phys. stat. sol. 18, K53 (1966)

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Influence of Tetrahedral Ni^{2+} Ions on the Magnetic Properties of YIG

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In a previous paper (1) we have shown by studying the anisotropic energies and the lattice constants of NiO doped yttrium iron garnet single crystals (GeO_2 being used for charge compensation), that Ni^{2+} ions enter the tetrahedral (24d) sites although in a very small quantity. It is known that Ni^{2+} ions (d^8) cause Jahn-Teller distortions of the oxygen tetrahedra, as for example in nickel ferrite chromites (2). However, when its concentration is very low as in our case, one could expect the distortions to occur only locally, though the structure as a whole could still conserve the cubic symmetry. This type of distortion is known as dynamic Jahn-Teller distortion.

The deformations being oriented at random, one can not expect them to modify the cubic nature of the overall anisotropy as measured by the usual methods, though such deformations do seem to influence the line width (3). In order to verify the above hypotheses in our materials, we have studied in this note: 1. the angular dependence of the field for resonance H_o, in order to see if it could be described adequately by the two constants K_1 and K_2 of cubic anisotropy and 2. the line width and its temperature dependence.

Two compositions of doped YIG containing 0.25 and 1.3 weight% NiO were investigated. Spheres used for the measurements were of about 0.4 mm diameter polished to 5 μm. They were oriented by the usual X-ray techniques such that H_{DC} could be applied in the (110) plane and they could be rotated about the [110] axis. The measuring frequency was about 9100 MHz and the temperature range of investigations

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Table 1

	NiO 0.25%		NiO 1.3%	
	20 °C	-190 °C	20 °C	-190 °C
$\frac{K_1}{M}$	-19	+190	-12	+375
$\frac{K_2}{M}$	-	-460	-	-690

was from -190 to +60 °C.

Angular Dependence of H_o By applying Kittel's equation for resonance to crystals of cubic symmetry one can write:

$$\left(\frac{\omega}{\gamma_{eff}}\right)^2 = \left[H_o + \frac{K_1}{M}\left(2 - \sin^2\theta - 3\sin^2 2\theta\right) + \frac{K_2}{2M}\sin^2\theta\left(6\cos^4\theta - 11\sin^2\theta\cos^2\theta + \sin^4\theta\right)\right] \times$$

$$\times \left[H_o + \frac{K_1}{M}\left(2 - 4\sin^2\theta - \frac{3}{4}\sin^2 2\theta\right) - \frac{K_2}{2M}\sin^2\theta\cos^2\theta\left(3\sin^2\theta + 2\right)\right],$$

where ω is the measuring frequency, γ_{eff} the effective gyromagnetic ratio (given by ge/2mc, where g is the spectroscopic splitting factor), H_o the field for resonance, K_1, K_2 the two constants of anisotropy, M the saturation magnetization and θ the angle between H_o and [001] axis in the (110) plane.

From experimentally determined values of H_o along [001], [110], and [111] directions at -190 and +20 °C, K_1/M and K_2/M were calculated for the above temperatures (Table 1) and these values in turn were used to compute the angular dependence of H_o both at -190 and +20 °C. These curves were compared with those obtained experimentally. Fig. 1 shows the results obtained at -190 °C for both compositions (the results at 20 °C are not shown since K_1, K_2 being quite low the angular dependence of H_o is less remarkable), and the agreement seems to be satisfactory. This indicates that the two cubic constants K_1 and K_2 are quite adequate to describe the anisotropic energy. So the dynamic Jahn-Teller distortions do not seem to perturb the cubic symmetry of the anisotropy as we could expect it.

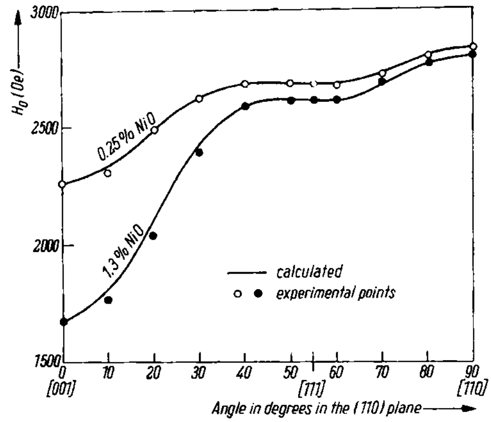

Fig. 1

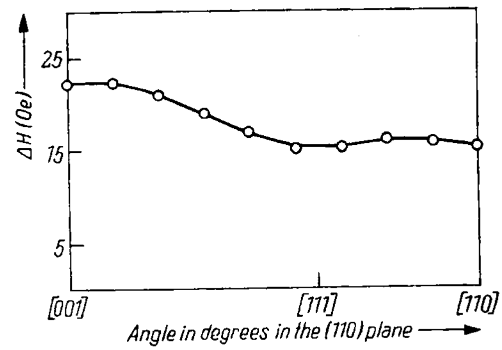

Fig. 2

Line Width ΔH The angular dependence of ΔH studied in these materials shows an anisotropic behaviour with a maximum along the [001] direction. Fig. 2 shows the result for YIG + 0.25% NiO. The line width also increases with the NiO content.

As the temperature is decreased, ΔH increases, this being most pronounced along the [100] direction as shown in Fig. 3. The variation of ΔH along the [110] direction, being similar to that along [111], is omitted in the figure for clarity.

This increase in line width can not be attributed to non-saturation effects, since H_0 is still higher than the demagnetizing field $4\pi M/3$ and further the [100] direction actually becomes the easy axis at lower temperatures (1). It is interesting to remark that a similar behaviour of ΔH was observed in the case of YIG containing Mn^{3+} ions, which was supposed to be caused by the dynamic Jahn-Teller distortions of the oxygen octahedra occupied by Mn^{3+} ions (3). The rf field is considered to be coupled to the distortion, by either bulk magneto-strictive effects or the local anisotropy of the Jahn-Teller site. In our case, this increase may

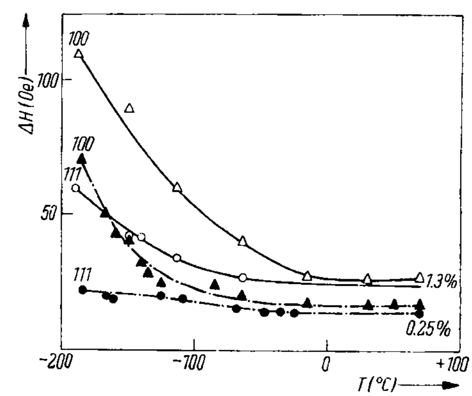

Fig. 3

be attributed in the same way to the dynamic distortions of the oxygen tetrahedra occupied by Ni^{2+} ions. It is seen that the increase in ΔH say at -190 °C over its value at 20 °C, in the case of Ni^{2+} ions is smaller than it is for Mn^{3+}. This may be due to the actual concentration of tetrahedral Ni^{2+} ions which is extremely low.

Jahn-Teller distortions of the dynamic type seem to be caused by the tetrahedral Ni^{2+} ions in YIG, as shown by the low temperature increase of the line width. The angular dependence of ΔH is also found to be anisotropic. Such distortions however do not seem to perturb the global cubic anisotropic energy.

The very valuable discussions with Dr. R. Vautier is greatly appreciated and acknowledged.

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(Received October 11, 1966)