Ferrimagnetic Resonance in Gadolinium Iron Garnet

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Ferrimagnetic resonance has been observed in gadolinium iron garnet from −192° to 72°C. The apparent g factor and line width have their maximum values at the compensation point (13°C). The coincidence of the maximum g with the vanishing of the magnetization implies that the g factors of the Gd^{+3} and Fe^{+3} are equal. The temperature dependence of the integrated intensity of the absorption is very similar to that of the magnetization. Below −150°C, both g and the line width increase with decreasing temperature.

We have observed ferrimagnetic resonance in polycrystalline gadolinium iron garnet and found that the apparent g value goes through a maximum at the temperature at which the magnetization vanishes. Gadolinium iron garnet $Gd_3Fe_2(FeO_4)_3$ is one of a group of ferrimagnetic oxides first reported by Bertaut and Forrat.[1] Pauthenet[2] discovered the compensation points, i.e., vanishing of the magnetization at a temperature below the Curie point, in rare earth iron garnets when the rare earth was any of the elements from gadolinium through thulium. Figure 1 shows a magnetization-temperature curve of gadolinium iron garnet with the compensation point at 13°C.

The sample, a sphere of 0.033 in. diameter, was mounted on an axial copper post in a cylindrical transmission cavity, operated in the TE_{011} mode. A small amount of diphenyl-picryl hydrazil[3] was also mounted on the post and its resonance ($g=2.0036$) was used to obtain an accurate field calibration. Thermal conduction through the copper post was used to maintain the temperature of the sample at various values between −192° and 72°C. The klystron was stabilized on the cavity frequency of 9479 Mc/sec by an automatic frequency-control loop. Line shapes were recorded using a Hewlett-Packard reflectometer essentially in the manner of White and Solt.[4] A precision attenuator was used to obtain line widths in regions of high sample absorption.

The apparent g factors, calculated from the equation $\hbar\omega=g\beta H$, and the full line widths at half-maximum absorption are plotted in Fig. 2. The integrated intensity of the absorption (peak height times line width) is shown in Fig. 1. Its temperature dependence is quite similar to that of the magnetization. Although the absorption was too weak to detect in the immediate vicinity of the compensation point, the maxima in g and the line width appear to coincide with the vanishing of the magnetization. Both the line width and g begin to increase below −140°C. This is approximately the temperature at which Dillon[5] observed a rapid increase in the anisotropy of a single crystal of yttrium iron garnet and may indicate the influence of anisotropy on the apparent g factor of polycrystalline samples.

Wangsness[6] has shown that the maximum g should occur at the temperature at which the angular mo-

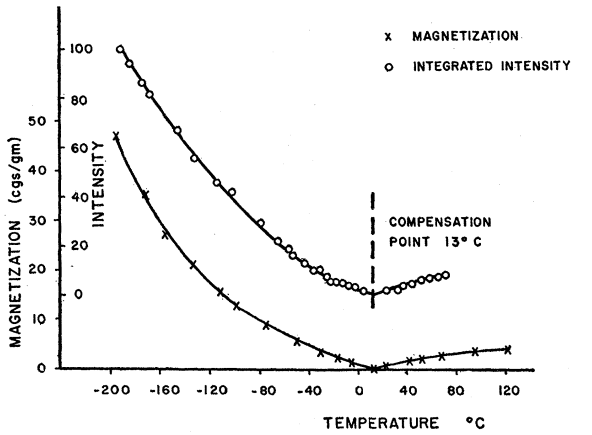

FIG. 1. Temperature dependence of the magnetization and of the integrated intensity of the resonance absorption of gadolinium iron garnet. The product, peak height times line width, has been used as an approximation to the integrated intensity.

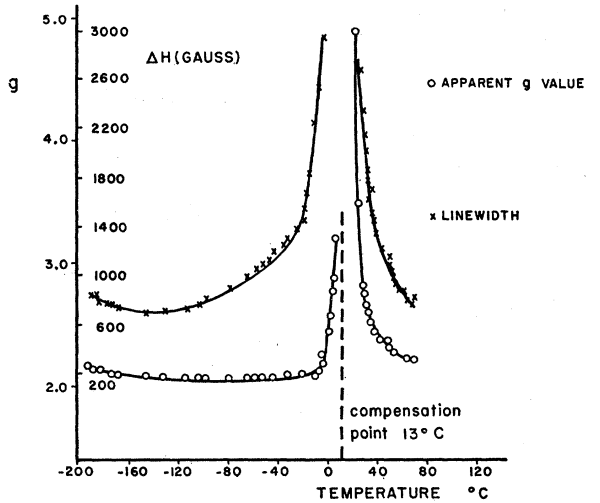

FIG. 2. Apparent g values and line widths at 9479 Mc/sec of a 33-mil polycrystalline sphere of gadolinium iron garnet.

[1] F. Bertaut and F. Forrat, Compt. rend. **242**, 382 (1956).
[2] R. Pauthenet, Compt. rend. **243**, 1499 (1956).
[3] We wish to thank Dr. Howard S. Jarrett of E. I. du Pont de Nemours Company for a gift of the dpph sample.
[4] R. L. White and I. H. Solt, Jr., Phys. Rev. **104**, 56 (1956).
[5] J. F. Dillon, Jr., Phys. Rev. **105**, 759 (1957).
[6] R. K. Wangsness, Am. J. Phys. **24**, 60 (1956).

mentum goes to zero. The observed coincidence of the maximum g with the vanishing of the magnetization implies that the g factors of the Gd^{+3} and Fe^{+3} ions are equal. This equality of the g factors is not surprising since the ground states of both ions are S states. This behavior is in marked contrast to that observed in ferrites[6,7] where the angular momentum and the magnetization vanish at different temperatures. The simultaneous compensation of the magnetization and angular momentum in gadolinium iron garnet is probably unique among presently known ferrimagnetic materials.

The preliminary results reported here were obtained in a magnet with a maximum available field of approximately 3700 gauss. Further work at higher magnetic fields, higher frequencies, and with single crystals as well as polycrystalline material is in progress. The single-crystal measurements are particularly desirable for quantitative tests of theoretical predictions of the resonance behavior near the compensation point.

Note added in proof.—J. F. Dillon, Jr., has kindly called our attention to similar measurements recently reported by Paulevé.[8] His results below the compensation point are quite different from those reported here.

[7] T. R. McGuire, Phys. Rev. **97**, 831 (1955).

[8] J. Paulevé, Compt. rend. **244**, 1908 (1957).

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Ion Desorption from Metal Surfaces*

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It is observed that relatively large positive ion currents can be thermally desorbed from W, Ta, and Mo surfaces even several days after bombardment of the gas-covered surface with low-energy positive nitrogen ions or electrons. No measurable ion current is desorbed if the surface has not previously been bombarded. The dependence of the desorption current on bombarding current and time, on nitrogen pressure, and on the desorption time and temperature is presented. It is postulated that ions or possibly excited neutral particles are captured in traps of several different depths on the metal surface and that as the surface temperature is increased the traps of least depth are emptied first.

We have observed that relatively large numbers of positive ions can be desorbed from tungsten[1] filament surfaces in nitrogen at about 10^{-6} mm Hg even several days after bombardment of the surfaces with low-energy nitrogen positive ions or low-energy electrons. Desorptions of ions[2] is accomplished simply by heating the filament surface to a moderate temperature. On tungsten, desorption of ions begins at approximately 850°C. After the filament has been cleaned by heating to about 2000°C,[3] no further ion current can be desorbed by subsequent heating until the tungsten surface is again bombarded. For tungsten bombarded with positive ions, the total number of positive ions which can be desorbed at some later time increases roughly proportionally with increasing bombardment time, with increasing nitrogen pressure, and with increasing ionizing current of electrons, other factors being equal.

If the temperature of the tungsten filament is increased slowly after bombardment has ceased, several peaks in the ion current desorbing from the surface are observed. This effect is shown in Fig. 1 for several values of ion bombarding energy. Similar curves were obtained for the ion current desorbed from a tungsten surface previously bombarded with low-energy electrons. The various peaks occurred at the same filament temperatures as those in Fig. 1 but with reduced intensity. Four prominent peaks are evident in the ion current curves of Fig. 1 and we have obtained other evidence which suggests there is additional structure in the curves. These ion current desorption curves were very reproducible. Successive runs made under identical conditions yielded practically identical curves.

If after bombardment the tungsten filament temperature is rapidly raised to a moderate temperature, the ion current desorbed from the surface decreases exponentially with the time the filament is held at constant temperature. If the temperature is raised high enough, several exponential decay rates are observed, the lower rates persisting after the higher rates have died out.

The effects described above are consistent with the hypothesis that neutral or charged particles are formed or are adsorbed on the surface during bombardment of the gas-covered surface by ions or electrons. To account for the several observed peaks in the ion desorption

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[1] Recently we have found that similar but not identical effects occur on tantalum and molybdenum.

[2] Secondary electron ejection at the ion collector by desorbed excited neutral particles was eliminated as a possibility by interposing a grid between the tungsten filament and the ion collector and noting the large decrease in ion collector current when the grid was charged positively.

[3] This temperature is believed to be high enough to remove any surface contamination except perhaps oxygen. Measurements were made in a mercury pumped bakeable ultra-high vacuum system where contamination could be held to a minimum.