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Superconducting properties of A-15 $V_{75-x}M_xGa_{25}$ compounds: M = Ti, Cr, Mn, Fe, Co, and Ni

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Superconducting transition temperatures T_c and their pressure derivatives dT_c/dp have been determined for V_3Ga based ternary compounds containing $3d$-element substitutions for V. The superconducting transition temperatures decrease while the normalized pressure derivatives, $(1/T_c)(dT_c/dp)$ increase systematically for all 3rd element additions. These results suggest that the form of the T_c equation is not affected by rapid variations in the electronic density of states $N(E)$, as suggested by some models for superconductors of the A-15-structure type. Analysis of the data in terms of the McMillan T_c equation and the more recent T_c equation of Birnboim show that the electron-phonon coupling parameter λ scales uniquely with the electron-per-atom ratio $\mathfrak{z}$ and is approximately proportional to the electronic density of states at the Fermi level, $N(E_F)$. The volume derivative of λ, as determined from dT_c/dp data, remains approximately constant as the electron-per-atom ratio varies near that of V_3Ga ($\mathfrak{z} = 4.5$). The only significant difference in the two model T_c equations, i.e., McMillan or Birnboim, is in the absolute values of the parameters λ and $d\ln\lambda/d\ln V$, not in systematic variations.

I. INTRODUCTION

The highest reported superconducting transition temperatures are found among stoichiometric A_3B compounds possessing the A-15 crystal structure, where A is a transition-metal atom and B is a non-transition-metal atom. High transition temperatures in these compounds are generally ascribed either to large electronic density of states at the Fermi level, $N(E_F)$, or to anomalies in the phonon spectrum.[1-3] Density-of-states models for describing superconductivity in A-15 compounds apply particularly well to V-based compounds where the largest $N(E_F)$ values are found.[4]

The functional form of T_c on $N(E_F)$ is not, however, well established in high-T_c, A-15 compounds since $N(E)$ varies rapidly over typical phonon energies in the region near E_F. These rapid variations influence normal-state properties, such as Knight shifts,[1,3] but their importance in determining the form of the T_c equation has not been demonstrated.

V_3Ga has the highest known $N(E_F)$ value of any A-15 compound and its measured Knight shift indicates considerable variation in $N(E)$ near E_F.[1,2] Furthermore, studies of the $V_{75}Ga_{25-x}Sn_x$ and $V_{75}Ga_{25-x}Si_x$ systems[4,5] have previously shown that T_c correlates well with $N(E_F)$. Thus, V_3Ga-based ternary systems are ideal for experimentally testing the influence of rapid $N(E)$ variations on the functional form of the T_c equation.

In the work reported here, V atoms in V_3Ga have been systematically replaced with other $3d$-transition-metal atoms denoted by M, where M = Ti, Cr, Mn, Fe, Co, and Ni to form $V_{75-x}M_xGa_{25}$ compounds, where x is the atomic concentration of M atoms. Superconducting transition temperatures in $V_{75-x}M_xGa_{25}$ compounds were first reported by Savitskii *et al.*[6]; however, only a relatively few compounds were measured, which vitiated an accurate determination of T_c as a function of M concentration. Subsequently, Girgis, Odoni, and Ott[7] reported a more complete study of the Cr, Mn, and Fe ternary systems which clearly showed systematic behavior in the T_c data. This article extends investigations of the T_c dependence in $V_{75-x}M_xGa_{25}$ compounds to the Ti, Co, and Ni systems and also reports on the effects of hydrostatic pressure on T_c. Systematic variations of T_c and dT_c/dp are observed for all the M alloy series. The results are analyzed and compared with several theoretical forms of the T_c equation.

SAMPLE PREPARATION

Samples were prepared by melting the constituent elements in an atmosphere of high-purity argon. They were homogenized, subsequently wrapped in tantalum foil, and annealed under vacuum at 800 °C for approximately four weeks. Solubility limits of the M atoms in A-15 V_3Ga varied from complete solubility for Cr to only a very few atomic percent for Ni. Final compositions were determined from a microprobe analysis

(±0.5%) and lattice parameters a_0 were measured by x-ray methods. Lattice parameters decreased linearly with Cr, Mn, Fe, Co, and Ni content and increased with Ti content. The magnitude of change in lattice parameters varied with M type in proportion to Pauling's atomic radii, except for Ni. Neutron diffraction studies were made to determine the distribution of M atoms and the degree of crystallographic long-range order.[8] It was observed that the M additions replaced mainly the V atoms, i.e., they occupied the $6c$ lattice sites. Complete details of the sample preparation and crystallographic and metallographic studies are reported elsewhere.[7]

TRANSITION TEMPERATURES T_c

Superconducting transition temperatures were measured inductively with a standard ac mutual-inductance bridge. The transition widths were typically 0.5 K wide. T_c was always defined as the midpoint of the transition.

All samples reported here had a final 800-°C thermal ordering anneal; however, the effects of a lower-tamperature ordering anneal were examined in some of the samples. The largest effect was noted in binary V_3Ga where the 800-°C annealed sample had a T_c of 14.1 K while the 600-°C sample had a T_c of 14.7 K. Such ordering effects are well documented in the literature[9] and are due to an increase in the degree of crystallographic long-range order, i.e. V atoms on the $6c$ lattice sites and Ga atoms on the $2a$ sites. As M atoms are added, systematic differences in T_c between the two anneals rapidly disappear and were unobservable at concentrations of 5% or greater. This result is consistent with the fact that at higher M concentrations, a small percentage of the M atoms occupy the Ga $2a$ lattice sites. For instance, in $V_{67.5}Fe_{7.5}Ga_{25}$, approximately 95% of the Fe atoms were on the $6c$ sites while the remaining 5% were on the $2a$ sites. This M disorder dominates over thermal disorder at large M concentrations; thus, longer-time lower-temperature thermal anneals have little systematic effect on T_c in the higher-concentration compounds.

The results of these investigations are shown in Fig. 1 where T_c is plotted against M concentration x. Definite families of curves, parametrized by the M type, appear when the data are plotted in this manner (similarly, plots of T_c versus the lattice parameter a_0 gave families of curves depending on M type). The initial change of T_c with M concentration is shown in Table I. Since these numbers refer to initial slopes of T_c with respect to concentration, values will depend slightly on the ordering anneal; however, in the Co system, where such effects were most extensively studied, the difference in initial slope determinations for samples with an 800-°C versus a 600-°C anneal was small—approximately equal to the uncertainty in the quoted value itself.

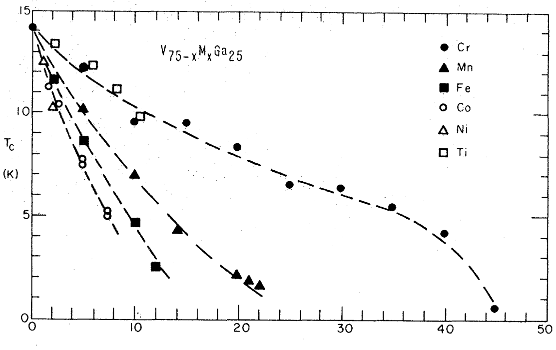

FIG. 1. T_c vs concentration for $V_{75-x}M_x Ga_{25}$ compounds. (Dashed lines are merely to guide the eye).

If one converts these dT_c/dx values into $dT_c/d\mathfrak{z}$ values, where $\mathfrak{z}$ is the valence-electron-per-atom ratio, then, to within experimental error,

$$\left|\frac{dT_c}{d\mathfrak{z}}\right| \approx 40\ \mathrm{K}/\mathfrak{z}\,,$$

a constant for all systems. Thus universal $\mathfrak{z}$ dependence persists, in fact, over most of the alloy concentration ranges as shown in Fig. 2. Only the high-concentration Cr data deviate slightly from the universal behavior. (This effect in Cr, as will be discussed later, is most likely due to a concentration-induced change in the phonon frequencies.) It thus appears that the superconducting transition temperatures for these ternary A-15 systems are controlled predominantly by the number of valence electrons per atom. This result is consistent with expectations of density-of-states models describing superconductivity in A-15-structure-type compounds.

PRESSURE EFFECTS $(1/T_c)(dT_c/dp)$

The apparatus for measuring the effects of pressure on T_c, shown schematically in Fig. 3, was a standard piston-cylinder clamp apparatus where-

TABLE I. Initial changes of T_c with M additions.

	dT_c/dx (K/at.%)	$dT_c/d\mathfrak{z}$ $(K/\mathfrak{z})$
Ti	−0.40 ± 0.05	40 ± 5
Cr	−0.40 +0.03	−40 ± 3
Mn	−0.85 ± 0.04	−42 ± 2
Fe	−1.05 ± 0.1	−35 ± 4
Co	−1.6 ± 0.1	−40 ± 4
Ni	−1.7 ± 0.2	−34 ± 5

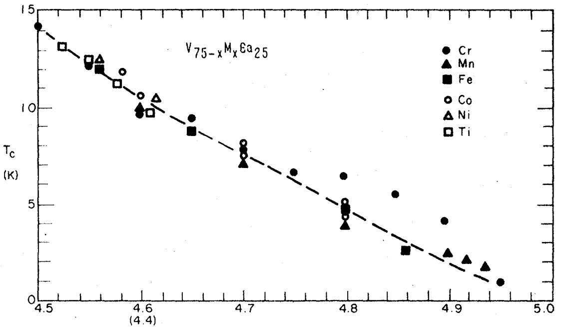

FIG. 2. T_c vs $\mathfrak{z}$ ratio for $V_{75-x}M_xGa_{25}$ compounds. $\mathfrak{z}$ values for Ti alloys are indicated by a decreasing scale shown in parentheses below the abscissa. (Dashed line is merely to guide the eye.)

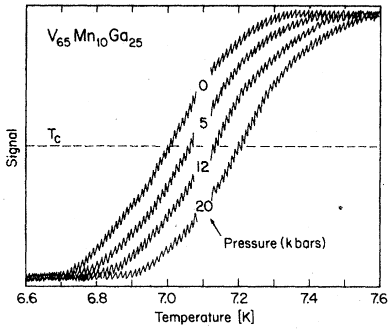

FIG. 4. Magnetic susceptibility vs temperature showing the superconducting- to normal-state transition as a function of pressure.

by hydrostatic pressures to approximately 20 kbar could be applied to the sample. The pressure cylinder was hardened BeCu having a 5-mm bore while the piston material was tungsten carbide. The sample, along with a pressure calibrant and the pressure transmitting fluid (glycerine), were all contained inside a nylon cell. Pressure was applied at room temperature in order to ensure a hydrostatic evnironment, whose importance in pressure studies of A-15 compounds has been emphasized by Smith,[10] and retained by a lock-nut mechanism. Pressures were determined at low temperatures by simultaneously measuring T_c of the In calibrant whose $T_c(p)$ curve is well documented.[11] T_c was measured inductively while slowly sweeping the temperature which was determined with a germanium resistance thermometer.

The effect of pressure on A-15 compounds is not large, in fact, the total shift for the compounds reported here is less than the width of the transition temperature itself. Nevertheless, the shapes of the transitions proved invariant under pressure, indicative of a hydrostatic environment, and the midpoint was reproducibly defined to about 20 to 30 mK. Since the total shifts were from 0.05 K to approximately 0.25 K at 20 kbar, such an accuracy is necessary to obtain reliable dT_c/dp values. Fig. 4 shows actual data for the $V_{65}Mn_{10}Ga_{25}$ sample as a function of pressure. From data such as these, values for T_c and dT_c/dp were obtained.

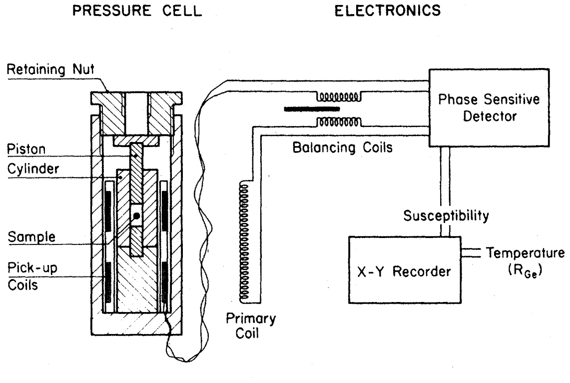

FIG. 3. Schematic of pressure cell and magnetic-susceptibility detection bridge.

Table II lists the results of pressure measurements where T_c, the pressure derivative dT_c/dp, and the relative pressure derivative $(1/T_c)(dT_c/dp)$ are shown as functions of the parameters x and $\mathfrak{z}$. The relative pressure derivatives are related to volume derivatives of T_c through the relation

$$\frac{d\ln T_c}{d\ln V} = -\frac{1}{\kappa T_c}\frac{T_c}{dp}, \tag{1}$$

where κ is the isothermal compressibility of the sample. For purposes of comparing data from a variety of samples, this volume derivative is more

TABLE II. Values of T_c, dT_c/dp, $(1/T_c)(dT_c/dp)$, and $\mathfrak{z}$ for $V_{75-x}M_xGa_{25}$ compounds.

Sample M_x	T_c (K)	$\frac{dT_c}{dp}$ (10^{-6} bar^{-1})	$\left(\frac{1}{T_c}\right)\left(\frac{dT_c}{dp}\right)$ (10^{-5} K/bar)	$\mathfrak{z}$
(V_3Ga)	14.1	1.2	0.80	4.50
Fe_2	11.8	1.0	0.85	4.56
Co_2	11.4	0.9	0.80	4.58
$Ti_{2.5}$	12.4	1.2	0.95	4.47
Fe_5	8.5	1.0	1.2	4.65
Mn_5	10.1	1.2	1.2	4.60
Cr_5	12.1	1.3	1.1	4.55
Co_5	7.2	0.8	1.1	4.70
$Ti_{7.5}$	11.3	1.2	1.1	4.42
Mn_{10}	7.0	1.0	1.4	4.70
Mn_{15}	4.2	0.6	1.4	4.80
Cr_{15}	9.9	1.4	1.4	4.65
$Co_{7.5}$	4.2	0.5	1.2	4.80
Cr_{30}	6.4	0.65	1.0	4.80

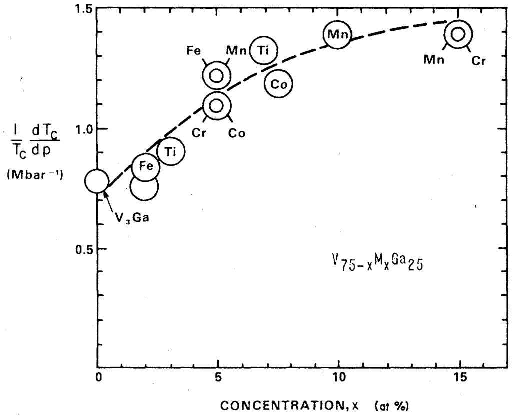

FIG. 5. Relative pressure derivations of $V_{75-x}M_xGa_{25}$ compounds vs M concentration, x.

meaningful than the pressure derivative alone. The value of $(1/T_c)(dT_c/dp)$ for binary V_3Ga determined in this study $[(0.8 \pm 0.1) \times 10^{-6}\ \text{bar}^{-1}]$ agrees quite well with the value determined previously by Smith[10] $[(0.75 \pm 0.03) \times 10^{-6}\ \text{bar}^{-1}]$.

Figure 5 shows the relative derivatives plotted against x. In spite of the experimental scatter, it is immediately apparent that the relative pressure derivatives increase as one adds M atoms, rising to a value that is almost double that of binary V_3Ga.

DISCUSSION AND ANALYSIS

Since T_c correlates best with the $\mathfrak{z}$ ratio, rather than M type or concentration x, it suggests that T_c is dominated by electronic properties such as the electronic density of states $N(E)$. The electronic density of states affects T_c through the electron-phonon coupling parameter λ according to the formula[12]

$$\lambda = N(E_F)\langle I^2\rangle / M\langle\omega^2\rangle\ , \tag{2}$$

where $N(E_F)$ is the electronic density of states at the Fermi level, $\langle I^2\rangle$ is an electron-phonon matrix element, M is the atomic mass, and $\langle\omega^2\rangle$ is an average phonon frequency. E_F itself is a function of the $\mathfrak{z}$ ratio.

To obtain λ from T_c data, one must have an equation relating λ to T_c. Standard forms of the T_c equation assume a phonon-limited range for the attractive electron-electron interaction; however, for materials possessing the A-15 crystal structure, many alternative equations have been proposed[13-18] based on an electronically limited interaction. These equations assume (i) that $N(E_F)$ is large and sharply peaked near E_F falling essentially to zero within an energy range of less than 1 mRy (<150 K), and (ii) that such a functional dependence of $N(E)$ will alter the basic form of the interaction.

The effects of hydrostatic pressure can be used to test the validity of these electronically limited T_c equations. Such models predict positive pressure derivatives of T_c.[19] V-based A-15 compounds (but not Nb-based compounds) have positive pressure derivatives[10] and are thus in qualitative agreement with these models assuming large and sharply peaked $N(E)$ at E_F. As one adds extra electrons to the d band, in $V_{75-x}M_xGa_{25}$ compounds, the Fermi energy moves away from the region of sharply varying $N(E)$ and the relative pressure derivative $(1/T_c)(dT_c/dp)$ should decrease. The increase in $(1/T_c)(dT_c/dp)$, with $\mathfrak{z}$ ratio as shown in Fig. 5 clearly violates the predictions of these models. Thus, even though positive pressure shifts in V_3Ga compounds are in accord with those models requiring sharp structure in $N(E)$, systematics of the pressure derivatives are not compatible with them. Hence, sharp structure in $N(E)$ near E_F does not appear to alter the basic form of the phonon-limited T_c equation.

The equation for T_c assuming a phonon-limited energy range for the attractive electron-phonon interaction, has the general form

$$T_c \sim \Theta \exp - 1/g(\lambda\mu^*)\ , \tag{3}$$

where Θ is an average phonon frequency and g is the net electron-electron interaction which depends on the repulsive Coulomb parameter μ^* and the attractive electron-phonon parameter λ. Nettle[20] has suggested that λ is not strongly effected by sharp electronic structure since it involves an average over the phonon energy range, i.e., $\lambda \rightarrow \bar{\lambda}$, where $\bar{\lambda}$ is given by Eq. 8 in Ref. 20.

The most common specific form for Θ and g was given by McMillan[12] in 1967 based upon a solution of the Eliasberg equations for the Nb phonon spectrum:

$$\begin{aligned} &\Theta = \Theta_D/1.45\ ,\\ &g^{-1} = 1.04(1+\lambda)/[\lambda - \mu^*(1+0.62\lambda)]\ , \end{aligned} \tag{4}$$

where Θ_D is the Debye temperature. Further computer modeling by Allen and Dynes[21] based on the same approach as used by McMillan, but generalizing to different phonon spectra and to larger λ, has led to a different Θ in Eq. (4), but for $\lambda < 1.5$ the difference is only in the type of phonon average used to obtain Θ. More recently, Birnboim and Gutfreund[22-24] formulated another T_c equation based on the ideas of Appel and Kohn[25] who suggested that the natural way to describe the electron-phonon interaction in materials with transition metals is by employing the Wannier or atomic-site representation rather than the Bloch representation.

Using this localized description of electronic states in narrow-d-band compounds, Birnboim and Gutfreund again solved the Eliasberg equations under the same assumptions as used by McMillan to obtain

$$\Theta = 1.83\Theta_D$$

and

$$g^{-1} = 1.13(1+2.25\lambda)/(\lambda - 1.3\mu^*)\,. \qquad (5)$$

This relation should be valid over the same λ range as is McMillan's since similar assumptions about the phonon spectrum were made.

Debye temperatures for V_3Ga and Cr_3Ga have been reported[2] as 310 K and 584 K respectively; hence, a change in Θ_D is expected in ternary compounds. Debye temperatures for the ternary systems reported here, however, were not experimentally measured. It was therefore necessary to estimate their values from results of previous measurements on an analogous A-15 system. For the $V_{75-x}Cr_xSi_{25}$ alloy system, T_c and Θ_D have been determined as a function of x.[26] The data show that Θ_D increases approximately linearly with x for $x<30$ and then remains constant at the value of $\Theta_D(Cr_3Si)$ over the remainder of the composition range. For the $V_{75-x}M_xGa_{25}$ alloy systems it was assumed that Θ_D varied in a similar manner between the end points of 310 and 584 K, i.e.,

$$\Theta_D \approx 310 + 9x\,, \quad x<30$$

$$\Theta_D \approx 584\,, \quad x>30\,.$$

The electron-phonon parameter $\lambda(\mathfrak{z})$ was determined for the alloys reported here by inverting the T_c equations of McMillan and of Birnboim. In order to reduce the effects of uncertainties in the absolute values of Θ_D and/or μ^*, systematic variations in λ were obtained by normalizing to the value of binary V_3Ga, i.e. $\lambda(4.5)[T_c(4.5)=14.1\text{ K}]$. Figure 6 shows the $\mathfrak{z}$ systematics of $\lambda(\mathfrak{z})$ as analyzed by both the McMillan and the Birnboim formulations. All data fall on a universal $\mathfrak{z}$ curve. The Cr data points which did not follow the same $T_c(\mathfrak{z})$ curve as that of the other M alloys are no longer distinguishable when $\lambda(\mathfrak{z})$ are compared. This result is due to the fact that Θ_D is a function of x. Although T_c depends slightly on x (from Θ_D), λ appears uniquely determined by the $\mathfrak{z}$ value. Differences in $\lambda(\mathfrak{z})/\lambda(4.5)$ for the two models are small and can be reduced by slight changes in the prefactors of the T_c equation; hence, one cannot differentiate between the models on the basis of these $\mathfrak{z}$ systematics.

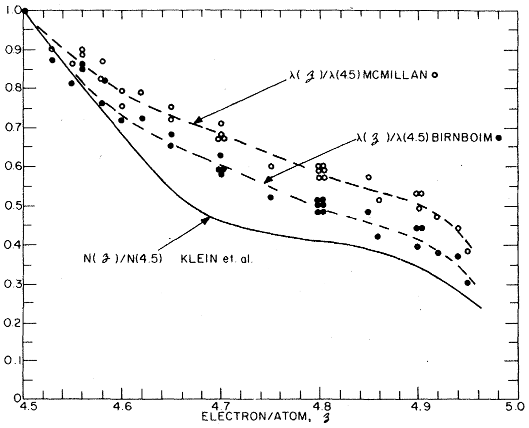

FIG. 6. Ratios of $\lambda(\mathfrak{z})/\lambda(4.5)$ as determined by both the McMillan and Birnboin models (data plus dashed lines) and $N(\mathfrak{z})/N(4.5)$ from calculations of Klein *et al.* (solid line) vs $\mathfrak{z}$ value.

Also shown in Fig. 6 is the ratio $N(\mathfrak{z})/N(4.5)$ as determined from recent band-structure calculations of Klein *et al.*[27] The curve represents a hand-drawn smoothed curve approximating the calculated density of states. According to Eq. (2), $N(\mathfrak{z})/N(4.5)$ should be directly comparable to $\lambda(\mathfrak{z})/\lambda(4.5)$ provided that the rigid-band-model approximation is valid and that the quantity $\langle I^2\rangle/M\langle\omega^2\rangle$ is constant. For V-based compounds where other $3d$-transition-metal atoms are substituted for V, the product $\langle I^2\rangle/M\langle\omega^2\rangle$ may be expected to remain approximately constant due to the similarity in the $3d$-electron-shell configuration.[5] The data analyzed by either method do indeed follow the general trends of the theoretical $N(E)$ calculation although numerical agreement is not exact. Agreement could perhaps be improved by plotting the ratios of $\bar{N}(\mathfrak{z})$ as suggested by Nettles,[20] where $\bar{N}(\mathfrak{z})$ is the density of states averaged over the phonon spectrum. These data, however, are not available. The qualitative agreement of Fig. 6 suggests that to a first approximation, the rigid-band assumptions and the assumed constancy of $\langle I^2\rangle/M\langle\omega^2\rangle$ are valid in these V-based ternary systems.

Pressure derivative measurements give information about the volume dependence of λ. Differentiating Eq. (2), one obtains

$$\frac{d\ln\lambda}{d\ln V} = \frac{d\ln N(E_F)}{d\ln V} + \frac{d\ln\langle I^2\rangle}{d\ln V} + 2\gamma\,, \qquad (6)$$

where $\gamma = -d\ln\Theta/d\ln V$. Differentiating Eq. (3) (assuming $d\mu^*/dV=0$), one obtains $d\ln\lambda/d\ln V$ in terms of experimentally measured parameters:

$$\frac{d\ln\lambda}{d\ln V} = \left[\gamma - \left(\frac{1}{\kappa T_c}\right)\left(\frac{dT_c}{dp}\right)\right] \Big/ \left[\left(\ln\frac{\Theta}{T_c}\right) f(\lambda\mu^*)\right]\,, \qquad (7)$$

where $f(\lambda\mu^*) = (1/g)(dg/d\lambda)$.

The volume dependence of the appropriate average phonon frequency γ is an additional unknown parameter which complicates interpretation of pressure data. In the alloy systems studied here, the quantity $\langle I^2\rangle/M\langle\omega^2\rangle$ appears to be approximately constant, independent of $\mathfrak{z}$, x, and a_0; hence, the volume change of $\langle I^2\rangle/M\langle\omega^2\rangle$ is expected to be small, i.e.,

$$\frac{d\ln\langle I^2\rangle}{d\ln V}\approx-\frac{d\ln(1/\langle\omega^2\rangle)}{d\ln V}\approx-2\gamma \tag{8}$$

For A-15 materials,

$$-\frac{d\ln\langle I^2\rangle}{d\ln V}\approx\frac{2}{3}a_0q<2$$

(Refs. 10 and 19; q is a constant describing the exponential decay of the localized d wave function). Hence, the value of γ is expected to be less than 1, which is approximately one order of magnitude smaller than the term $(1/\kappa T_c)(dT_c/dp)$ in Eq. (7) [$\kappa\approx 0.14\times10^{-6}$ bar^{-1} (Ref. 28)]. Using Eq. (8) and the fact that γ is small compared with $(1/\kappa T_c)(dT_c/dp)$, Eqs. (6) and (7) reduce to

$$\frac{d\ln\lambda}{d\ln V}\approx\frac{d\ln N(E_F)}{d\ln V}\approx\left[-\left(\frac{1}{\kappa T_c}\right)\left(\frac{dT_c}{dp}\right)\right]\Big/\left[\left(\ln\frac{\Theta}{T_c}\right)f(\lambda\mu^*)\right]. \tag{9}$$

Smith[29] has recently shown that no correlation exists between Grüneisen parameters γ_G and the pressure derivatives of T_c in various samples of V_3Si. This lack of correlation gives additional support to the approximation of neglecting γ in Eq. (7).

As with extracting λ from T_c data, it is imperative to have specific forms for Θ and g before $d\ln\lambda/d\ln V$ can be obtained from the data using Eq. (9). With the McMillan formula, one has

$$\Theta=\Theta_D/1.45$$

and

$$f(\lambda\mu^*)=\frac{(1+0.38\mu^*)}{(1+\lambda)(\lambda-\mu^*-0.62\lambda\mu^*)}, \tag{10}$$

while with the Birnboim formula

$$\Theta=1.83\Theta_D$$

and

$$f(\lambda\mu^*)=\frac{1+2.93\mu^*}{(\lambda-1.3\mu^*)(1+2.25\lambda)}. \tag{11}$$

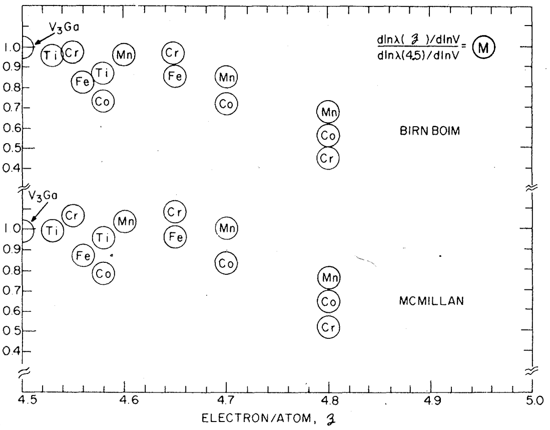

FIG. 7. Ratio of $(d\ln\lambda/d\ln V)/[d\ln\lambda(4.5)/d\ln V]$ as determined by both the McMillan and Birnboim models.

Figure 7 shows the experimentally determined values of $d\ln\lambda/d\ln V$ normalized to the value for V_3Ga, $\mathfrak{z}=4.5$. Whereas the relative pressure derivatives increase with M additions, the strong $\mathfrak{z}$ dependence of the normalizing function $[\ln(\Theta/T_c)]f(\lambda\mu^*)$ causes the normalized relative derivatives, i.e., $d\ln\lambda/d\ln V$, to remain approximately constant. The upper scale refers to the Birnboim analysis while the lower curve refers to the McMillan analysis. To within the scatter in the data there is no difference in the systematic variations of $d\ln\lambda/d\ln V$ between the two approaches. The data show that $d\ln\lambda/d\ln V$ is approximately constant until the $\mathfrak{z}$ value becomes greater than 4.65 and then it begins to fall. As with T_c, $\mathfrak{z}$ appears the most appropriate parameter for describing the data since plots of $d\ln\lambda/d\ln V$ against either x or a_0 leads to families of curves whereas the $\mathfrak{z}$ dependence is more universal to all M systems.

CONCLUSIONS

The data on T_c and dT_c/dp presented here on the $V_{75-x}M_xGa_{25}$ alloy systems support the concept that the superconducting transition temperature is determined by a phonon-limited energy range for the attractive electron-phonon interaction electron-phonon interaction and that sharp structure in the density-of-states curve has little effect on the functional form of the T_c equation. Our results show that, at least for the V_3Ga-based systems studied here, λ is directly related to $N(E_F)$, or perhaps more specifically for materials where $N(E)$ varies rapidly with energy near E_F, to a density of states averaged over a typical phonon energy range in a manner as suggested by Nettle.[20] Likewise, it is suggested that for such a system, the volume derivative of $\bar{\lambda}$ should be

TABLE III. Values of λ and $d\ \ln\lambda/d\ \ln V$ for various Θ_D and μ^* according to the McMillan (M) and Birnboim (B) models. $T_c(V_3Ga) = 14.1$ K.

	$\Theta_D = 310$ K				$\Theta_D = 350$ K			
	λ		$-d\ \ln\lambda/d\ \ln V$		λ		$-d\ \ln\lambda/d\ \ln V$	
μ^*	M	B	M	B	M	B	M	B
0.05	0.74	1.19	3.2	4.7	0.69	1.08	3.0	4.2
0.10	0.87	1.40	3.1	4.5	0.82	1.28	2.9	4.0
0.15	1.01	1.61	3.0	4.3	0.95	1.47	2.8	3.9

dominated by the volume derivative of $\overline{N}(E_F)$.

Determinations of λ from T_c as well as the determination of $d\ln\lambda/d\ln V$ depend on the particular T_c equation employed. A comparison of McMillan's equation to that suggested recently by Birnboim show that the two equations behave in a similar systematic manner. Absolute values for λ and $d\ln\lambda/d\ln V$ are, however, quite different for the two models. Table III lists values of λ and $d\ln\lambda/d\ln V$ for V_3Ga determined by the two equations for several values of Θ_D and μ^*. Theroetical calculations of λ and $d\ln\lambda/d\ln V$ should be able to distinguish between the two models since the values differ significantly.

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