Structural and superconducting phase transitions in V_3Si samples with various defect concentrations

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The temperature of the structural transition, T_M, and that of the superconducting transition, T_c, have been studied experimentally as functions of the defect concentration in the intermetallic compound V_3Si. It is found that T_M falls off monotonically with increasing defect concentration, while T_c goes through a maximum where the temperatures of the structural and superconducting transitions coincide.

In the temperature interval 17–30 K, V_3Si of stoichiometric composition undergoes a structural transition,[1] apparently second-order, from a cubic phase to a tetragonal phase with $c/a = 1.0024$. The physical reasons for the structural transition and its effect on the superconducting properties of V_3Si and other A-15 compounds have been the subject of extensive discussions,[2–8] primarily from the theoretical standpoint. It has been suggested that the structural transition corresponds to the appearance[9] or intensification[10] of superconductivity. In this letter we report an experimental study of the structural and superconducting phase transitions in V_3Si samples with various defect concentrations. We detected both transitions from the corresponding jumps in the specific heat.

The composition of these V_3Si samples was nearly stoichiometric. The defect concentration was determined by measuring the residual electrical resistance. The resistivity ratios $\alpha = \rho_{300\ \mathrm{K}}/\rho_{18\ \mathrm{K}}$ were 50, 31, 21, 19, 16, 14, 12, 11, and 3.4. The specific heat of samples with a mass on the order of 1 g was measured by an adiabatic method[11] over the temperature interval 4.5–30 K both without a magnetic field and with a magnetic field of induction up to 20 T. The temperature was measured with a carbon resistance thermometer,[12] with a correction for the effect of the magnetic field.[13] The operation of the calorimeter was tested by measuring the specific heat of a sample of pure copper; it was found that the error in the measurement of the specific heat does not exceed 1% in magnetic fields up to 8 T or 2% up to 20 T.

A magnetic field suppressed the superconductivity of V_3Si, so that we were able to study its specific heat in the normal (non-superconducting) state down to the lowest temperatures. Figure 1 shows the temperature dependence of the specific heat of several V_3Si samples in the normal state (with the superconductivity being suppressed by a magnetic field). On the curves of the specific heat for samples with low defect concentrations we can clearly see jumps due to a structural transition. These jumps actually occur over a short interval along the temperature scale, apparently because of an inhomogeneity of the samples. The temperature at which the jump occurs, T_M, ranges from 20.5 K at $\alpha = 50$ to 13 K at $\alpha = 12$. The curves of the specific heat of samples with a high defect concentration ($\alpha \leqslant 11$) do not exhibit the structural features caused by structural transitions. The rapid evolution of the structural feature upon a slight

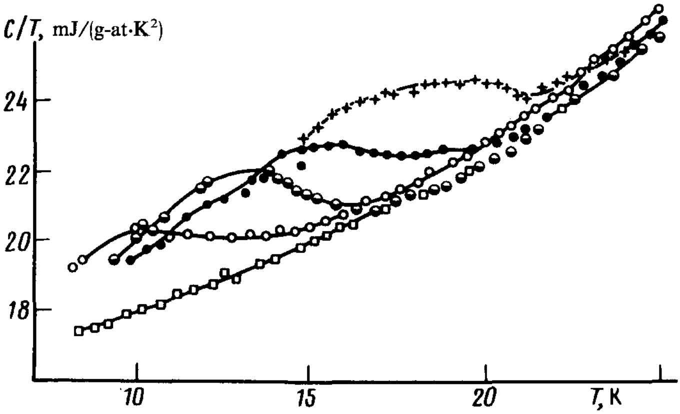

FIG. 1. Specific heat of several V_3Si samples in a strong magnetic field, which suppresses superconductivity. $+$—$\alpha = 21$; ●—$\alpha = 19$; ○—$\alpha = 16$; ◐—$\alpha = 14$; □—$\alpha = 11$.

change in the defect concentration also shows that these features in the specific heat are in fact due to a phase structural transition. Certain samples exhibit a slight decrease in the transition temperature T_M as the magnetic field is increased. For the sample with $\alpha = 50$ the decrease in T_M in a field of 16 T is 0.9 K, in good agreement with the result of Ref. 14.

According to the present understanding,[2,3,5] the reason for the structural transition in intermetallic compounds of the A-15 type is a sharp structural feature (a narrow peak, for example) in the electron-state density near the Fermi level. The decrease in the temperature of the structural transition which we observed upon the imposition of a magnetic field and also with increasing defect concentration can be attributed to a

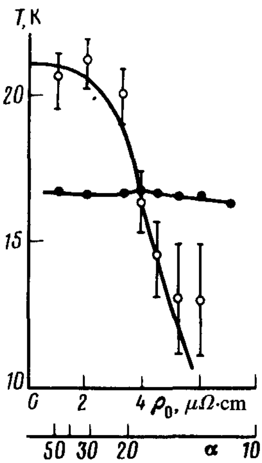

FIG. 2. Temperature of the structural transition, T_M, and temperature of the superconducting transition, T_c, vs the residual resistivity. ○—T_M; ●—T_c.

spreading of this structural feature in the electron-state density due to either a splitting in the magnetic field or a scattering of electrons by defects.[15,16]

Figure 2 shows the temperature of the structural transition, T_M, and that of the superconducting transition, T_c, vs the residual resistivity ρ_0, which is proportional to the defect concentration. The error bars show the width of the structural transition; the width of the superconducting transition corresponds to the size of the circle itself. We see that T_M falls off with increasing ρ_0, while T_c initially increases, goes through a maximum where the temperatures of the structural and superconducting transitions coincide, and then falls off slowly. The height of this maximum does not exceed 0.15 K, which is less than 1% of T_c. Consequently, at the time of the structural transition there is no significant increase in T_c, and the decrease in T_c with distance from the structural transition is extremely slow.

Whether the structural instability is a primary cause of the high values of T_c in A-15 compounds has been discussed repeatedly in the literature.[3–5,8] A variety of mechanism have been suggested to explain why T_c increases at or near the structural transition: an intensification of the electron-phonon interaction upon a structural transition,[9] a softening of the lattice due to a structural instability,[8] an increase in the electron-state density as the electron spectrum becomes more dielectric,[10] and an interaction of electrons with so-called structural excitations.[7] The behavior of T_c which we have observed near the structural transition indicates that these mechanisms are apparently not operating in A-15 compounds, and it supports the conclusions of Refs. 5 and 6, according to which the changes in T_c result from changes in the electron-state density accompanying a structural transition.

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