Suppression of Hard Bubbles in Magnetic Garnet Films by Ion Implantation

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I. INTRODUCTION

Hard bubbles are cylindrical magnetic domains which differ from normal bubbles in their static and dynamic properties.[1–3] They form and collapse at fields considerably higher than normal bubble domains (hence the name "hard bubbles") and, under the action of a gradient in the perpendicularly directed magnetic field, they have a component of motion either to the right or to the left rather than straight down the gradient (right- and left-handed hard bubbles). Under the influence of a small alternating field superimposed on the dc bias field, normal bubbles oscillate in size or strip out in a random manner, whereas hard bubbles tend to strip out in an S-shape and rotate in either a counterclockwise direction for the normal S-shape or clockwise for the reverse S-shape. It has been found that high-speed propagation using permalloy overlay circuits is impossible in materials which are prone to hard bubble formation.

II. DISCUSSION

A recently proposed model[2,4] suggests that a hard bubble differs from a normal bubble in the nature of the spin arrangement within the domain wall. A hard bubble has a large number of "Bloch lines" or Bloch-to-Néel transitions around its circumference, all right-handed or left-handed, so that a twisted spin arrangement is locked in. A normal bubble presumably has no Bloch lines. It is predicted that a bubble with only two Bloch lines would have properties very similar to those of a normal bubble.[4]

It has been shown[5] that hard bubbles do not form in certain double-layer films. For example, in a layer with normal bubble properties grown on top of a layer with smaller magnetization, in an appropriate bias field, the lower layer is saturated and bubbles are formed only in the upper layer. These bubbles have an extra 180-degree domain wall parallel to the film surface near the interface between the two layers. In the model described above,[2,4] the locked-in twisted spin arrangement can unwind in the presence of this bottom domain wall, leaving only two Bloch lines, resulting in bubbles which are not measurably "hard".

A "lid" on a bubble should be just as effective as a "bottom" domain wall in eliminating hard bubbles. Ion implantation can be used to provide this "lid" by producing a thin layer of garnet near the top surface in which the easy axis of magnetization is parallel to the surface,[6] not perpendicular as in the bubble-supporting lower region. In such a structure, each bubble has a 90-degree domain wall parallel to the film surface in the shallow implanted layer.

In previous studies[6] it has been shown that the effect of ion implantation is to expand the lattice of rare-earth iron garnets. Since the implanted layer is constrained by the rest of the material, it is free to expand only in a direction perpendicular to the surfaces. Parallel to the surface, the implanted region is in compression. For a magnetic garnet with negative magnetostriction, this lateral compression induces a magnetic easy axis parallel to the surface, whereas in typical bubble materials the easy axis is perpendicular to the film as a result of growth-induced and stress-induced anisotropy.

The result of hydrogen ion implantation in a (111) LPE film of a typical bubble garnet of composition $(YGdTm)_3(FeGa)_5O_{12}$ is shown in Fig. 1. The dose was 2×10^{16} H/cm^2, at an energy of 100 keV. Figure 1a shows the characteristic comb-like "anomalous strip" pattern of magnetic domains formed by rapid demagnetization from the saturated state in the unimplanted area on the left, and the absence of this pattern in the implanted area on the right. In Fig. 1b, these domains have been cut into strips and a bias field of 70 Oe was applied. Many strips in the unimplanted area have not yet formed bubbles in the 70 Oe bias field. In higher fields these became hard bubbles with collapse fields up to 105 Oe. Hard bubbles could not be formed in the implanted area by this rapid demagnetizing method or the pulse methods.[1] All of the bubbles on the right-hand side of Fig. 1b were normal in behavior, with collapse fields of 75 $\pm$ 1 Oe. The bubbles which adhered to the edge of the implanted region were also normal, but they collapsed at 83 Oe. This edge effect can be used to form "rails" for bubble propagation, as will be discussed in a later publication. Away from the border, the strip widths, bubble diameters, and normal bubble collapse fields were very similar in the implanted and unimplanted areas.

In this material, doses from 10^{16} to 10^{17} H/cm^2 at energies from 25 keV to 300 keV were effective in eliminating hard bubbles. Similar results have been obtained with three other garnet compositions of current interest, all with negative values of magnetostriction in the (111) direction, normal to the film. These compositions were:

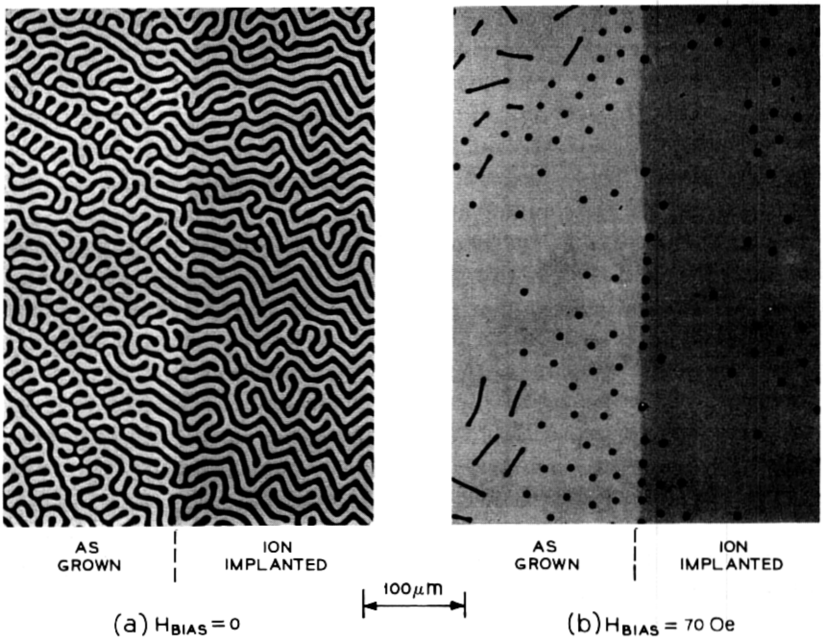

Fig. 1—The effect of hydrogen ion implantation in a magnetic garnet film of composition $(YGdTm)_3(FeGa)_5O_{12}$. (a) Rapidly demagnetized state. The unimplanted area on the left shows the comb-like pattern of magnetic domains, typical of materials in which hard bubbles form. This pattern is absent from the implanted area on the right. (b) Bias field of 70 Oe applied. Many of the domains in the unimplanted area are still strips. At higher fields they form hard bubbles with collapse fields up to 105 Oe. All of the bubbles in the implanted part have normal characteristics with collapse fields near 75 Oe.

$$(YGdYb)_3(FeGa)_5O_{12}$$

$$(GdEr)_3(FeGa)_5O_{12}$$

$$(YEuYb)_3(FeGa)_5O_{12}$$

In the last of these, a dose of 1×10^{16} H/cm^2 at 100 keV was not sufficient to suppress hard bubbles, but 5×10^{16} H/cm^2 gave the desired result. This is consistent with the smaller magnetostriction coefficient in this composition. A larger strain is therefore required to overcome the anisotropy perpendicular to the film and provide a layer with magnetization parallel to the surface.

A film of $(YGdTm)_3(FeGa)_5O_{12}$ was implanted with helium ions at an energy of 300 keV. A dose of 10^{15} He/cm^2 did not suppress hard bubbles, but no hard bubbles could be formed in areas implanted to

10^{16} He/cm^2 or 10^{17} He/cm^2. This result contradicts earlier findings[6] that He^4 implantation is not effective in changing magnetic anisotropy. However, it is consistent with a large increase in lattice constant (up to 1.5 percent) observed by X-ray diffraction in this case.[7]

The coercivity and mobility of these implanted films are within the range measured on the same materials before implantation, and with careful attention to cleanliness, no magnetic defects are introduced in the implantation process. The margins for propagation, generation, and detection in several implanted films have been equivalent to those measured in unimplanted regions of the same films.[8]

Preliminary annealing experiments have been undertaken to determine the thermal stability of the hard bubble suppression effect. In one specimen, bombarded with 1×10^{16} H/cm^2 at 100 keV, the effect was still present after successive 1/2 hour anneals at 100°C intervals in O_2 up to 1000°C. In another specimen, hard bubbles reappeared after 1/2 hour at 300°C. This difference is probably associated with the level of normal anisotropy in the starting material. These experiments indicate that aging should not be a problem for devices operated near room temperature.

III. CONCLUSIONS

The ion implantation method should be effective in suppressing hard bubbles in any garnet material which has negative magnetostriction in the direction perpendicular to the film surface. It is a reliable, reproducible, and inexpensive method and may therefore be preferable to the alternative double-layer technique.

IV. ACKNOWLEDGMENTS

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The Effect of a Second Magnetic Layer on Hard Bubbles

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A new class of magnetic bubbles designated as hard (and intermediate) bubbles has been found to be a common feature in many bubble garnet films.[1] These hard bubbles have been very disruptive to the operation of bubble circuits since they not only have a much lower mobility than normal bubbles, but also tend to move at an angle rather than parallel to the direction of the driving field gradient. Fortunately, it has recently been found that the presence of a second magnetic layer apparently eliminates these hard bubbles.[2,3] This second layer can either be a growth layer with a sufficiently small moment so that its magnetization under a bias field is always oppositely directed to the magnetization within the bubble,[2] or it can be a layer with magnetization perpendicular to the bubble magnetization. This latter layer might be produced by ion implantation to the point where a stress-induced uniaxial anisotropy in the plane of the film overcomes the previously existing anisotropy.[3] We propose in this B.S.T.J. Brief that the apparent elimination of these hard bubbles is due to the presence of the domain wall between the bubble and this second layer.

The static and dynamic properties of these hard bubbles have recently been accounted for by a model[4,5] which assumes that the domain wall which forms the perimeter of the bubble is segmented into Bloch segments of opposing polarity separated from one another by Néel segments as shown in Figs. 1a and b. As long as the spin rotation of Fig. 1b is always clockwise or counterclockwise as one proceeds around the bubble perimeter, then such a segmented configuration remains