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FERROMAGNETIC RESONANCE STUDIES IN HIGH HYDROSTATIC PRESSURE

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The apparatus for studying ferromagnetic resonance under high hydrostatic pressure is described as well as the results of FMR measurements on YIG with pressure up to 6.5 kbars. The anisotropy constants and their changes with pressure are calculated.

Much information about the intercrystalline interactions can be obtained by studying the behaviour of a crystal under high hydrostatic pressure. When the hydrostatic pressure is applied to the cubic crystal, the unit cell remains cubic and the lattice constant will be reduced in proportion to the compressibility. There are two dominant factors determining the magnetic properties of magnetic crystals: the exchange interactions and crystalline field interactions. They are connected with the interionic spacings in the crystal. Variations in these spacings, as a result of compression, will cause changes in the exchange fields, which would be exposed by variations in magnetization and a change in the local crystalline fields, which would cause variations in magnetic anisotropy. One of the experimental methods to define the magnetocrystalline anisotropy and magnetization of magnetic crystals is the ferromagnetic resonance method.

The studying of FMR spectrum under high hydrostatic pressure was started rather long ago [1–3]. These measurements were not developed for a long time mainly because of the technical difficulties. The resonators, which were used in [1–3] were partly filled up with a liquid. The dielectrical properties of that liquid changed as a function of pressure. The Q factor was lowered and the resonance frequency drifted with increasing pressure. Use of a ceramic resonator made of Al_2O_3 solved this problem [4]. Al_2O_3 allowed one to minimalize the resonator size because of the large value of its dielectric constant $\varepsilon \sim 10$.

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In this paper the high pressure vessel employed for high hydrostatic pressure FMR measurements will be described. The whole device setup is shown on Fig. 1. The cylindrical resonator 1 of size $\varnothing\,11.2\times12.3$ mm was made of monocrystalic Al_2O_3 and works in TE_{112} mode. The resonators walls are covered with a metalic silver layer 2 (vacum dusted first and then electrolytically grown). The sample 3 is placed in a cylindrical hole 4 fixed at half of resonators hight. The resonator stands on plug 5 with cylindrical port $\varnothing\,7$ mm. Plugs and resonator surfaces which will be in a contact are polished to optical accuracy and they are used to seal the pressure chamber. The brass pilot sleeve 6 is put on the plug; this centres the resonator in the vessel. Plug 5 and washer 7 are pressed in vessel by a screw 8.

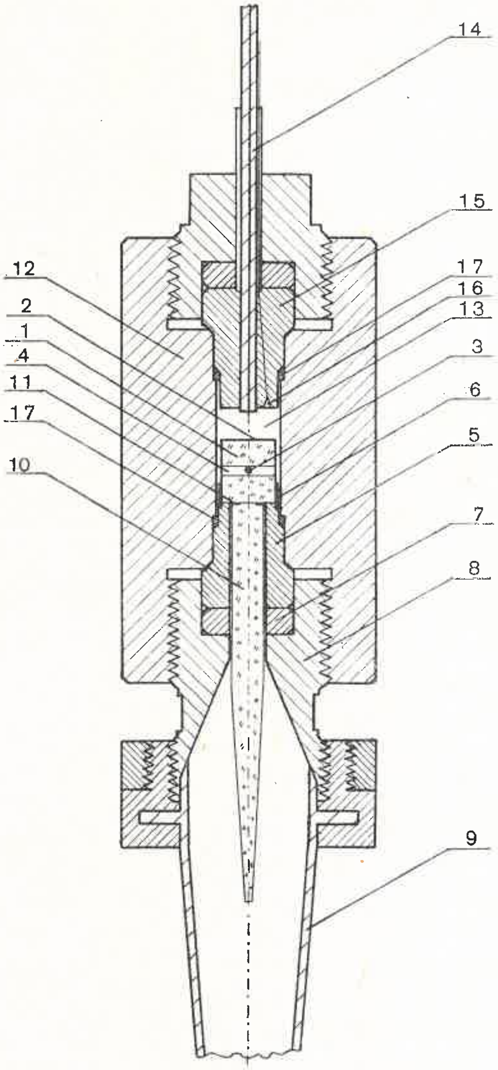

Fig. 1. High pressure setup for ferromagnetic resonance measurements

The inside walls of this screw are cut conically and are passed into the TEM-TE mode converter 9. Cylindrical hole in plug, washer and screw are filled with the monocrystalline Al_2O_3 10. This part, wedge ended, is put into the waveguide and couples the resonator with the microwave circuit. A similar structure was used in [5, 6]. The reflection effect and microwave power dissipation can be neglected in this kind of coupling in contrast to structures based on coaxial lines [1–4]. This type of coupling device based on rectangular waveguide was described first by Stankowski et all in [6]. The silver layer is dusted on the surface of the sapphire element and the 3 mm undusted place is left in the middle of that surface. In this case we get a better coupling of waveguide and resonator. In the construction presented in [6] there is no possibility of regulating the coupling between the resonator and other part of the microwave circuit. Absence of this regulation makes some measurements difficult (i.e. the investigations of ferromagnetic samples strongly coupled with the system or even paramagnetic one with large microwave power dissipation). In the high pressure vessel described in this paper the problem was solved as follows: The coupling can be regulated by the rotation of the TEM-TE mode converter around the sapphire wedge. Using the waveguide sector, which is rectangular on one end and circular on the other, gives the next possibility of coupling regulation by rotation of the sapphire wedge, with respect to a stable resonator. This kind of construction eliminates the anisotropic properties of sapphire elements 1 and 10 of which the optical axis is not parallel to the symmetry axis.

The resonator is placed inside the thick, high walled pressure cylinder 12. Gaseous helium 13 is used as a pressure transferring medium. The gas passes through the capillary 14 and gets to the high pressure bomb. The electric seal wire 16 for the thermocouple is in the plug as well as the capillary. All parts of high pressure bomb equipment are made of nonmagnetic Be–Cu alloys. The brazen packing rings 17 make the setup hermetic.

Pressure is obtained from a high pressure compressor type IF 012A [7]. The manganin coil inside the compressor is used to determine the actual pressure value. Using the resonator described above we can get 8 kbar pressure. This restriction arises from the small fastness of the resonator which is caused by its small dimensions and the hole inside. If TE_{113} mode resonator ($\varnothing\, 11.7 \times 17$ mm) is used higher pressure can be obtained.

The bomb can be mounted to any standart EPR or FMR reflectivetype X-band spectrometer. External modulation with frequency 50 — 150 Hz may be applied to get the derivative of the absorption curve. The small dimensions of the whole device allow one to place it into the cryostat. Then the measurements at liquid nitrogen temperatures can be performed.

That apparature was used in FMR spectra investigations on a monocrystalline $Y_3Fe_5O_{12}$ sample at room temperature and with pressure up to 6.5 kbar. The analysis indicates that a small number of Fe^{+2} ions were present in the monocrystal measured. The X-ray oriented spherical sample $\varnothing\, 0.4$ mm was stuck to the rod with pointcontact and placed in the resonator. The crystalographic plane $(\bar{1}10)$ was perpendicular to the symmetry axis of the resonator. The angular dependence of the resonance field was investigated for a few values of pressure. The sticker used to mount the sample can induce unaxial strains in that sample because of its compressibility. In our experiment line broadening was not remarkable. So we think that the pressure acting on the sample was really hydrostatic (usually a resonance line becomes broader when unaxial stress is applied).

The anisotropy constants K_1/M and K_2/M were determined [9] (for some values of pressure) from values of the resonance field when a constant magnetic field was acting along [100], [110], [111] crystal axes. The first anisotropy constant decreases with increasing pressure

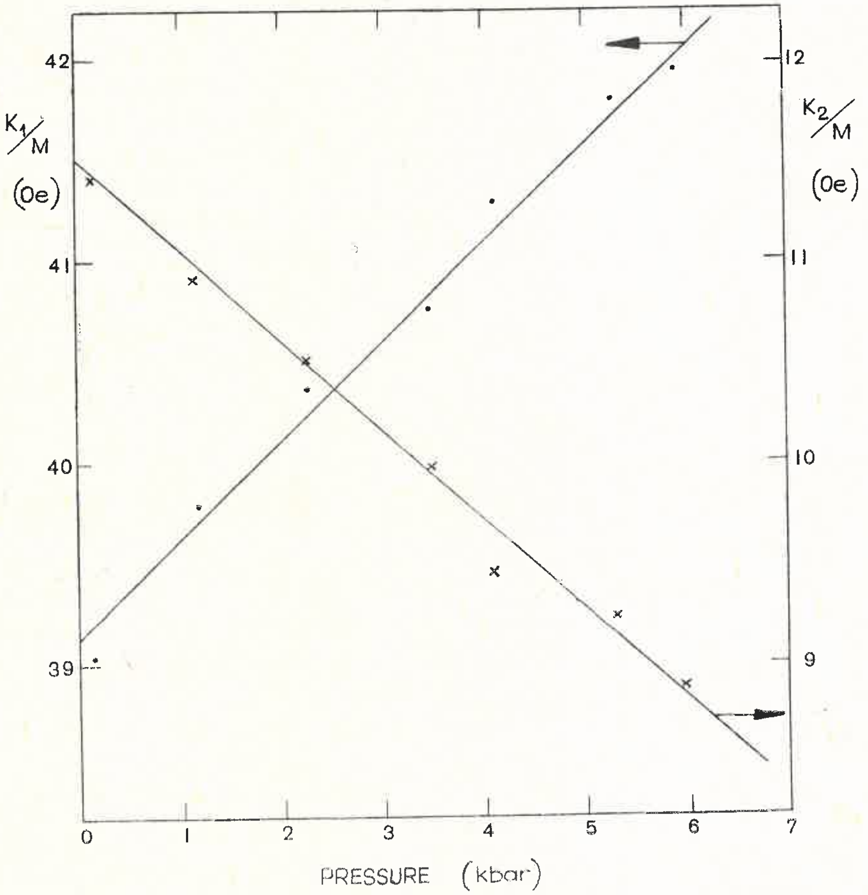

Fig. 2. Pressure dependence of the first and second anisotropy constants in yttrium iron garnet

$$\frac{K_1}{M} = -(39.2+4.7\ 10^{-4}p)\ [\mathrm{Oe}] \tag{1}$$

and the second one incrases with increasing pressure

$$\frac{K_2}{M} = -(11.45-4.4\ 10^{-4}p)\ [\mathrm{Oe}] \tag{2}$$

(pressure p expresed in bars).

The plots of K_1/M and K_2/M versus pressure are shown on Fig. 2. Taking the dependence of pressure on magnetization $4\pi M = 1776+1.710^{-3}p$ (gauss) from [2] one can calculate the change of K_1 and K_2 as a function of pressure

$$\frac{dK_1}{dp} = 0.0728\ [\mathrm{erg\,cm^{-3}bar^{-1}}], \quad \frac{1}{K_1}\frac{dK_1}{dp} = 13.11\ 10^{-6}\ [\mathrm{bar^{-1}}], \tag{3}$$

$$\frac{dK_2}{dp} = -0.061\ [\mathrm{erg\,cm^{-3}bar^{-1}}], \quad \frac{1}{K_2}\frac{dK_2}{dp} = -37.6\ 10^{-6}\ [\mathrm{bar^{-1}}]. \tag{4}$$

The influence of high hydrostatic pressure on the anisotropy of YIG was investigated in [2, 8]. In both papers only the changes with pressure of first anisotropy constant were defined and the following results were obtained: $d(K_1/M)/dp = 3.15\ 10^{-4}$ [2] and $(1/K_1)dK_1/dp = 7.26\ 10^{-6}$ [8]. The pressure dependence of the anisotropy constant which was obtained in [2, 8] is weaker than that obtained in this paper. The difference is probably caused by two reasons: 1° neglecting the influence of pressure on the K_2 (its values change opposite to K_1) and 2° the large values of K_2 obtained in investigated monocrystal of $Y_3Fe_5O_{12}$. The adjustment of one anisotropy constant to the measured values of the resonance fields gives the following pressure dependence: $d(K_1/M)/dp = 3.95\ 10^{-4}$.

The value dK_1/dp (3) obtained in the present paper is in better accordance with theoretical accounts for room temperature $dK_1/dp \sim 0.091$ [8]. It shows that, in consideration of the influence of high hydrostatic pressure on magnetocrystalline anisotropy, neither the second anisotropy constant not its varying with pressure can be neglected.

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