V. ACKNOWLEDGMENT

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Multilayer Epitaxial Garnet Films for Magnetic Bubble Devices–Hard Bubble Suppression

By A. H. BOBECK, S. L. BLANK, and H. J. LEVINSTEIN

(Manuscript received May 26, 1972)

A conventional magnetic bubble material consists of a magnetic garnet film deposited on a nonmagnetic substrate. Garnet films with stress- and/or growth-induced uniaxial anisotropy are deposited by chemical vapor deposition (CVD) or liquid phase epitaxy (LPE) usually on $Gd_3Ga_5O_{12}$ substrates. In this B.S.T.J. Brief we report on the properties of multilayer garnet films deposited by LPE.

An extremely important property of the multilayer epitaxial films that we will describe is the complete absence of hard bubbles.[1] Hard bubbles differ from normal bubbles in both their static[2] and dynamic[3] behavior. It is quite unlikely that garnet films which support hard bubbles will find use in devices. Hard bubbles generally have much lower wall mobilities than normal bubbles and their presence severely limits the data rates.

The work on multilayered magnetic films was originated after the study of a series of single-layer epitaxial films of nominal composition $Gd_{2.34}Tb_{0.66}Fe_5O_{12}$ grown on (111)-oriented $Nd_3Ga_5O_{12}$ substrates.[4] Strip domains differing in both width and Faraday contrast were often observed in these films. It was determined that the wide, high-contrast

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A variation in composition through the height of the epitaxial layer producing a magnetization and/or wall energy gradient can account for many of the effects observed in these films. W. J. DeBonte[5] has determined stability criteria for surface bubbles.

The classic magnetic bubble is a reversed volume of magnetization in the shape of a right cylinder the stability of which has been reported by A. A. Thiele.[6] However, as already noted above, some epitaxial films exhibit behavior not predicted by Thiele's theory. In an attempt to produce in a more controllable manner the equivalent of some of these films, several two-layer and three-layer epitaxial garnet films were prepared. We searched, for example, for multilayer combinations that would support bubbles over a wider range of bias field than single-layer films.

The cross section of the standard bubble domain is illustrated in Fig. 1a. This bubble is bounded by a domain wall which W. J. Tabor, et al.,[1] report can contain a large number of Bloch-Néel transitions. In Fig. 1b, a magnetic layer intermediate to the bubble supporting layer and the substrate has been added. If the intermediate layer ① is assumed saturated by an external bias field, as it would be if the bubble collapse field in layer ① is much less than the strip-to-bubble transition in the upper layer ②, then an additional domain wall at the base of the cylinder will be present. By providing a "cap" to the

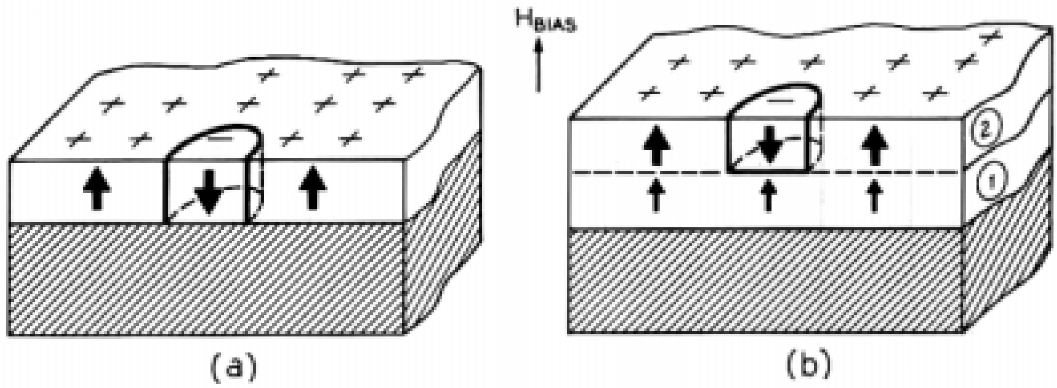

Fig. 1—(a) Sectional view of a conventional bubble domain found in a uniform single-layer garnet film deposited on a nonmagnetic substrate. (b) Addition of an inner low-moment magnetic layer, saturated upward by the bais field, provides a domain wall "cap" to the base of the bubble. This is defined as a Type I bubble.

bubble, the degrees of freedom available to the wall geometry are apparently reduced to those that allow normal bubbles and not hard bubbles.[7] When viewed in a polarizing microscope, surface bubbles have subtle shadings which convey the impression that they are more hemispherical than cylindrical.

Evidence that the adjacent garnet layers exchange couple is found in the presence of an effective bias field very similar in nature to that reported by T. W. Liu, et al.,[8] for $Co_{3.2}Cu_{1.3}Fe_{0.5}Ce_{0.25}Sm_{0.75}$ films deposited on $Sm_{0.55}Tb_{0.45}FeO_3$ platelets. The effective bias field H_{ex} derived there becomes, for our configuration, $H_{ex} = \sigma_{w12}/2h_2M_{s2}$ where σ_{w12} , h_2 , and M_{s2} are the wall energy of the interface, thickness, and magnetization of layer ②, respectively. It has been determined experimentally that adjacent garnet films do exchange couple at their interface and that the exchange energy is at a minimum when their respective Fe sublattices align parallel. For the bubble geometry of Fig. 1b, the effective bias field H_{ex} adds to the external bias field. Examples are found, however, where the polarity of H_{ex} is such that H_{ex} subtracts from the bias field.

Refer to Fig. 2a. In this two-layer configuration, garnets are chosen with compensation temperatures on opposite sides of room temperature. In actual two-layer specimens the demagnetized strip domains assume a variety of configurations with that illustrated in Fig. 2b being typical of most. Solid arrows define net magnetization directions and dotted arrows tetrahedral Fe sublattice directions. The latter is included so that we may establish the location of the interfacial domain wall energy. With a suitable external bias field, strip domains in the layer ① disappear and surface bubbles are stable in layer ②. Note that the interfacial domain wall lies *outside* the bubble and the bias field needed to collapse the bubble is therefore increased over that needed to collapse a bubble in an identical but isolated upper layer. Hard bubbles are eliminated in this bubble geometry which we designate Type II just as they were in the geometry of Fig. 1b which we designate Type I. Type II bubbles should attract one another at close spacings.

The direction of magnetization of the lower layer of Fig. 2c depends critically upon the thickness h_1 of the lower film. By comparing the applied field energy of the bottom layer to the interfacial domain wall energy, it can be shown that $h_1 > \sigma_{w12}/H_A \rightarrow M_{s1}$ is a necessary inequality for Type II bubbles. For typical garnet film parameters of $\sigma_w = 0.2$ erg/cm^2, $H_{bias} = 100$ Oe, and $M_{s1} = 4$ gauss, the calculated minimum for h_1 is 5 μm.

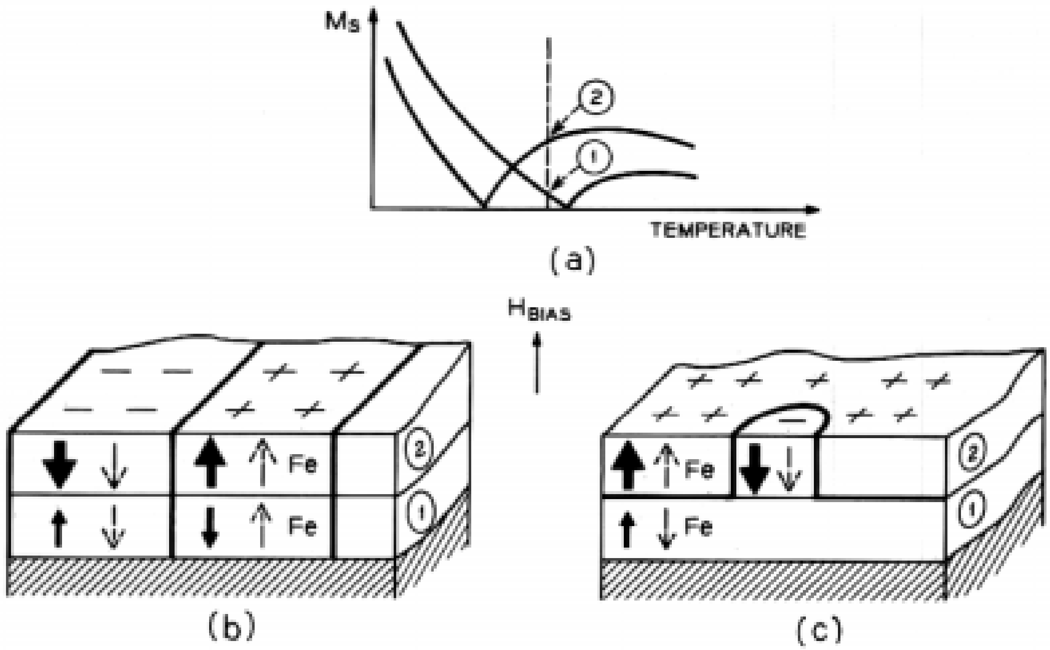

Fig. 2—(a) Garnet layers with compensation temperatures on opposite sides of the operating temperature are used in this two-layer film. (b) Domain pattern at zero bias. Solid arrows indicate net magnetization, dotted arrows the tetrahedral Fe sublattice orientation. (c) At operating bias a Type II bubble is observed since interfacial domain walls are present wherever the Fe is aligned antiparallel.

Multilayer films prepared for this study include both Type I and Type II double-layer films and a Type I triple-layer film. In the latter example, completely enclosed bubble domains reside in the middle layer of the three-layer sandwich. The films were grown on (111)-oriented $Gd_3Ga_5O_{12}$ substrates by the "dipping" technique utilizing super-cooled melts.[9,10] The apparatus and experimental details have been discussed in detail elsewhere.[9,10] Melts were contained in cylindrical platinum crucibles 3.8 cm diameter by 5 cm height. A platinum partition was welded into the crucible allowing two melts of different compositions to be contained in the same furnace. Melts used for upper and lower layers were adjusted to saturate at the same temperature within ±5°C.

One such film consisted of an 8-μm, high-moment upper layer of $Er_{1.8}Eu_{1.2}Fe_{4.34}Ga_{0.66}O_{12}$ garnet grown epitaxially on a 6-μm, low-moment lower layer of $Er_{1.8}Eu_{1.2}Fe_{3.79}Ga_{1.21}O_{12}$. At zero bias the strip domain pattern for this two-layer film is indistinguishable from that of a single-layer film. There is maximum Faraday rotation and strips are equal in width. It is only with an applied bias that the undulating surface domains are seen. Surface and composite bubbles can coexist in this film. Surface bubbles range from 20–4 μm in diameter over a bias range of 38–63 Oe. Composite bubbles range from 20–10 μm for a 48–63 Oe bias range.

A second example is a two-layer film composed of a 5-μm, high-moment upper film ② of $Tm_{0.35}Y_{1.59}Gd_{1.06}Ga_{0.62}Al_{0.43}Fe_{3.95}O_{12}$ garnet grown epitaxially on a 5-μm, low-moment lower film ① of $Tm_{0.24}Y_{1.50}Gd_{1.26}Ga_{0.76}Al_{0.36}Fe_{3.88}O_{12}$. Film ① has a compensation temperature at +27°C; film ② at −18°C. Either Type I or Type II surface bubbles can be established with this combination. Above 23°C Type I bubbles are supported, below 20°C either Type I or Type II bubbles can be established, there being a hysteresis in the magnetized state of layer ①. At a temperature such as 10°C the operating bias fields for Type I and Type II bubbles are displaced by 12 Oe indicating the H_{ex} = 6 Oe. Using $H_{ex} = \sigma_{w12}/2h_2M_{s2}$ we calculate $\sigma_{w12} \sim 0.1$ erg/cm^2.

This film, which has a domain wall mobility of 500 cm/s-Oe, has been used successfully in devices at 100-kHz data rates.

The fabrication of multilayer films adds a further complication to the process of manufacturing bubbles supporting magnetic films. The eventual utilization of films made by this approach will depend upon the outcome of other solutions being considered for the hard bubble problem. An alternate approach is ion implantation[11] into a single-layer film.

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