional element comprises a magnetoresistance detector element and further comprising means for detecting changes in resistance of said detector element.



In other words, to produce a one millivolt signal, the detector is one hundred microns in length. On a permalloy pattern having a thickness of 0.3 microns and a stage-to-stage period of twenty microns for moving domains having nominal diameters of about six microns, adjacent elements in a stage are on about six-micron centers and are two microns wide. A stack of forty elements at the detector stage provides an output signal of 1.0 millivolt for a six-micron domain moved for example in an epitaxially grown film of YGdLaY₃ garnet, 6 microns thick. The detector is strobed with pulses of 6.5 milliamperes of 2 microsecond duration. The in-plane field is 20 oersteds. Propagation operation in excess of one hundred kilohertz have been achieved in such arrangements. A bias field typically of 80 oersteds is employed.

For comparison, a magnetoresistance detector having a geometry to correspond to domains of six microns produces signals of 60 microvolts in a like environment.

The embodiments described are only illustrative and various other embodiments can be devised. For example, the magnetoresistance element need not correspond to the apices of the propagation pattern. The position of the element depends upon the designed orientation of the in-plane field when an output signal occurs (viz: when the interrogation pulse is applied). In the illustrative arrangement, the output signal occurs when the in-plane field is directed upward as indicated by arrow H in Fig. 1 at a time when a domain is moved to the apices of the chevron pattern. If an output signal is desired at a time when the in-plane field is directed to the right as viewed in Fig. 1, the magnetoresistance element would correspond to the right edges of the elements of the chevron rather than in the position shown in Fig. 1. Moreover, a common (magnetoresistance) element advantageously intersects each chevron element squarely in an output stage to maximize the output signal.

WHAT WE CLAIM IS:—

1. A magnetic device comprising a layer of material in which single wall domains can be moved, and an arrangement of elements defining stages, including an output stage, in a channel for moving a said domain therealong in response to a varying magnetic field, each of said stages being defined by a plurality of said elements, the arrangement being such as to provide an expanded said domain at said output stage.

2. A magnetic device comprising a layer of material in which single wall domains can be moved, and an arrangement of elements defining stages, including an output stage, in a channel for moving domains therealong in

response to a varying magnetic field, and wherein the number of elements defining one of said stages is greater than the number of elements defining a stage adjacent said one stage.

3. A device according to claim 1 or 2, wherein the number of elements defining said stages increase stage by stage in the direction of domain movement and reaches a maximum number at said output stage.

4. A device according to claim 3, wherein the number of elements defining stages following the output stage decreases stage by stage in said direction.

5. A device according to any one of claims 1 to 4, wherein the elements defining the output stage comprise like elements, and wherein the output stage further comprises an additional element interconnecting said like elements and having substantially the same thickness as said like elements.

6. A device according to claim 5, wherein the elements defining said stages are arranged such that, in operation, a said domain moves along the channel when said magnetic field reorients in the plane of the layer.

7. A device according to claim 6, wherein the width of said additional element is substantially the same as the width of a said like element.

8. A device according to claim 6 or 7, wherein said elements defining the output stage are V-shaped and wherein the additional element connects the apices of the V-shaped elements.

9. A device according to any one of claims 6, 7 or 8, wherein the elements defining a stage other than said output stage comprise like elements, said other stage further including a second additional element interconnecting the elements defining that stage, and wherein the device includes means electrically connecting said additional elements.

10. A device according to claim 9, wherein the elements defining said other stage comprise V-shaped elements and wherein the second additional element interconnects the apices of those V-shaped elements.

11. A device according to claim 9 or 10, wherein said second additional element comprises magnetically soft material and said other stage is defined by relatively few of the elements compared with the number of elements defining said output stage.

12. A device according to claim 9 or 10, wherein said other stage comprises a stage adjacent to said output stage.

13. A device according to any one of claims 6 to 12, wherein said additional element comprises a magnetoresistance detector element and further comprising means for detecting changes in resistance of said detector element.



14. A device according to any one preceding claim, wherein said channel comprises a closed path.

- 5 15. A device substantially as herein described with reference to the accompanying drawing.

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