HIGH-FREQUENCY ANTIFERROMAGNETIC RESONANCE IN IRON BORATE ($FeBO_3$)

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In antiferromagnets with weak ferromagnetism and anisotropy of the "easy plane" type (space group D_{3d}^{b}), the antiferromagnetic resonance (AFMR) spectrum has a low-frequency branch and a high-frequency one [1 - 4]:

$$(\omega_1/\gamma)^2 = H(H + H_D) + H_{\Delta 1}^2 , \tag{1}$$

$$(\omega_2/\gamma)^2 = 2H_A H_E + H_D^2 + HH_D + H_{\Delta 2}^2 , \tag{2}$$

where $\gamma = ge/2mc = \mu/\hbar$ is the gyromagnetic ratio, H_D is the Dzyaloshinskii field, H is the external magnetic field perpendicular to the C_3 axis, H_A and H_E are respectively the effective anisotropy and exchange fields, and $H_{\Delta 1}^2$ and $H_{\Delta 2}^2$ are the isotropic energy gaps resulting either from the hyperfine interaction [3] or from magnetostriction [4].

The low-frequency AFMR branch (1) was investigated in detail for many known antiferromagnets belonging to the space group D_{3d}^6, with "easy plane" anisotropy.

AFMR was observed in $FeBO_3$ in [5], where its temperature dependence was investigated at one frequency. The AFMR corresponding to the low-frequency branch was investigated in a wide frequency interval in [6], where it was shown that formula (1) holds true at temperatures below ∿310°K.

The high-frequency branch in $FeBO_3$ has not been observed before, and the present paper is the first report of its experimental observation and study.

Unlike the case of easy axis antiferromagnets, where the energy gap at T = 0°K can be determined in a number of cases from the sublattice-flipping field, in antiferromagnets of the "easy plane" type the energy gap is not known beforehand. Observation of the corresponding AFMR therefore entails considerable experimental difficulties.

The search and study of high-frequency AFMR in $FeBO_3$ was carried in the wavelength range $\lambda = 0.3 - 1.7$ mm[1] in constant magnetic fields up to 100 kOe at temperatures T = 4.2 - 350°K.

When the sample was mounted in such a way that the external magnetic field was in the basal plane, we observed absorption lines corresponding to both the high-frequency and the low-frequency branch of the AFMR (Fig. 1). In the temperature interval from 4.2 to 350°K (T_N = 348°K), we investigated the dependence of the frequency of the AFMR corresponding to the high-frequency branch on the external magnetic field. Figure 2 shows by way of an example the dependence of $(\omega/\gamma)^2$ on H for three temperatures. The continuous lines were obtained by processing the experimental data (points) by formula (2) and least squares. A similar processing, carried out for all temperatures at which measurements were made, has made it possible to find the temperature dependences of H_D and $H_C = [2H_A H_E + H_D^2 + H_{\Delta 2}^2]^{1/2}$ (Fig. 3). It should be noted that the energy

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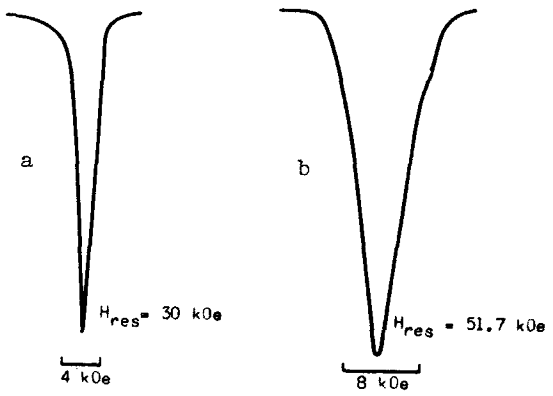

Fig. 1

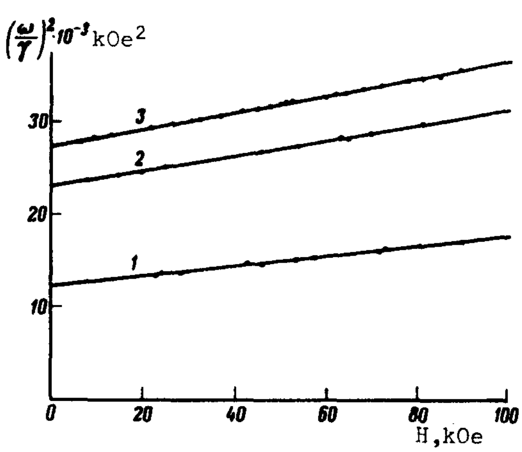

Fig. 2

Fig. 1. a) Absorption line corresponding to low-frequency AFMR branch at room temperature, H_{res} = 30 kOe, λ = 1.98 mm; b) Absorption line corresponding to high-frequency AFMR branch, T = 4.2°K, H_{res} = 51.7 kOe, λ = 0.598 mm.

Fig. 2. Square of the AFMR frequency vs. the external magnetic field. Line 1: T = 300°K (H_D = 54.7 kOe). Line 2: T = 198°K (H_D = 85.1 kOe). Line 3: T = 4.2°K (H_D = 92.7 kOe).

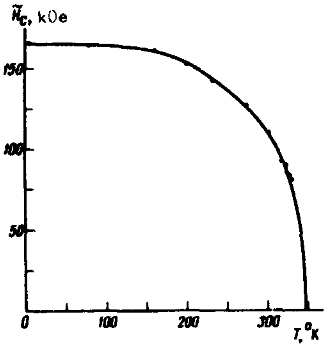

Fig. 3. Temperature dependence of the energy gap H_c in the high-frequency branch of the spin-wave spectrum in $FeBO_3$.

gap in the spin-wave spectrum in iron borate is much larger than in the manganese carbonate $MnCO_3$ and hematite α-Fe_2O_3 which have been investigated to date.

The high-frequency resonance in the absence of an external magnetic field at T = 0°K corresponds to a wavelength λ = 0.61 mm for $FeBO_3$ and λ = 2.4 mm for $MnCO_3$ [7]. In α-Fe_2O_3, the high-frequency AFMR is observed at a wavelength λ = 1.5 mm [8].

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[1] A.S. Borovik-Romanov, Zh. Eksp. Teor. Fiz. 36, 766 (1959) [Sov. Phys.-JETP 9, 539 (1969)].
[2] E.A. Turov, ibid. 36, 1254 (1959) [9, 890 (1959)].
[3] A.S. Borovik-Romanov, N.M. Kreines, and L.A. Prozorova, ibid. 45, 64 (1963) [18, 46 (1964)].
[4] A.S. Borovik-Romanov and E.G. Rudashevskii, ibid. 47, 2095 (1964) [20, 1407 (1965)].
[5] R.C. LeCrow, R. Wolfe, and J.W. Nielsen, Appl. Phys. Lett. 14, 352 (1969).
[6] L.V. Velikov, E.G. Rudashevskii, and V.N. Seleznev, Tezisy Vsesoyuznoi konferentsii po magnetizmu (Abstracts of All-union Conference on Magnetism), Krasnoyarsk, June 1971).
[7] P.L. Richards, J. Appl. Phys. 35, 850 (1964).

[8] L.V. Velikov and E.G. Rudashevskii, Zh. Eksp. Teor. Fiz. 56, 1557 (1969) [Sov. Phys.-JETP 29, 836 (1969)].

PARAMETRIC GENERATION WITH CdSe CRYSTAL PUMPED BY $CaF_2:Dy^{2+}$ LASER

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Coherent radiation sources that can be tuned in range from 0.5 to 3.7 μ have by now been produced on the basis of parametric generation (cf., e.g., [1]). However, the range from 3 to 10 μ, which has not yet been mastered, is of great interest for a large number of physical investigations, such as laser photochemistry, and molecular spectroscopy.

We have obtained, for the first time, parametric generation with the semiconducting crystal CdSe. The wavelengths of the parametric radiation were 3.37 and 7.86 μ.

CdSe is a uniaxial positive crystal ($n_e > n_o$), belongs to the point symmetry group 6mm, is transparent in the wavelength range from 0.75 to 20 μ, is of high optical quality, and its absorption coefficient in the transparency region does not exceed 0.01 cm^{-1}.

The only parametric interaction possible in the CdSe crystal is of the type o = e + o. In this case the effective nonlinear coefficient is $d_{eff} = 2d_{15}\sin\theta$, where θ is the angle between the wave vector of the pump radiation and the optical axis of the crystal, and d_{15} is the nonlinear optical coefficient with value 0.74×10^{-7} cgs units [2]. From the data on the refractive indices [3, 4] it follows that CdSe has 90° synchronism, and the maximum range of tuning of the parametric frequencies is obtained when the pumping wavelength is ∿2.5 μ.

The pumping source was a Q-switched $CaF_2:Dy^{2+}$ laser with emission wavelength 2.36 μ operating with a repetition frequency 1 Hz. The Q switching was with a Pockels cell using an $LiNbO_3$ crystal [5, 6] or with a rotating prism, in analogy with [7], and the generation consisted of pulses of 30 - 40 nsec duration with peak power 10 MW.

The resonator of the parametric generator was made up of two plane-parallel dielectric mirrors coated on a fluorite substrate. The effective feedback in the resonator was produced at only one parametric wavelength λ = 3.37 μ, for which the reflection coefficient exceeded 99%. The transmission of the mirrors at the other parametric wavelength, λ = 7.86 μ and at the pump wavelength λ = 2.36 μ was 80 and 85%, respectively. The CdSe crystal was 2.5 cm long, the plane-parallel end faces were cut at an angle 90° to the optical axis.

We observed the parametric-radiation signal when the pump power density exceeded the threshold value 3 MW/cm^2. In our experiment we registered the long-wave parametric radiation, whose wavelength was determined with an IKM-1 monochromator to be 7.86 ± 0.02 μ. The figure shows the calculated tuning curves for the parametric radiation in CdSe pumped at a wavelength 2.36 μ. We used in the calculation the values of the parametric-generation wavelengths for 90° synchronism. The parametric radiation power at 7.86 μ was ∿5 kW at a pump power close to threshold (∿1 MW), corresponding to the conversion coefficient 0.5%. Damage to the dielectric mirrors of the parametric generator did not make it possible to raise the pump power density noticeably above the threshold value. The CdSe crystal exhibited much better endurance to the action of the pump than