Letters to the Editor

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Effect of Precipitation Hardening on the Superconducting Transition of an Aluminum Alloy*

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THIS letter reports the preliminary results of an experimental investigation of the changes in superconducting properties which accompany the precipitation hardening of an alloy. It was necessary to choose a precipitation hardening system whose major constituent was a superconductor and preferably a system whose mechanical and metallurgical properties had been reasonably well investigated. For these reasons the aluminum alloy Alcoa 63*S* was chosen. Its composition is 0.7 percent Mg, 0.4 percent Si, more than 98 percent Al, and traces of other elements. The precipitation hardening in this alloy is associated with the precipitation of the Mg and Si from a supersaturated solid solution in the form of the compound Mg_2Si. The heat treatment of the alloy first requires a soaking at 575°C to disperse the Mg and Si in solid solution followed by a water quench to room temperature. In the quenched alloy the Mg and Si are in supersaturated solution and the specimen is quite soft, being only slightly harder than pure aluminum. The alloy is hardened by reheating it to an intermediate temperature (in our case 175°C) so that precipitation can proceed by diffusion. For a given intermediate temperature the hardness, tensile strength, etc., increase with time to a maximum value (after about 24 hours) and then decline slowly with continued heating. If the precipitation of Mg_2Si is allowed to proceed until substantially complete, the specimen becomes soft again and this is designated as the annealed condition. The specimens used in this study were machined into the shape of ellipsoids of revolution from lengths of commercial bar stock.[1] Efforts to recrystallize the ellipsoids as single crystals removed the magnesium from the alloy and so the present measurements were made on polycrystalline material.

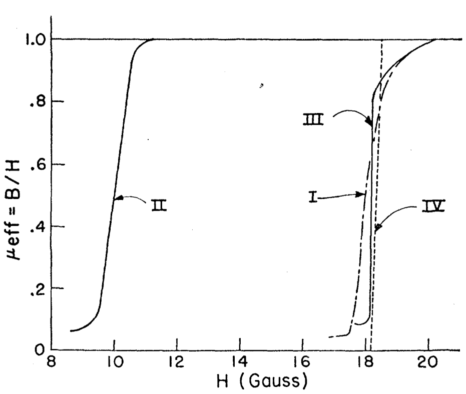

FIG. 1. Superconducting transitions for the aluminum alloy 63*S* showing the effect of heat treatment. All transitions shown above were measured at $T=1.049$°K. (I) quenched alloy; (II) fully hardened alloy; (III) annealed alloy; (IV) pure aluminum.

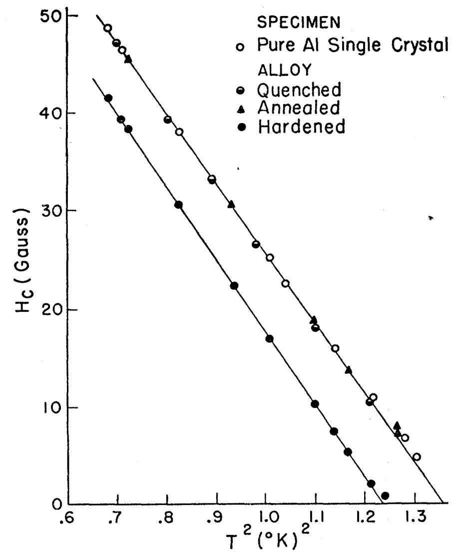

FIG. 2. Temperature dependence of critical field for aluminum alloy 63*S* for different heat treatments. Data for pure aluminum are included for comparison.

The superconducting measurements were made by a sensitive ballistic induction technique which measures the flux change in the specimen when the external magnetic field is changed by uniform stepwise increments. The measuring method makes it possible to follow the flux changes in the specimen as it goes from the superconducting to the normal state or visa versa. We have found it convenient to represent the transition in terms of the "effective" permeability of the specimen as a function of the applied magnetic field. A plot of this type is shown in Fig. 1 on which are represented the superconducting transitions for an alloy specimen in several conditions of hardness. The abscissa of Fig. 1 is a considerably expanded scale and it will be noted that the alloy transitions are relatively narrow. The measuring method employed makes it possible to compare the transition of an alloy specimen with a pure single crystal of aluminum of identical shape on the same experimental run. As can be seen in Fig. 1, the transition for the alloy in the quenched condition closely approximates that of pure aluminum. The maximum displacement of the transition corresponds to maximum hardness of the alloy specimen, and the transition for an

annealed specimen again approximates that for pure aluminum.

The experimentally determined critical fields have been plotted as a function of the square of the temperature in Fig. 2. Data for the alloy specimens in the quenched, fully hardened, and annealed conditions are shown together with data for pure, single crystalline aluminum. Besides the relatively large magnitude of the displacement produced by hardening, it is noteworthy that analysis of the slopes of the alloy transition curves indicates that the electronic specific heat in the normal state is not affected by the hardening process. The observed changes in the superconducting properties are attributed to the internal strain in the aluminum lattice which develops as the Mg_2Si begins to precipitate. It is hoped that work still in progress on the superconducting properties in intermediate conditions of hardness will yield further information on the way in which the stress fields in these specimens develop.

From the viewpoint of the atomic theories recently advanced by Fröhlich[2] and by Bardeen,[3] the substantial displacement of the critical field curve can be interpreted as due to a change in the vibration spectrum of the lattice. The validity of this interpretation can be examined by experiments on the effect of precipitation hardening upon the Debye temperature. From a simple argument based on the Fröhlich-Bardeen concept it can be shown that the Debye temperature for a superconductor should vary inversely with its critical temperature when the changes are induced by lattice strains. The magnitude of the changes in critical temperature observed in the present work are believed to be sufficiently large to correspond to measurable changes in the Debye temperature of this alloy if the above proportionality is correct. An investigation of this possibility is now being carried out.

* This work has received partial support from the Office of Ordnance Research.
† On leave from Preston Laboratories, Butler, Pennsylvania.
[1] Kindly supplied to us by the Aluminum Company of America.
[2] H. Fröhlich, Phys. Rev. 79, 845 (1950).
[3] J. Bardeen, Revs. Modern Phys. 23, 261 (1951).

Distribution of Trapping Levels in Cadmium Selenide

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TRAP distributions in phosphors have been investigated with the glow curve technique by many workers including Randall and Wilkins,[1] Klasens,[2] Bude,[3] Gillson,[4] and Johnson and Williams.[5] The technique involves cooling the phosphor in the dark, irradiating, and then warming again in the dark after the original phosphorescence has decayed to equilibrium. During the warming process the phosphor glows as traps are emptied by thermal activation and the intensity of glow is measured as a function of the temperature. The temperature at which the glow peak occurs is proportional to the energy depth of the traps and the height of the peak is proportional to the number of traps at that temperature.[1]

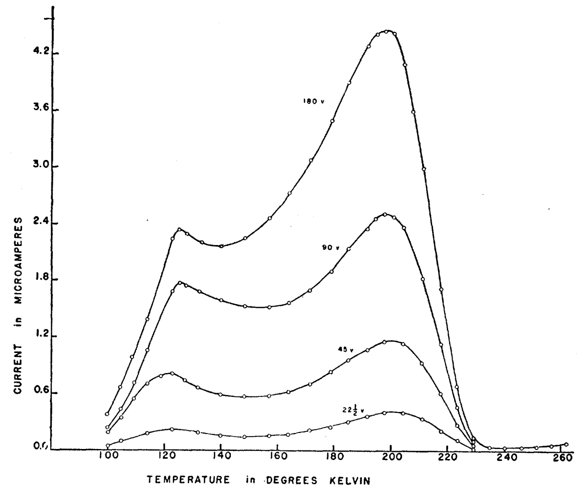

FIG. 1. "Electrical glow curves" taken in CdSe with various bias potential differences.

An analogous procedure for the investigation of trap distributions in photoconductors is suggested by the work of Herman and Hofstadter[6] with willemite reported in 1940 and that of Frerichs[7] with cadmium sulfide in 1949 where current pulses, instead of light pulses, occur during the warming of photoconducting materials, in the dark. Measurements of this nature were made by Dutton and Maurer[8] in 1953 on KCl and KBr who also measured absorption after irradiation, but both before and after warming, that gave definite correlation between absorption peaks and current peaks. Herman and Hofstadter used ultraviolet, Frerichs gamma rays, and Dutton and Maurer x-rays.

Figure 1 exhibits "electrical glow curves" for a crystal of cadmium selenide (4 mm long by 1-mm^2 cross section) for each of four different bias potential differences and shows peaks at 125°K and 200°K for warming rates of about 2 degrees per minute. The slow increase of conductance above 235°K, as shown on the 180-volt curve, is presumed to be the normal semiconductor increase of conductance with temperature. No further peaks were observed when the temperature was raised to 360°K. Furthermore, if the cycle of cooling and warming is performed without irradiation at the low temperature, no current is observed during the warming. The sample was kept in vacuum of about 10^{-6} mm of Hg to prevent condensation at the low temperatures. The excitation was produced with a small tungsten lamp operated at its normal power rating of six watts.

Although the curves in Fig. 1 were all taken from the same sample of CdSe, other samples were investi-