Extended Abstracts of the 1994 International Conference on Solid State Devices and Materials, Yokohama, 1994, pp. 820-822

Photo-Acoustic Sensitivity of Hematite Single Crystals

V.Preobrazhensky, A.Kiselev

Moscow Institute of Radio Engineering, Electronics and Automation. 117454 Moscow, Russia.

Effect of light on elastic subsystem via magneto-elastic interaction in hematite ($\alpha-Fe_2O_3$) single crystals nominally pure and Al^{3+} for Fe^{3+}partially substituted is studied experimentally. The phenomenon observed as a short-time shift of acoustic eigenmode frequency under the lighting is interpreted as a result of local photo-thermal effect on hexagonal magneto-crystalline anisotropy.

1. INTRODUCTION

Effect of light on crystal elastic subsystem is of interest for wireless remote control of high Q-factor solid resonators, optical signal detecting and nondestructive evaluation of crystal quality. Hematite single crystals are advanced materials with elastic parameters controllable by external forces (magnetic fields, pressure, light etc.)[1]. Effect of optical irradiation on magneto-elastic resonance in hematite single crystals transparent at $\lambda > 1\ \mu m$ has been observed in visible and infrared spectrum bands[2]. The results of detail study of photo-acoustic sensitivity are presented here. The short-time shift ΔF of acoustic eigenmode frequency arising straight away off illumination switching on is under consideration in contrast with slow optically induced effects studied earlier[3]at low temperature in iron borate crystal similar to hematite by magneto acoustic properties.

2. EXPERIMENTAL METHOD AND RESULTS.

The experiment have been carried out by using of disk acoustic resonator (diameter 6 mm, thickness 3 mm) cut out in basal plane of single crystal $\alpha-Fe_2O_3$ or $\alpha-(Fe_{0.96}Al_{0.04})_2O_3$. Magneto-elastic oscillations of"contour -shear" eigenmode have been excited by rf-magnetic field and detected by inductance coil placed near the crystal. Light beam of He-Ne laser of maximum power 8 mW ($\lambda = 0.63\ \mu m$ or $\lambda = 1.15\ \mu m$) has been focused on a sample surface at the center of disk. Resonance frequency F and its optically induced shift ΔF have been observed and measured by means of characteriograph. Specific time of resonance frequency response correspondent to maximum ΔF was estimated as 0.1s by using of light intensity modulation with variable period. Practically linear dependence photo-induced frequency shift ΔF on light intensity has been observed. The measured value ΔF is strongly dependent on DC-magnetic field strength and its direction in basal plane of crystal (see fig.1,2). The dependencies of F and ΔF on temperature for $\alpha-Fe_2O_3$ and $\alpha-(Fe_{0.96}Al_{0.04})_2O_3$ compound are presented in fig.3,4.

3. DISCUSSION

Magnetic field dependencies of

photo-acoustic sensitivity demonstrate magneto-elastic origin of the effect. Thermal mechanism is indicated in particular by correspondence of $\Delta F(T)$ and derivative $\partial F/\partial T$ in fig.3. Thus the observed phenomenon one can classify as photo-thermo-magneto-acoustic (PTMA) effect. Taking into account magneto-elastic interaction frequency of "contour-shear" acoustic eigenmode can be obtained in form[4]:

(1) $F(H)=F\ (1-\zeta^2(H))^{1/2}$,

where $F^2=0.28\ (C_{11}-C_{12}-C^2_{14}/C_{44})d^{-2}$, C_{ij}- elastic moduli, d- diameter of disk, $\zeta(H)$- magnet-oelastic coupling coefficient, $\zeta^2(H)=2H_EH_{ms}{}^{(1)}/\Delta(H)$, $\Delta(H)=H(H+H_D)+2H_EH_{ms}{}^{(2)}+2H_EH_A\ \mathrm{Cos}6\theta$, H_A, H_E, H_D- effective fields of hexagonal anisotropy, exchange and Dzyaloshinskii-Moriya interactions, $H_{ms}{}^{(1,2)}$- magnet-oelastic fields, θ - angle between magnetic field H and binary axis in basal plane. The result of F(H) calculation by formula (1) for parameters $2H_EH_{ms}{}^{(1)}/H_D=125$ Oe, $2H_EH_{ms}{}^{(2)}/H_D=132$ Oe, $2H_EH_A(T=300K)/H_D=14$ Oe is presented on fig.1a by line. Clearly expressed in fig.2 sixfold anisotropy of PTMA-effect can be explained taking into account anomalous increasing[5] of the inplane anisotropy $H_A(T)$ near spin reorientation (Morin transition) temperature T_M ($T_M=260$K for α-Fe_2O_3 and $T_M=215$ K for α-$(Fe_{0.96}Al_{0.04})_2O_3$). The main contribution to the PTMA sensitivity has to be proportional to derivative $\partial F/\partial H_A$. Calculated curve $\partial F/dH_A$ is presented in fig.1b by line.

Hematite is not transparent for visible light so optically induced short-time perturbations of coupling coefficient at $\lambda=0.63\ \mu m$ can be mainly localized near the surface of sample. Such a "sub-surface" PTMA-effect is sensitive to properties of near surface layers. The results presented on fig.3 illustrate correspondence of local (near surface and the focal spot) and bulk (averaged all over the crystal) anisotropic properties for nominally pure α-Fe_2O_3 crystal. Essential difference of local and bulk anisotropy for $Al^{3+}$for Fe^{3+} partially substituted crystal is illustrated by fig.4. Qualitatively different dependencies of F(T) and $\partial F/\partial T$ on temperature one can explain assuming easy axis of magnetization near illuminated region declined from its averaged direction in the volume. Removal of the discrepancy has been observed when wide infrared beam of $\lambda=1.15\mu m$ was used.

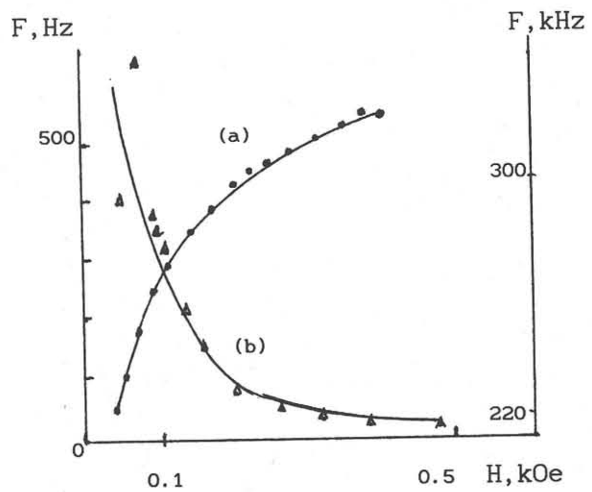

Fig.1 Photo-induced shift ΔF-(b) and resonance frequency F-(a) vs magnetic field (α-Fe_2O_3):

$\theta=\pi/6$, T=300 K.

Displacement of focal spot along the crystal surface can lead to variations of ΔF value and sign as well. This effect can be explained as a result of distortions of crystal caused by inhomogeneous distribution of defects. Sensitivity of PTMA effect to local anisotropy may be useful for local testing of crystal quality. In conclusion it's relevant to

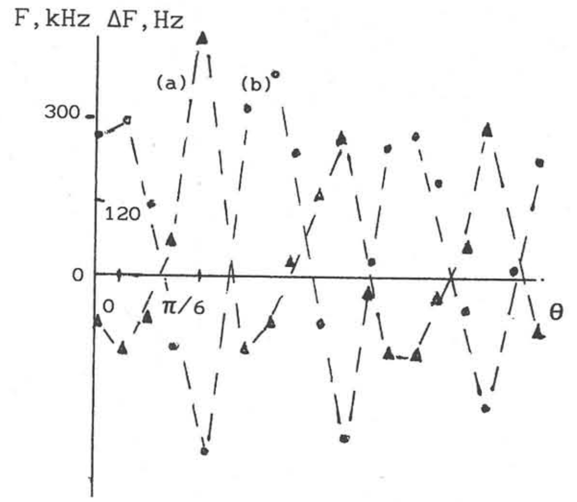

Fig.2 Photo-induced shift ΔF-(a) and resonance frequency F-(b) dependencies on magnetic field direction in basal plane (α-Fe_2O_3) H=100 Oe, T=300 K.

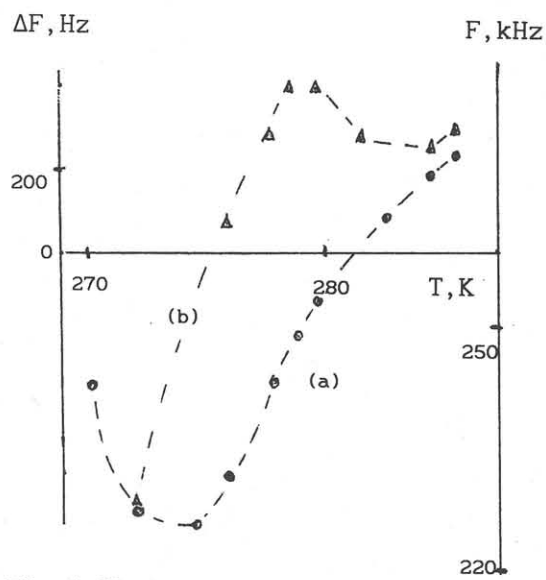

Fig.3 Photo-induced shift ΔF-(b) and resonance frequency F-(a) vs temperature(α-Fe_2O_3). H=110 Oe, $\theta=\pi/6$

point out the main contribution of magneto-elastic interaction to photo-acoustic sensitivity of hematite as an illustration to the general concept[1)] of search and elaboration of materials with controllable parameters on basis of coupled subsystem dynamics.

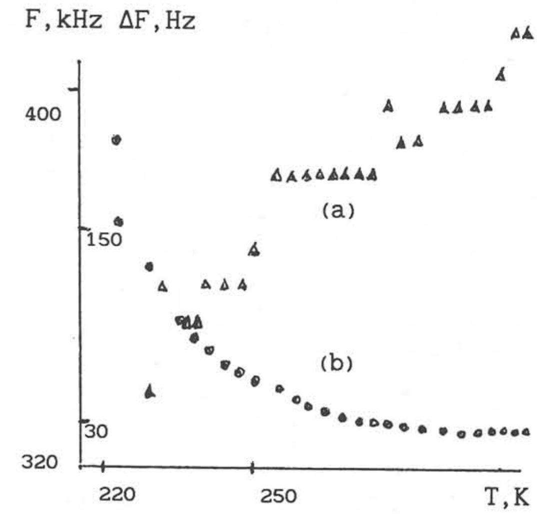

Fig.4 Photo-induduced shift ΔF-(a) and resonance frequency F-(b) vs temperature for α-$(Fe_{0.96}Al_{0.04})_2O_3$. H=86 Oe, $\theta=\pi/6$.

ACKNOWLEDGEMENTS

Authors thank V.Moshkin for help in measurements. Work was supported by Russian Foundation of Fundamental Investigations.

REFERENCES

1) V.Ozhogin, V.Preobrazhensky. J.Magn.Magn.Mat.,100(1991) 544.
2) V.Ozhogin, V.Preobrazhensky, A.Kiselev et.al. J.Appl.Phys. 73(1993) 6177.
3) M.H.Seavey. Sol.State Comm. 12(1973) 49.
4) E.Andruschak,N.Evtikhiev et al. Sov.Phys.Acoust. 27(1981) 170.
5) A.Bogdanov. Sov.Phys.Solid State 14(1972) 3362.