from 4.2 to 2°K increases the intensity of the effect by nearly 5 times. Such a dependence can obviously not be attributed to changes in the damping of sound with change in temperature [3].

2. We were unable to excite in similar fashion sound oscillations in an indium plate (d = 0.3 mm) in either the normal or superconducting state, although in the latter case there was no electronic sound attenuation at all.

Fig. 2

This gives grounds for suspecting that the observed excitation of sound in Bi is due to some specific mechanism. The mechanism whereby sound is excited when direct current flows through Bi is known [4]. It is possible that a similar mechanism - emission of sound as a result of large electron drift velocity - exists also in the anomalous skin effect. Estimates show that the average skin-current density in our experiments reached 1000 A/cm^2, leading to an average drift velocity $\bar{v} = i/ne$ on the order of 10^5 cm/sec. Further experiments are needed to clarify the sound-excitation mechanism.

The authors are grateful to Academician P. L. Kapitza for the opportunity to perform the experiments at the Institute of Physics Problems, and Yu. V. Sharvin for interest in the work.

[1] Y. Eckstein, A. W. Lawson, and R. H. Reneker, J. Appl. Phys. 31, 1534 (1960).
[2] S. I. Aksenov, B. A. Vikin, and K. V. Vladimirskii, JETP 28, 762 (1955), Soviet Phys. JETP 1, 609 (1955).
[3] D. H. Reneker, Phys. Rev. 115, 303 (1959).
[4] L. Esaki, Phys. Rev. Lett. 8, 4 (1962).

FERROELECTRIC EFFECT IN A LASER BEAM

A. A. Chaban
Acoustics Institute, Moscow
Submitted 18 October 1966
ZhETF Pis'ma 5, No. 1, 20-23, 1 January 1967

A powerful laser beam produces by electrostriction a strong deformation in a crystal. This results in an electric field that is constant in time. In piezoelectrics the field is due to the piezoelectric effect and can be comparable in magnitude with the amplitude of the electric field of the light beam. In this case, breakdown phenomena and destruction of the

crystal can be expected. A constant electric field is produced also in a non-piezoelectric crystal in a self-focusing laser beam [1], owing to the inhomogeneity of the deformation over the section of the beam [2]. Its intensity can amount to $\sim 10^3$ V/cm.

We consider first a piezoelectric crystal uniformly illuminated by a linearly polarized laser beam. Electrostriction gives rise to a deformation:

$$u_{ij} = \tfrac{1}{2} R_{ijkl} E_k E_l, \tag{1}$$

where E_i is the amplitude of the electric field of the light wave and R_{ijkl} is the electrostriction tensor. The piezoelectric properties lead to polarization of the crystal:

$$P_m = e_{mij} u_{ij} = \tfrac{1}{2} e_{mij} R_{ijkl} E_k E_l, \tag{2}$$

where P_m is the dipole moment per unit volume and e_{mij} is the piezoelectric tensor. If we consider by way of a rough estimate an infinite layer of matter with boundaries perpendicular to the x axis, then the electric field due to polarization is

$$E_x^0 = -4\pi P_x.$$

Putting $e_{ijk} \sim 10^5$ cgs esu and $R_{ijkl} \sim 10^{-12}$ cgs esu, we can readily find that

$$E_x^0 \sim 10^{-6} W, \tag{3}$$

where E_x^0 is in V/cm and W is the light-wave flux density in W/cm^2. Thus, when $W \sim 10^8$ W/cm^2, a potential difference of ~100 V will appear on a layer 1 cm wide. (Allowance for the finite dimensions of the crystal will, of course, not change the order of magnitude.) An investigation of the potential difference induced by light in peizoelectric crystals can identify experimentally the deformations actually produced by the light field. It is not excluded that they may differ from those obtained for static values of R_{ijkl} (the author is indebted to G. A. Askar'yan for a discussion of this question).

The intensity E^0 of the constant electric field may become particularly large when the laser beam is focused or self-focused in the piezoelectric crystal. In either case the light intensity will vary strongly over the cross section, i.e., the time-constant electric field, which is determined by the condition div $\underset{\sim}{E}^0 = 4\pi$ div $\underset{\sim}{P}$, will also vary strongly over the cross section. In first approximation we have for the absolute magnitudes $E^0 \sim 4\pi P$. (We note that, from simple geometric considerations, $u_{zz} \simeq 0$ in the case of a narrow self-focused beam propagating along the z axis, but for a rough estimate of the orders of magnitude effects of this kind are insignificant.) Then the constant electric field can again be estimated from (3), except that now the estimate pertains to the absolute magnitude of E^0. When $W = 10^{12}$ W/cm^2, corresponding to a light beam with electric field amplitude $E \simeq 10^7$ V/cm, the constant field is $E^0 \sim 10^6$ V/cm. Thus, at high light-beam power, we can expect electric breakdown under the influence of E^0, and consequently damage to the crystal. It seems to us that under definite conditions this ionization mechanism is stronger than multiphoton ionization under the influence of light. In fact, if we assume that the mean free path of the

electron in the conduction band is $\sim 10^5$ cm (for "hot" electrons it can, generally speaking, be much larger), then the electron will receive between two collisions an energy of ~10 eV, i.e., impact ionization may occur. Under the influence of the alternating electric field of the light wave, on the other hand, the electron will acquire in the conduction band, as can be readily established, an energy $e_0^2E^2/2m\omega^2 \sim 10^{-1}$ eV (e_0 is the electron charge, m its mass, and ω the frequency of the light). Thus, impact ionization and the occurrence of an electron avalanche are possible only under the influence of a constant field. If the impact ionization is attained, then the constant field plays apprently the decisive role (of course, the electrons produced by multiphoton ionization can be important in the occurrence of an electronic avalanche).

Since the free electrons produced when the atoms are ionized weaken the field E^0, the crystal may at first glance not become damaged during the time of action of the light pulse, even at so high a beam intensity. However, for an effective compensation of E^0, the concentration of the electrons should amount to $n \sim P/e_0 d$, where d is the diameter of the beam or of the focal spot. When $d \sim 10^{-2}$ cm and $W \sim 10^{12}$ W/cm^2 we get $n \sim 10^{14}$ cm^{-3}. At such conduction-electron concentrations, if their mobility is not too high, the light can be completely absorbed over a distance smaller than 1 cm [3]. Then simple estimates show that the heating during the time of action of the light pulse amounts to thousands of degrees. This will damage the crystal in the region under consideration.

We know of two investigations of the passage of a laser beam through a piezoelectric [4,5]. In [4] the role of the constant electric field should, on the basis of the foregoing estimates, be quite large, and allowance for it may explain some interesting peculiarities of stimulated scattering, observed in [4]. (In [4], $E \simeq 2 \times 10^7$ V/cm even without self-focusing; this value was used in the foregoing estimates.)

Upon focusing or self-focusing of the light beams, an electric field that is constant in time will apear in crystals with symmetry centers because of the inhomogeneity of the deformation over the cross section of the beam or of the focal spot. According to [2], the dipole moment per unit volume in a piezoelectric crystal subject to a deformation described by a displacement vector u_j is given by

$$P_i = \gamma_{ijkl} \frac{\partial^2 u_j}{\partial x_k \partial x_c} . \tag{4}$$

With this,

$$\gamma_{ijkl} \sim \frac{e_0}{a} , \tag{5}$$

where a is the lattice period. Then the time-constant electric field due to the inhomogeneity of the deformation under the influence of the laser beam, can be estimated in analogy with the foregoing

$$E^0 \sim 10^{-8} \frac{W}{k} , \tag{6}$$

where E^0 is written in units of V/cm, W in W/cm^2, $k = d/\lambda$, and λ is the wavelength of the light wave in the medium. For example, when $W \sim 10^{12}$ W/cm^2 and $k \sim 10$ we have $E^0 \sim 10^3$ V/cm. It is now clear that in very narrow self-focused beams in a non-piezoelectric crystal the intensity of the time-constant electric field can exert a most appreciable influence on the properties of the medium.

[1] G. A. Askar'yan, JETP 42, 1567 (1962), Soviet Phys. JETP 15, 1088 (1962); V. I. Talanov, Izv. vuzov, Radiofizika 7, 564 (1964); R. Y. Chiao, E. Garmire, and C. H. Townes, Phys. Rev. Lett. 13, 479 (1964).

[2] Sh. M. Kogan, FTT 5, 2829 (1963), Soviet Phys. Solid State 5, 2069 (1964).

[3] T. S. Moss, Physical Properties of Semiconductors (Russ. Transl.), M., 1961.

[4] S. V. Krivokhizha, D. I. Mash, V. V. Morozov, V. S. Starunov, and I. L. Fabelinskii, JETP Letters 3, 378 (1966), transl. p. 245.

[5] M. S. Brodin, V. N. Vatulev, and S. V. Zakrevskii, JETP Letters 2, 317 (1965), transl. p. 201.

ELECTRON PARAMAGNETIC RESONANCE IN LITHIUM CONTAINING IMPURITIES OF GROUP IIB METALS

N. S. Garif'yanov, B. M. Khabibullin, E. G. Kharakhash'yan, and A. L. Bezzubov
Kazan' Physico-technical Institute, USSR Academy of Sciences

Submitted 20 October 1966
ZhETF Pis'ma 5, No. 1, 24-25, 1 January 1967

The fact that the spin-lattice relaxation time T_1 of the conduction electron in lithium does not depend on the temperature, and the strong effect exerted on T_1 by the purity of the initial metal [1], give grounds for assuming that the main mechanism of spin relaxation is spin-orbit interaction of the conduction electrons with the impurity atoms. Therefore a study of solid solutions of different metals in lithium is of special interest. However, no systematic research has been carried out on the influence of controllable impurities on the EPR spectrum.

We report here the results of investigations of the effect of small admixtures of Zn, Cd, and Hg on the EPR line width in Li. As is well known [2], these metals form primary solid solutions in Li in a narrow range of concentrations. The initial material was ~99% pure LE-1 lithium (measured time $T_1 = 9.4 \times 10^{-9}$ sec). The alloy was prepared in an atmosphere of pure helium and dispersed by ultrasound in dehydrated paraffin to an average particle size $\lesssim 8$ μ. The measurements were made at 9320 MHz and room temperature.

It follows from the experimental data (see the figure) that the peak line width δH increases linearly with increasing c in the investigated concentration interval.

To estimate the spin-orbit interaction of the electrons with the impurity atoms in the metal, we used the expression given in [3] for the relaxation time: