uid crystal. At low $q_\perp$ the layer fluctuations are quenched by the boundaries more severely than the corresponding splay mode of a nematic. This is a demonstration of the large attenuation length perpendicular to the layers. For the range of relatively large $q_\perp$ studied, the undulations are purely damped, as predicted by de Gennes.

From the angular dependence of their damping time we have derived for the first time in a smectic-A a measurement of the diffusivity of orientation, which we find comparable to that of a nematic. From the thickness dependence of the damping time, one can deduce a reasonably accurate value of λ, the penetration length of de Gennes. Measurements of the temperature dependence of λ using this method are currently under way.

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Influence of Electronic Lifetime on the Lattice Instability of V_3Si

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The magnetic field dependence of the structural transformation temperature of a single crystal of V_3Si has been measured up to 156 kOe. Quantitative agreement with the Weger-Labbé-Friedel model is obtained with appropriate band parameters and a density of states that accounts for finite lifetimes of the d electrons.

A number of superconductors with a high critical temperature T_c exhibit soft phonon modes at low temperature. This may be accompanied by a lattice instability in good quality samples which is manifested as a cubic-to-tetragonal structural transformation at a well-defined temperature T_M. Such transitions have been observed in V_3Si, Nb_3Sn, and $Nb_3Ge_{0.25}Al_{0.75}$ with values of T_M that are sample dependent but are about 22, 45, and above 24 K, respectively.[1] These compounds have the β-tungsten structure, in which the transition-metal ions are arranged in linear chains. Weger[2] and Labbé and Friedel[3] noted that in a tight-binding model the d electrons are confined to these chains. The structural instability is then viewed as a band-structure Jahn-Teller effect in which the electronic energy is lowered through a partial removal of the degeneracy of the chains.

Dieterich and Fulde[4] pointed out that a magnetic field can be used to test this model, because the Zeeman energy of the d-electron spin partially removes the degeneracy. Recently, Maita and Bucher[5] reported results for a single-crystal sample of V_3Si with $T_M = 21.3$ K in which the transformation temperature was lowered by 0.26 ± 0.01 K upon application of $H = 90$ kOe. This is about 30% smaller than the value predicted by Dieterich and Fulde[4] and more recently by Ting *et al.*[6] on the basis of the Weger-Labbé-Friedel (WLF) model. Three explanations have been advanced for the discrepancy: (1) Maita and Bucher suggest that electron lifetime effects and an accompanying change in the density of states might be the cause, but no numerical evaluation for T_M was made; (2) Stollhoff[7] calculates that doubling the Fermi energy to $E_F \approx 40$ K for the $m_l = \pm 2$ d bands would improve agreement; and (3) Weger points out that the observed value is precisely what is expected from a degenerate Fermi system whose density of states can be expressed as a Taylor series about E_F.[8] The last explanation is not consistent with the WLF model whose presently

accepted Fermi energy ($E_F \approx 21$ K) implies a nondegenerate system near T_M.

We have measured T_M of a single crystal of V_3Si up to $H = 156$ kOe. We find that T_M has a quadratic dependence on field, $\Delta T_M/T_M(0) = -\alpha \times[\mu_B H/kT_M(0)]^2$, a fact that justifies comparison of experimental results with the lowest-order predictions mentioned above. However, both $T_M(0)$ and α for this sample differ from the values reported by Maita and Bucher. The differences nevertheless can be *quantitatively* understood by taking account of both lifetime effects and a higher Fermi energy.

The single crystal which we have studied has a residual resistance ratio (RRR) $R(300\text{ K})/R(17.5\text{ K}) = 40$. The structural transition was detected through measurements of the sample length with a capacitance dilatometer. At $H = 0$, the temperature coefficient of lattice expansion abruptly changes at $T_M = 20.15$ K. This is also where the electrical resistance displays an anomaly.[9] The field dependence of T_M was determined for H parallel to the [100] direction, with a superconducting magnet providing fields up to 55 kOe, and with an electromagnet providing fields up to 156 kOe.

The inset of Fig. 1 gives a schematic of the experimental arrangement. The sample is mounted in the space A surrounded by an oxygen-free high-conductivity (OFHC) copper chamber B. This is enclosed by a second OFHC copper can D, and the interior (A and C) contains helium gas at 1-Torr pressure. The region E is evacuated, with liquid helium surrounding the stainless-steel can F. Containers B and D are used to establish temperature uniformity and reduce the ac component of the field from the high-field magnet. Chamber B is heated electrically to sweep through the structural transformation at constant field, and the temperature of the sample was measured with a capacitance thermometer,[10] calibrated on each run against a Ge resistance thermometer at $H = 0$. Experiments with the thermometers immersed in liquid hydrogen demonstrated that the capacitance thermometer is insensitive to fields up to 150 kOe, in agreement with previous studies.[11] The results of these experiments are shown in Fig. 1. The observed reduction of T_M depends quadratically on H, with a best-fit value of $\alpha = 0.11$ to a precision of better than 10%.

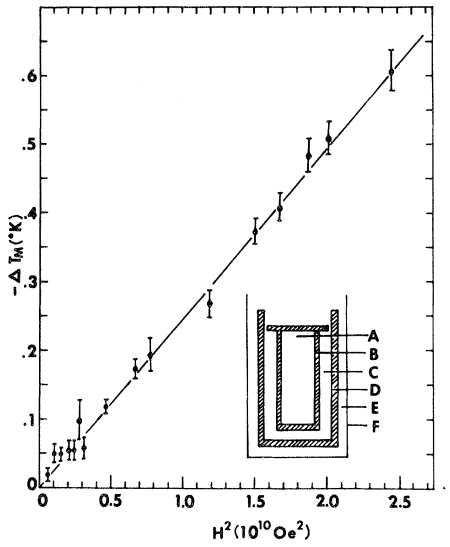

FIG. 1. Observed reduction of T_M with field. Inset, experimental arrangement.

We investigated the possibility of a systematic error which might arise from temperature gradients within the sample holder as a result of eddy-current heating from the ac component of the field. This would cause a spurious apparent temperature shift which is quadratic in H. We repeated the experiments using liquid hydrogen surrounding the can F, and with helium gas in the regions A, C, and E. At $H = 0$ we found $T_M = 20.17$ K, in good agreement with the previous results. The value of α is slightly lower, with $\alpha = 0.09$. Therefore, we conclude that the value appropriate for this sample is established as $\alpha = 0.10 \pm 0.02$. This value is substantially below the result $\alpha = 0.150 \pm 0.006$ obtained by Maita and Bucher at 90 kOe and $\alpha = 0.21$ predicted for the WLF model.[4,6] The value of $T_M(H = 0)$ is also lower than for the sample of Maita and Bucher.

We propose that the chief difference in the samples is the mean lifetime τ of the d electrons, as is indicated by the lower value of the resistance ratio for our sample (RRR = 40) as compared with their sample (RRR = 60). To evaluate the effect of finite scattering rate $\Gamma = 1/2\tau$, we have reformulated the one-dimensional density of states for independent fermions, including scattering effects to second order in the one-electron Green's function. Since the impurity potential is screened by s and d electrons, it is short range and therefore independent of $\vec{k}$ for small k: $V(\vec{k} - \vec{k}') \approx V$. Following Abrikosov, Gor'kov, and Dzaloshinskii,[12] the imaginary part of the Green's function yields the density of states per V atom:

$$N(E) = \frac{4}{\pi(2|E_0|)^{1/2}}\left[\frac{(E^2+\Gamma^2)^{1/2}+E}{2(E^2+\Gamma^2)}\right]^{1/2}, \qquad (1)$$

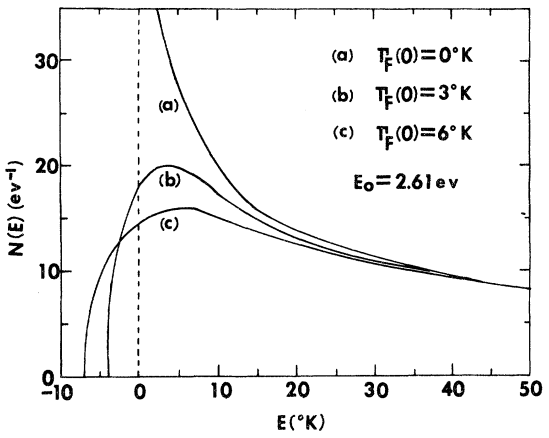

FIG. 2. Density of states for several scattering rates $\Gamma_F(0)$.

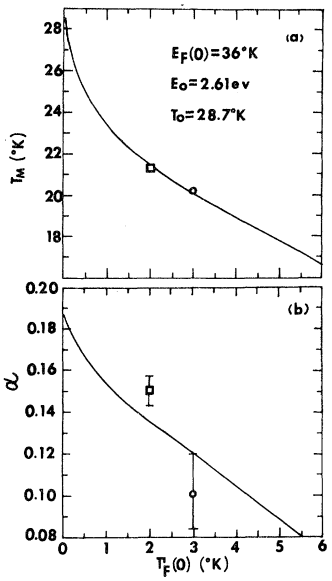

FIG. 3. Predicted dependence of (a) T_M and (b) α on scattering rate. Circles, respective values for the sample investigated in this study; squares, values for the sample of Maita and Bucher (Ref. 5).

where the parameter Γ is a function of energy and is determined by the condition $\Gamma(E)=\pi n|V|^2 \times N(E)$. The number of impurities is denoted by n. The parameter Γ is proportional to $N(E)$ because the transition rate from a given state is proportional to the number of unoccupied states with the same energy (elastic collisions).[13] In the limit $\Gamma \to 0$, Eq. (1) reduces to the clean limit $N(E) \sim E^{-1/2}$ characteristic of a one-dimensional system at low E.

In Fig. 2 we show $N(E)$ for several values of $\Gamma_F(0)$, the value of Γ at the Fermi level at $T=0$. It is interesting that the shape of $N(E)$ for large Γ is suggestive of the step-function density of states introduced by Cohen, Cody, and Halloran[14] to describe with some success the temperature dependence of several features of β-tungsten compounds.

We can then use this modified density of states to study T_M and α as a function of $\Gamma_F(0)$. The methods of calculating T_M and α are described in detail in Ref. 6. There is one free parameter, so we chose $T_M(\Gamma=0) \equiv T_0 = 28.7$ K in order to account for our value for T_M. As ingredients in the calculation we take the number of d electrons per V atom to be $Q=0.062$ as determined from specific-heat measurements.[15] If we use the experimental value of the shear elastic constant[1] at $T=300$ K and take $\epsilon_0 = 2.5\times10^{-3}$ as a reasonable value[16] for the tetragonal strain at $T=0$, then we have $A'=34.6$ as the high-temperature elastic constant, $E_0=2.61$ eV as the band half-width, and $aq=1.07$, where a is the interatomic distance and q is the Slater coefficient describing the asymptotic behavior of atomic d orbitals. The Fermi energy thus found is $E_F(T=0)=36$ K for $\Gamma_F(0)=0$. With these parameters we can calculate T_M and α as a function of $\Gamma_F(0)$. The results are shown in Figs. 3(a) and 3(b), respectively.

Since the relative contributions of s and d electrons to the electrical conductivity are not known, we cannot evaluate $\Gamma_F(0)$ directly from transport data. However, we can establish a maximum lifetime (or minimum scattering rate) by assuming that the electrical conductivity is entirely due to d electrons. A resistivity $\rho=1.8$ $\mu\Omega$ cm for our sample at $T \approx 20$ K[9] yields a minimum value $\langle\Gamma\rangle = 4.5$ K, corresponding to $\Gamma_F(0)=3$ K. This implies a mean free path of about 400 Å. As stated previously, this value of $\Gamma_F(0)$ and the observed T_M for our sample were used to establish the value of T_0 in the clean limit. The location of T_M for the sample of Maita and Bucher is then fixed by the relative value of the RRR's and, as shown in Fig. 3(a), the curve accounts for it very well. The trend for the values of α is then automatically predicted by the calculation. The agreement between the prediction of the modified WLF model and the experimental results is satisfactory.[16] Our measured value of α disagrees with the value $\alpha=0.15$ predicted[8] for a degenerate electron gas with a density of states without fine structure near E_F even if lifetimes are included, because such an influence should maintain a smoothly varying density of states, and α

would be independent of $\langle\Gamma\rangle$.

We have shown that the modified WLF model predicts that T_M and α are sensitive to $\langle\Gamma\rangle$, in agreement with observations. The minimum value of $\langle\Gamma\rangle$ deduced from the resistivity shows that it is essential to take account of lifetime effects. The span of values for T_M shown in Fig. 3(a) is approximately the range within which the structural transformation has been found to occur. In view of Fig. 3(a) it is not surprising that inhomogeneous samples exhibit "smeared" transitions. We cannot of course preclude the possibility that other effects such as internal strains may influence T_M. These appear to be important in less-pure specimens where T_M does not correlate with the RRR. We cannot expect that the results presented here can be extrapolated to indefinitely large values of $\Gamma_F(0)$. In real materials, a high concentration of impurities will disrupt the quasi one-dimensional character[17] and may change the value of Q. However, the success of the step-function density of states[18] for Nb_3Sn of low RRR suggests that the large-$\Gamma(0)$ limit for $N(E)$ may still have qualitative validity.

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