Strain-Induced Softening of Certain Eutectics

H. Suhl
Institute for Pure and Applied Physical Sciences, University of California, San Diego, La Jolla, California 92093

and

B. T. Matthias[(a)]
Institute for Pure and Applied Physical Sciences, University of California, San Diego, La Jolla, California 92093, and Bell Laboratories, Murray Hill, New Jersey 07974

and

S. Hecker and J. L. Smith
Los Alamos Scientific Laboratory, Los Alamos, New Mexico 87545

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It is suggested that the considerable softening of the lattice of certain superconducting eutectic mixtures, and the accompanying increase in transition temperature are the result of large unrelieved strains that weaken the effective spring constant between neighboring atoms.

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In a recent publication, Matthias *et al.*[1] reported a marked reduction of the Debye temperature of the Ir-Y eutectic from pure iridium or YIr_2, that temperature decreasing to about 0.4 of the value for pure iridium or 0.5 for YIr_2 at about 22 at.% yttrium. Other evidence of "softening" of the lattice is the manifold increase in superconducting transition temperature[2] over that of the constituent phases and, of course, the lowered melting point.

We propose that these softening effects are the ultimate result of unrelieved long-range coherency strains extending throughout the approximately 1000-Å-thick lamellae of this eutectic. The coherency strains are a result of the lattice mismatch between successive layers of Ir and YIr_2. The lattice spacing of YIr_2 is slightly smaller than twice that of Ir; the difference is about 2% (see Krikorian[3]). Studies of the results of such a mismatch on the eutectic NiAl-Cr have been reported by Cline *et al.*,[4] who varied it by alloying with molybdenum which segregates in the chromium-rich phase. They concluded that especially for plate structures below a critical thickness of the plates, the long-range coherency strains may remain unrelieved by interface dislocations.

If this is also the case in the Y-Ir eutectic, then the reduction in Debye temperature may be due to a widening in the YIr_2 lattice spacing along the lamellae. In that distorted configuration the ions are no longer situated at their original potential minima, but rather in regions of considerably less curvature of the potential surface. For example, suppose that the ions interact via a Lennard-Jones 6-12 potential, and that the effect of the mismatch is equivalent to an additional constant force parallel to the lamellae. For simplicity, assume the undistorted lattice is simple cubic, and that it is stretched along one particular crystal axis. For a Lennard-Jones 6-12 potential, 10.9% strain along one of the crystal axes will reduce one of the three frequency-versus-wave-number branches to zero altogether if only nearest-neighbor forces are taken into account. The total specific heat is a sum of the specific heat due to the separate branches, which vary as the inverse cube of the maximum frequency of that branch. The total specific heat is therefore dominated by the softest branch. A 2% strain would give a Debye temperature reduced by the factor of 0.5 (the full curve is shown in Fig. 1).[5] It is to be noted that for a Morse potential the reduction factor would generally be much less. If the constant a in the Morse potential $\{\exp[-2(r-r_0)/a]-\exp[-(r-r_0)/a]\}$ is itself equal to the position of the minimum r_0 the branch will not be depressed to zero until the strain reaches ln2, about 60%. Thus if our suggestion is correct, the observations allow one to choose between at least grossly different model potentials[6] for YIr_2.

One possible objection to this mechanism is that the compound could begin to deform plastically at the strain of 2×10^{-2} needed for our explanation. It must be remembered, however, that in the actual situation in this eutectic, the layers are very thin (1000 Å) and it is in a highly constrained situation, with a local stress state very different from uniaxial tension. It may also be

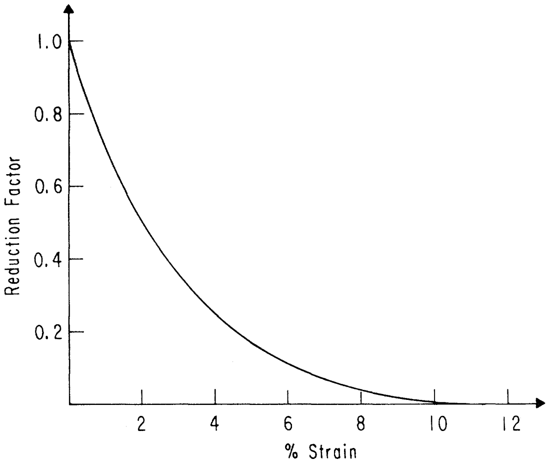

FIG. 1. Depression of one of the phonon branches against percent strain for nearest-neighbor Lennard-Jones 6-12 potential.

that the coherency strains are, in fact, relieved periodically by some interface dislocations, leaving, however, a semicoherent interface which still leads to effects of the type described above.

Finally, preliminary x-ray diffraction data on arc-cast specimens and x-ray powder pattern data on annealed specimens suggest, that for various compositions, there can be a definite lattice contraction in the iridium layers and a probable expansion of the YIr_2 layers of the eutectic mixture. Since yttrium atoms are larger than iridium atoms, these results could not originate from a simple extended solubility or homogeneity range. Previous powder patterns from arc-cast specimens[1] failed to reveal any crystallinity in either eutectic phase. We believe that this resulted from strains introduced during powder fabrication.

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[a] Deceased.

[1] B. T. Matthias, G. R. Stewart, A. L. Giorgi, J. L. Smith, Z. Fisk, and H. Barz, Science 208, 401 (1980).

[2] C. C. Tseui and W. L. Johnson, Phys. Rev. B 9, 4742 (1974).

[3] N. H. Krikorian, J. Less-Common Met. 23, 271 (1971).

[4] H. E. Cline, J. L. Walter, E. F. Koch, and L. M. Osika, Acta Metall. 19, 405 (1971).

[5] Though these numbers were evaluated for nearest-neighbor interaction only (not strictly permissible for a cubic lattice), we have verified that inclusion of further neighbors does not significantly change the result.

[6] R. A. Johnson, J. Phys. F 3, 295 (1973).

Observation of Inelastic Impurity Scattering of Electrons in the Resistivity of Potassium-Rubidium Alloys

C. W. Lee, W. P. Pratt, Jr., J. A. Rowlands,[a] and P. A. Schroeder
Physics Department, Michigan State University, East Lansing, Michigan 48824

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The resistances of *K*Rb alloys have been measured by new high-precision techniques (1 part in 10^7) from 180 mK to 4 K. Below 1.3 K a term proportional to the residual resistivity and to T^2 is positively identified. It is believed that this is the long sought for contribution to the resistivity from inelastic impurity scattering of electrons.

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In 1964 Taylor,[1] following the lead of Koshino,[2] calculated the effect on the electrical resistivity of the scattering of electrons by the thermal motion of impurities. His conclusion was that at sufficiently low temperature

$$\rho = \rho_0 + A_I \rho_0 T^2 + BT^5, \qquad (1)$$

where ρ_0 is the residual resistivity (proportional to concentration c) and

$$A_I = \pi^2 \hbar^2 K_{\text{av}}^2 / 2Mk\Theta^3, \qquad (2)$$

where K_{av} is an averaged scattering vector of value close to $2k_F$ (k_F is the Fermi wave vector),