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Acoustoelectric Current Saturation and Sound Velocity in Tellurium Crystals under Hydrostatic Pressure

By

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In Te crystals the piezoelectric interaction of drifting carrier with phonons (1) leads to saturation of the current at a critical field E_c when the drift velocity of the carriers μE_c exceeds the sound velocity v_s:

$$v_s = \mu E_c \ . \tag{1}$$

If v_s is known, it is possible to determine the mobility μ from the measured critical field E_c. We have investigated the influence of hydrostatic pressure on the critical field for extrinsic Te crystals. The conductivity of such crystals is known to increase considerably with pressure due to an increase of the hole mobility (2, 3). The critical field, therefore, is expected to depend strongly on pressure, too.

The Te crystals had an extrinsic hole concentration of about 10^{16} cm^{-3}. Thin Au wires were molded in as electrodes in a four-probe arrangement. Current flow was parallel to the X as well as to the Z axis. To avoid heating of the samples, voltage pulses (duration 2 μs) were applied with a repetition frequency of 1 Hz. A conventional high pressure system provided hydrostatic pressure of up to 4000 bar. Using a mixture of n-penthan and methylbuthan as transmitting medium, the measurements could be performed at 170 K where the samples were sufficiently far in the extrinsic range.

Fig. 1a shows the current voltage characteristics for $\vec{j} \parallel \vec{X}$ at different pressures. In the ohmic region the slope of the curves increases with pressure indicating the enhancement of the conductivity with a coefficient of $\Pi_\sigma = d\ln\sigma/dp = 1.3\text{x}10^{-4}$ bar^{-1}. Since the crystals are in the extrinsic range where the hole concentration is considered to be independent of temperature and pressure, this increase of the conductivity has to be explained by an increase of the mobility (2, 3).

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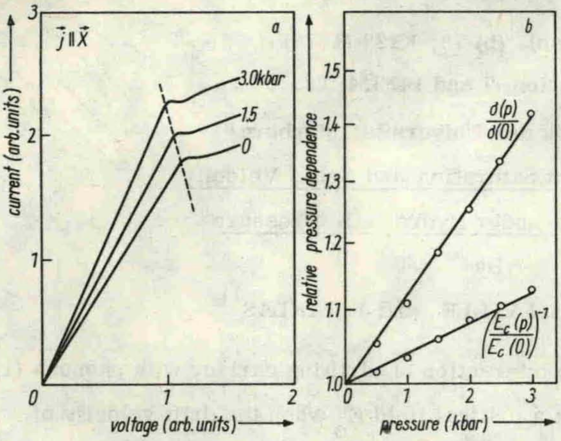

Fig. 1. I-U characteristics for $\vec{j} \parallel \vec{X}$ at different pressures (a) and pressure dependence of conductivity σ and critical field E_c (b)

The sound velocity of solids generally is only weakly influenced by pressure, the coefficients being around 10^{-6} bar^{-1}. If Te does not exhibit a substantially different behaviour, one expects according to relation (1) that at a pressure of 3000 kp/cm^2 the critical field shifts by about 40% to lower values due to the increase of the mobility. Remarkably the observed decrease of E_c is much smaller (Fig. 1b). In this figure $\sigma(p)/\sigma(0)$ is plotted versus pressure together with $(E_c(p)/E_c(0))^{-1}$ which according to relation (1) is equal to $\mu(p)/\mu(0)$ if v_s is constant. Evidently, the mobility determined by relation (1) has a much weaker pressure dependence than the conductivity, the coefficient being $4x10^{-5}$ bar^{-1} for the mobility and $1.3x10^{-4}$ bar^{1} for the conductivity. That is a rather surprising result since according to Hall effect measurements the hole concentration does not depend on pressure (2). This discrepancy is even more pronounced for $\vec{j} \parallel \vec{Z}$ where E_c is found to be completely independent of pressure. This result indicates that the mobility obtained from equation (1) is different from the Hall mobility though both are found to exhibit the same temperature dependence.

In principle a particularly strong pressure dependence of the sound velocity v_s could explain this result. Therefore, we have measured the pressure dependence of v_s in Te in different crystal directions and polarizations using conventional technqiues.[2)] In Fig. 2 the ratio $v_s(p)/v_s(0)$ is shown as a function of pressure. For $v_s(0)$ at zero external pressure good accordance was found with the values published in the literature (4). Obviously there is a considerably stronger pressure dependence for waves with $\vec{k} \perp \vec{Z}$ than for those with $\vec{k} \parallel \vec{Z}$. Such behaviour is expected from the anisotropy of the bonding in Te crystals. The LA-phonon modes with $\vec{k} \parallel \vec{X}$ and TA modes with $\vec{k} \parallel \vec{Y}$ can interact with drifting carriers by their piezoelectric fields.

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2) The crystals were kindly provided by Prof. P. Grosse.

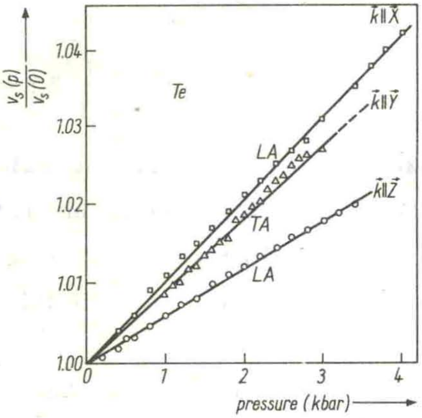

Fig. 2. Pressure dependence of the sound velocity

In their case a pressure of 3 kbar leads to an increase of v_s by about 3% corresponding to pressure coefficients of 10^{-5} bar^{-1} and 9×10^{-6} bar^{-1}, respectively. These values are relatively large as compared to other solids and indicate a pronounced anharmonicity of the lattice potential perpendicular to the Z axis. However, these coefficients are by far too small to account for the weak pressure dependence of the critical field.

This behaviour cannot be explained by a pressure dependence of the value of the attenuation constant α of the sound waves. Saturation takes place when α becomes negative because then the acoustic wave gains energy from the current carriers. The critical field where this effect sets in, is defined by $\alpha = 0$, which occurs when the drift parameter $\gamma = 1 - \mu E_c/v_s$ vanishes. That condition leads to equation (1). The observed discrepancy indicates that off-axis modes are important for the acoustoelectric effects in Te not only for $\vec{j} \parallel \vec{Z}$ but also for $\vec{j} \parallel \vec{X}$. In case of interaction with off-axis modes the orientation of the k vector of the sound wave with respect to the direction of the drift field becomes an important parameter which enters relation (1) (see reference (5)). If by pressure the contribution of these modes is diminished, the pressure dependence of the critical field will be less than expected from the pressure dependence of the mobility.

It is interesting that in trigonal selenium a quite similar behaviour has been observed (6). In this case from the absence of any pressure dependence of the critical field with $\vec{j} \parallel \vec{Z}$, it was concluded that the hole mobility was independent of pressure although the conductivity increased strongly. As has been demonstrated here, such a conclusion is not justified. In Se like in extrinsic Te the pressure dependence of the conductivity is supposed to originate mainly from an increase of the hole mobility.

References

(1) J.H. MCFEE, Physical Acoustics, Vol. IV, Part A, Academic Press, New York 1966 (p. 1).

(2) D. LOND, Phys. Rev. 101, 1256 (1956).

(3) W. BECKER, W. FUHS, and J. STUKE, phys. stat. sol. (b) 44, 147 (1971).

(4) P. GROSSE, Springer Tracts mod. Phys. 48 (1969).

(5) G. QUENTIN and J.M. THUILLIER, Proc. Internat. Conf. Phys. Semicond., Kyoto 1966 (p. 493).

(6) F. DOLEZALEK and W. SPEAR, J. non-cryst. Solids 4, 97 (1970).

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