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Piezoelectric interaction in controlling the effective electron temperature and the non-ohmic mobility characteristics in GaN and other III-V compounds at low lattice temperature.

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ABSTRACT

In a compound semiconductor which lacks inversion symmetry, the free electrons interact simultaneously with the piezoelectric and acoustic phonons. This combined interaction principally controls the electrical transport at low lattice temperatures. Again, at low temperatures, the electrons in some of the compounds may be significantly perturbed for comparatively low fields, say, even for a fraction of a volt cm^{-1} or so, which effectively seem to be high enough, and the material exhibits electrical non-linearity. Such a perturbed ensemble then attains a field dependent effective electron temperature T_e which exceeds the lattice temperature T_L . The relative importance of the piezoelectric interaction in controlling the field dependence of the effective electron temperature, and therefrom, the non-ohmic mobility characteristics have been analyzed here under the condition of low lattice temperature. The numerical results obtained for InSb, InAs and GaN are studied in details. When compared with the experiments, the results here seem to give the same qualitative picture in respect of the variation of the non-ohmic mobility with the electric field for the indium compounds. The results being interesting stimulate further work in the same field.

Keywords: Non-equilibrium electrons; Effective high fields; Low lattice temperature; Effective electron temperature; Non-ohmic mobility.

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1. Introduction

The electrical characteristics of any semiconductor is determined by the various interactions which the electrons may have with the lattice defects under the prevalent conditions of the experiment. In compound semiconductors, where the constituent atoms are partially ionized and the materials possess lower inversion symmetry, the intrinsic acoustic vibrations of the lattice atoms produce an electric field, and this gives rise to piezoelectric scattering potential along with the deformation potential. The piezoelectric scattering is known to be quite important in many semiconductors under the condition of relatively lower lattice temperature. Some of these semiconductors possessing values of piezoelectric coupling constant K_m^2 over a wide range, are now widely used for the device purposes. For example: GaN ($K_m^2 = 0.0324$) is commonly used for light emitting diodes, InSb ($K_m^2 = 7.29 \times 10^{-4}$) for infrared detectors, InAs ($K_m^2 = 2.8 \times 10^{-4}$) as well as InSb for galvanomagnetic devices. The electrical transport in such materials is controlled by the combined interaction with the deformation potential and the piezoelectric phonons at low temperatures. Since these materials are polar in nature the interaction with the polar-optical phonons may contribute to the transport process under the condition of high temperature when a sufficient number of polar optical phonons may be generated.

The importance of the piezoelectric scattering relative to that due to the deformation potential scattering of the electrons in controlling the electrical transport in the presence of low fields in many compounds has already been studied [1-3].

But in the presence of relatively high field, the free electrons may be significantly perturbed from the state of thermodynamic equilibrium with the host lattice atoms. Under this condition, the electrons attain a field dependent effective temperature T_e that exceeds the lattice temperature T_L , and the material exhibits electrical non-linearity. In the low temperature regime, where the piezoelectric scattering is important, the onset of the non-linearity may start even for a field of only few volt cm^{-1} . For example, in compounds like n-InSb or n-InAs, the non-linearity may be observed even for a field of a fraction of volt cm^{-1} or so [4].

Though the theory of high field transport, in principle, may be developed through solving the Boltzmann Transport equation, but to arrive at an analytical solution of the transport equation is beset with much mathematical difficulties, unless one makes simplifying approximation, which more often than not compromises with the physical validity of the results. However, if the carrier concentration is large, so that the energy exchange between the carriers is much faster than that between the carriers and the lattice, the carriers share their energy ε mainly amongst themselves and the energy distribution for a non-degenerate ensemble of carriers may be approximated by the Maxwellian distribution at a field dependent carrier temperature T_e [1,4,5]. The field dependence of T_e may be obtained from the solution of the energy balance equation of the electron phonon system. Such dependence has already been obtained solely for the individual interactions, like acoustic, piezoelectric etc. [6]. But, as has already been said, the interactions that take place under the prevalent conditions of the experiment are usually a combination of a few individual interactions. Hence to calculate the field dependence of the effective electron temperature for some combined interactions of the electrons, the energy balance equation needs to be solved afresh taking into account all the individual scatterings simultaneously.

The non-ohmic mobility characteristics $\mu(E)$ in the presence of relatively high fields may now be obtained from [5]

$$e\mu E^2 = \left\langle \frac{d\varepsilon}{dt} \right\rangle_{\text{combined interaction}} \quad (1)$$

where e is the electronic charge, E is the applied electric field, and $\langle \frac{d\varepsilon}{dt} \rangle$, the average energy loss rate for the same combination of interactions, that needs to be calculated taking all the individual scattering into account simultaneously.

Since the piezoelectric scattering is important in the relatively low lattice temperature regime, where, for some compounds, particularly with lower values of the effective mass m^* , like InSb or InAs having $m^* \sim 10^{-2} m_0$ (m_0 being the free electron mass), an electric field of a fraction of a volt cm^{-1} or so, may appear to be high enough to perturb the electron ensemble significantly, and thus electrical non-linearity may be exhibited at that field. On the other hand, for GaN, which possesses quite a high value of the piezoelectric coupling constant, the onset of the electrical non-linearity takes place at somewhat high fields because of its nearly ten times heavier effective mass than that of the Indium compounds.

The purpose of this communication is to solve the energy balance equation for the electron phonon system for the combined interaction with deformation potential and piezoelectric phonons and thus to obtain the electric field dependence of the effective electron temperature. Next the high field mobility characteristics is obtained from (1) for the same combination of interactions. Since the energy loss rate due to acoustic interaction is already known [5], the same is calculated for the piezoelectric interaction in order to get $\langle \frac{d\varepsilon}{dt} \rangle$ for the combined interaction. Numerical results are obtained for InSb, InAs and GaN. The results are analyzed in details and compared with other available data. The results clearly exhibit the importance of the piezoelectric scattering in controlling the non-ohmic transport characteristics in the presence of relatively high fields under the condition of low lattice temperature.

2. Development

2.1. Field dependence of the effective electron temperature for the combined interaction with piezoelectric and deformation acoustic phonons.

The energy balance condition for the electron phonon system can be symbolically written as [4-6]

$$\int_{\vec{k}} \left. \frac{\partial f(\vec{k})}{\partial t} \right|_{\text{field}} \varepsilon d\vec{k} = \sum_j \int_{\vec{k}} \left. \frac{\partial f(\vec{k})}{\partial t} \right|_j \varepsilon d\vec{k} \quad (2)$$

where $\left. \frac{\partial f(\vec{k})}{\partial t} \right|_j$ is the time rate of change of the high field distribution function $f(\vec{k})$ of the electron ensemble due to the j^{th} collision mechanism, ε is the energy of an electron with wave vector $\vec{k}$. The distribution function $f(\vec{k})$ for the non-equilibrium carriers may be written in the diffusion approximation as

$$f(\vec{k}) = f_0(\varepsilon) + k f_1(\varepsilon) \cos\theta \quad (3)$$

$f_0(\varepsilon)$ being the isotropic part of the distribution and θ is the angle between $\vec{k}$ and the drift field $\vec{E}$.

Let us consider a volume of an isotropic, non-degenerate semiconductor material with a single, parabolic, spherically symmetric conduction band. Considering the four processes of absorption and emission of a phonon of wave vector $\vec{q}$ in course of the electronic transition between the states $|\vec{k} + \vec{q}\rangle$ and $|\vec{k} - \vec{q}\rangle$ due to the combined interaction with the piezoelectric and the deformation potential acoustic phonons, one can obtain from the perturbation theory [5, 6]

$$\sum_j \left. \frac{\partial f_0(\vec{k})}{\partial t} \right|_j = \left(\frac{W}{\tau_{ace}} + \frac{1}{\tau_{pze}} \right) W^{\frac{1}{2}} \frac{d^2 f_0}{dW^2} + \left[\frac{W^{\frac{1}{2}}(W+2)}{\tau_{ace}} + \frac{W^{-\frac{1}{2}}(W+1)}{\tau_{pze}} \right] \frac{\partial f_0}{\partial W} + \left(\frac{2W^{\frac{1}{2}}}{\tau_{ace}} + \frac{W^{-\frac{1}{2}}}{\tau_{pze}} \right) f_0 \quad (4)$$

where $W = \frac{\varepsilon}{k_B T_L}$. τ_{ace} and τ_{pze} are the energy independent factors of the expressions for the energy relaxation time for the interaction with the acoustic and the piezoelectric phonons respectively. They are given by, $\tau_{ace} = \frac{\pi \rho \hbar^4}{2\sqrt{2} m^{*5/2} E_1^2 (k_B T_L)^{1/2}}$; $\tau_{pze} = \frac{\sqrt{2} \pi \hbar^2 \epsilon_{sc} (k_B T_L)^{1/2}}{m^{*3/2} e^2 K_m^2 u_l^2}$ ρ is the density, $\hbar = \frac{h}{2\pi}$; h being the Planck's constant, k_B is the Boltzmann constant, E_1 is the deformation potential constant, ϵ_{sc} is the static dielectric constant and u_l is the average acoustic velocity.

Now using (4) one can carry out the collision integral in (2) in the energy domain and obtain

$$\sum_j \int_k \left. \frac{\partial f_0(\vec{k})}{\partial t} \right|_j \varepsilon d\vec{k} = \left[\frac{2\pi(2m^*)^{\frac{3}{2}}}{\hbar^3} \right] \left[\frac{n_0 \hbar^3 (k_B T_L)^{\frac{5}{2}} T_n}{(2\pi k_B T_e)^{\frac{3}{2}} \tau_{ace}} \right] \left[2(3T_n + P) - T_n \left\{ 2(T_n + 2) + P \left(1 + \frac{1}{T_n} \right) \right\} \right] \quad (5)$$

where $T_n = T_e / T_L$, $P \equiv \frac{\tau_{ace}}{\tau_{pze}} = \frac{\rho \hbar^2 e^2 K_m^2 u_l^2}{4m^* k_B T_L E_1^2 \epsilon_{sc}}$

The rate of change of the distribution function due to the field for the combined interaction is given by [4-6]

$$\left. \frac{\partial f_0(\vec{k})}{\partial t} \right|_{\text{field}} = \frac{2}{3} \frac{eE}{\hbar} \int \mathcal{E}^{-1/2} \frac{d(\mathcal{E}^{3/2} f_1)}{d\mathcal{E}} \varepsilon d\vec{k} \quad (6)$$

where $f_1 = \frac{-e\hbar\tau_{eff}}{m^*} \left(\frac{\varepsilon}{k_B T_L} \right)^{-1/2} E \frac{\partial f_0}{\partial \varepsilon}$; $\tau_{eff} = \frac{\tau_{acm} \tau_{pzm} W^{1/2}}{\tau_{acm} + \tau_{pzm}}$; τ_{acm} and τ_{pzm} are the energy independent factors of the expressions for the momentum relaxation time for the interaction with the acoustic and the piezoelectric phonons respectively. They are given by, $\tau_{acm} = \frac{\pi \rho \hbar^4 u_l^2}{\sqrt{2} m^{*3/2} E_1^2 (k_B T_L)^{3/2}}$; $\tau_{pzm} = \frac{e^2 m^* (k_B T_L)^{1/2} K_m^2}{\pi 2^{3/2} \hbar^2 \epsilon_{sc}}$

Now using (6) one can in principle carry out the integral in (2) that involves the field term, in the energy domain. But the presence of the piezoelectric scattering in the combination of interactions, characteristically makes the integral diverge as $\varepsilon \rightarrow \infty$ [5,6]. As such, the upper limit of energy is set at several times the average thermal energy, say $n k_B T_e$ ($n \gg 1$), beyond which there would be hardly any electron. The finite, maximum value of n is to be suitably chosen so as to make the result convergent. Thus one can obtain

$$\int_k \left. \frac{\partial f(\vec{k})}{\partial t} \right|_{\text{field}} \varepsilon d\vec{k} = \frac{4n_0 (T_L)^{\frac{1}{2}} e^2 E^2 \tau_{acm}}{3\sqrt{\pi} m^* k_B^2 T_e^{\frac{5}{2}}} I_p \quad (7)$$

where

$$I_P = \frac{(nk_B T_e)^3 e^{-n}}{(nk_B T_e + Pk_B T_L)} - (k_B T_e)^2 \left[n^2 e^{Y_1} \left\{ \ln(Y_2) + \sum_{i=1}^{\infty} \frac{(-Y_2)^i}{i!} \right\} - 2e^{Y_1} \left[\left(\frac{Y_2^2}{2} \right) \left(\ln(Y_2) - \frac{1}{2} \right) - Y_1 Y_2 (\ln(Y_2) - 1) + \sum_{i=1}^{\infty} \frac{(-1)^i}{i!} \left\{ \frac{Y_2^{i+2}}{i+2} - Y_1 \frac{Y_2^{i+1}}{i+1} \right\} \right] \right] - (k_B T_e)^2 2e^{Y_1} \left[\left(\frac{Y_1^2}{2} \right) \left(\ln(Y_1) - \frac{1}{2} \right) - Y_1^2 (\ln(Y_1) - 1) + \sum_{i=1}^{\infty} \frac{(-1)^i}{i!} \left\{ \frac{Y_1^{i+2}}{i+2} - Y_1 \frac{Y_1^{i+1}}{i+1} \right\} \right]$$

where $Y_1 = \frac{P}{T_n}$ and $Y_2 = n + \frac{P}{T_n}$

Now equating (5) with (7) one can obtain the field dependence of the effective electron temperature for the combined interaction with the piezoelectric and deformation acoustic phonons.

2.2. Energy loss rate for the combined interaction with the piezoelectric and deformation acoustic phonons.

The field dependence of the effective electron temperature being known, one can now calculate the non-ohmic mobility characteristics using (1), when the average energy loss rate of the non-equilibrium ensemble of electrons for the same combination of interactions is known.

Again starting from the perturbation theory one may first calculate the energy loss rate of a carrier of energy ε by summing over all the possible emission and absorption processes that such a carrier may undergo in making transition to and from the states of $|\vec{k}+\vec{q}\rangle$ and $|\vec{k}-\vec{q}\rangle$. Then the loss rate needs to be averaged over the distribution of carrier energies. Proceeding in this way the expression for the average loss rate for interaction with deformation acoustic phonons has already been available [5]. It takes the form

$$\left\langle \frac{d\varepsilon}{dt} \right\rangle_{ac} = \frac{8\sqrt{2}}{\pi^{3/2}} \frac{E_1^2 m^{*5/2}}{\hbar^4 \rho} (k_B T_e)^{3/2} \left(\frac{T_L}{T_e} - 1 \right) \quad (8)$$

Proceeding in the same manner one can get the following expression for the average loss rate for interaction with the piezoelectric phonons

$$\left\langle \frac{d\varepsilon}{dt} \right\rangle_{pz} = \frac{e^2 K_m^2}{2\pi^3 (2\pi)^{3/2}} \frac{u_l^2 m^{*3/2}}{\epsilon_{sc} \hbar^2} (k_B T_e)^{1/2} \left(\frac{T_L}{T_e} - 1 \right) \quad (9)$$

$$\text{Thus } \left\langle \frac{d\varepsilon}{dt} \right\rangle_{Combination} = \left\langle \frac{d\varepsilon}{dt} \right\rangle_{ac} + \left\langle \frac{d\varepsilon}{dt} \right\rangle_{pz} \quad (10)$$

Using (10) a relationship between $\left\langle \frac{d\varepsilon}{dt} \right\rangle_{Combination}$ and T_e can be plotted. The figure 1 describes the dependence of energy loss rate of the electrons upon their effective temperature in samples of InSb, InAs and GaN. The Figure 1 is further used to determine the non-ohmic mobility for the three samples.

Figure 1: Dependence of energy loss rate of electrons upon the effective electron temperature in the samples of InSb, InAs and GaN. The combined interaction of the electrons with the acoustic and the piezoelectric phonons are taken into account. The curves 1a-1c for the samples of InSb and similarly the curves 2a-2c for the samples of InAs, are obtained from (10) at the lattice temperatures of 4.2K, 20K and 77K respectively. The curves 3a-3c for the samples of GaN are also obtained from (10) at the lattice temperatures of 77K, 125K and 300K respectively.

Now the non-ohmic mobility characteristics for the combined interaction of the non-equilibrium carriers may be obtained from (1)

3. Comparison of Results and Discussion

In this short communication we have made a theoretical analysis to study the importance of the piezoelectric scattering relative to that of acoustic scattering in controlling the non-ohmic transport characteristics of some III-V compound semiconductors. Since the piezoelectric interaction is important at relatively low temperatures, and at such low temperature regime the electron ensemble in compounds like InSb or InAs which possess a low value of the effective mass, gets heated up even for a field of a fraction of a volt/cm. So, such a low field appears to be effectively high enough to perturb the electron ensemble significantly from the state of thermodynamic equilibrium with the lattice atoms. As such, we choose to limit our discussion mainly over the portion of the transport characteristics that may be obtained for low lattice temperatures and for apparently low fields. Such a choice would ensure that (i) piezoelectric scattering remains an important interaction. (ii) The electron ensemble is heated up and (iii) sufficient number of polar optical phonons are not generated, so that the interaction with such phonons

hardly comes into play. The results of similar studies for the importance of piezoelectric scattering in controlling the ohmic characteristics of compound semiconductors are already obtained by others [3]

In the present analysis, the effective electron temperature characteristics are first obtained for the combination of interactions with the piezoelectric and the acoustic phonons. Then the non-ohmic mobility characteristics are obtained from the electron temperature characteristics using the energy balance equation.

The field dependence of the effective electron temperature for the individual scattering is known to be quite simple, obeying the laws [6] $T_n(T_n-1) \sim E^2$ and $(1-1/T_n) \sim E^2$ respectively for the interaction with the deformation acoustic phonons and the piezoelectric phonons. But it appears from (5) and (7) that the same field dependence for the combination of the two interactions is quite complex. As such, this results in a much complex field dependence of the mobility of the non-equilibrium electrons.

To depict a quantitative picture of the two characteristics we consider non-degenerate samples of InSb, InAs and GaN. The material parameters that are used for the numerical evaluation of the characteristics of these materials are given in Table 1. Each of the samples are lightly doped with shallow donors, whose ionization energy is of the order of or lower than $k_B T_L$. The concentration of the materials are less than the effective density of states N_c , so that the Fermi level remains within the band gap. Under these conditions the degeneracy sets in for $N_d \sim 5 N_c$ and the carrier concentration $n_0 \sim 0.15 N_d$, where N_d is the donor concentration [7, 8]. As such the carrier concentrations may be taken to be $10^{12}/\text{cm}^3$, $10^{13}/\text{cm}^3$ and $10^{14}/\text{cm}^3$ for InSb, InAs and GaN respectively. However, it may be noted that, when (5) is equated to (7) to obtain the field dependence of the effective electron temperature, under the prevalent conditions of interest here, the concentration n_0 cancels out. As has already been said, n is suitably chosen for the convergent results. The effective electron temperature characteristics have been calculated from the present analysis taking $n=5$ for both InSb and InAs and $n=10$ for GaN.

It may be noted that, for the lower values of P , the consideration of only a few terms are sufficient for the convergence of the summation over P that are involved in the expression for the function I_P . Obviously for Indium compounds, the lower values of K_m^2 and the higher values of E_i^2 keep P quite low even for lower temperatures, around 4.2K. The values are 3.55 and 8.35 for InSb and InAs respectively. As T_L increases, P reduces more and more, that in turn makes it possible to truncate the summation earlier, without compromising with the convergence of the results. On the other hand, the value of P turns out to be nearly two orders of magnitude higher at $T_L=4.2\text{K}$ for GaN. Hence this requires quite a large number of terms to get the convergent results for GaN unless the lattice temperature is increased accordingly, say around 77K, so as to reduce the value of P sufficiently, which in turn makes the truncation of the summation possible after a much lesser number of terms.

The characteristics of the effective electron temperature and that of the non-ohmic mobility of the electrons relative to μ_0 , the zero field value, as obtained from the present analysis under the condition when the combined interaction with the piezoelectric and acoustic phonons takes place in the samples considered here, are represented in figures 2, 3 and 4. To make a ready comparison of the importance of the piezoelectric scattering relative to that of the intrinsic acoustic scattering in controlling the non-ohmic transport of the electrons, the figures for the non-ohmic characteristics for the sole interaction with the intrinsic acoustic phonons have also been included in the figures.

It may be seen from the figures that, when the piezoelectric interaction is considered in combination with that due the deformation acoustic phonons, significant qualitative as well as quantitative changes in the non-ohmic transport characteristics are effected over the low ranges of the electric field and the lattice temperature. The changes are much more perceptible for the mobility characteristics

compared to the effective electron temperature characteristics. In any case however, the combination with the piezoelectric interaction effects greater changes, the lower the temperature. At higher fields however, the characteristics for the combined interaction tend to that due to the acoustic interaction only, as the importance of the piezoelectric interaction reduces more and more. This picture continues till the lattice temperature and the field is high enough so that the interaction with the polar optical phonons begins to be more and more important.

Figure 2

Figure 2: Dependence of effective electron temperature and normalized non-ohmic mobility upon the electric field in InSb. Curves 1a-1c and 3a-3c show the effect of acoustic scattering in determining the field dependence of the effective electron temperature and the normalized non-ohmic mobility respectively for the different lattice temperatures. Curves 2a-2c and 4a-4c give respectively the field dependence of the effective electron temperature and of the non-ohmic mobility for the combined scattering of the electrons with the acoustic and the piezoelectric phonons. The curves marked a, b and c are respectively for the lattice temperatures of 4.2K, 20K and 77K. A comparison of the curves 1a-1c with the curves 2a-2c reveals the effects of the piezoelectric scattering on the field dependence of the effective electron temperature. Similarly the comparison of the curves 3a-3c with the curves 4a-4c displays the effects of the same piezoelectric interaction on the field dependence of the non-ohmic mobility.

Figure 3

Figure 3. Dependence of effective electron temperature and normalized non-ohmic mobility upon the electric field in InAs. Curves 1a-1c and 3a-3c show the effect of acoustic scattering in determining the field dependence of the effective electron temperature and the normalized non-ohmic mobility respectively for the different lattice temperatures. Curves 2a-2c and 4a-4c give respectively the field dependence of the effective electron temperature and of the non-ohmic mobility for the combined scattering of the electrons with the acoustic and the piezoelectric phonons. The curves marked a, b and c are respectively for the lattice temperatures of 4.2K, 20K and 77K. A comparison of the curves 1a-1c with the curves 2a-2c reveals the effects of the piezoelectric scattering on the field dependence of the effective electron temperature. Similarly the comparison of the curves 3a-3c with the curves 4a-4c displays the effects of the same piezoelectric interaction on the field dependence of the non-ohmic mobility.

Figure 4

Figure 4: Dependence of effective electron temperature and normalized non-ohmic mobility upon the electric field in GaN. Curves 1a-1c and 3a-3c show the effect of acoustic scattering in determining the field dependence of the effective electron temperature and the normalized non-ohmic mobility respectively for the different lattice temperatures. Curves 2a-2c and 4a-4c give respectively the field dependence of the effective electron temperature and of the non-ohmic mobility for the combined scattering of the electrons with the acoustic and the piezoelectric phonons. The curves marked a, b and c are respectively for the lattice temperatures of 77K, 125K and 300K. A comparison of the curves 1a-1c with the curves 2a-2c reveals the effects of the piezoelectric scattering on the field dependence of the effective electron temperature. Similarly the comparison of the curves 3a-3c with the curves 4a-4c displays the effects of the same piezoelectric interaction on the field dependence of the non-ohmic mobility.

There is no such experimental data available, which shows the importance of only the piezoelectric scattering relative to that of acoustic scattering in controlling the non-ohmic transport in semiconductors. Experiments which have been performed, provide data of the non-ohmic transport characteristics over a wider regime of the lattice temperature and the electric field [4, 9-12]. Such experimental data reflects the results of the combination of all relevant types of interaction of the electrons, not just for the combination of the piezoelectric scattering only with the acoustic scattering. However, the results obtained here for Insb and InAs over the limited range of the lattice temperature and the field provide qualitatively the same

picture in respect of the variation of the mobility with the electric field as that which follow from the experiments[11,12]

Since, piezoelectric scattering is important for low temperatures, some other low temperature features need to be considered for the refinement of the present analysis. Under the condition, when the lattice temperature is low, the equipartition approximation for the phonon distribution is hardly valid [5, 13]. Hence the true phonon distribution should be taken into account. However, at low temperatures, the average thermal energy of electrons being comparable with the energy of the acoustic phonons, the electron –phonon collision becomes inelastic. Thus phonon energy needs to be considered carefully in the energy balance equation of the electron phonon system. Apart from that, at low temperatures the electrostatic screening of the scattering potential should also be taken into account [1]. Still again, the piezoelectric coupling constant being highly anisotropic, the tensorial nature of the constant should also be considered [5, 14]. All these factors need to be given due consideration for further refinement of the present analysis. All the factors cannot be taken up at a time for a detailed analysis. Each may have to be considered separately. However, the results obtained from the present analysis being already interesting, it stimulates further work in the same field.

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Table 1: Material Parameters

Material	m^*/m_0	u_l (m/s)	ρ (kg/m ³)	K_m^2	ϵ_{SC} (F/m)	E_1 (eV)
InSb	0.014	3.7E+3	5.78E+3	7.29E-4	1.55E-10	20
InAS	0.022	3.09E+3	5.61E+3	2.822E-4	1.286E-10	5.8
GaN	0.2	5E+3	6.1E+3	3.24E-2	8.41E-11	8