Low-frequency maxima of phonon state density and the exponential term of the resistance of superconductors with A-15 lattices

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It is found that the energy position of the low-frequency maxima of the phonon density of states T^* and the characteristic temperature T_0 of the exponential resistance term in superconductors with A-15 lattices are monotonic functions of the atomic weight of the compound. It is observed that for each compound the value of T_0 coincides with T^*. The result is attributed to a phonon selection that is caused by the topology of the Fermi surface.

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The superconductors with the highest transition temperatures, the alloys with A-15 lattice, have a number of anomalous properties.[1–4] Their study is

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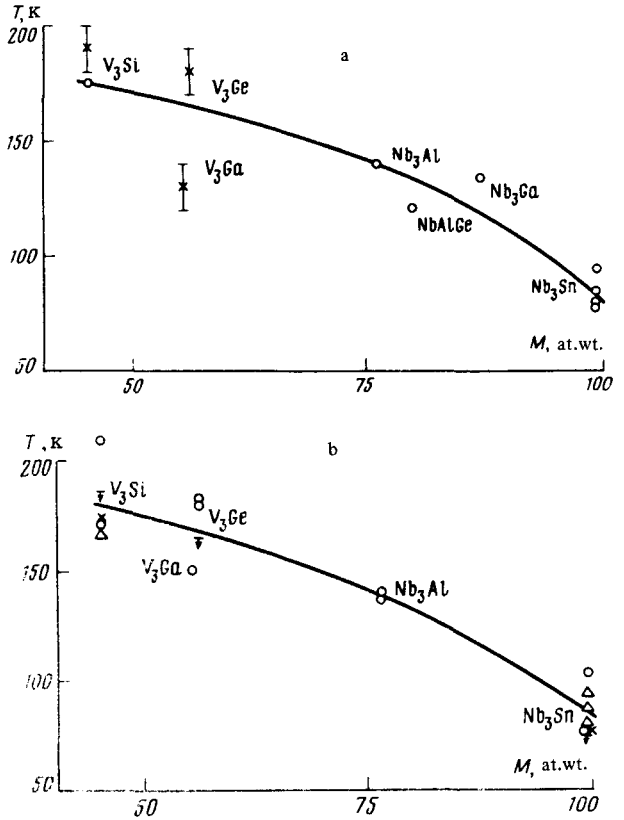

FIG. 1. a) Characteristic temperature T_0 vs the atomic weight of $A_{0.75}B_{0.25}$ compounds with A-15 lattices. b) Dependence of the position of the low-frequency peak of the state density, T^*, on the atomic weight of $A_{0.75}B_{0.25}$ compounds with A-15 lattice.

essential for the understanding of the causes of the high critical parameters of such compounds.

1. One of the distinguishing properties of these compounds is the anomalous temperature dependence of the conductivity, first observed in Nb_3Sn.[5] The resistance $R(T)$ as a function of the temperature can be described for such compounds, in a wide range of T, by introducing an additional term $\sim \exp(-T_0/T)$.[5] Exponential terms in $R(T)$ with a characteristic temperature T_0 in the interval 120—180 K were obtained recently for Nb_3Al, Nb_3Ga, NbAlGe and V_3Si.[6–7] An analysis of the data for the superconductors V_3Ge and V_3Ga[8] also points to the possibility that their $R(T)$ dependences can be described satisfactorily by a term of the same type.

T_0 turns out to be a monotonic function of the atomic weight of the compound (Fig. 1a). The points on Fig. 1 show the values of T_0 from[5–7], and the crosses are the results of the reduction of the data of[8]. The underestimate of T_0 of

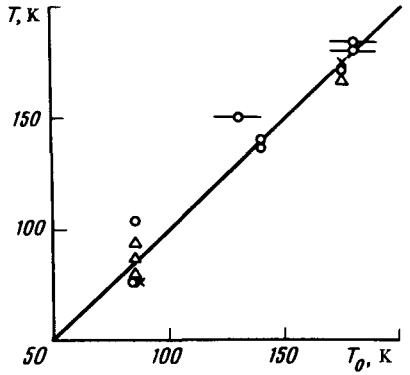

FIG. 2. Correlation of the position of the low-frequency peak T^* of the phonon density of states with the characteristic temperature T_0 for A-15 compounds. The straight line corresponds to the condition $T^* = T_0$.

V_3Ga may be due to the relatively small number of experimental points on the $R(T)$ curve.[8] The observed correlation between T_0 and the atomic weight undoubtedly points to a connection between the exponential term in the resistance and the phonon spectrum of the compound.

2. Another feature of A-15 compounds is that their spectra contain low-frequency maxima of the phonon density of states. Such a maximum was first observed in tunneling investigations of Nb_3Sn.[9,10] Its energy position coincided with the characteristic temperature T_0 obtained in[5], and for the same samples in[11]. Recently low-frequency phonon state-density maxima were also obtained for a number of A-15 compounds from data on inelastic neutron scattering.[1,12–14]

The position T^* of the low-frequency maximum of the phonon state density correlates with the atomic weight (Fig. 1b). The figure shows the positions of the low-frequency maxima of the phonon density of states (points) and of the effective phonon spectrum $\alpha^2F(\omega)$ (triangles). For the phonon spectra we used the low-temperature data from[1,12–14], and for $\alpha^2F(\omega)$ the data of[1,9,10]. In addition, Fig. 1b shows for NB_3-Sn and V_3Si the energies of the transverse phonons TA [100] near the boundary of the Brillouin zone[1] (crosses), and also estimates of these quantities for a number of alloys, obtained from the known elastic shear moduli (bars with arrows). All these quantities are in good agreement for each alloy.

The result indicates that in the investigated A-15 compounds the low-frequency phonon peak is determined mainly by the transverse phonons TA[100]. This is also attested by the similarity of the phonon spectra of the compounds (in particular, the V_3Ga spectrum is practically identical with the Nb_3Sn spectrum if the frequency scale is changed by a factor 1.25).[14]

3. It is seen from Figs. 1(a) and 1(b) that the $T_0(M)$ and $T^*(M)$ curves practically coincides. This follows particularly clearly from Fig. 2, where the values of T^* are plotted as functions of T_0 for those materials for which both are known. The straight line on Fig. 2 corresponds to the condition $T^* = T_0$ (the notation is that of Fig. 1b). This agreement means that the exponential term of the resistance of an A-15 compound and the value of T_0 are determined by scattering of electrons from phonons with energies near T^*.

A similar connection between the exponential resistance term and the low-frequency phonon peak is adduced also from the fact that the relative magnitude of the exponential term is sensitive to the height of the peak. In Nb_3Al, where only a weak peak is observed,[12,13] the exponential resistance term referred to the term that is linear in T is smaller by two orders of magnitude than in Nb_3Sn.[6]

The observed regularities might find an explanation if the A-15 compounds were to have a phonon-number peak at an energy $T^* \approx T_0$. This, however, is not always the case.[7] It must therefore be assumed that selection of phonons with energies $\sim T^*$ takes place.[5,7] The possibility of such a selection is determined by the form of the Fermi surface of the A-15 compound.[1,15] It appears that the selection is due to scattering of electrons from states corresponding to Fermi-surface sections with small curvatures (the vicinity of the point X).

4. The positions T^* of the low-frequency maxima of the phonon state density in A-15 compounds depend on the temperature T,[1,12-14] and shift towards higher frequencies with increasing T. The change of T^* from room temperature to low temperatures ranges from 3% in V_3Ge to 20% in Sb_3Sn and correlates with the critical temperature T_c of the compounds.[14,16] The quantities T^* and T_0 by themselves do not correlate with T_c.

The curves shown in Fig. 1 make it possible to estimate the expected values of T^* and T_0 for the superconductors with the highest temperature Nb_3Ge and Nb_3Si. For Nb_3Ge we get $T_0 = 116$K, $T^* = 117$ K, and for Nb_3Si we get $T_0 = 140$ K, $T^* = 138$K. The estimate of T_0 agrees with experiments on Nb_3Ge films with high T_c.[17]

The results confirm the conclusion drawn for Nb_3Sn in[8], that the different phonons exert different influences on the properties of A-15 compounds.

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