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DOMAIN PROPAGATION DEVICE WITH HIGH DOMAIN MOBILITY

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FIG. 1

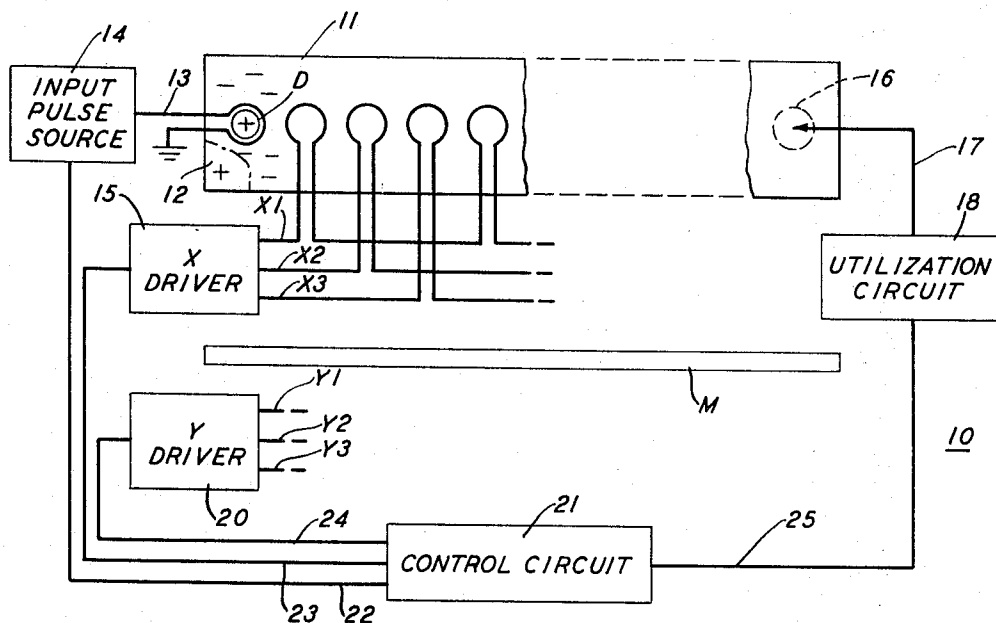


FIG. 2

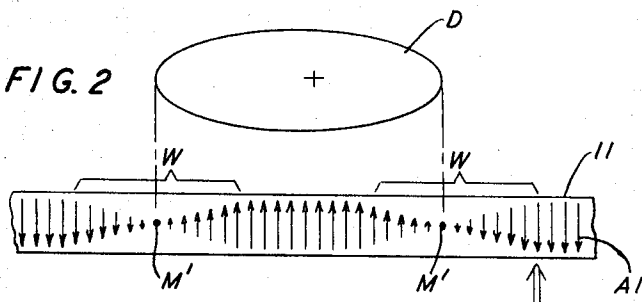
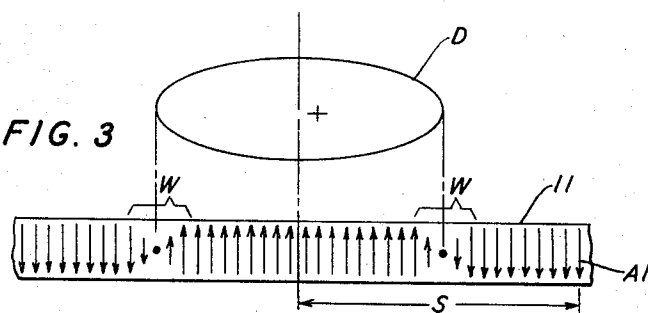


FIG. 3



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DOMAIN PROPAGATION DEVICE WITH
HIGH DOMAIN MOBILITY

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6 Claims

ABSTRACT OF THE DISCLOSURE

Single wall domain propagation devices, in which domains of specified diameter are propagated, are shown to be characterized by high domain mobility if the ratio of the diameter of the domain to the width of the domain wall encompassing that domain is made low.

FIELD OF THE INVENTION

This invention relates to domain propagation devices and, more particularly, to such devices including a sheet of magnetic material in which, for example, single wall domains are moved in response to propagation fields in excess of a propagation threshold characteristic of the material.

BACKGROUND OF THE INVENTION

The term "single wall domain" designates a reverse-magnetized domain which has a single domain wall thereabout and a geometry (i.e., diameter) independent of the boundary of the sheet in which such a domain is moved. Single wall domains are well known in the art. "Ferromagnetic Domains" by E. A. Nesbitt, published 1962 by the Waverly Press and also the Journal of Applied Physics, volume 30, pages 217-225, February 1959, for example, describe such domains. Copending application, Ser. No. 579,931, filed Sept. 16, 1966, for A. H. Bobeck, U. F. Gianola, R. C. Sherwood, and W. Shockley, now Pat. 3,460,116, in addition, discloses the use of such domains in the context of a two-dimensional shift register (propagation) operation.

Single wall domain propagation devices may be operated in what may be thought of as two different modes of operation. One mode is called the "bias-dominated" mode and is characterized by high stability in domain size during operation. The operation is in the presence of a bias field of a polarity tending to collapse domains and it is from the prominent role of this field in the operation that the mode designation is derived. Copending application Ser. No. 664,524, filed Aug. 30, 1967, for A. A. Thiele discloses optimum sheet thicknesses and corresponding coercivity and bias ranges for obtaining preferred operation in the bias-dominated mode. The other mode is called the "coercivity-dominated" mode and is characterized by a coercivity sufficiently high to retain any shape to which a domain may be changed during operation.

SUMMARY OF THE INVENTION

The present invention is based on calculations and experimentation indicating that the mobility of single wall domains is related to the anisotropy of the sheet in which those domains are moved. The mobility may be made large if the anisotropy of the sheet, operated in the preferred range of the bias-dominated mode, is low preferably in a range such that a factor

$$Q = \frac{|M_s|^2 L_d^2}{\pi A}$$

is as low a value above about three as possible where M_s is the saturation magnetization of the sheet and L_d and

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A are, respectively, the material length and the exchange energy characteristic of the sheet. The material length is defined as π times the energy per unit area of the domain wall divided by the demagnetization energy per unit volume for an infinite sheet with a normal magnetization.

In practice, mixtures of materials can be specified for providing the desired anisotropy and, thus, the corresponding value for the Q factor. For fixtures of erbium (Er) and samarian (Sm) orthoferrite, for example, the lowest uniaxial anisotropy is obtained at temperatures near a reorientation temperature characteristic of the material. For operation at room temperature, compositions are chosen such that the reorientation temperature occurs just above room temperature as it does in $\text{Er}_{0.32}\text{Sm}_{0.68}\text{FeO}_3$, or just below room temperature as it does in $\text{Er}_{0.38}\text{Sm}_{0.62}\text{FeO}_3$.

BRIEF DESCRIPTION OF THE DRAWING

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

FIGS. 2 and 3 are cross-sectional views of a portion of the arrangement of FIG. 1.

DETAILED DESCRIPTION

FIG. 1 shows a single wall domain propagation device 10 including a sheet 11 of magnetic material in which single wall domains, represented by a domain D, are moved from input to output positions. Sheet 11 is assumed to be saturated magnetically in a negative direction away from the viewer in FIG. 1. A single wall domain D, then, may be represented by an encircled plus sign where the plus sign indicates the direction of magnetization and the circle represents the single domain wall. Similarly, a source of positive magnetization (domains) is represented at 12 by an encompassed plus sign.

A conductor 13 couples an input position which is adjacent source 12. Conductor 13 is connected between an input pulse source 14 and ground. When source 14 pulses conductor 13, the latter generates a field which attracts a domain from source 12. If a pulse is absent, at a particular time, from conductor 13, an absence of a domain occurs at the input position. The presence and absence of domains represents binary ones and zeroes, respectively, for propagation to a remote output position.

The movement of the presence and absence of domains in a domain propagation medium is controlled by patterns of propagation fields which attract domains. Conductors X1, X2, and X3 are shown in FIG. 1 for this purpose. The conductors couple consecutively offset positions along the path of propagation between input and output positions, and the pattern of coupling repeats. Thus, conductor X1 couples first, fourth, etc. positions along the path of propagation as shown in the figure. Similarly, conductors X2 and X3 couple the second, fifth, etc. and couple the third, sixth, etc. positions between the input and output positions respectively. Conductors X1, X2, and X3 are connected to an X driver 15 and are pulsed consecutively thereby during operation for generating consecutively offset fields for advancing domains. The repeat pattern of couplings causes those fields to be generated in patterns which synchronize the advance of next consecutive bits thus providing a built-in timing with which inputs and outputs are synchronized also. Information is advanced in this manner until an output position is reached.

The output position is designated by a broken circle 16. An arrow 17 represents an output coupling to the output position. Such a coupling may be electrical or optical in nature. If electrical, arrow 17 represents a conductor connected between utilization circuit 18 and ground. If optical, arrow 17 may represent a beam of polarized monochromatic light and utilization circuit 18

would be a photocell and analyzer combination arranged to detect the presence and absence of polarized light via Faraday rotation for indicating the presence and absence of a domain in the output position respectively.

Only a single domain propagation channel is shown in FIG. 1. Single wall domains, however, are capable of multidimensional movement. Thus, propagation channels in a Y direction orthogonal to the channel shown may be present. Moreover, channels parallel to the one shown may also be present and information may be moved from channel to channel controllably. To move information in a Y direction, Y propagation conductors are utilized. These too are operated in a three-phase manner as described for the X conductors and are coupled to positions along the Y direction arranged similarly to those described for the X couplings. FIG. 1 shows the Y conductors Y1, Y2, and Y3 connected to a Y driver 20.

A magnet, represented by block M in FIG. 1, suitably shaped to provide a field of the requisite magnitude, is positioned adjacent sheet 11.

Source 14, drivers 15 and 20, and circuit 18 are connected to a control circuit 21 via conductors 22, 23, 24, and 25, respectively. The various sources, drivers, and circuits may be any such elements capable of operating in accordance with this invention.

This invention is directed primarily at the mobility of domains in sheet 11. A domain moves when an attracting field in excess of a propagation threshold characteristic of the material is generated at a position offset from the position occupied by the domain. Generally, the amount by which that field exceeds the threshold determines the speed at which the domain moves so long as a nucleation threshold, also characteristic of material, is not exceeded. If the latter threshold is exceeded, spurious domains are nucleated and information is lost.

The speed at which domains move in a particular sheet of material is also dependent on the material parameters. It has been found that the mobility of domains may be maximized by choosing those parameters such that the value of

$$Q = \frac{|M_s|^2 L_d^2}{\pi A}$$

is low. The expression is in a form particularly well suited for rare earth orthoferrites which presently appear most practical for single wall domain propagation devices. The terms $|M_s|$ and A for orthoferrites are essentially constants and L_d is measurable in terms of the thickness of the sheet and the diameter at which single wall domains collapse in a sample material as described in the aforementioned copending application.

A qualitative understanding of the improved mobility in accordance with this invention may be gained from a consideration of the configuration of the spin directions in a domain wall. Orthoferrites are characterized by a preferred direction normal to the plane of sheet 11. When viewed in cross section, a domain in a sheet of orthoferrite has spins directed upward and the remainder of the sheet has spins directed downward. The extent of the domain is indicated by the encircled plus sign (domain D), the projections of the limits of which on sheet 11 of FIG. 2 indicate the correspondence with the cross-sectional view.

The domain wall W encompassing domain D has a width determined by exchange and anisotropy considerations as is well known. Anisotropy considerations alone would lead one to expect an abrupt change in direction of spins from an upward to a downward orientation as shown by the arrows in FIG. 2. Exchange consideration alone would lead one to expect an infinite transition region between spins of opposite orientations. In any given material, a finite transition region does exist and it is of a width indicative of the relative values of the exchange and anisotropy forces. The transition region thus constitutes the domain wall, spin directions therein accom-

modating themselves to the extreme orientations in the limiting positions of the wall and being consecutively incrementally further rotated into the sheet from the upward to the downward orientations as is well understood.

Let us assume that the wall is localized, and that spin rotation in the wall is uniform. When a field is applied as shown by the upward directed double arrow in FIG. 2, all the spins in the wall rotate simultaneously. A relatively wide wall for domain D as shown in FIG. 2 includes next adjacent spins within the wall which are at slight angles with respect to one another. A relatively narrow wall for the domain D as shown in FIG. 3 includes within the wall next adjacent spins which are at larger angles with respect to one another. The rate at which a given spin rotates is independent of the width of the wall. But in the wider wall, each spin need rotate through an angle which is small compared to a correspondingly positioned spin in the narrow wall. Thus, the wider the wall, the smaller the angle between the spins and the shorter the time required to rotate a particular spin in the wall to the orientation of the next adjacent spin in the direction opposite to the direction of movement of the wall.

The mobility of a domain increases if the width of the domain wall is large relative to the diameter of the domain. The domain D has the same diameter in FIG. 3 as in FIG. 2. The width (w) of the wall is different, however. If we let S represent the distance between the center of the domain D and the position represented by arrow A1 in FIGS. 2 or 3, it may be seen that the wall occupies a larger fraction of that distance in FIG. 2 than it does in FIG. 3. An applied field couples to the entire wall in each instance. For the configuration of FIG. 2, it takes a time $t(=S/t_0)$ for the center of domain D to be moved to the position of arrow A1. For the configuration of FIG. 3, it will take a time $t_1 > t$ for the center to be moved that distance. But the mobility of domains is measured by distance over time and since

$$\frac{S}{t} > \frac{S}{t_1}$$

the mobility in the first instance is higher.

The time inequality may be understood on a more quantitative basis in the following terms. For a given wall shape and velocity, the rate of rotation of a given spin is inversely proportional to the wall width. If the spins are subject to an invariant viscous damping (usually called Gilbert damping) then the mobility is inversely proportional to wall width, since the total amount of energy available for flipping a particular spin to a different orientation is fixed.

There is a practical limit to the width of a domain wall. The domain D, as shown in FIG. 2 for example, extends between the positions of dots M' and M' representing the mean position for the domain wall (in cross section). Half the wall is within what is normally considered the domain. Consequently, if the wall width were twice the domain diameter, the domain would be all wall. In this condition, $Q=2$ and the demagnetization field equals the nucleation field. This limit clearly cannot be reached and a wall width to domain diameter ratio, Q , of between three and ten is about the best possible from the standpoint of maximized mobility.

The range of from three to ten is necessary to permit flexibility in determining margins of operation. A single wall domain, for example, expands (runs out) uncontrollably or collapses in response to first and second fields respectively. The range between the "run out" field and the "collapse" field varies. A range acceptable for operation may be determined experimentally providing a corresponding Q value of between three and ten.

In practice, even a value $3 < Q < 10$ is difficult to achieve particularly in orthoferrites. However, the lower the anisotropy the larger the number of domain walls and the greater the width of each wall. Consequently, a de-

crease in the anisotropy of a material is desirable for increasing mobility of domains in the material, i.e. since

$$Q = \frac{\text{domain diameter}}{\text{wall width}}$$

the wider the wall, the smaller the Q factor.

A typical anisotropy field for an unmixed orthoferrite, i.e., YFeO_3 , yttrium orthoferrite, is 10^5 oersteds (anisotropy field

$$H_a = 2 \frac{K}{M_s}$$

where K is the first anisotropy constant). Orthoferrites may be mixed, however, to provide lower anisotropy. For example, the $\text{Sm}_x\text{Er}_{1-x}\text{FeO}_3$ system provides materials with low anisotropies at various temperatures including room temperature. $\text{Sm}_4\text{Er}_6\text{FeO}_3$ specifically provides an anisotropy of about 4×10^3 oersteds at room temperature which provides a Q of about 60. A Q of about 100 or lower is acceptable. "Physics Letters," Aug. 28, 1967, volume 25A, No. 4, pages 297-298, describes mixtures of orthoferrites, and corresponding anisotropies, useful in accordance with this invention.

The Q factor is defined above in terms suitable for orthoferrites because the magnetization and the exchange energy terms are conveniently constant. These terms actually can be changed for orthoferrites but by means which also change both the Curie temperature and magnetic moments characteristic of the materials. Changes in the Curie temperatures and moments of orthoferrite materials useful for single wall domain propagation devices are not necessarily desirable, however.

In other materials also useful for single wall domain propagation devices, the magnetization and the (room temperature) exchange energy may be changed. The Q factor for these materials may also be expressed as

$$Q = \frac{2H_a}{4\pi M_s}$$

where H_a is the anisotropy field as noted above (that required to rotate the magnetization from an easy to a hard axis). Barium ferrite, $\text{BaFe}_{12}\text{O}_{19}$, is one such material. The magnetization and exchange energy of barium ferrite may be changed by including, for example, nonmagnetic materials therein. This is described in Smit and Wijn, "Ferrites," John Wiley & Sons, 1959; see pages 204 and 208. Barium ferrite, for example, gives a Q of about 7.0 on the basis of the above formula. When zinc is added, however, as in $\text{BaZn}_{1.5}\text{Fe}_{17.5}\text{O}_{27}$, $Q=4.6$. These hexagonal oxides are difficult to make, reproducibly, of suitable thicknesses for the propagation of domains having optimum diameters.

We must recognize that in practice when the anisotropy of a material is changed (with everything else held constant), the optimum domain size changes, a fact which is ignored herein. The optimum domain size may be determined in accordance with the teachings of the above-mentioned copending application however. Consequently,

the parameters of a magnetic sheet for single wall domain propagation may be specified prior to the fabrication of the sheet.

For the coercivity-dominated mode, similar considerations relating nucleation threshold to wall width dictate as low a nucleation threshold as possible to provide high mobility. In the coercivity-dominated mode, the minimum wall curvature may be taken as the domain diameter.

It is to be understood that the embodiments described are merely illustrative of the principles of this invention and, accordingly, various modifications may be made therein without departing from the scope and spirit thereof.

What is claimed is:

1. A magnetic device comprising a material in which reverse-magnetized domains are propagated in response to fields in excess of a threshold characteristic of the material, said domains having a first dimension in the direction of propagation and a first domain wall, characterized in that the ratio of said first dimension to the width of said first domain wall is less than about 100.

2. A magnetic device comprising a sheet of magnetic material in which a single wall domain is moved in response to consecutively offset propagation fields in excess of threshold characteristic of said material, characterized in that the ratio of the diameter of said domain to the width of the domain wall encompassing said domain is from between three and ten to about 100.

3. A magnetic device in accordance with claim 2 wherein said magnetic material comprises a rare earth orthoferrite wherein the value

$$Q = \frac{|M_s|^2 L_d^2}{\pi A}$$

is in a range of from between three and ten to about 100 where M_s is the saturation magnetization of the material, A is the exchange energy, and L_d is a length characteristic of the material.

4. A magnetic device in accordance with claim 3 wherein said material comprises $\text{Sm}_x\text{Er}_{1-x}\text{FeO}_3$.

5. A magnetic device in accordance with claim 2 wherein said magnetic material is characterized by a value

$$Q = 2 \frac{H_a}{4\pi M_s} < 100$$

where H_a is the anisotropy field required to rotate the magnetization from an easy to a hard axis, and M_s is the saturation magnetization of the material.

6. A magnetic device in accordance with claim 5 wherein said magnetic material is barium ferrite.

References Cited

Bell System Technical Journal, "Properties & Device Applications of Magnetic Domains in Orthoferrites," by A. H. Bobeck, vol. 46; 1967, pp. 1901-1925.

JAMES W. MOFFITT, Primary Examiner