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3,534,346

MAGNETIC DOMAIN PROPAGATION ARRANGEMENT

Filed May 28, 1968

2 Sheets-Sheet 1

FIG. 1

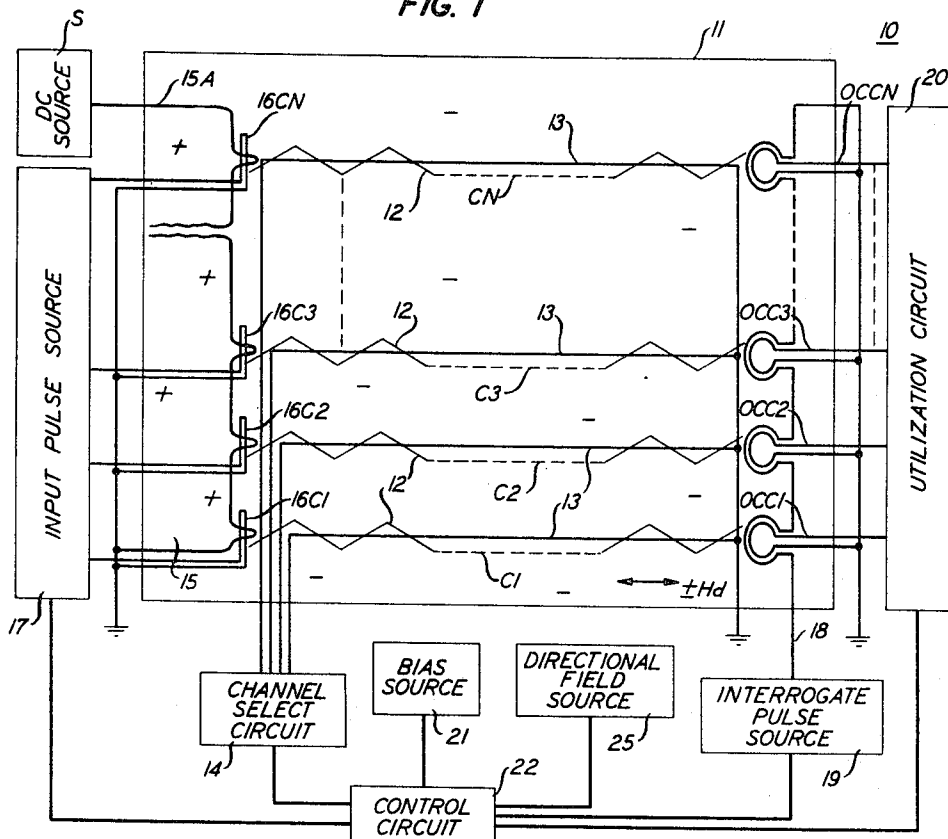
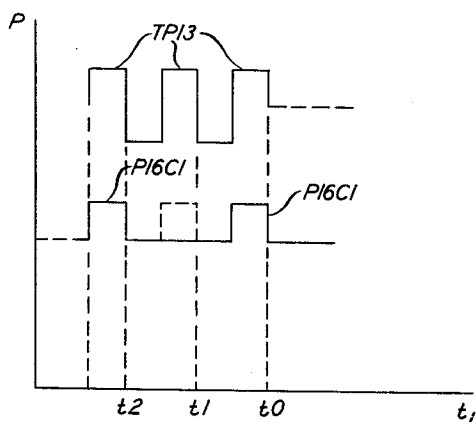


FIG. 3



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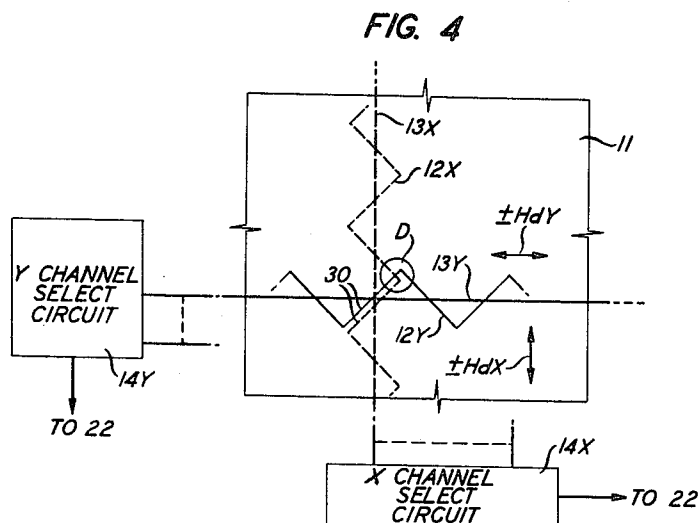
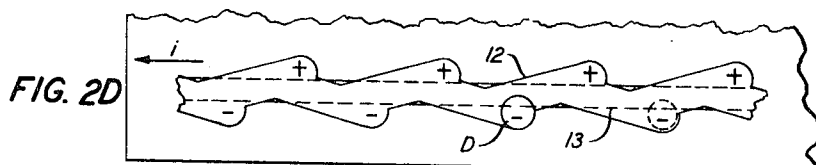
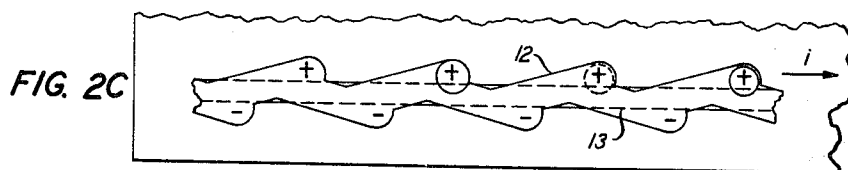
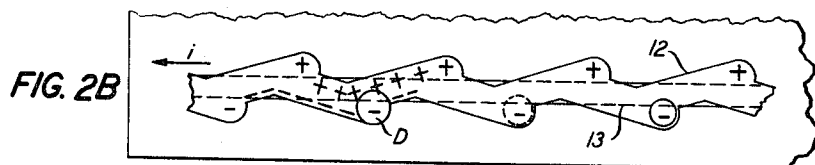
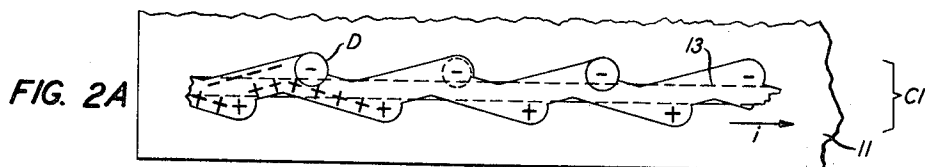
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MAGNETIC DOMAIN PROPAGATION ARRANGEMENT

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MAGNETIC DOMAIN PROPAGATION ARRANGEMENT

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U.S. Cl. 340—174

9 Claims

ABSTRACT OF THE DISCLOSURE

A single wall domain is propagated, in a sheet of magnetic material, along an axis aligned with a single conductor in which a current signal flows. A channel of propagation for the domain is defined by a soft magnetic overlay which has a zig-zag configuration defining stable positions for domains alternative ones of which are on opposite sides of the conductor. The positions to one side of the conductor are stable domain positions for one polarity of current; the positions to the other side are stable domain positions for the opposite polarity of current. Directionality of domain movement is provided by asymmetry in the overlay pattern or by a directional field in the plane of the sheet. A uniform bias field maintains the domains at a prescribed diameter. Shift register operation is achieved in the absence of discrete propagation conductors.

FIELD OF THE INVENTION

This invention relates to domain propagation arrangements and, more particularly, to arrangements in which single wall domains are propagated in a sheet of magnetic material.

BACKGROUND OF THE INVENTION

Single wall domains are reverse-magnetized regions encompassed by a domain wall which closes on itself to form, illustratively, a cylindrical geometry the diameter of which is a function of the material parameters. Inasmuch as the boundary of the domain is independent of the boundary of the sheet, multidimensional movement of the domains can be realized.

A simple convention permits the visualization of single wall domains. Most sheets of material in which single wall domains can be moved are characterized by a preferred direction of magnetization substantially normal to the plane of the sheet. We may adopt the convention that positive and negative directions for the magnetization are up out of and down into the plane of the sheet respectively. A single wall domain in this context may be visualized as an encircled plus sign and the magnetization in the remainder of the sheet may be represented by minus signs. The Bell System Technical Journal (BSTJ), volume 46, No. 8, October 1967, pages 1901 et seq., describes single wall domains, various operations employing the movement of single wall domains, and suitable materials in which those domains can be moved.

Selective movement of a single wall domain is realized normally by the generation of a localized attracting field (viz., field gradient) at a position offset from the position occupied by a domain. In accordance with the assumed convention, a discrete conductor in the form of a loop coupled to a position offset from that occupied by a domain generates an appropriately placed localized positive field (up out of the plane) when pulsed. The domain moves to the position of the loop in response.

When an attempt is made to miniaturize single wall domain devices, it is realized that single wall domains can be obtained with geometries far smaller than the smallest dimensions realizable for the circuitry required to move

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them. There are a variety of reasons for this. The loop shape geometry of a discrete propagation conductor, for example, occupies more space than say a single conductor. Moreover, drive wiring economy and the need to provide directionality in the propagation channels dictate three-phase propagation operation pulsing as is well understood. Consequently, only one position in three may be occupied by a domain in practice although the positions may overlap one another. Further, drive current requirements dictate minimum cross sectional areas for conductors. But photo deposition techniques do not permit closely spaced conductors to have disproportionate widths and thicknesses without risking short circuits between adjacent conductors. As a result, as much as ten mils is allocated per bit location, yet domains of the order of microns can be realized. Discrete propagation conductors cannot be eliminated entirely either without reducing the capability of moving domains selectively.

An object of this invention is to provide a domain propagation arrangement in which single wall domains can be propagated in the absence of discrete propagation conductors and in which domain movement along selected channels can be realized.

BRIEF DESCRIPTION OF THE INVENTION

The invention is based on the discovery that a variety of overlay patterns, of a soft magnetic material such as permalloy, on the surfaces sheets of magnetic material in which single wall domains can be moved, exhibit changing magnetic pole patterns in response to changing magnetic fields. It has been found further that these overlay patterns can be chosen so that single wall domains can be made to follow the changing pole patterns from input to output positions in the absence of discrete propagation conductors. Moreover, the pole-changing fields can be provided in a manner to permit channel selection for domain movement.

In one embodiment, zig-zag shaped permalloy overlays are deposited on a sheet of thulium orthoferrite between input and output positions for single wall domains. A conductor is aligned with the axis of each zig-zag overlay. Bipolar pulses applied to a selected conductor generate in the associated overlay a changing pole pattern which is followed by domains only in the selected channel. Directionality in domain movement is determined by asymmetry in the shape of the overlay or by a direction determining field in the plane of the sheet.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic representation of a domain propagation arrangement in accordance with this invention;

FIGS. 2A, 2B, 2C, and 2D are schematic illustrations of a portion of the arrangement of FIG. 1 showing consecutive domain positions during operation;

FIG. 3 is a pulse diagram of the operation of the arrangement of FIG. 1; and

FIG. 4 is a schematic representation of an alternative domain propagation arrangement in accordance with this invention.

DETAILED DESCRIPTION

FIG. 1 shows a domain propagation arrangement 10 in accordance with this invention. The arrangement comprises a sheet 11 of a material in which single wall domains can be moved along propagation channels between input and associated output positions.

Overlays 12 define propagation channels for domains in sheet 11. Each overlay pattern has a generally zig-zag geometry shown schematically in FIG. 1 and in more specific detail in FIG. 2A. Each zig-zag geometry is accompanied by a conductor 13 which is aligned with the axis of the associated zig-zag pattern and positioned illustratively between overlay 12 and sheet 11. The conductors 13

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are connected between a channel select circuit 14 and ground. The channels are designated C1, C2, C3, . . . and CN as shown in FIG. 1.

The input positions to the various channels are shown to the left of the zig-zag patterns in FIG. 1. The positions are defined by the extended tips of a large domain 15 of positive magnetization in accordance with the assumed convention. Hairpin conductors 16C1, 16C2, 16C3, . . . and 16CN intersect the extended tips and serve to sever those tips, when pulsed, to provide domains for propagation in the associated channels. Conductors 16 are connected between an input pulse source 17 and ground for selective operation thereof.

The geometry of large domain 15 is maintained by a conductor 15A connected between a D.C. source S and ground. The conductor 15A outlines domain 15 and generates a positive field in the region of that domain. This operation is disclosed in copending application Ser. No. 579,931 filed Sept. 16, 1966, now Pat. No. 3,460,116, for A. H. Bobeck, U. F. Gianola, R. C. Sherwood and W. Shockley.

The output positions are to the right of the zig-zag overlays as viewed in FIG. 1. The output positions are defined by a conductor 18 which couples serially the terminal positions to the extreme right of the overlays. Conductor 18 serves to collapse domains occupying any of the so-coupled positions when the conductor is pulsed. Conductor is connected between an interrogate pulse source 19 and ground.

A plurality of output conductors couple the output positions also. The output conductors are designated OCC1, OCC2, OCC3, . . . and OCCN to correspond to the associated channel designations. Each of the output conductors is connected between a utilization circuit 20 and ground.

For domain movement in accordance with this invention, a specified diameter for each single wall domain is maintained. A bias field is provided for this purpose. This bias field is normal to the plane of sheet 11 in a direction to contract domains. In keeping with the adopted convention, the bias field is negative, that is to say, directed downward into sheet 11. The bias field is generated conveniently by a coil (not shown) encircling sheet 11 and lying in the plane of the sheet. Alternatively, a permanent magnet may be used for this purpose. Block 21, designated "bias source" represents the source of such a field.

The various sources and circuits are connected to a control circuit 22 for synchronization and energization. Such sources and circuits may be any such elements capable of operating in accordance with this invention.

FIGS. 2A, 2B, 2C, and 2D show the consecutive positions to which a domain D is propagated in accordance with this invention. We will assume an arbitrary starting position for the domain in FIG. 2A in an illustrative propagation channel C1. To avoid confusion, a domain is represented as a circle without a plus sign. The plus and minus signs shown in FIGS. 2A-2D indicate pole concentrations only.

Although generally of a zig-zag geometry, the magnetic overlay pattern is shown in FIG. 2A, illustratively, as having an additional curved area at each position therealong where its slope changes direction. The domain D in FIG. 2A is shown mating with one such curved area. The curved areas serve as stable positions for domains. The geometry of the overlay 12, specifically, permits domain movement only in the prescribed direction from stable position to stable position illustratively because of its asymmetrical shape. For the geometry shown, movement is to the right as viewed in FIG. 2A.

The contribution of the asymmetry of the overlay may be understood as follows. When a current flows in a conductor 13, negative and positive poles are generated in the associated overlay as is clear from the familiar right-hand rule. These poles are indicated fully to the right in FIG. 2A. For the convention adopted and for the assumed

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relative positions of overlay 12, conductor 13, and sheet 11, negative poles attract a domain and positive poles repel a domain. A domain introduced at the left in FIG. 2A tends to move upward toward the negative charges and away from the positive charges always remaining essentially underneath the overlay. But the diameter of the domain is chosen to be about the same size as the width of the overlay. Therefore, the domain does not move fully away from the positive charges because of the geometry of the overlay but, rather, moves to the right, as viewed, to increasingly negative positions.

The curved area in which domain D is shown in FIG. 2A is the most negative available position for a domain introduced from the left as shown in the figures. The domain can move no further to the right without moving to a relatively positive position.

On the other hand, when the current in conductor 13 reverses, as indicated by the arrow *i* in FIG. 2B, the pole distribution changes. Domain D again moves to increasingly negative positions. But the negative positions are now below wire 13 as viewed in FIG. 2B. Movement is again to the right because the asymmetrical geometry of the overlay provides the nearest increasingly negative path in that direction. The domain moves until it occupies the next stable position as shown in FIG. 2B.

Further alternations of the current applied to conductor 13 produces changing pole patterns which attract a domain to corresponding positions as shown in FIGS. 2C and 2D and eventually attract the domain to an output position for detection.

Of course, more than one domain can be moved along a propagation channel. All such domains move synchronously in response to the alternations in current in conductor 13. The domains may occupy, for example, the positions of next adjacent (negative) curved areas in FIG. 2A. Information is represented by the presence (binary one) and absence (binary zero) of domains. A domain pattern so representing information also moves synchronously in a propagation channel.

The input implementation is synchronized with the propagation current alternations in conductor 13. Thus, a pulse appears on a selected input conductor, say 16C1 of FIG. 1, severing a domain from a large domain 15 when the closest stable position (curved area) of the overlay 12 of channel C1 is, say, negative as shown in FIG. 2A. If a pulse is absent at that time on conductor 16C1, the absence of a domain is provided for propagation. The absence of a domain is represented as a broken circle in FIG. 2A.

The output is synchronized with the propagation current alternations in conductor 13 also. For example, control circuit 22 activates pulse source 19 for pulsing interrogate conductor 18 to collapse any domains in output positions. Circuit 22 enables utilization circuit 20 synchronously. If a domain is present in an output position, a pulse is applied to circuit 20 by means of the corresponding output conductor OCC1.

FIG. 2A shows the domain pattern for the information 1 0 1. The information is introduced by pulses P16C1 applied selectively to conductor 16C1 at times *t*0 and *t*2 in the pulse diagram of FIG. 3. At time *t*1 in that figure, a pulse P16C1 is absent as shown by the broken pulse form there. The pulses can be seen to be synchronized with the positive alternations of the pulses +P13 in conductor 13. The conductor 13 for channel C1 may be pulsed selectively by input source 17 under the control of control circuit 22 for achieving selective movement of information in channel C1.

Asymmetry in the overlay pattern is not the only implementation for achieving directionality in domain movement. A directional field *H*_d may be provided in the plane of sheet 11 instead. The directional field is aligned with the conductors 13. The direction of that field is determinative of a net displacement of domains in the absence of asymmetry in the overlay pattern as alterna-

tively poled pulses are applied to a conductor 13. The directional field is represented by the double-headed arrow, also designated H_d , aligned with conductors 13 in FIG. 1. The field is generated by a magnet or a coil oriented normal to sheet 11 as is well understood in the art. Block 25 in FIG. 1 designated "directional field source" represents an appropriate implementation. Copending application Ser. No. 726,454, filed May 3, 1968, now Patent No. 3,518,643 for A. J. Perneski discusses one suitable implementation in greater detail.

The conductors 13 of FIG. 1, of course, can be oriented in a direction perpendicular to the orientation shown for them in FIG. 1. Moreover, the conductors and the associated overlays can be oriented in either direction in one implementation to permit domain propagation selectively in either of two perpendicular directions. This latter implementation requires both X and Y channel select switches designated 14X and 14Y in FIG. 4. A domain D in FIG. 4 accordingly finds itself in each of an X and a Y channel in each instance. Propagation of a domain in either channel proceeds as described above.

The conductor and overlay patterns intersect as shown in FIG. 4, those elements oriented in one direction conveniently being disposed on a surface of sheet 11 opposite to that on which the elements in the other orientation are disposed. Only negligible interactions are present due to the overlays in one orientation on domains being propagated in the other. Alternatively, the X and Y oriented overlays can be disposed on a single surface of sheet 11. In this arrangement, like oriented portions (30, FIG. 4) of the two overlays may be formed as a single common portion.

If a directional field is employed rather than asymmetry in the magnetic overlays for achieving domain directionality, a means, similar to that represented by block 25 of FIG. 1, is provided for generating fields $\pm H_d X$ and $\pm H_d Y$ as shown in FIG. 4. Such a means may comprise mutually orthogonal Helmholtz coil pairs disposed normal to the plane of sheet 11 in FIG. 1 with appropriate switching means. Such an implementation is well understood in the art and is not shown or discussed further herein. The above-mentioned copending application of A. J. Perneski discusses a suitable implementation in greater detail.

It has been found that domains may occupy stable positions spaced apart about three domain diameters. Since domains on the order of a micron have been observed, packing densities of more than a million bits per square inch are realizable in the absence of discrete propagation conductors. Photoresist techniques are sufficiently controlled to permit the realization of such packing densities with overlays and conductors having geometries of the type disclosed.

The relationship of about three to one between the repeat of the overlay pattern of FIG. 1 and a domain diameter is supported by the following example: Three mil diameter domains are moved in a sheet of thulium orthoferrite in the manner described in connection with FIG. 1. Magnetically soft permalloy overlays 2,500 angstrom units thick define propagation channels for the domains. The repeat for the overlay is about 10 mils. Conductor 13 has a diameter of about one mil and currents of about 100 milliamperes are applied to generate suitable pole patterns for effecting domain movement.

The overlay 12 may comprise any material which supports suitable pole patterns. Any high permeability thin magnetic film or a film having relatively low coercivity

and anisotropy to permit switching of flux therein by the external fields characteristic of magnetic domains is suitable. A typical material is a magnetically soft Permalloy.

What has been described is considered only illustrative of the principles of this invention. Numerous other arrangements in accordance with the principles of this invention may be devised by one skilled in the art without departing from the spirit and scope thereof.

What is claimed is:

1. A domain propagation arrangement comprising a sheet of material in which single wall domains can be propagated, bias means for providing in said sheet a bias field of a polarity to contract domains to a specified geometry, a first electrical conductor contiguous said sheet, means for applying positive and negative currents to said first conductor, and a first magnetic overlay aligned with said first conductor and having a generally zig-zag geometry defining to one side of said first conductor stable positions for domains when a current of a first polarity flows in said first conductor and defining to the other side of said first conductor stable positions for domains when a current of a second polarity flows in said first conductor.

2. A domain propagation arrangement in accordance with claim 1 wherein said first magnetic overlay of zig-zag geometry is asymmetric to foster domain propagation in a first direction and includes therealong curved areas for defining stable positions for domains propagated therealong.

3. A domain propagation arrangement in accordance with claim 1 wherein said first overlay comprises Permalloy.

4. A domain propagation arrangement in accordance with claim 1 also including means for generating selectively in the plane of said sheet a field in a first or second direction along said first conductor.

5. A domain propagation arrangement in accordance with claim 1 also including a second electrical conductor spaced apart from said first and a second overlay substantially identical with said first overlay similarly defining stable positions for domains when a current flows in said second conductor.

6. A domain propagation arrangement in accordance with claim 5 also including means selectively pulsing said first and second conductors.

7. A domain propagation arrangement in accordance with claim 6 including input means coupled to said sheet for selectively providing domains in stable positions defined by said first and second overlays.

8. A domain propagation arrangement in accordance with claim 7 also including means coupled to said sheet for selectively detecting the presence and absence of domains in stable positions defined by said first and second overlays.

9. A domain propagation arrangement in accordance with claim 8 wherein said first and second conductors are disposed transverse to one another.

References Cited

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