Energy-Dependent Behavior of Intrinsic Close-Pair Defects within Copper*

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The low-temperature substages of high purity copper, which are associated with close-pair Frenkel defects, have been measured following 2-Mev electron irradiations. Results are in the region of multiple defect production and show that a correlation exists between prior experimental work performed by lower energy electron and 10-Mev deuteron bombardments. It is evident that each intrinsic substage possesses a very definite dependence upon irradiation energy.

IRRADIATION of metals at very low temperatures, and the subsequent anneals, have resulted in defining stages whereby the change in a structure-sensitive property induced by bombardment is recovered within definite temperature intervals. Independent techniques of isochronal and isothermal annealing methods have shown[1] identical substages included within the low-temperature recovery stage (14–65°K) of high-purity copper. These substages for copper have been designated as I_A, I_B, etc., and have been identified by Corbett *et al.*[1] as due to various vacancy-interstitial interactions. Results of Corbett and Walker[2] indicate that the fraction of the total damage associated with the various substages show definite trends when the electron bombardment energy is varied from 0.65 to 1.4 Mev. This work, by bombardment at 2 Mev, extends former electron studies into the region where secondary displacements become significant, thereby almost doubling the range of bombarding energies studied.

Copper specimens, 99.999% pure, were bombarded with 2-Mev electrons at temperatures below 14°K. Samples were then subjected to isochronal anneals according to methods of previous investigators.[1] Results of resistivity changes are given in Table I.

Our discussion is limited to the first three substages since their intrinsic nature[1,3] enables some degree of comparison among results from independent laboratories. In the absence of more detailed theory we have arbitrarily, and perhaps crudely, chosen the average recoil energy as a gauge for comparison. In Fig. 1 we have therefore plotted the average recoil energy versus the percent of resistivity change which is recovered for I_A, I_B, and I_C. This figure includes the 10-Mev deuteron data of Magnuson *et al.*,[4] electron data of Corbett and Walker,[2] Sosin,[5] and the average values from Table I. It is gratifying that all data fit on smooth curves.

TABLE I. Experimental values for the magnitude of damage in the low-temperature recovery stage of copper for 2-Mev electron irradiation.

	Specimens			
2-Mev electrons/cm²(10^{16})	10.8	3.0	2.2	
Total change of resistivity (10^{-12} ohm-cm)	15.8	4.16	3.37	
Recovery stage				Average
I_A	2.6%	3.4%	3.0%	3.0%
I_B	12.0	12.2	11.8	12.0
I_C	10.0	7.9	9.8	9.3
<65°K	21.5	26.2	24.6	24.1

One notes the following conclusions from Fig. 1: (1) Results from this 2-Mev electron irradiation confirm and extend the trends suggested by the data of Corbett *et al.* (2) The 10-Mev deuteron data fit the same curves. (3) The major variation occurs near the threshold energy for displacement. (4) An increasing percentage of I_A for higher irradiation energies contradicts the intuitive behavior expected for close pairs. Any model of defect production and/or recovery must account for these facts. One such model is suggested by Sosin.

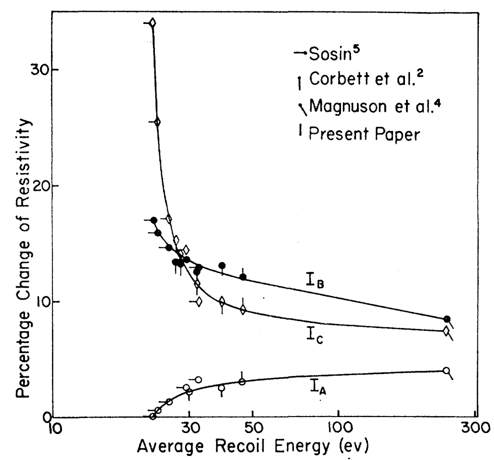

FIG. 1. Points corresponding to an average recoil energy of 240 ev indicates data obtained by 10-Mev deuteron irradiation. The remaining data was determined by electron irradiation. An average recoil energy of 46 ev pertains to average values listed in Table I, and values required for determining all other points are listed in reference 2 or 5.

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[2] J. W. Corbett and R. M. Walker, Phys. Rev. **115**, 67 (1959).
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[4] G. D. Magnuson, W. Palmer, and J. S. Koehler, Phys. Rev. **109**, 1990 (1958).
[5] A. Sosin (to be published).