

where a , the jump distance between interstitial positions, is 2.4 Å. Since the jump time as a function of temperature is known, the number of jumps, J , an interstitial might take during the quenching of a germanium sample from high temperature is given by the expression

$$J = \int \frac{dt}{\tau} \equiv \int \frac{dT}{\tau} \frac{dt}{dT}. \quad (5)$$

The cooling rate during the quenching process is governed by the radiation law. Therefore,

$$\frac{dT}{dt} = \left(\frac{dT}{dt} \right)_Q \frac{T^4}{T_Q^4}, \quad (6)$$

where T_Q is the temperature near the melting point from which the sample is quenched and $(dT/dt)_Q$ is determined at the temperature near the melting point by measuring the power required to maintain the sample at that temperature.

By use of Eqs. (3), (4), and (6), Eq. (5) yields

$$J = -\frac{3 D_0}{2 a^2} T_Q^4 \left(\frac{dT}{dT} \right)_Q \int_{T_Q}^{300^\circ\text{K}} e^{-E/RT} \frac{dT}{T^4},$$

where $T_Q \sim 1200^\circ\text{K}$ and $(dT/dt)_Q \sim -100^\circ\text{K}/\text{sec}$ for the particular samples used in our quenching experiments. The result is that $J = 2 \times 10^{12}$.

Thus, the total number of jumps that an interstitial can take during the quenching process is 10^{12} . This is an extremely high number of jumps; so high in fact that it is impossible to see how we could have quenched in any vacancies or interstitials during the quenching process. From Eq. (2) we see that there is at most one vacancy and interstitial in 10^8 atoms in a quenched sample. If the interstitials jump 10^{12} times during the quenching process, interstitials will have had occasion to jump close to vacancies and recombine with them. Therefore, it is impossible to envision how we are able to observe any concentration at all of quenched-in Frenkel defects.

If we had assumed that the vacancies were more mobile, and hence the mechanism of self-diffusion was vacancy diffusion, then the number of jumps which a vacancy would undergo in the cooling process would be about the same as the number of jumps calculated above for interstitials. In this case we would have also been led to the conclusion that no defects could be quenched into the sample.

A simple way of explaining the anomaly is to invoke ring diffusion as the mechanism for the self-diffusion in germanium. Zener⁵ has studied ring diffusion extensively in copper and has shown that the simultaneous interchange of several atoms in a ring requires less energy than the direct interchange of two atoms. The complexity of the covalent bonding in germanium makes it difficult to estimate the activation energy of ring diffusion for comparison with experiment. However,

since all atoms of the crystal can participate in ring diffusion, the atomic jump rates required for ring diffusion to explain the self-diffusion are slower by a factor of 10^8 than the jump rates of the defects if a defect mechanism were the correct mechanism of self-diffusion.

Another piece of evidence against defect diffusion explaining the self-diffusion comes from the work of Brown, Fletcher, and Wright⁶ who studied the annealing of bombardment damage in germanium. They find that the activation energy for the fastest-moving defect is 41 600 cal/mole. If we combine this energy of motion with the activation energy for production of defects, Eq. (2), we find the activation energy for self-diffusion by a defect mechanism to be 87 700 cal/mole which is 30 percent higher than the measured energy of self-diffusion.

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Thermal Bleaching of Color Centers

A. HALPERIN AND A. BRANER

Department of Physics, The Hebrew University, Jerusalem, Israel

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RECENTLY Hesketh and Schneider¹ have reported results of observations on the thermal bleaching of F -centers in KCl crystals colored by x-rays. Their bleaching curves showed peaks at about 170°K , which they have interpreted as due to a large scale restoration of F -centers. It was later suggested by Halperin and Garlick² that these absorption peaks, as well as similar peaks which appear on warming other crystals from low temperatures, are caused by vapor films which condense on the surfaces of the crystals.

We have now been able to eliminate completely these peaks by introducing an efficient liquid-air trap into the

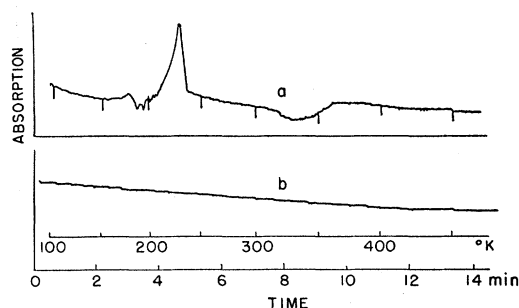


FIG. 1. Absorption of an uncolored KCl crystal on warming from 90°K : (a) showing the effects of condensed vapor films; (b) showing elimination of these effects by an effective trap.

evacuated cryostat near the crystal. Thus it was proved definitely that the peaks are due to condensed films and should not be related in any way to the color centers in the crystal.

The effect of this trap is illustrated in Fig. 1, which is a photocopy of two independent records of the absorption of an uncolored KCl crystal *vs* temperature, on warming the crystal from 90°K to about 500°K. Curve *a* was obtained with the aforementioned trap made ineffective by keeping it at room temperature. It shows the peaks due to condensed vapor films. The main peak at about 225°K corresponds to about 20 percent absorption in this case. (The small regular marks to the lower side of the curve are temperature indications from 100 to 450°K, every 50°K.)

Curve *b* shows the results of the same measurement repeated but this time with the trap kept at 90°K during warming. No traces are now left of the peaks which appeared in curve *a*. The small slope in the curve seems to be due to a slight increase in the transparency of the crystal with increase in temperature.

The undisturbed curve of the thermal bleaching of *F*-centers in a KCl crystal colored by x-rays at 90°K was now measured with the new arrangement. The trap was kept at 90°K during the time of x-irradiation and during warming after the irradiation, when the absorption of the crystal at 5500 Å was continuously recorded as function of time of warming. The rate of heating was kept nearly constant (about 25 deg/min for the range 120–600°K) by suitable adjustment of the power of the heater. A plot of the optical density *vs* temperature, as obtained from this record is given in Fig. 2. No restoration of *F*-centers takes place. The shape of the curve, however, shows that the trapped electrons leave the *F*-centers mainly at several fixed temperature regions, which indicates the existence of several activation energies. These measurements were repeated several times and found to be reproducible. Hesketh and

Schneider claim that in their measurements the “peaks” appeared only after *F*-irradiation at 90°K before warming. To check this, a crystal colored at 90°K was partially bleached optically by *F*-light before warming. However, the thermal bleaching curve obtained in this case was essentially the same as in Fig. 2.

The thermoluminescence of the same crystal colored similarly by x-rays at 90°K was also measured; once with a phototube sensitive in the ultraviolet-blue region as detector, and then with one of maximum sensitivity at about 9000 Å. Several luminescence peaks were recorded in these measurements and were found to fit well the temperatures at which *F*-centers are released, as obtained from Fig. 2. Thus, with the “blue” detector the main thermoluminescence peaks were at 220°K and 315°K (in addition to a few minor peaks). With the “red” detector a strong peak was obtained at 450°K and minor peaks at 220 and 350°K.

The existence of several activation energies for *F*-centers in KCl crystals was already reported from thermoluminescence experiments^{3,4} and from “current glow curves.”⁵ The temperatures of the peaks correspond fairly well to those obtained in the present work.

Investigation is being carried on and a fuller account will be published later.

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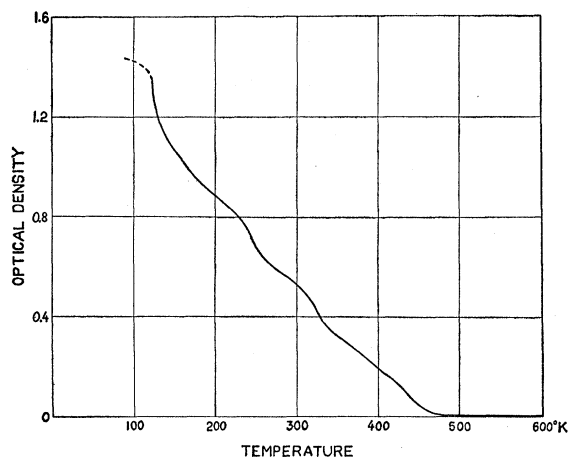


FIG. 2. Thermal bleaching curve of *F*-centers in a colored KCl crystal.

Dislocation Relaxations at Low Temperatures and the Determination of the Limiting Shearing Stress of a Metal

W. P. MASON

Bell Telephone Laboratories, Murray Hill, New Jersey

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RECENTLY, Bordon¹ has measured attenuation peaks at low temperatures in lead, aluminum, copper, and silver which indicate relaxation effects. Measurements of Bömmel² on lead single crystals whose Q^{-1} values are shown by Fig. 1 verify that this is a relaxation effect. Plotting the log of the frequency against the inverse of the absolute temperature, Fig. 2, one determines an activation energy U of 790 calories per mole with a constant $C = 2.9 \times 10^9$ in the equation $\omega_0 = Ce^{-U/RT}$.

It is shown that the values obtained agree with a displacement of a dislocation from a minimum energy position in a close-packed glide plane by one atomic spacing against the limiting shearing stress of the crystal. The model considered is one used by Koehler.³ Dislocations are tied down at irregular intervals by impurity atoms, giving loops of average length l .