Superconducting State Parameters of $IN_{1-x}Tl_x$ Binary Alloys

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(Received 31 December 2020, Accepted 02 February 2021, Published 09 February 2021)

Abstract

A universal model potential of Fiohais *et al.* with five local field correction functions due to Hartree (H), Taylor (T), Ichimaru-Utsumi (IU), Farid *et al.* (F) and Sarkar *et al.* (S) are used for the first time to study the superconducting state parameters viz. electron-phonon coupling strength λ, Coulomb pseudopotential μ^*, transition temperature T_C, isotope effect exponent α and effective interaction strength $N_O V$ of $In_{1-X}Tl_X$ binary alloys. Very strong effect of the various local field correction functions is established from the present study. The comparison with other such theoretical values is promising, which confirms the applicability of model potential in clarifying the superconducting natures of binary mixture.

1. Introduction

During last several years, the superconductivity remains a vibrant area of study in condensed matter physics starting from the innovation of superconductivity in the year 1911, and especially during last some years passed after the formulation of the BCS theory with continual discoveries of novel materials and with an increasing demand for novel devices for sophisticated technological applications. A large number of metals, alloys, compounds, bulk metallic glasses and also some heavily doped semiconductors are found as a superconductors with transition temperature T_C ranging from 1-18K and more [1-9]. There are very few researchers attempt to study the superconducting state parameters (SSP) of binary alloys based on model potential approach [3-5, 7]. Hence, in the present work, we investigate five superconducting state parameters (SSP)viz. electron-phonon coupling strength λ, Coulomb pseudopotential μ^*, transition temperature T_C, isotope effect exponent α and effective interaction strength $N_O V$ of $In_{1-X}Tl_X$binary alloyssuperconductors on the basis of a universal model potential of Fiohais *et al.*[10] with five employed different types of local field correction functions proposed by Hartree (H) [11], Taylor (T) [12], Ichimaru-Utsumi (IU) [13], Farid *et al.* (F) [14] and Sarkar *et al.* [15] to show the effect of the screening on the aforesaid properties. Here, we have adopted McMillan's [9] formulation for computing the superconducting properties.

2. Method of Computation

Five superconducting state parameters (SSP) viz. electron-phonon coupling strength λ, Coulomb pseudopotential μ^*, transition temperature T_C, isotope effect exponent α and effective interaction strength $N_O V$ are calculated using standard formulae given as follows [3-9]

$$\lambda = \frac{12\, m_b\, Z}{M\left\langle \omega^2 \right\rangle} \int_0^1 X^3 \left| V_S(X) \right|^2 dX, \tag{1}$$

$$\mu^* = \left[\frac{m_b}{\pi k_F} \int_0^1 \frac{dx}{X\varepsilon(X)} \right] \Bigg/ \left[1 + \frac{m_b}{\pi k_F} \ln\left(\frac{E_F}{20\theta_D} \right) \int_0^1 \frac{dx}{X\varepsilon(X)} \right], \tag{2}$$

$$T_C = \frac{\theta_D}{1.45} \exp\left[\frac{-1.04\,(1+\lambda)}{\lambda - \mu^*\,(1+0.62\,)} \right], \tag{3}$$

$$\alpha = \frac{1}{2}\left[1 - \left(\mu^* \ln\left(\frac{\theta_D}{1.45 T_C} \right) \right)^2 \frac{1+0.62\lambda}{1.04(1+\lambda)} \right], \tag{4}$$

and

$$N_o V = \left[\lambda - \mu^* \right] \Bigg/ \left[1 + \frac{10}{11}\lambda \right]. \tag{5}$$

Where $m_b$is the band mass of electron, M the ionic mass, $Z$the valance, $V_S(x)$ the screened model potential related to Fiohais *et al.* [10] and$\left\langle \omega^2 \right\rangle$ the averaged square phonon frequency which is calculated from the relation given by Butler [16] i.e.$\langle \omega^2 \rangle = 0.69\theta_D$, where $\theta_D$is the Debye temperature.Also, $\varepsilon(x)$ is the modified Hartree dielectric function [11],E_F the Fermi energy and $X = q/2k_F$ with k_F be the Fermi wave vector.

3. Results and Discussion

The input parameters and constants used in the present work are given in Table 1, while Table 2 shows presently computed data of superconducting state parameters (SSP) along with other such theoretical [7] and experimental [8] findings. It is observed that, among all five local field correction functions, the H-screening function [11] provides the minimum value while the F-function [14] gives the maximum value for most of the superconducting properties. Our presently computed data are found in qualitative agreement with the reported results either theoretical [7] or experimental [8]. The overall influence of all the local field correction functions with respect to H-function are found of the order of 21.42%-42.12% for λ, 5.71%-11.11% for μ^*, 55.91%-178.47% for T_C, 3.01%-8.57% for α and 15.50%-32.98% for $N_O V$, respectively. Therefore, all the superconducting properties are found to be quite sensitive to the variety of the local field correction function and viewing a significant deviation with the change in the function. Also, the effect of pseudopotential in strong coupling superconductor is large, however it plays a pivotal role in weak coupling superconductors which are at the boundary dividing the superconducting and non-superconducting region. Therefore, a small variation in the value of electron-ion interaction may prime to a sudden change in the superconducting properties of the material under investigation. Hence, the importance of an accurate form for the pseudopotential and local field correction functions are most important one for studying such properties.

Table 1. Input parameters and other constants for $In_{1-x}Tl_x$ binary alloys

Metallic Elements	Z	Ω_O (au)	θ_D (K)	m_b	α (au)	R (au)
In	3	175.90	109	0.89	3.397	0.423
Tl	3	191.67	87	0.82	3.360	0.439

Table 2. Superconducting state parameters $In_{1-x}Tl_x$ binary alloys.

Alloys	SSP	Present results					Exp t. [8]	Others [7]
		H	T	IU	F	S		
$In_{0.90}Tl_{0.10}$	λ	0.6791	0.9242	0.9515	0.9610	0.8245	0.85	1.09, 0.80, 0.92, 1.68, 1.31, 1.32, 1.25, 1.50, 1.46, 0.71, 0.85
	μ^*	0.1243	0.1358	0.1374	0.1377	0.1313	–	0.14, 0.13, 0.13, 0.15, 0.14, 0.14, 0.15, 0.14, 0.11, 0.12
	T_C (K)	2.2803	4.4070	4.6215	4.7034	3.5552	3.28	5.84, 3.33, 4.44, 9.68, 7.48, 7.56, 7.05, 8.69, 8.46, 2.75
	α	0.4241	0.4425	0.4433	0.4439	0.4369	–	0.44, 0.45, 0.45, 0.46, 0.47
	$N_O V$	0.3430	0.4284	0.4365	0.4394	0.3962	–	0.39, 0.43, 0.36

$In_{0.73}Tl_{0.27}$	λ	0.6287	0.8563	0.8817	0.8905	0.7641	0.933	1.05, 0.79, 0.88, 1.61, 1.26, 1.27, 1.20, 1.44, 1.40, 0.68
	μ^*	0.1231	0.1346	0.1362	0.1365	0.1302	–	0.14, 0.13, 0.13, 0.15, 0.14, 0.14, 0.14, 0.14, 0.11
	T_C (K)	1.7537	3.6489	3.8464	3.9215	2.8786	3.36	5.27, 3.14, 3.93, 8.92, 7.07, 7.14, 6.44, 7.99, 7.78, 3.36, 2.38
	α	0.4147	0.4366	0.4376	0.4383	0.4300	–	0.44, 0.45, 0.44, 0.46
	N_OV	0.3217	0.4058	0.4138	0.4167	0.3740	–	0.39, 0.42, 0.35
$In_{0.67}Tl_{0.33}$	λ	0.6140	0.8366	0.8614	0.8700	0.7465	0.899	1.04, 0.79, 0.87, 1.59, 1.25, 1.26, 1.19, 1.43, 1.39, 0.67, 0.90
	μ^*	0.1227	0.1342	0.1358	0.1361	0.1298	–	0.14, 0.13, 0.13, 0.15, 0.14, 0.14, 0.14, 0.14, 0.11
	T_C (K)	1.6081	3.4284	3.6201	3.6930	2.6850	3.26	5.12, 3.13, 3.80, 8.71, 6.66, 6.74, 6.28, 7.81, 7.60, 2.30, 4.51, 2.21
	α	0.4117	0.4347	0.4358	0.4365	0.4277	–	0.44, 0.44, 0.44, 0.46
	N_OV	0.3153	0.3989	0.4069	0.4098	0.3674	–	0.39, 0.41, 0.35
$In_{0.27}Tl_{0.73}$	λ	0.5464	0.7458	0.7681	0.7757	0.6658	1.09	1.092
	μ^*	0.1200	0.1314	0.1330	0.1332	0.1270	–	–
	T_C (K)	0.9910	2.4130	2.5717	2.6315	1.8182	3.64	5.59, 2.76
	α	0.3958	0.4252	0.4266	0.4274	0.4165	–	–
	N_OV	0.2849	0.3661	0.3740	0.3768	0.3356	–	–
$In_{0.17}Tl_{0.83}$	λ	0.5358	0.7316	0.7536	0.7611	0.6532	0.98	1.06, 0.90, 0.88, 1.61, 1.28, 1.29, 1.23, 1.46, 1.43, 0.70, 0.89
	μ^*	0.1193	0.1307	0.1322	0.1325	0.1263	–	0.13, 0.12, 0.12, 0.14, 0.13, 0.13, 0.14, 0.11
	T_C (K)	0.9032	2.2522	2.4044	2.4615	1.6858	3.19	4.92, 3.76, 3.65, 8.09, 6.24, 6.39, 6.02, 7.37, 7.18, 2.37, 3.47, 1.79

	α	0.3934	0.4238	0.4253	0.4261	0.4148	–	0.45, 0.45, 0.47
	$N_O V$	0.2801	0.3609	0.3687	0.3715	0.3306	–	0.43, 0.42, 0.36
$In_{0.07}Tl_{0.93}$	λ	0.5272	0.7202	0.7419	0.7492	0.6431	0.89	1.09, 0.94, 0.91, 1.66, 1.31, 1.32, 1.26, 1.50, 1.49, 0.71
	μ^*	0.1186	0.1299	0.1315	0.1317	0.1256	–	0.13, 0.12, 0.12, 0.14, 0.13, 0.13, 0.14, 0.13, 0.11
	T_C (K)	0.8332	2.1189	2.2653	2.3201	1.5776	2.77	5.09, 4.08, 3.82, 8.19, 6.48, 6.54, 6.19, 7.45, 7.41, 2.46
	α	0.3917	0.4229	0.4244	0.4253	0.4137	–	0.46, 0.46, 0.45, 0.46
	$N_O V$	0.2762	0.3567	0.3645	0.3673	0.3266	–	0.44, 0.43, 0.37

4. Conclusions

Lastly, we conclude here that, the presently computing superconducting state parameters of $In_{1-X}Tl_X$binary alloys are shown consistent results with the available experimental and theoretical data. Hence, such computation supports the applicability of Fiohais *et al.*'s universal model potential with five local field correction functions.

Acknowledgements

Computer facility developed under DST-FIST programme from Department of Science and Technology, Government of India, New Delhi, India and financial assistance under DRS-SAP-I from University Grants Commission, New Delhi, India is highly acknowledge by the authors.

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