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Magnetostriction in Yb-Doped YIG*

A. B. SMITH† AND R. V. JONES
Division of Engineering and Applied Physics, Harvard University, Cambridge, Massachusetts
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The magnetostriction constants of Yb-doped YIG have been determined from the stress dependence of ferromagnetic resonance[1,2] over the temperature range from 8° to 300°K. The samples measured had a nominal doping of 10% Yb. As is the case for strain-gage measurements[3] of λ_{111} in $Yb_{0.1}Y_{0.9}IG$, our resonance results indicate that λ_{111} has substantially the same value as has been measured in YIG.[4] On the other hand, both resonance and strain-gage results show that λ_{100} differs considerably from its YIG value. Our resonance results for λ_{100} in $Yb_{0.1}Y_{0.9}IG$ are shown in Fig. 1 together with strain-gage results obtained on different samples of the same nominal composition.[3] Also shown in this figure are the experimental results for YIG[4] and the temperature variation predicted for $Yb_{0.1}Y_{0.9}IG$ by a simple theory to be described below.

Many features of the observed temperature dependence of the magnetostriction in Yb-doped YIG can be qualitatively explained by considering just the low-lying doublet of the Yb^{3+} ions on the garnet c sites. The Boltzmann distribution over the doublet requires that any strain-induced change in doublet spacing will change F, the free energy per unit volume of the system, by an amount

$$\delta F=(n/6)\sum_i[\tfrac{1}{2}\tanh(\Delta_i/2kT)]\delta\Delta_i, \qquad (1)$$

where n is the number of Yb^{3+} ions per cc, Δ_i is the Yb^{3+} doublet splitting, and the summation is over the 6 differently oriented c sites in the garnet structure.[5] However, we know from the basic definition[6] of the magnetostriction constants that the free-energy change due to a strain e_{xx} is given by

$$\delta F=\tfrac{3}{2}(C_{12}-C_{11})\lambda_{100}e_{xx}. \qquad (2)$$

Therefore, if the strain-induced shifts $\delta\Delta$ are assumed temperature independent and if the differences between the rare-earth sites are neglected, a comparison of Eqs. (1) and (2) leads to the conclusion that λ_{100} must have a simple tanh temperature dependence. To show how closely the data fit such a tanh dependence, we have plotted the expression

$$C\tanh(40.6°K/2T)+(\lambda_{100})_{YIG} \qquad (3)$$

in Fig. 1 for comparison with the experimental results for $Yb_{0.1}Y_{0.9}IG$. We have neglected the differences in energy splittings between sites and have taken $\Delta_i=40.6°K$. This value is the correct one for 4 of the 6 types of sites when H is along a [100] direction.[7] The value of C required to achieve the fit shown in Fig. 1 is 6.1×10^{-6}. This result can be compared with the 3.6×10^{-6} value of λ_{100} measured by Flanders *et al.*[3] at 1.6°K and with the 8.1×10^{-6} value for the 0°K λ_{100} which has been predicted on the basis of uniaxial strain measurements[8] of the EPR of Yb^{3+} in diamagnetic hosts.

It is instructive to calculate what value of $\partial\Delta/\partial e_{xx}$ is implied by these results for C. Assuming the Yb's on all sites to be similarly aligned, Eqs. (1) and (2) applied to our data would yield $\partial\Delta/\partial e_{xx}=110$ cm^{-1}. This value can be compared with Orbach's theory[9] of the orbit-lattice relaxation time for Yb^{3+} garnets. A value of $\partial\Delta/\partial e_{xx}$ 30 times larger than the above figure would be required for his theory to yield the observed relaxation time. Since it is unlikely that the neglected effect of cancellations between the contributions of the differently oriented Yb sites could account for this large difference, our data seem to enforce Clarke *et al.*'s[10] conclusion that the orbit–lattice interaction is unimportant in this material compared to other processes. Another possibility is that Orbach's analysis should be modified to include explicitly the effect of the strain dependence of the exchange field.[11] The exchange-field strain dependence could account for direct transitions between the doublet states whereas Orbach's analysis considers only the strain dependence of the crystal field which, by Kramer's rule, cannot excite direct transitions.

The departure of the $Yb_{0.1}Y_{0.9}IG$ λ_{100} data from a tanh temperature dependence below 15°K is reminiscent of other low-temperature anomalies[12] in Yb-doped YIG and indicates that there are other important energy levels of the system beside the doublet we have considered. These other levels could be contributed by a small percentage of the Yb^{3+} ions residing on a sites rather than on c sites. Below 10°K we are apparently starting to see the "tail" of the tanh behavior contributed by a narrow splitting associated with these a site ions. The temperature behavior observed is thus consistent with the 4.5°K energy splitting of these a site ions determined by Penney.[13] As the data in Fig. 1 seems to indicate, these energy levels have a greater effect on the resonance measurement of magnetostriction than on strain-gage measurements.

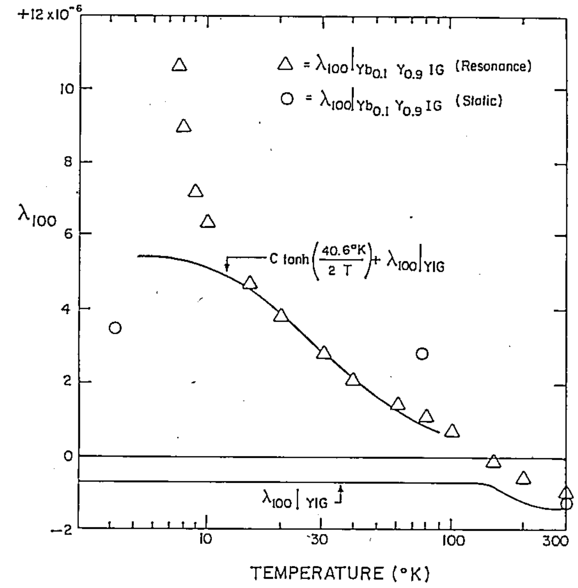

FIG. 1. The temperature dependence of the magnetostriction constant λ_{100} in $Yb_{0.9}Y_{0.9}IG$ as measured by both resonance and static methods. Also shown are λ_{100} for YIG and the results of a simple two-level theory (see text) for Yb-doped YIG.

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† Present address: Sperry Rand Research Center, Sudbury, Massachusetts.
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