Anomalous Electrical Resistivity and Defects in A-15 Compounds

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Measurements of the temperature dependence of the electrical resistivity and correlations observed with T_c for V_3Si, V_3Ge, and A-15 Nb-Ge show (i) the existence of a universal defect in the A-15 superconductors which is not nonstoichiometry, (ii) a normal state anomaly also strongly influenced by the defects, and (iii) evidence that T_c and the electron-phonon interactions for transport processes are ~ 100 times more sensitive to defectproducing sample modifications in the A-15 compounds than in Nb.

It has recently been shown[1,2] that, for A-15 Nb-Ge, the crucial condition for high superconducting transition temperatures was not the existence of exact stoichiometry as previously expected but the minimization of a generic defect to which this compound is susceptible. We report in this note[3] evidence that the defect has a universal behavior in a number of the well-studied A-15 superconductors, and that the defect has significant influence on some of the normal state anomalies as well as the superconducting transition temperature.

In a previous work[1] a correlation between T_c and electrical resistance ratio $\rho(300\text{ K})/\rho(25\text{ K})$ was found for a wide variety, both chemical and processing, of A-15 Nb-Ge sputtered films. A similar correlation has now been found[4,5] in V_3Si and V_3Ge. The results for as-grown V_3Si are given in Fig. 1. For resistance ratios ~ 1 to 3, where all Nb-Ge data fell, the correlations for the two systems look quite similar. The principal difference is that for V_3Si (and V_3Ge) one can obtain resistance ratios up to ~ 20 in these sputtered films which compare favorably with many bulk single-crystal results. Thus the low resistance ratios ($\lesssim 3$) in Nb-Ge (max $T_c \sim 23$ K) compared to V_3Si (max $T \sim 17$ K) are likely not due to impurities or some limitation of the sputtering process but indicate that the increases in T_c and difficulty of preparation are accompanied by an increase in the number of naturally occurring structural defects.

The clearest evidence that the T_c-resistance-ratio correlation is rooted in defects comes from defect-producing bombardment with 2-MeV ^{4}He particles (which do not stop in the film). These results, given in Fig. 1 and similar to that obtained in Nb-Ge[2] and V_3Ge, show that the correlation for as-grown films can be retraced in initially high T_c samples by the controlled introduction of defects at constant chemical composition.

The influence of defects on one of the well-known normal state anomalies is shown in Fig. 2 which gives the temperature dependence of ρ for seven films of Nb-Ge whose T_c's ranged from 23 K (lowest curve) to <4 K (highest curve).[5] The anomaly is the existence of large negative curvature in $\rho(T)$ first observed in Nb_3Sn by Woodard and Cody.[6] For our films the lower T_c's have been achieved by nonstoichiometry, nonoptimal growth, and by ^{4}He damage in initially high T_c films. Note that, at least in qualitative features, lower T_c's, however achieved, are accompanied systematically by the gradual loss of the Woodard and Cody anomaly. Similar data have also been obtained for V_3Si and V_3Ge. Thus, again, defects with a universal character (and not nonstoichio-

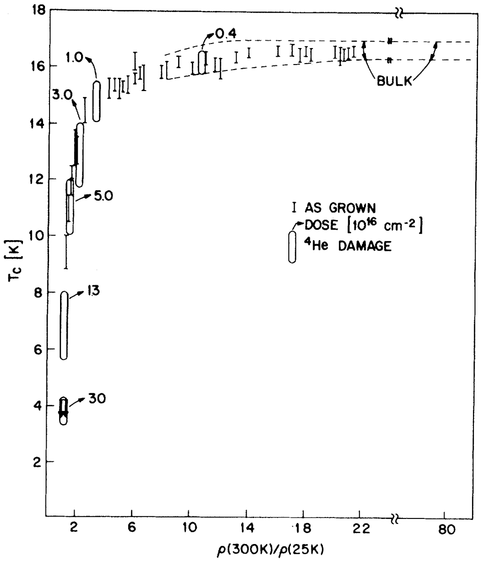

FIG. 1. T_c versus electrical resistivity ratio for as-grown and radiation damaged V_3Si sputtered films. Errors in absolute resistivities may be as high as 25% due mainly to film thickness uncertainties but temperature dependences are accurate to within 5%.

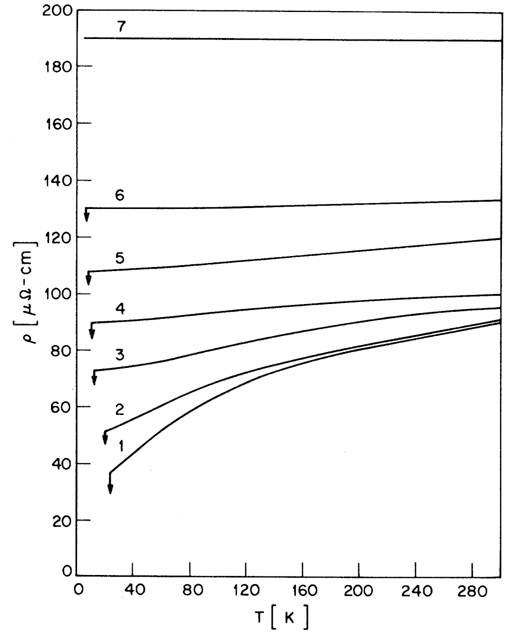

FIG. 2. Temperature dependence of the electrical resistivity for Nb-Ge films obtained with varying chemical composition, deposition temperatures, and subsequent ^{4}He damage. T_c's (in kelvin) are No. 1, 23.0–22.0; No. 2, 21.5–19.7; No. 3, 13–11.5; No. 4, 12.5–11.2; No. 5, 9.0–6.5; No. 6, 6.0–4.9; No. 7, < 4.2.

metry) are indicated.

Finally, note from Fig. 2 that lower T_c's are accompanied by the loss of not only the Woodard and Cody anomaly but almost all the thermal part of the resistivity $\rho_{\rm th} = \rho(300\text{ K}) - \rho(T_c)$ as well. $\rho_{\rm th}$ is a measure of the transport electron-phonon interaction for which some relation to T_c can be expected. Normally, $\rho_{\rm th}$ is not a parameter susceptible to large variations. Note from Fig. 2, however, that $\rho_{\rm th}(300\text{ K})$ can achieve very large values compared to a metal but can also be reduced to quite small values by processes which, we are assuming, always lead to formation of the crucial defects. Thus we see that, as measured by $\rho_{\rm th}$, not only can the electron-phonon interaction be very large in this material but that it can be strongly reduced by defects as well.

The extreme sensitivity to defects is best seen by comparison with Nb.[7] For the same ^{4}He bombardment or variations in sample growth which lead to the full range of T_c and $\rho_{\rm th}$ for Nb-Ge, the corresponding range in Nb is about two orders of magnitude smaller. Furthermore, when $\rho_{\rm th}$ of Nb-Ge becomes comparable to that for Nb (~15 μΩ cm) one finds comparable T_c's (~9 K) as well. Again, similar data have been obtained for V_3Si and V_3Ge.

The exact nature of the universal defect has not yet been established. Based on experiments published[1,2,8] and in progress, we believe that what is crucial to the defect state is the existence of a disordered structure obtained by numerous small bond-bending distortions from the A-15 lattice rather than the existence of a few bond-breaking defects. Although the causes of the disordered structure—antisite defects, vacancies, etc.—may not be the same in every case, we believe that it is the resulting distortions which produce much of the physically significant effects. Such defects may be, in addition, an important part of the soft mode and anharmonic behavior of these unstable high-T_c superconductors.

Additional data, details, and discussion of the electrical resistivity will be published elsewhere.[3]

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[1] L. R. Testardi, R. L. Meek, J. M. Poate, W. A. Royer, A. R. Storm, and J. H. Wernick, Phys. Rev. B 11, 4304 (1975).

[2] J. M. Poate, L. R. Testardi, A. R. Storm, and W. M. Augustyniak, Phys. Rev. Lett. 35, 19 (1975).

[3] Further details of this work are to be published.

[4] For V_3Si and V_3Ge most of the variations in T_c were achieved by different film growth conditions. Compositional variations were restricted to variations ~ 10% in the V/Si and V/Ge ratios about the stoichiometric value 3.

[5] H. Lutz, H. Weismann, O. F. Kammerer, and Myron Stronlin [Phys. Rev. Lett. 36, 1576 (1976)] have recently measured ρ between 4 and 575 K for a series of coevaporated Nb-Ge films with T_c's between 21 and 15 K. At least where experimental conditions overlap with those of Ref. 1 the data appear similar.

[6] D. W. Woodard and G. D. Cody, RCA Rev. 25, 39 (1964).

[7] J. M. Poate, L. R. Testardi, A. R. Storm, and W. M. Augustyniak, in *Applications of Ion Beams to Materials, 1975,* The Institute of Physics Conference Series No. 28 (The Institute of Physics, London, 1976), p. 176.

[8] L. R. Testardi, Solid State Commun. 17, 871 (1975).