

Superconducting state parameters of indium-based binary alloys

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Abstract. Our well-recognized pseudopotential is used to investigate the superconducting state parameters viz; electron–phonon coupling strength λ , Coulomb pseudopotential μ^* , transition temperature T_c , isotope effective exponent α and interaction strength N_0V for the $\text{In}_{1-x}\text{Zn}_x$ and $\text{In}_{1-x}\text{Sn}_x$ binary alloys. We have incorporated six different types of local field correction functions, proposed by Hartree, Taylor, Vashistha–Singwi, Ichimaru–Utsumi, Farid *et al* and Sarkar *et al* to show the effect of exchange and correlation on the aforesaid properties. Very strong influence of the various exchange and correlation functions is concluded from the present study. The comparison with other such theoretical values is encouraging, which confirms the applicability of our model potential in explaining the superconducting state parameters of binary mixture.

Keywords. Superconducting state parameters; indium alloys.

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1. Introduction

There are very few scattered attempts to study the superconducting state parameters of binary alloys based on model potential [1–3]. Hence, we thought it worthwhile to undertake the investigation of the superconducting state parameters of $\text{In}_{1-x}\text{Zn}_x$ and $\text{In}_{1-x}\text{Sn}_x$ binary alloys on the basis of our well-recognized model potential [4,5]. We have employed six different types of local field correction functions proposed by Hartree (H) [6], Taylor (T) [7], Vashistha–Singwi (VS) [8], Ichimaru–Utsumi (IU) [9], Farid *et al* (F) [10] and Sarkar *et al* [11] to show the effect of the exchange and correlation on the aforesaid properties. For the investigations of electron–phonon coupling strength λ , Coulomb pseudopotential μ^* , transition temperature T_c , isotope effective exponent α and interaction strength N_0V for the alloy A_{1-x}B_x , we have extended the way followed by McMillan for metals [2,3,12].

2. Method of computation

The mathematical expressions used for the present investigation of λ , μ^* , T_c , α and N_0V are [2,3,12]

$$\lambda = \frac{12m^*Z^*}{M\langle\omega^2\rangle} \int_0^1 X^3 |V_S(X)|^2 dx, \quad (1)$$

$$\mu^* = \left[\frac{m_b}{\pi k_F} \int_0^1 \frac{dx}{X\varepsilon(X)} \right] / \left[1 + \frac{m_b}{\pi k_F} \ln\left(\frac{E_F}{10\theta_D}\right) \int_0^1 \frac{dx}{X\varepsilon(X)} \right], \quad (2)$$

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

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

$$N_0V = [\lambda - \mu^*] / \left[1 + \frac{10}{11}\lambda \right], \quad (5)$$

where m^* is the effective electronic mass, m_b the band mass of electron, M the atomic mass, Z^* the effective valance, $\langle\omega^2\rangle^{1/2} = (\omega_L + \omega_T)/2$ the averaged phonon frequency, θ_D the Debye temperature, $V_S(X)$ the screened model potential, $\varepsilon(X)$ the modified Hartree dielectric function, E_F the Fermi energy and $X = q/2k_F$ with k_F being the Fermi wave vector.

Our well-recognized model potential used in the present investigation is written as (in a.u.) [4,5]

$$V_S(X) = \frac{-\pi Z^*}{\varepsilon(X)\Omega_0 X^2 k_F^2} \left[\cos(2Xk_F r_c) - \frac{(2Xk_F r_c)^2}{1 + (2Xk_F r_c)^2} \right]. \quad (6)$$

Here Ω_0 is the atomic volume and r_c the potential parameter, which is determined by using the first zero of the pseudopotential form factor.

3. Results and discussion

The input parameters used in the present investigation are given in table 1. Tables 2 and 3 give the presently calculated values of the superconducting state parameters along with other such findings [1–3]. It is seen from tables 2 and 3 that among all the six screening functions, the screening function due to H (only static, without exchange and correlation) [6] gives the minimum value of the superconducting state parameters while the screening function due to F [10] gives the maximum value. The numerical values of the

Table 1. Input parameters used in the computation.

Metal	k_F (a.u.)	Ω_0 (a.u.)	r_c (a.u.)	θ_D (°K)	M^*	m_b	$\omega_L \times 10^{-4}$ (a.u.)	$\omega_T \times 10^{-4}$ (a.u.)
Zn	0.8342	102.0	0.7915	309	0.86	0.93	7.644	3.696
In	0.7972	175.3	0.7341	109	1.39	0.89	5.439	2.389
Sn	0.8674	181.5	0.7120	195	1.29	0.93	6.177	3.135

Table 2. Superconducting state parameters of $\text{In}_{1-x}\text{Zn}_x$ alloy.

Prop.	Conc. x	Present results						Others
		H	T	VS	IU	F	S	
λ	0.0	0.7240	0.9491	0.9792	1.0212	1.0345	0.9146	0.26 [2], 0.67 [2], 0.80 [1] 0.73 [2], 0.81 [3], 0.84 [2], 1.74 [3]
	0.2	0.5450	0.7101	0.7324	0.7618	0.7715	0.6847	0.58 [2], 0.62 [3], 1.23 [3]
	0.4	0.4272	0.5534	0.5714	0.5928	0.6004	0.5339	0.48 [2], 0.50 [3], 0.90 [3]
	0.6	0.3456	0.4453	0.4610	0.4771	0.4835	0.4297	0.35 [3], 0.41 [2], 0.67 [3]
	0.8	0.2870	0.3681	0.3825	0.3950	0.4006	0.3551	0.27 [3], 0.35 [2], 0.52 [3]
	1.0	0.2437	0.3113	0.3252	0.3351	0.3403	0.3002	0.21 [3], 0.27 [2], 0.35 [3], 0.41 [2], 0.45 [2]
μ^*	0.0	0.1149	0.1226	0.1246	0.1259	0.1266	0.1214	0.09 [1], 0.10 [2], 0.11 [2], 0.12 [2], 0.13 [3], 0.15 [3]
	0.2	0.1162	0.1240	0.1260	0.1273	0.1280	0.1227	0.12 [2], 0.13 [3], 0.15 [3]
	0.4	0.1178	0.1258	0.1278	0.1292	0.1298	0.1244	0.12 [2], 0.13 [3], 0.14 [3]
	0.6	0.1200	0.1282	0.1303	0.1317	0.1323	0.1268	0.12 [2], 0.12 [3], 0.14 [3]
	0.8	0.1234	0.1320	0.1342	0.1357	0.1363	0.1305	0.12 [3], 0.12 [2], 0.138 [3]
	1.0	0.1305	0.1399	0.1424	0.1441	0.1449	0.1384	0.115 [2], 0.116 [3], 0.12 [2], 0.138 [3], 0.14 [2]
T_c (°K)	0.0	3.0162	5.1169	5.3518	5.7109	5.8161	4.8122	4.67×10^{-3} [2], 2.81 [2], 3.08 [2], 3.4 [1], 3.53 [3], 4 [2], 10.264 [3]
	0.2	1.3385	2.9147	3.1131	3.4064	3.4981	2.6646	1.75 [2], 1.86 [3], 7.66 [3]
	0.4	0.4492	1.3955	1.5418	1.7416	1.8110	1.2255	0.73 [3], 0.89 [2], 5.06 [3]
	0.6	0.0993	0.5258	0.6161	0.7257	0.7699	0.4347	0.11 [3], 0.39 [2], 2.84 [3]
	0.8	0.0108	0.1374	0.1795	0.2245	0.2466	0.1030	0.005 [3], 0.13 [2], 1.34 [3]
	1.0	0.0002	0.0168	0.0277	0.0385	0.0454	0.0103	4.1×10^{-5} [3], 0.013 [2], 0.027 [2], 0.41 [2], 0.58 [3], 0.85 [2]
α	0.0	0.4448	0.4575	0.4577	0.4591	0.4593	0.4562	0.44 [3], 0.44 [2], 0.448 [3], 0.45 [2], 0.46 [2]
	0.2	0.4044	0.4303	0.4311	0.4337	0.4342	0.4277	0.40 [3], 0.41 [3], 0.417 [2]
	0.4	0.3316	0.3839	0.3861	0.3909	0.3921	0.3788	0.34 [3], 0.35 [3], 0.474 [2]
	0.6	0.1935	0.3014	0.3075	0.3162	0.3189	0.2909	0.19 [3], 0.28 [3], 0.304 [2]
	0.8	-0.099	0.1413	0.1584	0.1750	0.1815	0.1181	-0.13 [3], 0.18 [2], 0.195 [3]
	1.0	-0.952	-0.265	-0.208	-0.171	-0.152	-0.328	0.09 [2], 0.11 [3], 0.24 [2], 0.40 [2], 0.95 [3]
N_0V	0.0	0.3673	0.4436	0.4521	0.4643	0.4679	0.4331	0.12 [2], 0.37 [2], 0.39 [3], 0.44 [3]
	0.2	0.2868	0.3562	0.3640	0.3748	0.3782	0.3464	0.30 [2], 0.32 [3], 0.34 [3]
	0.4	0.2228	0.2845	0.2920	0.3013	0.3044	0.2756	0.25 [2], 0.25 [3], 0.25 [3]
	0.6	0.1716	0.2257	0.2331	0.2409	0.2439	0.2178	0.18 [3], 0.21 [2], 0.21 [3]
	0.8	0.1297	0.1769	0.1843	0.1908	0.1937	0.1698	0.17 [2], 0.18 [3], 0.12 [3]
	1.0	0.0927	0.1336	0.1410	0.1464	0.1493	0.1272	0.08 [3], 0.14 [2], 0.19 [2], 0.17 [2]

Table 3. Superconducting state parameters of $\text{In}_{1-x}\text{Sn}_x$ alloy.

Prop.	Conc.		Present results					Others
	x		H	T	VS	IU	F	
λ	0.0	0.7240	0.9491	0.9792	1.0212	1.0345	0.9146	0.26 [2], 0.67 [2], 0.80 [1], 0.73 [2], 0.81 [3], 0.84 [2], 1.74 [3]
	0.2	0.7071	0.9220	0.9509	0.9907	1.0026	0.8887	0.73 [2], 0.77 [3], 1.63 [3]
	0.4	0.6935	0.8997	0.9277	0.9644	0.9762	0.8673	0.73 [3], 0.74 [2], 1.53 [3]
	0.6	0.6826	0.8812	0.9087	0.9432	0.9545	0.8496	0.69 [3], 0.76 [2], 1.44 [3]
	0.8	0.6740	0.8661	0.8932	0.9258	0.9367	0.8350	0.66 [3], 0.77 [2], 1.36 [3]
	1.0	0.6674	0.8537	0.8808	0.9117	0.9223	0.8231	0.64 [3], 0.72 [1], 0.78 [2], 0.791 [2], 0.82 [2], 1.30 [2], 1.28 [3]
μ^*	0.0	0.1149	0.1226	0.1246	0.1259	0.1266	0.1214	0.097 [1], 0.10 [2], 0.11 [2], 0.12 [2], 0.129 [3], 0.15 [3]
	0.2	0.1154	0.1231	0.1251	0.1264	0.1270	0.1219	0.12 [2], 0.13 [3], 0.149 [3]
	0.4	0.1162	0.1239	0.1258	0.1271	0.1278	0.1225	0.12 [2], 0.13 [3], 0.149 [3]
	0.6	0.1172	0.1249	0.1269	0.1282	0.1288	0.1235	0.12 [2], 0.13 [3], 0.149 [3]
	0.8	0.1186	0.1264	0.1284	0.1297	0.1304	0.1250	0.12 [2], 0.13 [3], 0.15 [3]
	1.0	0.1208	0.1288	0.1308	0.1322	0.1328	0.1273	0.092 [1], 0.11 [2], 0.12 [2], 0.121 [2], 0.133 [3], 0.152 [3]
T_c (°K)	0.0	3.0162	5.1169	5.3518	5.7109	5.8161	4.8122	4.67×10^{-3} [2], 2.81 [2], 3.08 [2], 3.4 [1], 3.53 [3], 4 [2], 10.264 [3]
	0.2	3.0419	5.2068	5.4519	5.8168	5.9550	4.8868	3.34 [3], 3.35 [2], 10.364 [3]
	0.4	3.1295	5.3932	5.6545	6.0301	6.1432	5.0524	3.19 [3], 3.74 [2], 10.567 [3]
	0.6	3.2977	5.7115	5.9973	6.3911	6.5120	5.3414	3.09 [3], 4.30 [2], 10.938 [3]
	0.8	3.5864	6.2356	6.5590	6.9835	7.1168	5.8218	3.07 [3], 5.11 [2], 11.602 [3]
	1.0	4.0935	7.1435	7.5292	8.0089	8.1634	6.6581	3.19 [3], 3.75 [1], 6.2 [2], 6.39 [2], 7.35 [2], 12.85 [3], 15.24 [2]
α	0.0	0.4448	0.4575	0.4577	0.4591	0.4593	0.4562	0.43 [3], 0.44 [2], 0.448 [3], 0.45 [2], 0.469 [2]
	0.2	0.4419	0.4551	0.4554	0.4568	0.4571	0.4538	0.43 [3], 0.44 [3], 0.445 [2]
	0.4	0.4389	0.4527	0.4530	0.4545	0.4547	0.4513	0.43 [3], 0.436 [3], 0.446 [2]
	0.6	0.4357	0.4502	0.4505	0.4520	0.4522	0.4487	0.42 [3], 0.429 [3], 0.446 [2]
	0.8	0.4321	0.4472	0.4476	0.4490	0.4493	0.4457	0.41 [3], 0.42 [3], 0.446 [2]
	1.0	0.4275	0.4433	0.4438	0.4453	0.4456	0.4417	0.39 [3], 0.40 [3], 0.437 [2], 0.44 [2], 0.45 [2]
N_0V	0.0	0.3673	0.4436	0.4521	0.4643	0.4679	0.4331	0.12 [2], 0.37 [2], 0.39 [3], 0.44 [3]
	0.2	0.3602	0.4346	0.4429	0.4545	0.4581	0.4242	0.37 [2], 0.376 [3], 0.42 [3]
	0.4	0.3541	0.4268	0.4350	0.4461	0.4495	0.4164	0.36 [3], 0.374 [2], 0.39 [3]
	0.6	0.3489	0.4199	0.4281	0.4388	0.4421	0.4096	0.35 [3], 0.379 [2], 0.38 [3]
	0.8	0.3444	0.4138	0.4221	0.4323	0.4355	0.4036	0.33 [3], 0.384 [2], 0.36 [3]
	1.0	0.3402	0.4082	0.4165	0.4262	0.4294	0.3980	0.16 [2], 0.32 [3], 0.34 [3], 0.39 [2], 0.55 [2]

aforesaid properties are found to be quite sensitive to the selection of the local field correction function and showing a significant variation with the change in the function. With respect to the static H-dielectric function [6] the influence of various local field correction functions on λ is 36% to 42%. Such influence on μ^* is 10% to 11%. These changes in λ and μ^* make drastic variation on T_c , α and N_0V . The experimental data for these properties for $\text{In}_{1-x}\text{Zn}_x$ and $\text{In}_{1-x}\text{Sn}_x$ are not available for detailed comparison but the comparison with other such theoretical values is encouraging, which confirms the applicability of our model potential in explaining the superconducting state parameters of binary mixture.

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