The modeling of the charge carrier scattering on the short-range potential in indium antimonide

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Abstract. The processes of the electron scattering on the short-range potential caused by interaction with polar and nonpolar optical phonons, piezoelectric and acoustic phonons, static strain centers and ionized impurities in n-InSb with defect concentration ~8.3×10^{14} cm^{-3} are considered. The temperature dependences of electron mobility and thermoelectric power are calculated.

Keywords: transport phenomena, charge carrier scattering, indium antimonide.

Introduction

Usually the electron scattering in indium antimonide was considered in relaxation time approximation or using the variational method. The common feature of these methods is the using of the long-range charge carrier scattering models for the description of the transport phenomena in this semiconductor. In these models it is supposed that either the charge carrier interacts with all the crystal (electron -phonon interaction) or it interacts with the defect potential of the impurity the action radius of which is equal to ~10 – 1000 a_0 (a_0 – lattice constant). However, such an assumption has next contradictions: a) it contradicts the special relativity according to which the charge carrier would interact only with the neighbouring crystal region; b) it contradicts the atomistic hypothesis according to which the charge carrier interacts (and transfers the energy respectively) only with one atom but not simultaneously with many atoms which are situated in different points of space. To eliminate these contradictions it is necessary to consider the following question – what object in the crystal absorbs the energy during the charge carrier scattering process? It can be either ionized (neutral) impurity atom or an atom which oscillates in the lattice site. During the scattering process all of these objects do not leave the boundaries of the elementary cell. Therefore the short-range charge carrier scattering models in zinc-blende II-VI [1-2] and in wurtzite III-V [3] semiconductors were proposed where it has been supposed that the carrier interacts with the defect potential only within the limits of one elementary cell. Here the following physical reasons were used: during the scattering the electron interacts only with neighboring crystal region (the short-range principle), after the scattering on this region the electron interacts with the next neighboring crystal region, etc. The aim of the present paper is the use of short-range models to describe the electron scattering on the various crystal lattice defects in indium antimonide.

Discussion

For the electron scattering on the nonpolar optical (NPO), acoustic (AC) phonons and static strain (SS) centre the interaction radius of the short-range potential is limited by one unit cell. For the electron scattering on the ionized impurity (II), polar optical (PO) and piezoelectric (piezoacoustic (PAC and piezooptic (POP)) phonons the interaction radius of the short-range potential is founded in a form $R=\gamma\, a_0$ (a_0 - lattice constant, γ – the respective fitting parameters).

It must be noticed that the strong power dependence of parameters γ sharply limits the choice opportunities of their numerical values.

The respective electron transition probability from state $\boldsymbol{k}$ to state $\boldsymbol{k'}$ caused by the interaction with defect potential was chose from [1,2]. To calculate the conductivity tensor components the method of a precise solution of the stationary Boltzmann equation was used [4]. Since the wave vector dependence from the energy $k = k(\varepsilon)$ is taken in the form of the polynomial then the calculation was limited by the case of $n = 5$, which differed from the case $n = 4$ less than $\sim 1\%$. Using this formalism one can obtain additional fitting parameter $\gamma_{SS}N_{SS}$ (we put γ_{SS}=1) for SS- scattering mode. The material parameters used for calculation are listed in Table 1.

The Fermi level was obtained from the electroneutrality equation:

$$n - p = N_D - N_A = 8.3\times10^{14}$$

where N_A and N_D - donor and acceptor concentration respectively.

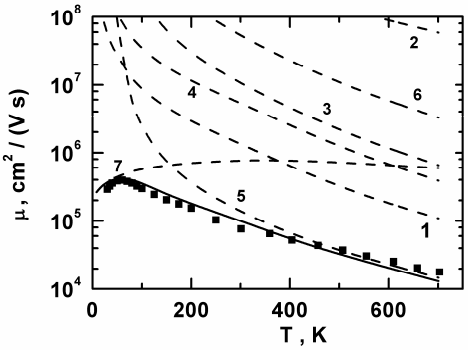

Fig.1. Temperature dependence of electron mobility in InSb. Solid line-mixed scattering mode; 1,2,3,4,5,6,7 – AC, II, NPO, PAC, PO,POP, SS –scattering modes respectively.

A comparison of the theoretical temperature dependences of the electron mobility and thermoelectric power was made with the experimental data presented in [5]. The obtained fitting parameters for different scattering modes are listed in Table II.

Material parameters

Table I.

Material parameter	Value
Lattice constant, a_0 (m)	6.47937×10^{-10}
Energy gap, E_g (eV)	$0.235 - 0.27\times10^{-3} T^2/(T+106)$
Energy equivalent of matrix element, E_p (eV)	23.2
Spin-orbit splitting, Δ (eV)	0.803
Density, ρ_0 (gm cm^{-3})	5.7747
Optical deformation potential, d_0 (eV)	26.8
Optical phonon energy, (meV)	
$\hbar\omega_{LO}$ (meV)	23.6
$\hbar\omega_{TO}$ (meV)	22.3
Acoustic deformation potential, (eV)	9.5
Sound velocity, c (m s^{-1})	
$c_{\parallel}$ (m s^{-1})	3.77×10^3
$c_{\perp}$(m s^{-1})	2.29×10^3
Piezoelectric tensor component, e_{14} (C m^{-2})	0.071

Parameters γ for different scattering modes

Table II.

γ_{PO}	γ_{PZ}	γ_{ID}	γ_{SS} Nss $\times 10^{-14}$ cm^{-3}
0.63	0.40	1.0	5.9

The theoretical $\mu(T)$ curve is presented in Fig.1. The solid line represents the curve calculated on the basis of the short-range models within the framework of the precise solution of the Boltzmann equation. It is seen that the theoretical curve well agree with experimental data in all investigated temperature range. To estimate the role of the different scattering mechanisms in Fig. 1 the dashed lines represent the appropriate dependences. It is seen that at low temperatures (T<100 K) the main scattering mechanism is static strain scattering. At high temperatures the contribution of the polar optical phonon scattering becomes dominant. In the same temperature range the acoustic phonon scattering also plays a prominent role. Other scattering mechanisms such as piezooptic and piezoacoustic phonon scattering, the ionized impurity and nonpolar optical phonon scattering give negligibly small contributions.

The theoretical temperature dependence of thermoelectric power demonstrates a sufficiently good agreement with experimental data (see Fig. 2) at high temperature region where the intrinsic ionization plays the dominant role.

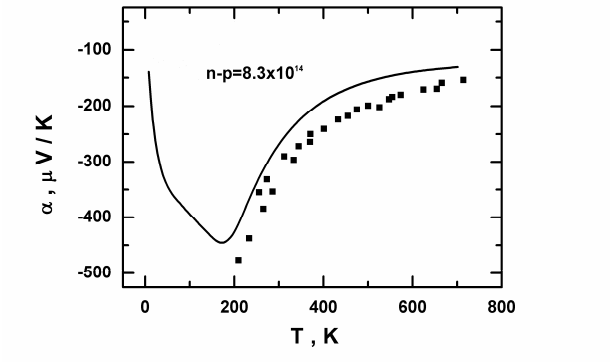

Fig.2. Temperature dependence of thermoelectric power in InSb.

For the region of the impurity conductivity the theoretical temperature dependences of thermoelectric power were compared with experimental data presented in [6]. As it seen from Fig.3 the theoretical curves coincide sufficiently well with experimental data.

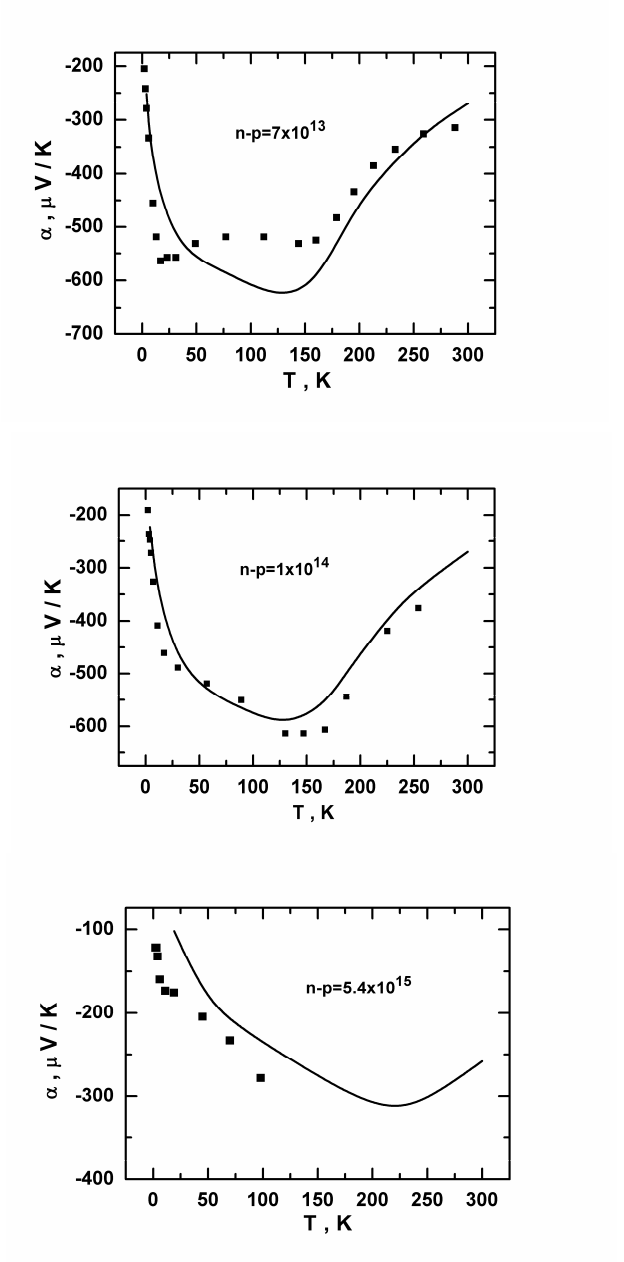

Fig.3. Temperature dependence of thermoelectric power in InSb crystals with different defect concentration.

Conclusion

On the base of the short-range principle the electron scattering processes on the various crystal lattice defects in indium antimonide were considered. A good agreement between the theory and experimental data in investigated temperature range was established.

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