LIFE MAGNETIC DOMAINS APPARATUS, LF.141

In 1908 Weiss proposed his domain theory to explain the magnetic properties of materials which theory was only confirmed by observation much later.

Today domains are not only understood but are being used for "memory" devices, using man-made garnet films which, in turn, make it possible for the behaviour under magnetisation to be observed and the properties of magnets in every day use to be explained. It is for these kind of experiments that the LIFE apparatus has been developed.

Principle

In the search for magnetic materials which could be used for the now commercially available bubble memories, Bobeck discovered in 1970 that ferrimagnetic garnets would meet the requirements and could be "engineered" to produce the very small, isolated cylindrical domains (called bubbles because of the end-on shape when viewed) which were stable yet capable of being formed, moved and destroyed when needed, at very high rates.

Ferrimagnetic garnets (FMG) grown in thin, single crystal (expitaxial) films are strongly anisotropic perpendicular to the film, but not along it. Because the films are thin (8-12μm) the easy-direction of the magnetic domains are also perpendicular to the film and point either into or out of it.

To achieve the correct orientation of the FMG, it has to be grown on the face of another single crystal of similar lattice size and gadolinium gallium garnet has been found the easiest to grow and use. Yttrium iron garnet was the original material studied, having the formula $Y_3Fe_5O_{12}$, but it was found possible to substitute the Y- and some of the Fe- ions by those of other elements having the correct atomic size to occupy specific ion sites in the crystal. In this way both the magnetic and optical properties could be controlled.

The material in this apparatus has the formula $Bi_{0.6}\ Tm_{2.4}\ Ga_{1.15}\ Fe_{3.85}\ O_{12}$ and is about 8μm thick and transparent.

Materials are magnetic because of the anisotropy and this in turn means there is interaction between the electrons when any electromagnetic radiation passes through. The resulting effect is to rotate, one way or the other, the plane of vibration of the radiation – the so called Faraday effect. Thus the plane of polarised light entering such a medium will be rotated during its passage to an extent due to the path length and the amount of interaction – the optical activity. The addition of Bi to the FMG considerably enhances this rotation, the direction depending on the magnetic direction of the domains.

The film of FMG is transparent and yellow in unpolarised light, but when viewed through crossed Polaroids, the pattern of the domains becomes visible as adjacent areas of light and dark. The pattern is typical of the material and in the unmagnetised remnant state, the FMG exhibits the striped (serpentine) forms of Figure 1. Figure 5 shows the structure of the domains, the width depending largely on the thickness of the film which, in turn, will determine the diameter of the bubbles. To view these and the domain patterns a microscope is required.

Ancillary Apparatus Required

(a) Student microscope x40 to x200 magnification; x100 is the optimum.
(b) Microscope lamp; or table-lamp up to 100W.
(c) Power unit 6V dc 1A with low ripple; or car battery and potentiometer (see Energising the Coil)
(d) Ammeter 1A fsd.
(e) Light Dependent Resistor (ORP.12).
(f) Modelling clay (Plasticine).
(g) Wheatstone bridge and galvanometer and battery,
OR
10k ohm 1W potentiometer, microammeter and dry cell (4.5V or 9V);
(h) Graph paper.

Fig. 1: Remnant state with equal areas of each domain. Magnetising field 0.00 H_{sat}

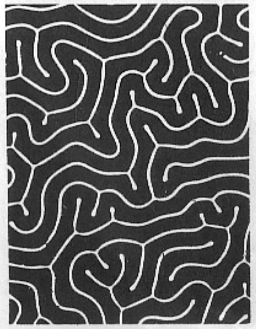

Fig. 2: Field 0.77 H_{sat}

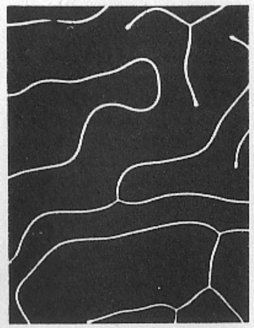

Fig. 3: Field 0.95 H_{sat}

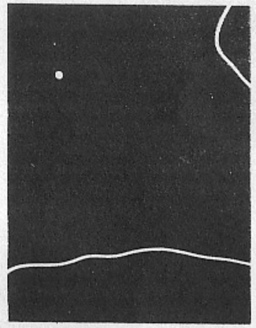

Fig. 4: Field 0.99H_{sat}

Note the 'bubble'.

The Microscope

Almost any student microscope providing at least x40 magnification (x100 is best) will serve to view the domain patterns. The "working distance" between the lower end of the objective and the top surface of the stage should be no less than 9mm.

It may be necessary to use a brighter light-source than that used for viewing biological specimens, especially when plotting hysteresis loops.

To make the domain pattern visible, it is necessary to work with plane polarised light and pieces of Polaroid are provided for this. One piece in the base of the apparatus acts as the "polariser"; a second Polaroid must be placed on the top of the bobbin to act as a rotatable "analyser". If a polarising microscope is available, then the Polaroid will not be necessary.

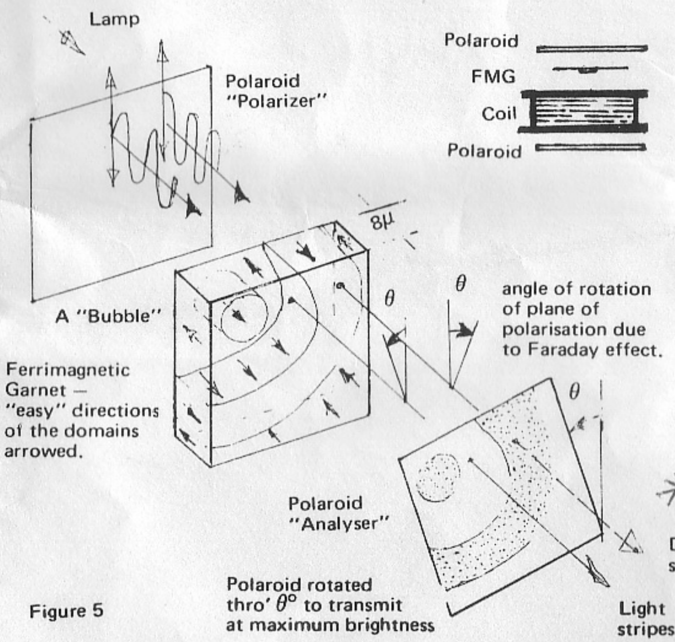

Figure 5

Viewing the Domains

Having positioned the Polaroid on the microscope or on the bobbin, the slide should be clipped to the stage, the illumination adjusted and the slide centred so that part of the edge of the FMG is in focus in the field of view. If a multiple objective instrument is used, first work at about x40 magnification to take advantage of the depth of focus.

Rotate the Polaroid on the bobbin until the background adjacent to the edge of the FMG is dark blue. Then, by a small rotation in either direction, position the Polaroid until a pattern is seen of yellow and brown stripes. If the depth of focus is small (eg. at x100) the uncoated surface may be in the focal plane, so the pattern will not be visible and refocussing will be necessary. Having the edge of the FMG in the field of view will be found helpful in locating the pattern initially.

However, because the FMG can remain fully magnetised (saturated) as a result of some previous experiment, the whole area of the FMG can be a *single* domain and show no obvious pattern. To verify this condition, cross the Polaroids to give a dark blue background, then rotate first in one direction and then the other, about the crossed position. The colour seen through the whole of the FMG will either turn from yellow through dark green (crossed position) to brown, or *vice versa.*

To return the FMG to the unmagnetised state, a reversing field is required, and a small strong permanent magnet is useful for this. Bring the end of the magnet carefully up to and as close as possible to the FMG; if the field is in the correct direction the overall domain will suddenly reverse at a certain field strength; at this point the magnet should be withdrawn carefully, and a striped pattern should then appear. If the pattern does not appear, then the FMG has become re-magnetised in the reverse direction and the process must be repeated with the opposite polarity (the other end of the magnet).

Similarly, if bringing up the magnet in the first place does not change the direction (colour) of the over-all domain, use the other pole and proceed as above.

With a few minutes practice the striped pattern (Figure 1) should be obtained without difficulty, and then its behaviour under the influence of the magnet's field (which is mainly in the plane of the FMG) can be studied.

IMPORTANT-- In this version of the MAGNETIC DOMAINS APPARATUS the Polaroid Polarizer and the Analyzer have been sealed in after being correctly oriented. A Polarizing Microscope should not be used. If no pattern is visible, the ferromagnetic garnet will have been left in a saturated state from an earlier experiment. To return it to the unmagnetised state see 'Viewing the Domains' Para. 4, ET SEQ.