LOW-TEMPERATURE LINE-WIDTH MAXIMUM IN YTTRIUM IRON GARNET

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Measurements of the ferromagnetic resonance line-width maximum in single-crystal yttrium iron garnet (YIG) were previously reported by Dillon.[1] His data show that the line width increases with decreasing temperature, reaches a maximum below liquid nitrogen temperature, and decreases again to approximately the room-temperature value at liquid helium temperatures. We have been investigating the nature of this line-width maximum at low temperatures to determine if the effect is intrinsic to ferromagnetic resonance and to determine its origin. The line widths reported in this paper are determined from the absolute absorption of the sample and the saturation magnetization vs T curve measured on single-crystal YIG. The large effects on the line width ΔH at room temperature due to inhomogeneous broadening by scattering from pits on the surface of a YIG sphere were evaluated previously.[2] Consequently, we measured ΔH vs T for a series of three spheres prepared using polishing papers having mean grit sizes of 15, 5, and 0.3 microns, respectively. These measurements were made at 9300 Mc/sec. Figure 1 shows that the ratios of maximum line widths to room temperature line widths are 2.5, 4, and 13, respectively, the larger ratios occurring for the better polished spheres. It is also clearly shown that the contribution to the line width due to surface preparation is essentially additive over the temperature range. We conclude therefore that the low-temperature line-width maximum is an intrinsic property of the material and not of the surface. Further, if perfect polishing were attained the line-width maximum would still be approximately 6 oersteds in this sample.

Earlier investigations on the same samples[3] have shown a small but repeatable frequency dependence of line width at room temperature. The line width ΔH (full width between half maximum values) is 0.44 oersted at 3000 Mc/sec and 0.52 oersted at 9300 Mc/sec along the [111] axis. Taking these measurements over the temperature range, there are three essential features. See Fig. 2. The line width maximum at 3000 Mc/sec is reduced by 40% in magnitude and is shifted from 40°K to 30°K. Also it is seen that the room-temperature frequency dependence of

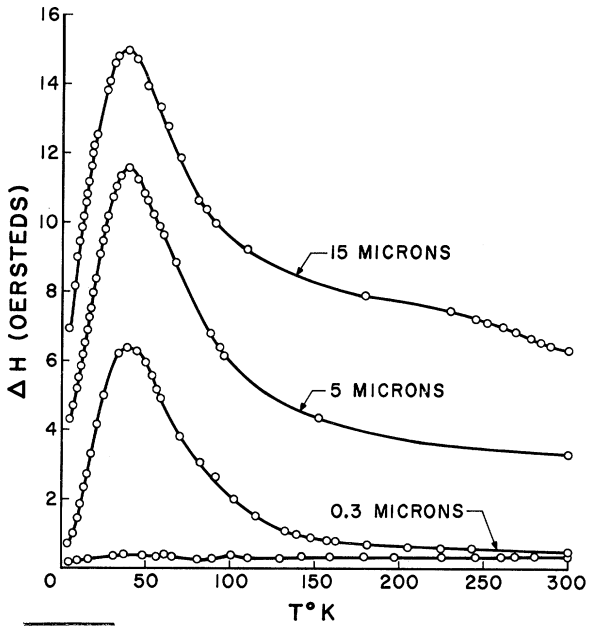

FIG. 1. ΔH vs T for single-crystal spheres of YIG 0.014 to 0.017 inch in diameter. H_{dc} oriented along the [111] axis. The labels on the curves indicate the mean grit size of the final polishing paper used to prepare the spheres. The lowest curve is Fig. 3 repeated here for comparison.

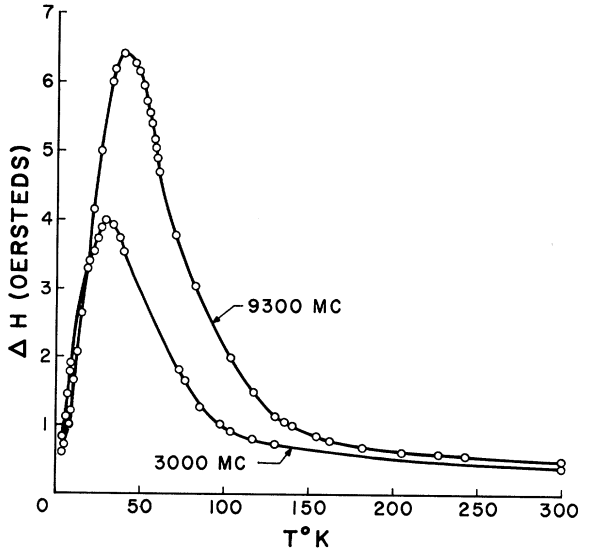

FIG. 2. ΔH vs T measured at 9300 and 3000 Mc/sec. H_{dc} oriented along the [111] axis.

line width is related to the mechanism of the low-temperature line-width maximum.

In considering the constituents that are used in growing[4] YIG, we recognized that the bulk yttrium oxide contains significant rare earth impurities. Further, the measured[5] spin-lattice relaxation times of the rare earth ions indicated that these ions could contribute strongly to the observed temperature variation of line widths in YIG. A detailed theory of this effect has been prepared by Kittel.[6]

The problem of purifying the yttrium oxide with respect to the rare earths was taken to Dr. Mark M. Woyski, of the Lindsay Chemical Division of the American Potash and Chemical Company. By using multiple exchange columns and by special processing against a small yield, he achieved at least a thousandfold reduction in the total rare earth content. The estimated total rare earth impurities are less than 0.1 part per million.

The results for YIG grown from the special purity yttrium oxide are given in Fig. 3 and for comparison superimposed on Fig. 1. It is seen that the rare earth contribution[7] to the ΔH maximum has been reduced from approximately 6 oersteds to slightly over 0.1 oersted, a ratio of about 50:1. It is tempting to identify the fine structure with individual rare earth ions, especially if we associate the peak at 100°K with Dillon and Nielsen's terbium line. Additional measurements will be needed to eliminate the possibility of other mechanisms, such as weakly interacting magnetostatic modes. An over-all feature of the data is the general decrease in line width from room temperature to liquid helium temperatures. This is the first time, to our knowledge, that this trend has been observed in ferromagnetic resonance. It is probable that the line width in this sample is limited by inhomogeneous broadening brought about by crystal imperfections, surface effects, and the rare earth ions near 4.2°K; and by thermal[3,8] processes at higher temperatures.

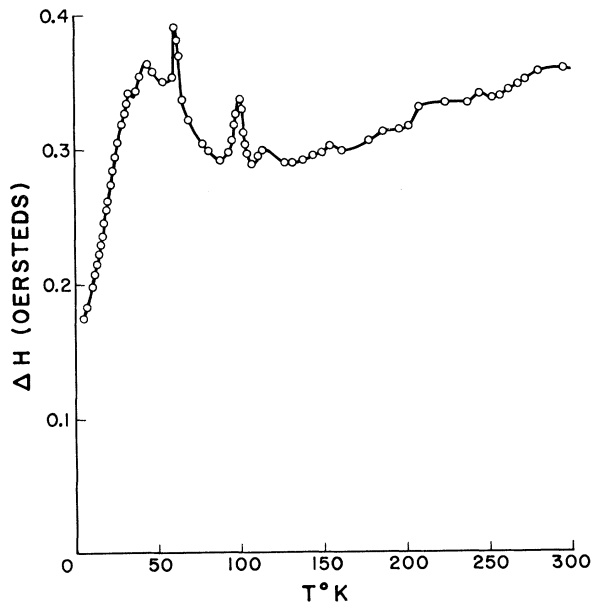

FIG. 3. ΔH vs T on a 0.020-inch diameter YIG sphere grown from yttrium oxide containing total rare earth impurities estimated to be less than 0.1 ppm. H_{dc} oriented along the [111] axis.

From the practical point of view it is interesting to note that $\mu''(\text{res}) = 14\,000$ at 4.2°K. From the theoretical point of view it can be expected that measurements on single-crystal YIG grown from such purity will yield more precise evaluation of the fundamental mechanism involved in spin-wave scattering and spin-lattice relaxation phenomena.

We should like to thank J. W. Nielsen for his advice through many discussions on the chemistry of garnets, and for his growing the garnets on which these data are based; J. F. Dillon for many helpful discussions; and H. E. D. Scovil for discussions on his measurements of rare earth relaxation.

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[2]LeCraw, Spencer, and Porter, Phys. Rev. 110, 1311 (1958).

[3]R. C. LeCraw and E. G. Spencer, J. Appl. Phys. 30, 185-S (1959).

[4]J. W. Nielsen, J. Appl. Phys. 29, 390 (1958); J. W. Nielsen and E. F. Dearborn, J. Phys. Chem. Solids 5, 202 (1958).

[5]B. Bleaney and H. E. D. Scovil, Proc. Phys. Soc. (London) A64, 204 (1951).

[6]C. Kittel, post-deadline paper 1959 Boston meeting of the American Physical Society; Phys. Rev. (to be published).

[7]J. F. Dillon and J. W. Nielsen in the preceding Letter [Phys. Rev. Letters 3, 30 (1959)] report on measurements in which deliberate amounts of specific rare earth ions have been added; this procedure allows them to measure effects due to particular ions.

[8]T. Kasuya, Progr. Theoret. Phys. (Kyoto) 12, 802 (1954).