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TRANSIENT SHAPES OF THE MAGNETIC BUBBLE DOMAINS DURING GRADIENT PROPAGATION AND OVERSHOOT*

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ABSTRACT

Characteristic transient shapes were observed for free magnetic bubble domains during gradient translation and overshoot using high speed photography with 10 nsec laser pulse illumination. The two flanks of the bubble start to expand transversely to the driven motion direction at about .5 μsec after the onset of a 7.4 Oe/rad, 2 μsec gradient field pulse. They expand transversely at 2.6 m/sec and continue for 3 μsec after the termination of the gradient pulse. During this expansion, the tip of the flanks move longitudinally at 2.6 m/sec lagging behind the bubble center moving at 5.3 m/sec. Considerable scatter exists in the transverse motion after the driven phase especially in the recovery where some bubbles require as long as 15 μsec to regain their round shape. The transverse expansion was found to be independent of the bias compensation applied; however, the transient distortion during the driven phase and the recovery time from the transverse expansion were sensitive to the compensation. This transverse motion as well as the transient shape of the bubble can be explained qualitatively on the basis of a model involving opposite winding vertical Bloch lines.

INTRODUCTION

Free bubble gradient translation is one of the most commonly used techniques to characterize the dynamics of magnetic bubble domains. Especially in as-grown garnet samples, the recent discovery of the overshoot(1-4) and the creep(5,6) has shown that the dynamics of bubble translation is more complex than initially assumed and that high speed photography is an essential tool for the investigation of gradient translation. Vertical wall twists, i.e., opposite winding vertical Bloch-lines, were found to exist in bubbles after gradient translation(7) and were subsequently shown to be a major source of the translational overshoot and creep(6). In this paper new and detailed observations on free bubbles during gradient propagation will be presented. Expansion of the bubble in the direction transverse to the translation direction(8) is observed during the driven translation and was found to continue for several μsec after the termination of the gradient field pulse. This transverse motion as well as the transient shape of the bubble will be explained on the basis of vertical wall twist generation during the driven translation and subsequent relaxation of the resulting dynamic structure during overshoot.

EXPERIMENT

Multiple exposures of free magnetic bubble domain were recorded on video tape using an optical sampling microscope(9) with 10 nsec laser pulse illumination and a silicon intensified target (SIT) TV camera with an image persistancy of 60 msec. Multiple exposure recording was done by flashing the laser several times during the image retention time thus superimposing the images on the silicon target. A gradient field was obtained by pulsing current through a pair of copper parallel conductors with 1x30-μm cross-section and 130 μm separation. Bubbles were positioned ∼4μ from the center and primed before every translation by a sequence of weak gradient field pulses (∼.6 Oe/rad) followed by two bias field expansion pulses 10 Oe in magnitude for 2 μsec. The bubbles were then translated by a single gradient field pulse. A bias compensation pulse was used to properly adjust the bias during the gradient pulse. This pulse compensated for the original starting position as well as the changing center of the moving bubble where the center of the moving bubble was considered as the middle between the front and rear wall along the propagation direction. The compensation pulse varied linearly from 8 Oe to 25 Oe for Fig. 1. Creep was induced by bias field pulsing as done previously(6). The sample used was the as-grown version of the Tm doped sample previously described(7).

RESULTS AND DISCUSSION

A typical series of the four exposure photographs showing the bubble at various times during a gradient propagation and overshoot are shown in Fig. 1. For each sequence, the four exposures, from left to right, are the static bubble before the application of the gradient

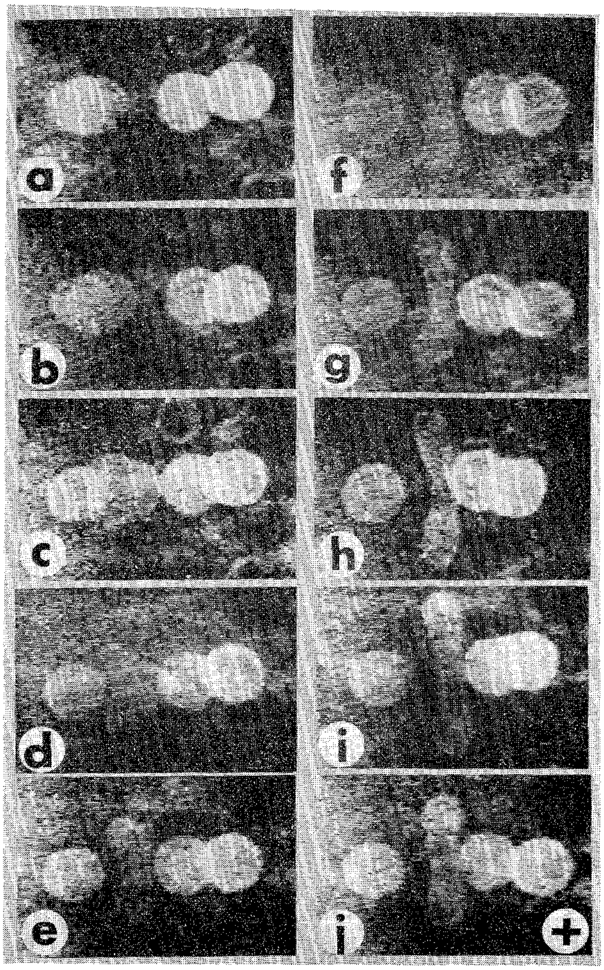

Fig. 1. Multiple exposure photographs of the magnetic bubble. First exposure (left most) is the static bubble before the translation; second is the transient bubble shape at (a) 0.4, (b) 0.7, (c) 1.3, (d) 2, (e) 2.6, (f) 3.4, (g) 4.2, (h) 5.5, (i) 8, and (j) 11.3 μsec after the onset of a 7.4 Oe/rad, 2 μsec gradient field pulse; third is the static shape after the end of the translational overshoot; fourth is the static shape after the bias field pulsing. Cross is 4 μm.

field pulse, the moving bubble at a specific time after the onset of the gradient field pulse, the static bubble after the overshoot and, finally, after the creep. The time of the transient exposure after the onset of the gradient field pulse is indicated in the figure caption. The bias was compensated to within ±.8 Oe during the gradient pulse. A 75 Oe bias field was applied that is 9 Oe above the strip-out and 15 Oe below DC collapse. The details of the overshoot and the creep have been discussed elsewhere(6); however, the overshoot and the creep exposures are included here as a reference while focusing attention on the transient bubble shape.

Transient shape distortion starts as a triangular deformation in the front of the bubble about 0.4 μsec after the onset of the gradient field pulse, as seen in Fig. 1a, and continues through the driven phase seen at 0.7 μsec, 1.3 μsec and 2 μsec in Fig. 1b, 1c and 1d, respectively. The deformation also occurs in the rear as it first becomes flat and then, as the driven translation proceeds, the rear wall curves forward. The wall sections at the ends of the two flanks can be seen moving outward and lagging behind the center of the bubble. This transverse expansion of the bubble starts at about .5 μsec at about the same time as the shape deformation becomes observable. By the end of the pulse, Fig. 1d, the tips of the two flanks have fallen well behind the middle portion of the bubble and the transverse expansion, as well as triangular distortion, are well established. During overshoot, the triangular deformation in the front disappears in less than .5 μsec (Fig. 1e) while the transverse expansion can be seen to continue until at least 6 μsec after the end of the pulse (Fig. 1i). During this phase of the motion, the shape of the bubble looks like a short stripe with the two ends bent slightly toward the rear. Finally, the recovery after the transverse expansion proceeds at a much slower rate than the expansion.

The quantitative results of the transverse displacements as well as the related translation are shown in Fig. 2. Curve (a) shows the longitudinal displacement in the down gradient direction of the bubble center as a function of time. Curve (b) shows the longitudinal displacement (in the down gradient direction) and curve (c) the transverse displacement (normal to the gradient direction) of the tips of the two flanks of the bubble as a function of time. The drive parameters are the same as for Fig. 1. The numbers used for the data points indicate the starting location of the translation with respect to the center of the parallel gradient conductors in units of μm. The bias field compensation pulse is adjusted so that number 5 represents the properly compensated bubble, lower numbers overcompensated and higher numbers undercompensated. It can be seen that the logitudinal motion of the center of the bubble (Fig. 2 curve a) is not sensitive to compensation during the driven translation with very little scatter evident, as was previously observed for shorter translations at this drive(6). A velocity of 5.3 m/sec is observed that is consistent with the saturation velocity measured by radial expansion for this sample. At the end of the gradient pulse, however, the motion seems to nearly stop even though the bubble center will ultimately move another 7 μm, since the average total displacement after overshoot is 16 μm. The increased scatter in overshoot, previously observed, is also clearly evident here. When the longitudinal displacement of the bubble flanks is observed (Fig. 2 curve b), it can be seen the flanks lag behind the center, moving at 2.6 m/sec compared to 5.3 m/sec and that their motion seems unaffected by the end of the gradient pulse. Transverse expansion can clearly be seen, starting at about .5 μsec after the onset of the gradient field pulse. The flanks expand linearly with respect to time with a velocity of 2.1 m/sec and continue after the 2 μsec gradient field pulse with no noticeable change in expansion rate before reaching the maximum expansion. The recovery rate is much slower with from 4.5 to 16 μsec required for bubbles to regain their static circular shape. As indicated by the numbers on the figure, the major factor in the scatter of this recovery is the degree of bias field compensation. Overcompensated bubbles have a smaller maximum transverse expansion and faster recovery rate.

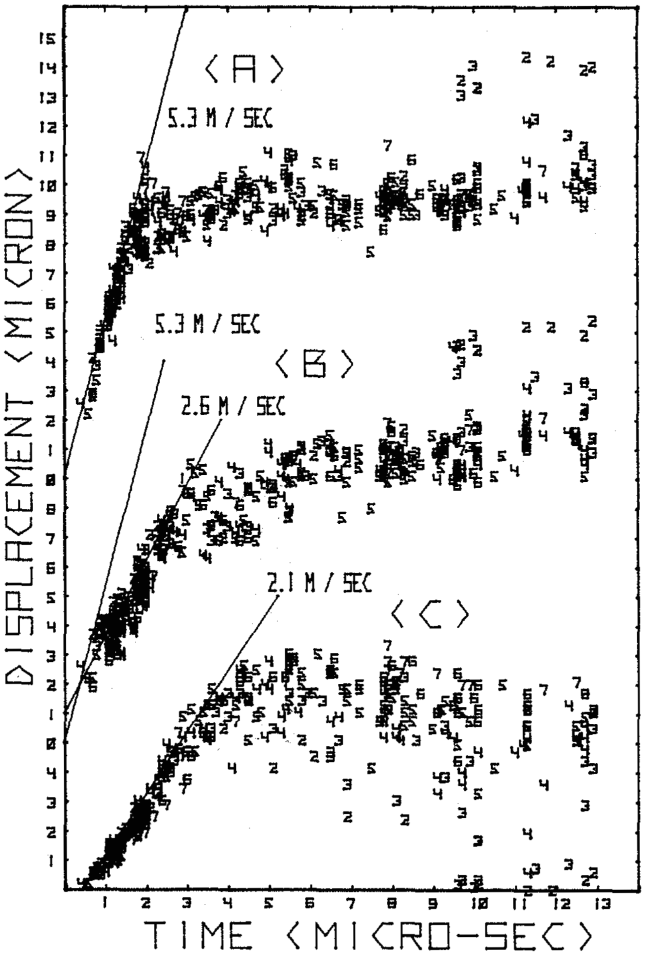

Fig. 2. Displacement of (a) average of front and rear bubble wall parallel to the gradient, (b) tip parallel to the gradient, (c) tip normal to the gradient as a function of time after the beginning of a 7.4 Oe/rad, 2 μsec gradient field pulse. Numbers in the curves indicate the degree of compensation with 5 being the properly compensated case; >5 overcompensated; <5 undercompensated.

The transverse motion and bubble distortion observed during translation and overshoot can be explained qualitatively by a model involving vertical wall twists, i.e., opposite winding vertical Bloch lines (VBL) pairs. It was previously shown(6) that vertical wall twists are the dominant factor in the explanation of overshoot and creep. For bubbles in driven translation, vertical wall twists are continuously generated at the front and rear wall and pushed to the flanks by the g-force forming a bundle of VBL's of one sense on one flank and of the opposite sense on the other. For long driven translations, these VBL's become overcrowded and seek to find more room by extending the perimeter of the bubble. This action is similar to the dependence of strip length on applied field(10). A rough estimate to the maximum number of VBL's involved in a bundle can be made from the maximum relative oscillatory precession on the aximuthal angle in the wall ($\gamma\Delta H_z$) with each twist giving a VBL pair. For the present experiment, VBL's would be generated at a rate of 26 VBL's/μsec at the front and rear wall or 52 VBL's/μsec added to the bundle on each flank. Using the VBL length calculated by Hubert(11) (L_o=0.5μm), a VBL bundle 13 μm long would be on one flank at the time distortion starts (0.5 μsec) compared to 15 μm half bubble perimeter and at the end of the pulse the bundle would be 52 μm compared to the measured 22 μm half perimeter. Such an estimate neglects many details but does show that it is possible and reasonable to have overcrowding of the VBL bundle as the flanks become a dominant source for the wall motions involved.

The verticle wall twist model accounts for the details of the transient motion seen in Fig. 1. For the bubbles in driven translation, the g-forces tend to compress the cluster of the VBL on the tips of the flanks The stress on these tips increases as more VBL's are generated. If the overall g-force on the tip is high enough, it will push the tip outward and cause the transverse expansion. The low mobility characteristics of the highly compressed VBL bundle will slow the translation velocity of the tips and cause them to lag behind the bubble center. When the gradient pulse is over, the front end, which has few VBL's, is pulled back quickly by wall tension. The tightly wound VBL's which were trailing behind on the two flanks relax to a less compressed, therefore, a lower energy, structure. This relaxation results in a forward motion of the VBL's toward the front as well as toward the middle part of the bubble. The forward motion of the VBL's will provide a gyroscopic effect field to continuously expand the two flanks outward. The motion of the VBL's toward the middle of the rear wall would cause an effective gyroscopic field to move the rear wall forward. Since the transverse expansion of the tip was caused by part of the VBL's moving toward the front, the center of the tight winding section, will lag benind the tip and ride on the rear wall. The further traveling of the VBL's to the front of the bubble requires a propagation of the VBL's along the outer edge of the tips which again provides a gyroscopic effect field to expand the tips. As can be seen on Fig. 1(g), (h) and (i) the size of the two tips are bigger than those in Fig. 1(f) and (j) which are before and after this mode of motion. Finally the annihilation of the opposite sense VBL's in the middle front and back wall will relieve the overcrowding and allow the stripe to contract back while still providing a motivating source for the translational overshoot as discussed previously(6).

The transverse expansion during the overshoot provides direct evidence that only vertical structures are important in bubble overshoot. The total bubble wall length continues to increase during overshoot so that horizontal structures that might be in the wall would be increasing in length, an impossibility if these same structures are the ones providing the energy necessary to continue the translational motion. It can be clearly concluded that horizontal structures must play a minor role in the overshoot process.

Double exposure photographs of the bubble at the beginning and the end of gradient field pulse with various degrees of bias field compensation is shown in Fig. 3. A 2 μsec linear rise bias field pulse with the beginning and the end magnitude of 13 and 49 Oe was used. Due to the differences in the initial starting location, bubbles Fig. 3(a)-(d) experienced a bias field change of -1 Oe, 0 Oe, 6 Oe and 7.6 Oe, respectively. Again the transverse expansion can be clearly seen. It can be seen that bias field compensation has a significant effect on the transient bubble shape. The shape differences indicate that the distribution of VBL's are very sensitive to the bias field compensation and hence, should be the dominant cause for the observed scatter overshoot as well as scatter in the overshoot angle.

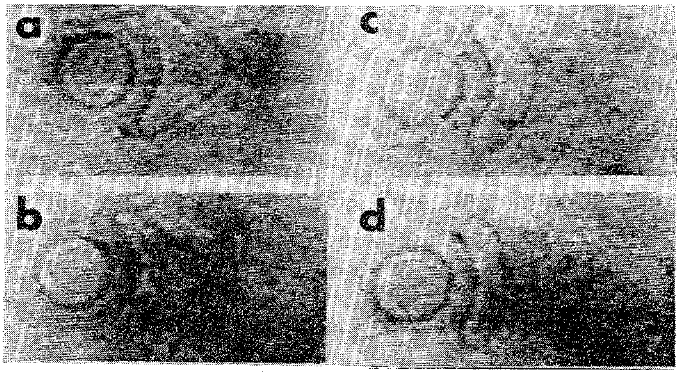

Fig. 3. Double exposure photographs of the magnetic bubble; left is the static shape before the translation and right is the transient shape at the end of a 16 Oe/rad, 2 μsec gradient field pulse. Bias change at the beginning of the pulse is (a) -1 Oe, (b) 0 Oe, (c) 6 Oe and (d) 7.6 Oe. Bubble is 9.2 μm diameter.

CONCLUSION

Bubble distortion and transverse expansion was observed in an as-grown sample during and after a driven gradient translation. The observed motion can be explained on the basis of overcrowded vertical wall twists but not Bloch-curves or Bloch-rings. Bubble distortion was shown to be very sensitive to bias field compensation and could account for the large scatter normally observed in gradient propagation experiments.

FOOTNOTES AND REFERENCES

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