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ABSTRACT

The J_c vs H curve for $Nb_3(Al_{0.8}Ge_{0.2})$ was measured and compared with that of the binary compound Nb_3Al. The Nb-Al-Ge alloy curve had a "peak" and its resistive critical magnetic field, $H_r(J=0)$, was above 220 kG at 4.2°K. The composition of the ternary alloy was determined and found to be closer to the ideal 3:1 atomic ratio than that of the binary alloy.

Matthias, et al.[1] have reported a substantial increase in the superconducting critical temperature of Nb_3Al from about 18°K to above 20°K by the addition of Ge and subsequent annealing to form a well-ordered alloy of nominal composition $Nb_3(Al_{0.8}Ge_{0.2})$. They hypothesize that improved stoichiometry of the alloy over that of its pseudobinary components was responsible for the higher T_c. The superconductors with the largest known critical magnetic fields are A-15 compounds with high T_c: Nb_3Sn, T_c = 18.5°K, $H_{c_2} > 220$ Kg;[2] V_3Ga, T_c = 15°K, $H_{c_2} > 220$ Kg.[3,4] Since Matthias, et al. did not report critical field data for the new compounds, we determined the J_c vs H characteristics of several Nb-Al-Ge and Nb_3Al alloys.

The samples, prepared from elemental powders of Nb, Al and Ge, were pressed at 25 ksi into pellets and arc-melted in a non-consumable electrode arc furnace under a 300-350 torr argon atmosphere. Each 10-15 gram button was melted and inverted four times to improve homogeneity. The T_c values given in Table I were measured by detecting the inductance change of a coil surrounding small pieces of the arc-melted ingot. J_c vs H data were obtained on specimens spark-cut from the ingot. A four-wire probe technique was used to obtain the critical current density in pulsed magnetic fields with J perpendicular to H. The pulse rise-time varied with maximum applied field from 11.5 msec at 30 kG to 8.5 msec at 240 kG. In order to prevent excessive heating of the sample at high current densities, the dc current was initiated before the field pulse and terminated just after the maximum field was reached. The samples were tested at 4.2°K in both the as-cast condition and after annealing for three days at 950°C.

The Nb_3Al alloy (A-2) was a single phase compound containing the maximum amount of aluminum.[6] The Nb-Al-Ge alloys were multiphase with a continuous second phase which was responsible for their superconducting properties. The results of microprobe analysis for the Nb-Al-Ge alloys, with corrections for absorption, fluorescence,[7] and atomic number effect,[8] are shown in Table I. The sums of the Al and Ge content in the secondary phase were 22.9 and 21.7 at. % for the ternary alloys, as compared with 21.5 at. % Al for the binary alloy. The compositions of the ternary compounds can be written as $Nb_{3.36}(Al_{.72}\,Ge_{.28})$ for C-2 and $Nb_{3.61}(Al_{.72}\,Ge_{.28})$ for C-10.

The single phase Nb_3Al alloy (A-2) and the as-cast Ge alloy with highest T_c (C-10) were chosen for J_c vs H measurements. Some discussion of the criteria used in determining the data points is required. Below 500 amp/cm^2 noise became such a problem that reliable data could not be obtained at fields above 200 kG. This was true even when the sample was firmly attached to the magnet so as to reduce the relative motion between the two. Furthermore, the position of a J_{cs} point (chosen as 2% of full normal resistance) was extremely sensitive to dH/dt; e.g., for the binary alloy at a current density of 350 amp/cm^2, a critical field of 12 kG was associated with a dH/dt of 19 kG/msec and a field of 45 KG with 10 kG/msec. Thus, an additional criterion used for J_{cs} was that the field be at least one-half maximum at the 2% point. J_{cn} is the point at which complete transition to the normal state was observed.

The J_c vs H results are presented in Figs. 1 and 2 for the annealed binary (A-2) and ternary (C-10) compound respectively. These results are not appreciably different from those obtained with the same samples prior to annealing. Although the upper critical field of the annealed binary and ternary compounds was of the order of 250 kG, there was a significant difference in the shapes of the J_c vs H curves. The Nb-Al-Ge alloy had a broad "peak" in the J_{cs} vs H curve at fields between about 140 and 200 kG. Within this region, the material was perfectly superconducting (e.g. at values of J up to about 1000 amp/cm^2), whereas the binary alloy exhibited perfect superconductivity only below about 70 kG at the same current density. The peak effect has been associated with structural defects such as interstitial or substitutional impurities, high dislocation density induced by cold work, and non-superconducting precipitates or second phases.[5, 10, 11, 12] Broad peaks, such as observed in the ternary alloy, have been reported for cold-worked multiphase solid solutions of transition metals.[11, 12] In the present instance, the peak effect in the Nb-Al-Ge alloy may be due to the multiphase microstructure, composition gradients across phase boundaries, or local internal stresses associated with fluctuations in Ge content in the superconducting phase. Since the voltage developed across the sample was dependent on dH/dt (the speed with which flux enters the sample), it seems reasonable to conclude that J_{cs} would be shifted to higher fields, i.e. the peak will be broadened, when the ternary compound is tested in steady fields.[13]

The discontinuities in the J_{cn} curves shown in Figs. 1 and 2 are due to sample heating at high current densities; each segment represents data taken at a different maximum applied field. Since the rise-time to critical field is shorter for the higher maximum fields, the higher values of J_{cn}, which result at the faster rise times, are the more accurate reflection of the $4.2^{o}K$ performance. The resistivity was calculated at two different current densities and averaged. Resistivity and sample size are presented in the last column of Table I. The higher resistivity of the ternary alloy is to be expected in view of its multiphase microstructure.

Finally, we note that an extrapolation of J_{cs} for the Nb-Al-Ge alloy (C-10) to low current density indicates that $H_r(J=0)$ for this sample is well above 220 kG. This is at least as high as reported for Nb_3Sn and V_3Ga, which have the highest known values of resistive critical magnetic field.

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8. The exact correction for this effect is not known. We used one of the forms suggested by Castaing with values for the correction factors as collected by Wittry. See ref. 9.

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Table I. Composition, Microstructures, T_c, and Resistivity

Alloy	Microstructure	Composition, atomic %	Method of Analysis	T_c, °K [c] As-Cast onset	T_c, °K [c] As-Cast mid-point [d]	T_c, °K [c] As-Annealed [e] onset	T_c, °K [c] As-Annealed [e] mid-point	Resistivity at 4.2°K, [f] μ ohm-cm, and (Sample cross-sectional area, cm^2) As-Cast	Resistivity at 4.2°K, [f] μ ohm-cm, and (Sample cross-sectional area, cm^2) As-Annealed [e]
A-2	Single phase	21.5 Al, 0 Ge	weight loss, microstructure, phase diagram	18.17	17.97	18.02	17.28	47.0 (6.45×10^{-3})	34.0 (6.45×10^{-3})
C-2	three phase, secondary phase continuous	primary phase: 15.3 Al, 3.2 Ge secondary phase: 16.4 Al, 6.5 Ge tertiary phase: (a)	microprobe analysis (b)	18.41	18.38	19.13	19.04		
C-10	three phase, secondary phase continuous	primary phase: 11.0 Al, 2.1 Ge secondary phase: 15.7 Al, 6.0 Ge tertiary phase: (a)	microprobe analysis (b)	18.50	18.45	19.15	18.97	55.4 (9.70×10^{-3})	49.3 (9.70×10^{-3})

(a) small amount of tertiary phase, probably a σ-phase solid solution.

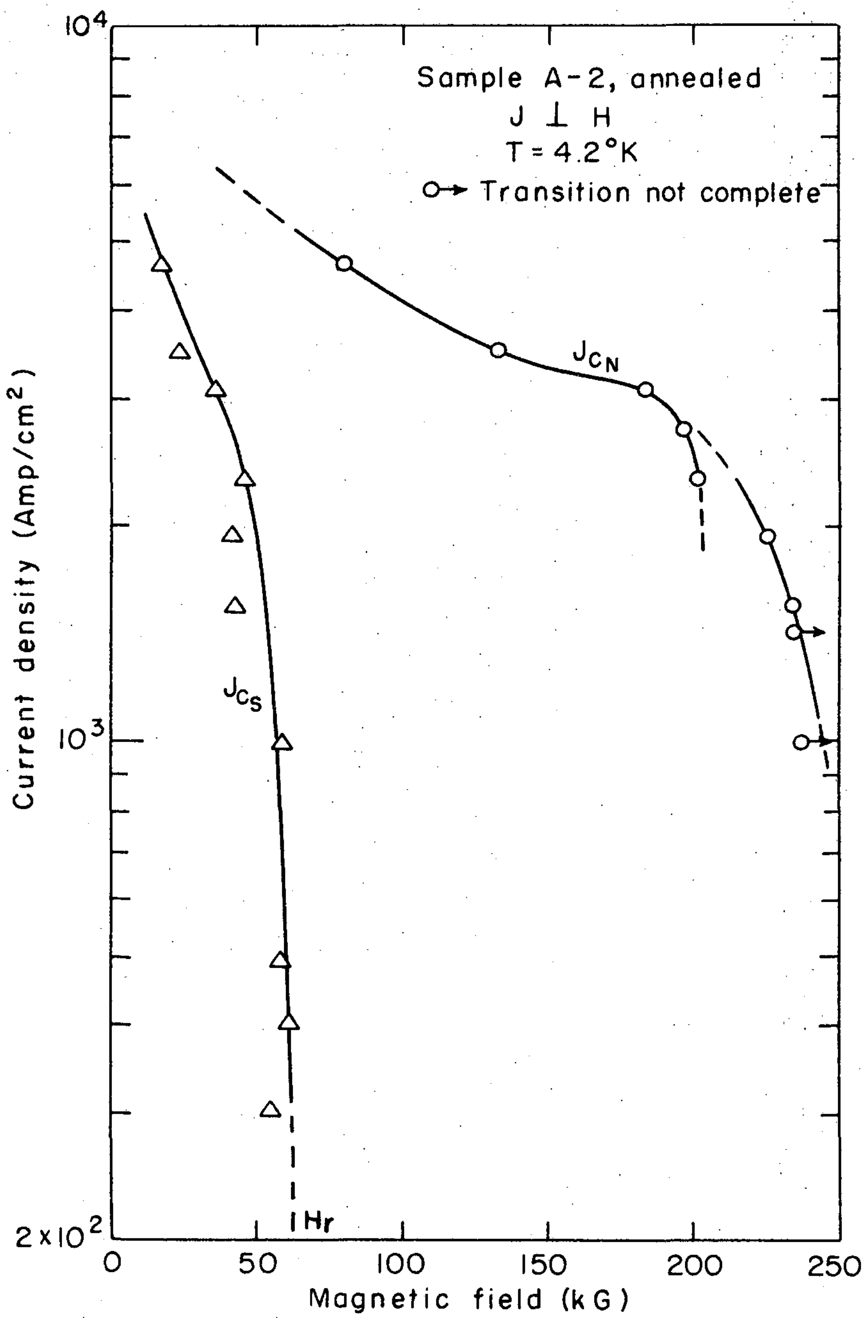
(b) corrected for absorption, fluorescence, and atomic number effect (see text).

(c) end-point of transitions uncertain due to "tail".

(d) temperature at 50% signal change.

(e) 72 hours at 950°C.

(f) obtained from J_c vs H oscilloscope traces.



XBL 6712-1966

Fig. 1 J_c vs H curves for alloy A-2, single phase Nb_3Al, in a pulsed magnetic field. $T_c = 17.28°K$.

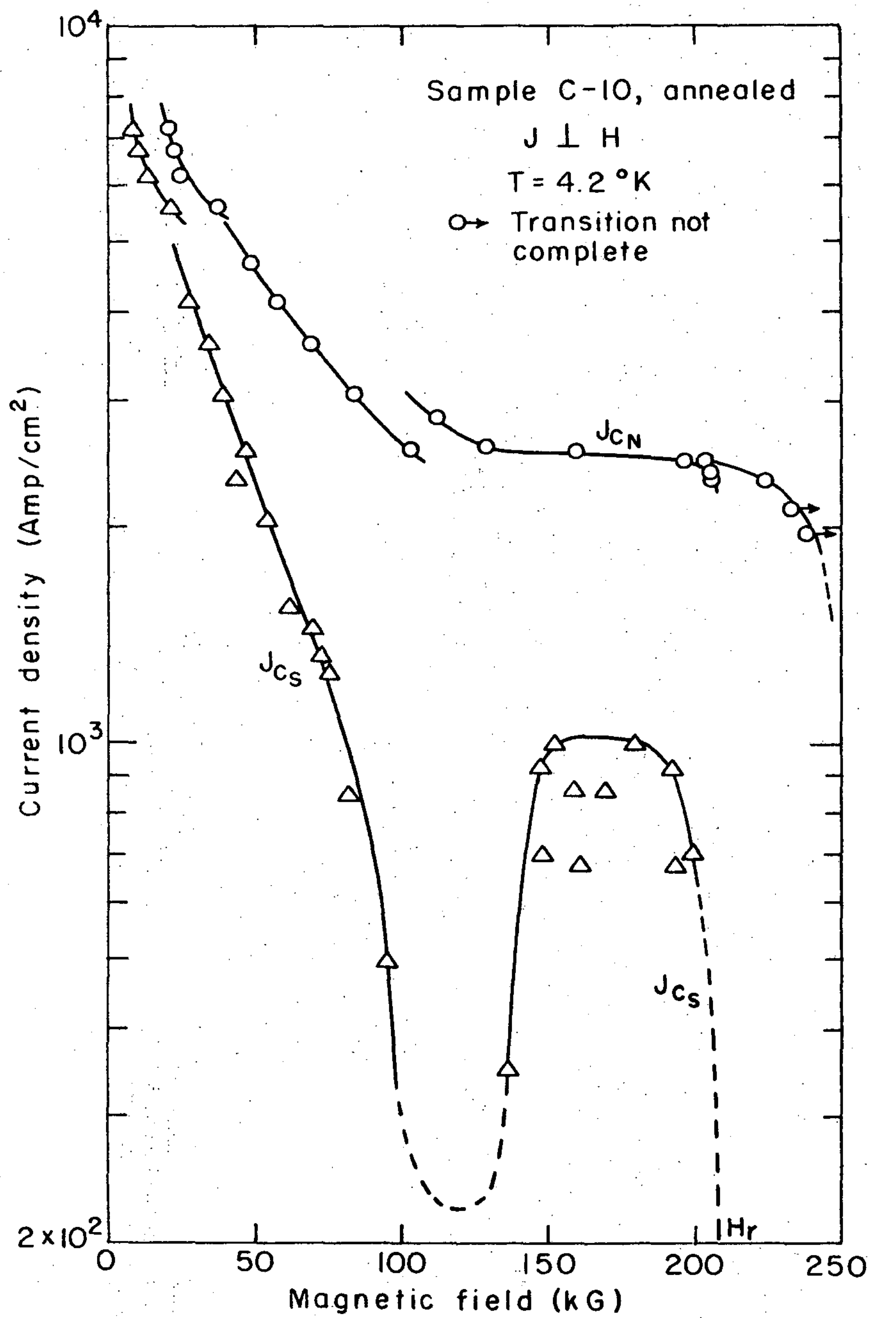


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Fig. 2 J_c vs H curves for alloy C-10, multiphase alloy of nominal composition $Nb_3(Al_{0.8}Ge_{0.2})$ in a pulsed magnetic field.
T_c = 18.97°K.