Temperature dependence of highfrequency electron mobility in Ga0.47In0.53As

D. Chattopadhyay

Citation: Journal of Applied Physics **51**, 1850 (1980); doi: 10.1063/1.327757
View online: http://dx.doi.org/10.1063/1.327757
View Table of Contents: http://scitation.aip.org/content/aip/journal/jap/51/3?ver=pdfcov
Published by the AIP Publishing

Temperature dependence of high-frequency electron mobility in $Ga_{0.47}In_{0.53}As$

D. Chattopadhyay
Institute of Radio Physics and Electronics, 92 Acharya Prafulla Chandra Road, Calcutta 700009, India

(Received 17 July 1979; accepted for publication 14 August 1979)

Frequency and temperature dependences of the real and the imaginary parts of the high-frequency electron mobility in $Ga_{0.47}In_{0.53}As$ are theoretically studied by an iterative solution of the Boltzmann equation. The high-frequency effects are found to be described by the Drude model unless a high accuracy is desired. The calculated results are sensitive to the value of the alloy scattering potential.

PACS numbers: 72.30. + q, 72.80.Ey, 72.20.Fr

There has been considerable interest in recent years in $Ga_xIn_{1-x}As$ ($x \approx 0.5$) mixed crystal because of its usefulness in optoelectronic and high-frequency devices.[1,2] The quality of a material for device applications is judged by a study of its electron transport coefficients. The dc transport coefficients of $Ga_xIn_{1-x}As$ have been investigated both experimentally and theoretically.[1-4] There has, however, been little effort to study the ac transport coefficients. In this communication we shall present the calculated results on the ac electron mobility of $Ga_{0.47}In_{0.53}As$, for which dc results are available.[1] The results given here may be used to compare with the experimental data when they appear.

The nonparabolicity of the conduction band has been considered by writing the energy (E) versus wave vector ($\mathbf{k}$) relation as

$$\frac{\hbar^2 k^2}{2m^*} = E(1+\alpha E) = \gamma(E), \tag{1}$$

where $\hbar$ is Planck's constant divided by 2π, α is the nonparabolicity parameter, and m^* is the band-edge effective mass corrected for the lattice disorder.[5]

Effects of polar optic, deformation potential acoustic, piezoelectric, alloy, and ionized impurity scatterings have been included. Influences due to mixing of wave functions, screening of the scattering probabilities by free carriers, and degeneracy of the electron distribution are also incorporated.

In the presence of an ac electric field $\mathscr{E} = \mathscr{E}_0 \exp(j\omega t)$, the distribution function may be written

$$f(\mathbf{k}) = f_0(E) - \frac{e\hbar\mathscr{E}}{m^*} k\,[\phi_r(E) + j\phi_i(E)]\frac{\partial f_0}{\partial E}\cos\theta, \tag{2}$$

where $f_0(E)$ is the thermal equilibrium Fermi-Dirac distribution function, e is the electron charge, θ is the angle between $\mathscr{E}$ and $\mathbf{k}$, and ϕ_r and ϕ_i are functions to be determined from the Boltzmann equation.

Substituting Eq. (2) in the Boltzmann equation and equating the real and imaginary parts one obtains

$$\lambda_0(E)\phi_r(E) - \omega\phi_i(E) = \left(\frac{d\gamma}{dE}\right)^{-1} + \lambda_+(E)\phi_r(E+\hbar\omega_0) + \lambda_-(E)\phi_r(E-\hbar\omega_0) \tag{3}$$

and

$$\lambda_0(E)\phi_i(E) + \omega\phi_r(E) = \lambda_+(E)\phi_i(E+\hbar\omega_0) + \lambda_-(E)\phi_i(E-\hbar\omega_0), \tag{4}$$

where $\hbar\omega_0$ is the optic phonon energy. $\lambda_0(E)$ is the sum of the scattering-out rate for polar optic scattering caused by absorption and emission of phonons and the relaxation rates

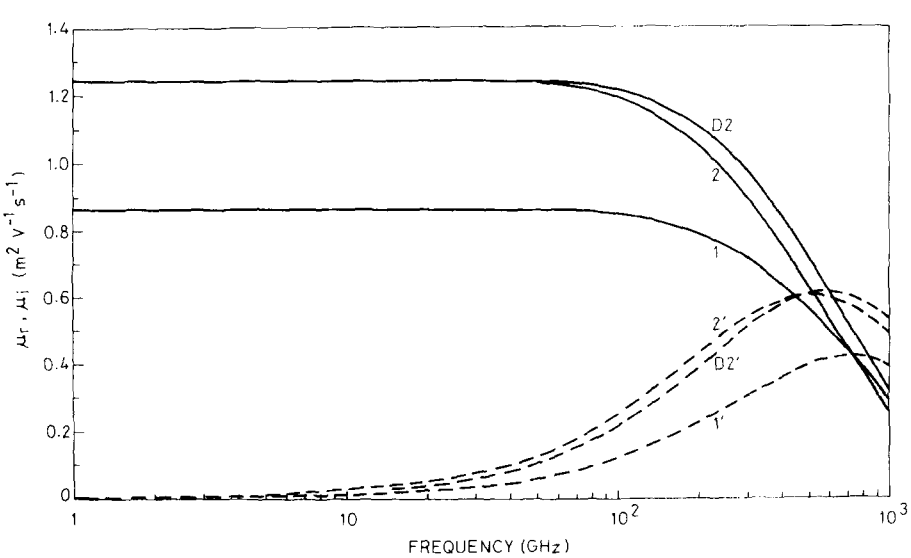

FIG. 1. Plot of the real part μ_r (solid curves) and the imaginary part μ_i (dashed curves) of mobility versus frequency at 300 K. Curves (1), and (1') are for $\Delta E_a = 1.15$ eV and curves (2) and (2') are for $\Delta E_a = 0.52$ eV. Curves D2 and D2' are obtained on the Drude model with parameters of curves (2) and (2').

 0021-8979/80/031850-02$01.10

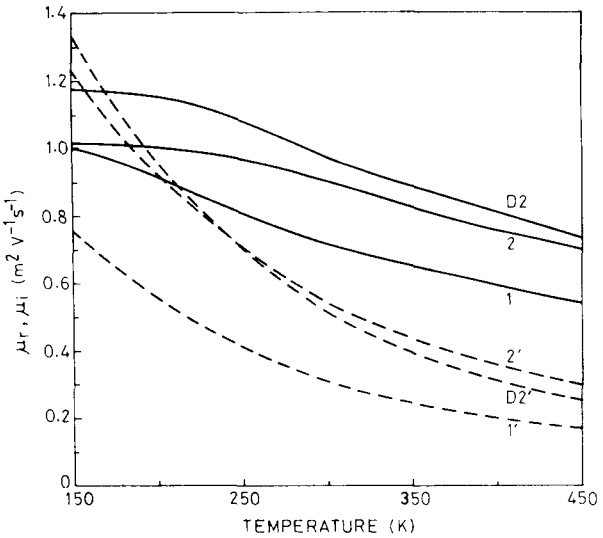

FIG. 2. Variation of μ_r (solid curves) and μ_i (dashed curves) with temperature for a frequency of 300 GHz. Curves (1) and (1') are for $\Delta E_a = 1.15$ eV and curves (2) and (2') are for $\Delta E_a = 0.52$ eV. Curves D2 and D2' have the same significance as in Fig. 1.

for other scattering mechanisms. $\lambda_+(E)$ and $\lambda_-(E)$ correspond to scattering-in rates for polar optic scattering due to emission and absorption of phonons, respectively. Expressions for λ_0, λ_+, and λ_- for the assumed scattering processes are well known.[4,6]

Equations (3) and (4) were solved by an extension of Rode's iterative method.[7] In the pth step of iteration $\phi_r(E)$ and $\phi_i(E)$ were obtained by using the values of $\phi_r(E \pm \hbar\omega_0)$ and $\phi_i(E \pm \hbar\omega_0)$ calculated in the $(p\text{-}1)$th step. For $p = 1$, $\phi_r(E \pm \hbar\omega_0)$ and $\phi_i(E \pm \hbar\omega_0)$ are taken to be zero. A discussion on the method and related convergence is given by Nag.[8] The complex ac mobility is given by $\mu_r - j\mu_i$, where

$$\mu_r = -\left(\frac{2e}{3m^*}\right)\int_0^\infty \gamma^{3/2}\phi_r \frac{\partial f_0}{\partial E}\,dE \times\left(\int_0^\infty f_0\gamma^{1/2}\frac{d\gamma}{dE}\,dE\right)^{-1} \tag{5}$$

and

$$\mu_i = \left(\frac{2e}{3m^*}\right)\int_0^\infty \gamma^{3/2}\phi_i \frac{\partial f_0}{\partial E}\,dE \times\left(\int_0^\infty f_0\gamma^{1/2}\frac{d\gamma}{dE}\,dE\right)^{-1}. \tag{6}$$

The material parameters used in the calculations were chosen from Ref. 4. There has been controversy over the choice of the alloy scattering potential ΔE_a. According to some authors, ΔE_a is the difference in band gaps between the constituent compounds.[3] Some authors, on the other hand, take ΔE_a as the difference in electron affinities between the constituent compounds,[9] while some prefer a different value on the basis of the electronegativity theory.[2] For $Ga_{0.47}In_{0.53}As$ the values of ΔE_a according to the three models are 1.15, 0.83, and 0.52 eV, respectively. Calculations have been done for two extreme values of ΔE_a, namely, 0.52 and 1.15 eV to study the sensitivity of the results to changes in ΔE_a. The ionized impurity concentration is taken equal to the free-electron concentration which is given a typical value of 10^{16} cm^{-3}.

The calculated values of μ_r and μ_i are shown in Figs. 1 and 2. It is interesting to compare the exact values with those obtained from the simple Drude theory. In this theory the effective relaxation time τ; is derived by writing the weak-field dc mobility as $\mu = e\tau/m^*$. In the estimation of μ, $\omega = 0$ and hence $\phi_i(E) = 0$. It is thus necessary to solve only Eq. (3) by the iterative technique of Rode.[7] The quantities μ_r and μ_i are then given by $\mu_r = (e\tau/m^*)(1+\omega^2\tau^2)^{-1}$ and $\mu_i = (e\omega\tau^2/m^*)(1+\omega^2\tau^2)^{-1}$. It is found from Figs. 1 and 2 that Drude values are close to exact values and unless a high accuracy is required the ac mobility can be estimated from the Drude model.

Figure 1 shows that at room temperature μ_r remains practically constant at the dc value up to a frequency of 100 GHz. Beyond this frequency μ_r decreases while μ_i increases to a maximum and then falls. This sort of behavior is readily predicted from the simple Drude expressions. Figure 2 shows that both μ_r and μ_i for 300 GHz decrease as the temperature rises from 150 to 450 K. These results can be explained from the fact that τ diminishes with increase of temperature.

It is found from Figs. 1 and 2 that the ac mobility is sensitive to the choice of ΔE_a. In particular, μ_i increases by a factor of 2 at 300 K and 200 GHz, and by a factor of 1.6 at 150 K and 300 GHz as ΔE_a changes from 1.15 to 0.52 eV. Analyses of dc mobility show[4] that ΔE_a would be close to 1.15 eV. It is indicated that additional information on ΔE_a can be obtained from experimental measurements of ac transport coefficients.

S.K. Sutradhar helped by punching the computer cards.

[1]Y. Takeda, A. Sasaki, Y. Imamura, and T. Takagi, J. Electrochem. Soc. **125**, 130 (1978).
[2]M.A. Littlejohn, J.R. Hauser, T.H. Glisson, D.K. Ferry, and J.W. Harrison, Solid-State Electon. **21**, 107 (1978).
[3]M. Glicksman, R.E. Enstrom, S.A. Mittleman, and J.R. Appert, Phys. Rev. B **9**, 1621 (1974).
[4]D. Chattopadhyay, S.K. Sutradhar, and B.R. Nag (unpublished).
[5]O. Berolo, J.C. Woolley, and J.A. Van Vechten, Phys. Rev. B **8**, 3794 (1973).
[6]D. Chattopadhyay and B.R. Nag, Phys. Rev. B **12**, 5676 (1975).
[7]D.L. Rode, Phys. Rev. B **2**, 1012 (1970).
[8]B.R. Nag, J. Phys. C **7**, 3541 (1974).
[9]J.R. Hauser, M.A. Littlejohn, and T.H. Glisson, Appl. Phys. Lett. **28**, 458 (1976).