

Figure 2 shows the intensities of the ionic and neutral scattering components as functions of the emission angle  $\psi$ . The curves differ in character: the ion intensity decreases monotonically on going over to smaller emission angles, while the curve for the neutrals has a broad maximum. This difference indicates that the angular distributions obtained for fast ions and for fast neutrals at identical angles of incidence ( $\alpha = \text{const}$ ) and scattering ( $\theta = \text{const}$ ) differ significantly from each other.

Figure 3 shows plots of  $I^+/(I^0 + I^+)$  against  $v_{\perp}$ , measured at bombarding-ion energies 20, 25, and 30 keV. We see that the results corresponding to different energies of the bombarding ions practically coincide. This indicates that the probability of ion neutralization is determined mainly by the normal component of the ion velocity. Figure 3 can thus be regarded as the experimental plot of  $1 - w_0 = f(v)$ , where  $w_0$  is the ion neutralization probability. (The intensity of the scattered-flux components having higher charges did not exceed 10%).

According to the calculations of [3], the share of ionized particles in the scattered flux should depend on the normal component of the velocity like  $\exp(-a/v)$  (the constant  $a$  is not defined by the theory). Yet it is seen that the results of Fig. 3 cannot be described by an exponential function. The quantity  $I^+/(I^0 + I^+)$  increases approximately linearly with  $v_{\perp}$ . It is curious to note that a similar dependence was observed by Veksler (see, e.g., [4]), although in an entirely different velocity region.

The authors thank S. N. Zvonkov for great help with the work, S.A. Evstigneev for constructing a number of parts of the installation, and O. B. Firsov for useful discussions.

- [1] E. S. Parilis, Second All-union Symposium on the Interaction of Atomic Particles with Solids, Moscow, 9 - 11 October 1972, Collected Papers (in Russian), p. 137.
- [2] V. M. Chicherov, ZhETF Pis. Red. 16, 328 (1972) [JETP Lett. 16, 231 (1972)].
- [3] Sh. Sh. Shekhter, Zh. Eksp. Teor. Fiz., 1973, in press.
- [4] V. I. Veksler and B. A. Tsipinyuk, Zh. Eksp. Teor. Fiz. 60, 1393 (1971) [Sov. Phys.-JETP 33, 753 (1971)].

#### RESONANT ABSORPTION IN UNIAXIAL CRYSTALS WITH CYLINDRICAL DOMAIN STRUCTURE

M. A. Sigal

Kiev State University

Submitted 11 April 1973

ZhETF Pis. Red. 17, No. 10, 563 - 566 (20 May 1973)

Resonant absorption due to precession of the magnetization of cylindrical domains was observed experimentally at millimeter wavelengths in the state of residual magnetization of a thin magnetoplumbite crystal.

It is known that in a single-crystal plate of a uniaxial crystal with easy magnetization axis (EMA) perpendicular to the basal plane, in the residual magnetization state (RM), there can occur various types of domain structures (strip, cylindrical), depending on the method of excitation. The so-called honeycomb structure, constituting a hexagonal lattice of cylindrical domains, was observed first in the RM state [1] in a thin magnetoplumbite crystal following the action of a saturating field  $H_{\text{sat}}$  making an angle  $\theta$  close to  $\pi/2$  with the easy axis. In the case  $\theta = 60 - 80^\circ$ , a structure of strip domains is produced, with boundaries parallel to the

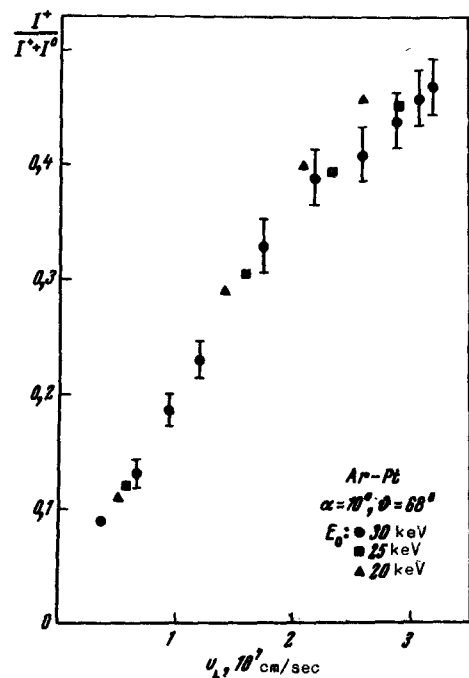


Fig. 3. Plot of the quantity  $I^+/(I^0 + I^+)$  ( $= 1 - w_0$ ) vs the normal component of the velocity at which the particle moves away from the target surface.  $E_0$  is the bombarding-ion energy.

projection of  $\vec{H}_{\text{sat}}$  on the basal plane.

A uniaxial crystal (thin spheroid,  $NM \ll H_a$ ) with plane-parallel domain structure ( $N_{\text{p.d.}} = 4\pi$ ), whose axis coincides with the easy magnetization axis in the absence of an external field, has a magnetic spectrum, connected with the precession of the domain magnetization, consisting of two absorption lines [3] with frequencies

$$\omega_{\perp} = \omega_a = \gamma H_a, \quad \omega_{\parallel} = \gamma [H_a (H_a + 4\pi M)]^{1/2}, \quad (1)$$

where  $H_a = 2K/M$  is the effective crystallographic-anisotropy field,  $N$  is the demagnetizing factor of the sample in the disk plane, and  $N_{\text{p.d.}}$  is the demagnetizing factor of plane-parallel domains.

Thus, in a thin crystal the frequency of the low-frequency maximum coincides with the frequency of the natural ferromagnetic resonance (NFR) in the effective crystallographic-anisotropy field, and the frequency shift  $\Delta\omega = \omega_{\parallel} - \omega_{\perp}$  in the position of the high-frequency resonance, the existence of which is due to dynamic demagnetization on the domain walls, depends only on the character of the domain structure (the demagnetizing factor of the walls) if  $H_a$  and  $M$  are constant. The two-frequency spectrum of a magnetoplumbite crystal with a strip domain structure was investigated experimentally in [4].

In the case of a thin crystal ( $NM \ll H_a$ ) with cylindrical domain structure, the spectrum of the natural frequencies of homogeneous precession consists in the absence of an external field of one line [3]

$$\omega_{\text{c.d.}} = \gamma [H_a (H_a + N_{\text{c.d.}} M)]^{1/2}, \quad (2)$$

where  $N_{\text{c.d.}}$  is the demagnetizing factor of a cylindrical domain.

Since the diameter of the cylindrical domain is much smaller than its height (the crystal thickness), we can take  $N_{\text{c.d.}} = 2\pi$ , and then

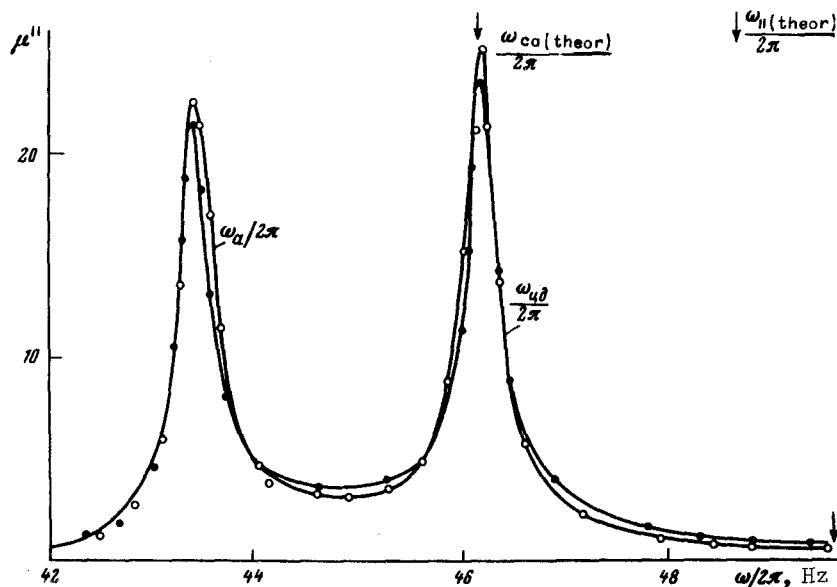
$$\omega_{\text{c.d.}} = \gamma [H_a (H_a + 2\pi M)]^{1/2}. \quad (3)$$

The resonant absorption due to precession of the magnetization of cylindrical domains has not been observed previously.

We investigated the spectra of the magnetic permeability, measured in the millimeter band, of thin magnetoplumbite thickness in the thickness range where there are now surface wedge-like additional domains. All the spectra measured for different angles  $\theta$  in steps of approximately  $1^\circ$ , in the range  $90^\circ > \theta > 84^\circ$ , consist of two absorption lines. The intensity and width of the low-frequency peak, and also its frequency, are practically independent of  $\theta$ , whereas the high-frequency peak undergoes considerable changes. When  $\theta$  decreases from  $90^\circ$ , an appreciable increase of the intensity and a decrease of the resonance curve are observed, after which the sequence of the change of intensity and width are reversed. In addition, the curve shifts somewhat towards higher frequencies. The most intense line was obtained at  $\theta = 86.5^\circ$ . The figure shows the frequency dependences of the imaginary part of the magnetic permeability  $\mu = \mu' - j\mu''$  of a crystal in the form of a disk of thickness  $d = 45 \mu$  and radius  $R = 1 \text{ mm}$ , measured at  $\theta = 86.5^\circ$ . There are two causes that make it unlikely that the low-frequency peak coincides with the frequency  $\omega_{\perp}$  excited in crystals with a strip domain structure by the component  $\vec{h}$  perpendicular to the walls. First, numerous observations [1, 2] have shown that at  $\theta = 87^\circ$  optimal conditions are produced for the nucleation of cylindrical domains, and in this case strip domains are not observed; second, if a mixed structure of cylindrical and strip domains were to exist, then a change of the orientation of the projection  $\vec{H}'_{\text{sat}}$  of the saturating field on the plane of the plate relative to  $\vec{h}$  would cause a change in the intensity of the low-frequency maximum and excitation of the frequency  $\omega_{\parallel}$ . It is seen from the figure that when the angle between  $\vec{H}'_{\text{sat}}$  and  $\vec{h}$  changes by  $\pi/2$ , the intensity of the low frequency peak remains practically unchanged, and  $\omega_{\parallel}$  is not excited.

It can therefore be assumed that the low-frequency peak occurs at the NFR frequency  $\omega_a$ , which coincides with  $\omega_{\perp}$  in thin crystals ( $\omega_{\perp}$  is equal to  $\omega_a$  at  $\theta = 75^\circ$  and  $\vec{H}'_{\text{sat}} \perp \vec{h}$ ). It is possible that the resonance  $\omega_a$  is connected with the precession of the magnetization of the crystal matrix, whose magnetization is opposite to that of the cylindrical domains. It should be noted that there is a considerable difference between the field  $H_a$  determined from the NFR ( $\omega_a = 43.4 \text{ GHz}$  at  $\gamma = 17.6 \text{ GHz/kOe}$  from (1),  $H_a = 15.5 \text{ kOe}$ ) and from the static measurements

Magnetic spectra of magneto-plumbite crystal; ● -  $h \perp H_{\text{sat}}$ ,  
○ -  $h \parallel H_{\text{sat}}$ .



( $H_a = 13.75$  kOe [5]).

The high-frequency peak represents resonant absorption connected with the precession of the cylindrical-domain magnetization. The arrow in the figure indicates the theoretical frequency  $\omega_{c.d.}$  calculated from [3], where  $H_a = 15$  kOe and  $M = 320$  G. The agreement with the experimental frequency is very good. Finally, this statement is also favored by the fact that the optimal conditions for the excitation of the most intense and narrowest maximum  $\omega_{c.d.}(\theta = 87^\circ)$  coincide with the optimal conditions for the nucleation of a cylindrical domain structure.

In conclusion, the author thanks E. I. Petropavlovskii for help with the measurements.

- [1] J. Kaczer and R. Gemperle, Czech. J. Phys. **B11**, 510 (1961).
- [2] G. S. Kandaurova, in: Logicheskie i zapominayushchie ustroystva na magnitnykh kristallakh (Logic and Memory Devices Using Magnetic Crystals), M. A. Boyarchenkov, ed., p. 38.
- [3] L. G. Onoprienko, O. I. Shiryaeva, and Ya. S. Shur, Izv. AN SSSR, ser. fiz. **28**, 504 (1964).
- [4] M. A. Sigal, Ukr. Fiz. Zhur. **15**, 909 (1971).
- [5] R. Pauthenet and G. Rimet, C. R. Acad. Sci. **249**, 656 (1959).

#### TEMPERATURE DEPENDENCE OF THE CONDUCTIVITY OF A THIN PLATE

M. Ya. Azbel', S. D. Pavlov, A. N. Vereshchagin, and I. A. Gamalya  
Kalmuck State University  
Submitted 13 April 1973  
ZhETF Pis. Red. **17**, No. 10, 566 - 570 (20 May 1973).

The dependence of the resistance of a plate of arbitrary thickness on the thickness and temperature is found, with allowance for electron diffusion (due to collisions with phonons) and for the arbitrary character of the electron reflection from the surfaces of the plate.

There have been many experimental studies of the resistance of thin metallic samples as functions of the temperature and dimensions (see [1], and also the review [2]). A consistent theoretical study of this question reduces to an analysis of the electron diffusion due to collisions with phonons between the walls of the sample, the reflection from which depends strongly on the angle of incidence on the wall. Nevertheless, the presently available theoretical papers deal with cases in which the sample is so thin that there is no diffusion [3-7].

We report here the first study of a general case of a plate of arbitrary thickness, and show that the form of the dependence of the resistance on the temperature varies significantly