

Letters to the Editor

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Electronic Hall Effect in NaCl*

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BY applying the pulsed light method of Pohl and his co-workers¹ to the measurement of electronic Hall effect in insulating photoconductors it has been possible to avoid the space-charge difficulties present in previous work.^{2,3} The electrode arrangement is shown in Fig. 1. The battery V_L sets up a potential

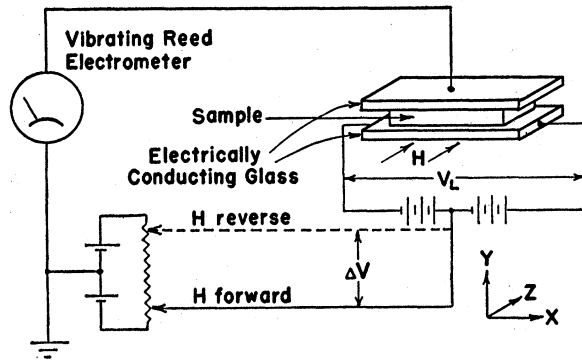


FIG. 1. Electrode arrangement for observing electronic Hall effect in insulating photoconductors.

gradient on the lower surface of the crystal, and thus an inhomogeneous field in the crystal which is, on the average, in the x direction. The upper plate is held at ground potential by the electrometer circuit; the potential of the entire lower plate can be changed with the potentiometer, and moving the potentiometer tap rotates the electric field in the crystal. The electrometer responds only to the component of charge flow which is in the y direction.

In making a measurement, a magnetic field is applied in the z direction, the crystal is illuminated with pulses of light a few seconds in duration, and the potentiometer is adjusted until the electrometer gives zero deflection during illumination. This means that the average charge flow in the crystal is in the x direction parallel to the electrodes, but the average electric field is at an angle, the Hall angle, to the electrodes. To eliminate space charge, the batteries are turned off between each observation of the electrometer, and the crystal is illuminated with a strong light.

The magnetic field is then reversed and the potentiometer is again adjusted as before, so that the average charge flow is again in the x direction but the average electric field has been rotated through twice the Hall angle. Using a theorem of Shockley,⁴ it can then be shown rigorously that (for small θ)

$$\frac{2\mu H}{c} = 2\theta = \frac{\Delta V}{D} \frac{\int n\tau dv}{\int E_x n\tau dv}$$

where μ is the mobility, H the magnetic field, c the velocity of light, θ the Hall angle, D the thickness of the crystal, n the number of electrons per unit volume released by the light, τ the mean

electronic lifetime, and E_x the x component of electric field in the crystal. The integrations are over the volume of the crystal.

This method differs from the conventional one in several ways. First, it is a transient method. Second, the electric field inside the crystal is rotated by external electrodes, rather than by the electrons under study. Finally, no attempt is made to inject or eject electrons through the surface of the crystal. The method cannot be applied directly to crystals having finite dark conductivity. It has already been applied to diamond.⁵

Both additively colored and x-rayed Harshaw NaCl crystals have been studied and the charge released from F centers in these crystals gives a Hall voltage polarity characteristic of electrons. At $82 \pm 2^\circ\text{K}$ the mobility is $250 \pm 50 \text{ cm}^2/\text{volt sec}$, and at 200°K the mobility is of the order of forty. The experimental error is due to noise in the conducting plates, F center bleaching, temperature variations, or possibly crystal imperfections. By violently quenching the crystal, its mobility can be reduced to as low as $150 \text{ cm}^2/\text{volt sec}$ at 82°K . These observations are in reasonable agreement with both the theory of Fröhlich and Mott⁶ and the more recent calculation of Low and Pines.⁷ Work is under way to improve and extend these measurements.

The help of many people in this work is gratefully acknowledged; the author wishes particularly to thank Dr. R. J. Maurer for his frequent suggestions and Dr. C. P. Slichter and his associates for the use of their magnet.

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² J. Evans, Phys. Rev. **57**, 47 (1940).

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⁵ A. Redfield, paper presented at the 1953 North Carolina meeting, Bull. Am. Phys. Soc. **28**, No. 2, 46 (1953).

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Some Electrical Properties of Strontium Titanate

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SOME properties of very pure synthetic strontium titanate single crystals grown at this laboratory by the flame fusion technique¹ have been investigated by electrical methods. It was felt that these preliminary measurements would be of interest due to the high dielectric constant of this material and its close relationship to the ferroelectric barium titanate. Strontium titanate, SrTiO_3 , like barium titanate above its Curie point, is a cubic crystal of the perovskite type.

The dc conductivity as a function of temperature is shown in Fig. 1. These measurements were made at a field strength of 2500 volts per cm with fired-on silver paste electrodes. If the conductivity is represented by the Boltzmann equation $\sigma = \sigma_0 \exp(-\epsilon/kT)$, then for $kT \ll \epsilon$ the activation energy is $E = 2\epsilon = 0.68 \text{ ev}$. This is very close to the value found by Cronemeyer² for slightly reduced rutile crystals, suggesting a conductivity mechanism similar to that in rutile involving electrons trapped at oxygen vacancies. Preliminary optical density measurements on a clear single crystal plate of strontium titanate have indicated a corresponding absorption peak in the neighborhood of 2μ (0.63 ev). The energy necessary to raise an electron from the valence band to the conduction band can be deduced from the position of the ultraviolet absorption edge at $395 \text{ m}\mu$, corresponding to an intrinsic activation energy of 3.15 ev. This assumption will be checked by high-temperature conductivity and photoconductivity measurements.

The dielectric constant ϵ' and the loss tangent $\tan\delta$ are shown in Fig. 2 as functions of temperature at various frequencies. On the scale shown, there is no substantial difference in the dielectric constant at the three frequencies. From 125°C to -50°C the

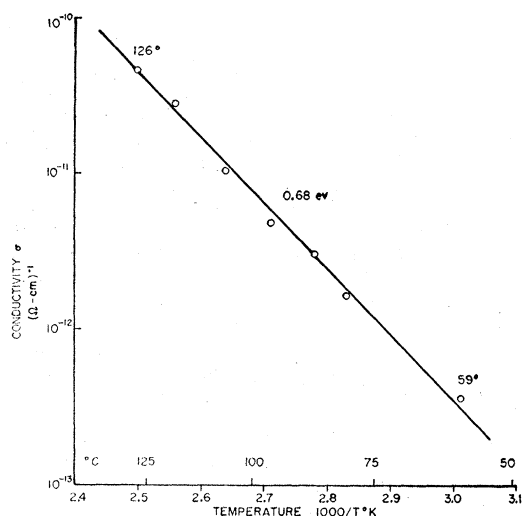


FIG. 1. The dc conductivity as a function of temperature.

dielectric constant can be fitted by a Curie-Weiss law curve, $\epsilon' = C/(T-\theta)$, with $C = 8.5 \times 10^4$, $\theta = 17^\circ\text{K}$. However, at -160°C , this curve gives a value of $\epsilon' = 880$, compared to a measured value of 815, thus indicating, in agreement with Hulm's results on

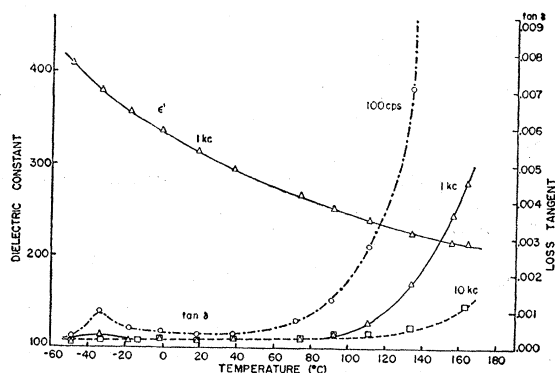


FIG. 2. The dielectric constant ϵ' and the loss tangent $\tan\delta$ as functions of temperature at various frequencies.

sintered strontium titanate,³ that a Curie-Weiss law curve based on high-temperature data should not be used to predict a ferroelectric Curie point for this material. It should be noted that the value of the dielectric constant for a single crystal was found

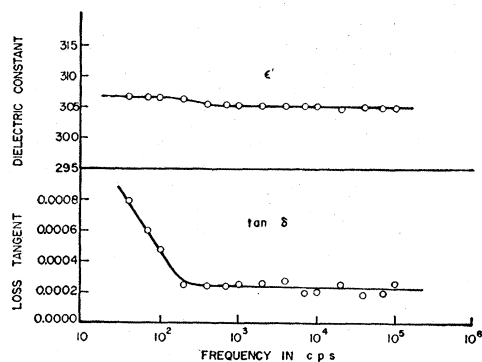


FIG. 3. The dielectric constant and loss tangent as functions of frequency at 25°C .

to be twenty percent higher than values found by Hulm and others⁴ for sintered specimens, although the latter values were corrected for porosity. The increase in loss tangent with temperature is presumably the result of the increase in conductivity of the crystal, but the cause of the peak at -30°C is not known.

The dielectric constant and loss tangent as functions of frequency at 25°C are shown in Fig. 3. The loss tangent appears to consist of a polarization loss, $\tan\delta = 0.00025$, substantially independent of frequency over the range studied, and a conductivity loss approximately inversely proportional to the frequency. The situation is complicated by space-charge effects in the crystal and at the boundaries where diffused silver ions from the electrodes form low-lying electron traps. A more detailed investigation is in progress.

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Evaporation of Copper from Germanium

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BECAUSE of the interest in "thermal" acceptors introduced into germanium by heat treatment^{1,2} and because of the fact that these acceptors may be due, at least in part, to copper as an impurity,^{3,4} the following results are believed to be significant. It has been found that if germanium is heat treated in a vacuum, the number of acceptors introduced at a given temperature and a given quench time is less than that corresponding to heat treatment in an atmosphere of helium (see Fig. 1).

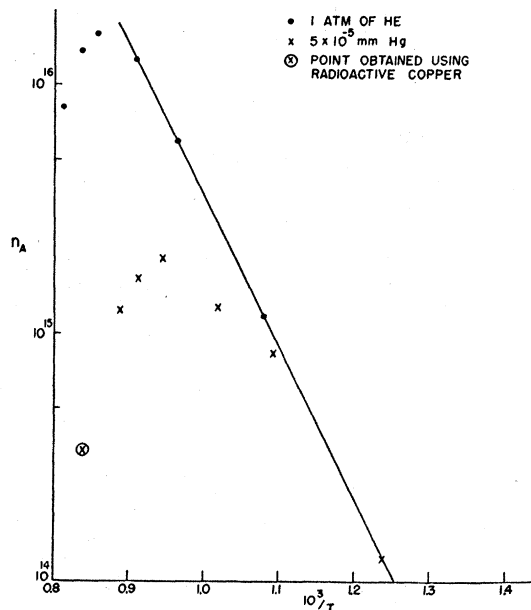


FIG. 1. Number of acceptors introduced as a function of the reciprocal of the heat-treatment temperature for two residual gas pressures.

In addition, radioactive copper was deposited on the surface of several samples of germanium by dipping the germanium in a solution of radioactive copper nitrate. This copper was then diffused into the germanium to within one percent of equilibrium by heating in one atmosphere of helium at 918°C . One of these samples was then etched to remove any excess copper from the