assistance and suggestions concerning the microwave components of the apparatus.

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QUENCHED-IN LATTICE VACANCIES IN COPPER

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Preliminary experiments on quenching and annealing of pure copper are reported. Thin copper wires, of 0.04- and 0.07-mm diameter,[1] were electrically heated in purified argon; the wires were 30 cm long in order to minimize the effects of nonuniform temperature at their ends. Quenchings were performed by natural cooling after disconnecting the power supply: the total cooling times were oscillographically measured and were about 0.45 sec for 0.04-mm wires and 1.2 sec for 0.07-mm wires. The initial cooling rate was estimated to be about 5×10^3 °C/sec for the thinner wires.

Up to twenty quenchings and annealings could be done with reproducible results using the same specimen: later on smaller changes of resistivity due to quenching were found, the results depending somewhat upon the history of the specimen.

The changes in resistivity $\Delta\rho$, measured at room temperature, are exponentially dependent on $1/T$ for both diameters of wires, provided the quenching temperature T is less than 1150°K. They tend to saturate at higher temperature and this fact indicates that cooling is not fast enough for retaining all defects within the quenched specimens at high temperature. Results which have been obtained at low quenching temperatures for both diameters of wires are given in Fig. 1. Extrapolation to the melting point of copper gives $\Delta\rho \simeq 2\times10^{-7}$ ohm cm, which, according to calculations by Jongenburger[2] and Abelès,[3] corresponds to a concentration of vacancies of about 1.5×10^{-3}. The formation energy of vacancies is equal to 1.0 ± 0.1 ev.

Isothermal annealing curves were obtained for temperatures ranging between 350°C and 470°C and with initial concentration of vacancies near to 10^{-5}; the recovery of quenched-in resistivity was almost complete in any case.

Results given in Fig. 2 refer to 0.04-mm wires and show an activation energy equal to about 1.3 ev. The number of jumps a defect makes before disappearing at sinks is 10^6-10^7.

On the other hand, annealing curves obtained with 0.07-mm wires suggest an activation energy for recovery near to 1.6 ev. This difference may be related to the slower cooling rate obtainable with these wires, the formation of complex defects due to clustering of vacancies being responsible for the higher activation energy. The effect is probably present to some extent even with the 0.04-mm wires, though it is presumable that 1.3 ev is nearer to the true value of the

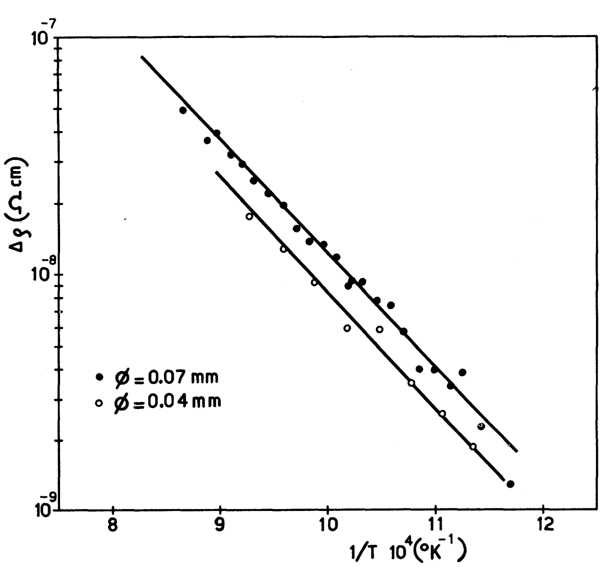

FIG. 1. Changes in resistivity due to quenching for 0.07- and 0.04-mm diameter copper wires.

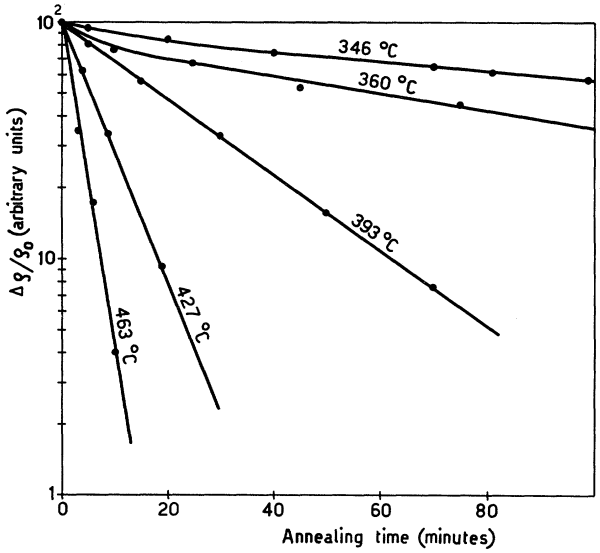

FIG. 2. Typical isothermal annealing curves. 0.04-mm wires quenched at about 930°K.

migration energy of vacancies. Recently Damask et al.[4] calculated the activation energy for migration of vacancies at 1.3 ev in copper.

The experimentally known value of the activation energy for self-diffusion in copper (2.05 ± 0.15 ev),[5] if combined with the above value of the energy for vacancy production, suggests that the migration energy of a vacancy must be somewhat larger than 1 ev, in agreement with the result by Granato et al.[6] This fact does not conflict with present annealing data.

A more accurate determination of the activation energy for migration of vacancies could have been obtained if faster quenchings were feasible: many attempts have been made to find out a suitable quenching agent, but they were unsuccessful, poor reproducibility having been achieved. Thinner copper wires might possibly be used with the purpose of getting shorter cooling times without loss of accuracy.

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THERMAL AND RADIATION ANNEALING OF Ge*

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It is found that about 50% of the defects produced by 1.10-Mev electron irradiation of Ge at temperatures near 10°K can be annealed either by heating to 80°K or by irradiating with electrons of energy less than the threshold for damage.

Nearly degenerate single crystals of n-type Ge ($n_0 = 7\times10^{17}/\text{cm}^3$) were used in this investigation. Samples, 60 to 80μ thick, were mounted in a cryostat which permitted measurement of Hall coefficient, R, and conductivity, σ, as a function of irradiation. The sample temperature was maintained by heat exchange through low pressure He gas to a liquid He reservoir. Temperature was measured by means of two calibrated carbon resistor thermometers, one soldered to each end of the sample. The resistors were shielded from the electron beam. The rise in sample temperature during irradiation was less than 6°. All measurements of R and σ were made at 4.2°K.

Both σ and carrier concentration, n, decreased almost linearly under 1.10-Mev irradiation. The change in mobility, $\Delta(R\sigma)$, accounted for about 60% of the change in σ. The rate of removal of carriers was 2 (carriers/cm^3) per (electron/cm^2). This is about twice the value obtained for nondegenerate samples at 78°K.

Figure 1 illustrates the thermal recovery of σ after 1.10-Mev irradiation. Each point represents the value at 4.2°K after 7.5 minutes at the temperature of anneal. Two recovery regions were observed. The first, near 30°K, was well defined on all anneals. The second was more or less distinct depending on the sample and its history. No further recovery was observed between 80° and 130°K. The recovery in Fig. 1 amounts to 50% of the change under irradiation. If a first-order recovery process is assumed, the 30°K recovery occurs with an activation energy of 0.04 ev. Values for the higher temperature recovery lie between 0.06 and 0.09 ev.

These results are in substantial agreement with those of Gobeli,[1] who observed thermal recovery in both n- and p-type Ge after irradiation near 4.2°K with 3.7-Mev α-particles. Cleland