Estimation of drift mobility in InGaAsP semiconducting alloys from photoluminescence at 77 and 300 K

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Abstract

In this work, we propose a method of calculation for estimating the drift mobility from photoluminescence (PL). The method is based on the difference between the temperature of the scattered carriers after thermalization and the lattice temperature. The effective carrier temperature and then the drift mobility of the samples using this effective temperature was calculated.

Keywords: Photoluminescence; Mobility; InGaAsP

1. Introduction

Photoluminescence (PL) has been developed as an important and powerful tool for the investigation and characterization of semiconductor materials and devices. In the present work, the PL spectra of Ga1-xInxAs1-yP1-y alloy semiconductors was used to calculate the effective carrier temperature and then the drift mobility of the samples using this effective temperature was calculated. The method is based on the application of the case of hot electron induced by electric field to those induced by photoexcitation because of their similarity. In both cases, the gas electron acquires an effective temperature given by the energy interchange in steady state with phonons, impurities and disorder [1].

2. Theory

The scattering mechanisms taken into account to calculate the mobility are: alloy scattering, ionized-impurity scattering and polar optical phonon scattering. The total mobility using the Matthiessen’s rule \( \mu^{-1} = \sum \mu_i^{-1} \) was obtained.

The electron mobility limited by polar optical phonon scattering may be written [2]

\[
\mu_{\text{PO}} = \frac{2m^*N_0^2\lambda e^2\hbar^2}{9\pi k_\text{po} e^2}\left(1 - \frac{1}{e^x_i}\right)^{1/2}\left[(e^{(4x_i^2)-1}K_1 + (e^{(4x_i^2)-1})K_0)^{-1}, (1)
\]

where \( m^* \) is the electron effective mass, \( \theta_\text{po} \) the Debye temperature of the LO phonons frequency, \( \omega_{\text{LO}} \), \( \chi_0 = h\omega_{\text{LO}}/kT_0 \) with \( T_0 \) the effective electron temperature, \( T_0 \) the lattice temperature, \( N_0 = (e^{v_1} - 1)^{-1} \), and \( e^x_i \) are the static and high-frequency dielectric constants, and \( K_0 \) and \( K_1 \) are the modified Bessel functions of second kind in \( \chi_0/2 \).

The mobility limit imposed by ionized-impurity scattering in the \( \Gamma_{1C} \) minimum may be written approximately according to the Brooks-Herring formula

\[
\mu_{\text{II}} = 3.28 \times 10^{15} e_s^2 T^{3/2} \left( m^*/m_0 \right)^{1/2} N_i \left[ \ln(1 + b) - \frac{b}{1 + b} \right]^{-1},
\]

where \( b = 1.29 \times 10^{14} e_s m^* T^{2n'} - 1 \), \( n' = n + (N_D - N_A - n) (n + N_A)N_D^{-1} \), and \( N_i = n + 2N_A \). In the expressions \( n \) is the electron density, \( e_s \) is the static dielectric constant and \( N_D, N_A \) the density of donors and acceptors, respectively.

Alloy scattering is thought to arise from non-periodic potential fluctuations caused by the distribution of atoms in...
the corresponding sublattice. In the quaternary alloys it is necessary to consider the distribution of Ga and In atoms in the group III sublattice and the distribution of the As and P atoms on the group V sublattice. The expression for the mobility imposed by alloy scattering is of the form [3]

\[
\mu_{AL} = \frac{8 \times 10^4 \sqrt{2} \hbar^4}{3\pi e \varepsilon_0 \varepsilon_\infty S(\alpha) (\Delta U) (m^*)^{-5/2} T^2},
\]

where \( S(\alpha) \) is the degree of randomness, being unity when there is a total disorder but becoming zero in a perfectly ordered structure. \( \Delta U \) is the alloy scattering potential (in eV) and it is a measure of the magnitude of the fluctuations caused by the atomic distribution variations.

3. Experimental part

The InGaAsP samples were grown by step-cooling liquid phase epitaxy at 650 °C lattice-matched on n-type (100) InP substrates using a graphite slider boat. The thickness of the epitaxial layers were around 3 mm.

We performed PL at 77 and 300 K. PL spectra were recorded employing a 15 mW He–Ne laser as the exciting light and a cold-finger cryostat. The luminescence response signal was equally focused in the monochromator. A SR-510 lock-in amplifier connected to a computer received and recorded the electrical response.

The carrier concentration was measured using a Hg-probe capacitometer.

4. Results

The PL emission spectra are described by the van Roosbroeck-Shockley relation given by [4]

\[
I_{PL} \propto (h\nu)^2 (h\nu - E_G)^{1/2} \frac{1}{1 + \exp \left( \frac{h\nu - E_F}{kT_E} \right)},
\]

where \( E_G \) is the band gap energy and \( E_F \) the Fermi level, and \( k \) is the Boltzmann constant.

The exponential factor dominates the fit of the high-energy region of the near edge maximum and leads calculate the effective carrier temperature \( T_E \), which usually is different and higher than the lattice temperature.

In order to calculate values of a given parameter \( A_Q \) we used an expression which permits the interpolation from the values corresponding to the respective binary compounds InAs, InP, GaAs and GaP, given by [3]:

\[
A_Q = (1-x)yA_1 + (1-x)(1-y)A_2 + xyA_3 + x(1-y)A_4.
\]

For evaluating Eqs. (1)–(3), we used the values of \( \Delta U \) reported in Ref. [3] and the value of \( m^* \) reported in Ref. [5].

Other needed physical parameters were obtained by interpolating the values of binary compounds according to composition of the quaternary alloy using the expression (5) [3]. The total density of ionized-impurity centers \( N_A + N_B \) was taken following [3] as an adjustable parameter. This procedure was verified, calculating the electron mobility in dependence of temperature for the alloy Ga0.15In0.85As0.31P0.69. The values of the calculated total drift mobility were in agreements with the values of the drift mobility from Ref. [3].

The effective carrier temperature \( T_E \) was calculated by fitting the experimental spectra in the spectra measured at 77 and 300 K with expression (4). Figs. 1 and 2 exemplify the exponential fit in the high-energy side of PL spectra at 300 K.

Fig. 1. Photoluminescence spectra with the fit curve for the CIP4 sample at 300 K.

Fig. 2. Spectrum of ln(Intensity) vs. \( h\nu \) with the fit curve for the IPP24 sample at 77 K.
and 77 K, respectively. The \( T_E \) values obtained and calculated drift mobility are shown in the Tables 1 and 2 for 300 and 77 K, respectively, and for all the measured samples. In the tables, the PL maximum position and the full width at half maximum (FWHM) are also shown.

In order to verify the procedure it was calculated the mobility value from the PL spectra, which is provided in Ref. [6] for a GaInAsP sample with net carrier concentration \( n = 2.8 \times 10^{16} \text{ cm}^{-3} \), \( N_D = 3.7 \times 10^{16} \text{ cm}^{-3} \) and Hall mobility at 295 K was \( \mu_H = 3850 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1} \), experimentally measured. From our calculation we obtained that \( \mu_T = 3717 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1} \) which agrees well with experimental value with a difference of about 5%.

In previous work [7], a similar method was useful in the determination of the drift mobility in Al\(_x\)Ga\(_{1-x}\)As at \( T \approx 300 \text{ K} \).

<table>
<thead>
<tr>
<th>Sample</th>
<th>( T_E ) (K)</th>
<th>( h\nu_{PL,\text{max}} ) (eV)</th>
<th>FWHM(_{PL} ) (eV)</th>
<th>( \mu ) (cm(^2) V(^{-1}) s(^{-1}))</th>
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</tr>
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<td>124</td>
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<th>Sample</th>
<th>( T_E ) (K)</th>
<th>( h\nu_{PL,\text{max}} ) (eV)</th>
<th>FWHM(_{PL} ) (eV)</th>
<th>( \mu ) (cm(^2) V(^{-1}) s(^{-1}))</th>
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</table>

Then we calculated the drift mobility of the two samples of interest at 77 and 300 K. The results are shown in Table 3.

5. Conclusions

In the work, a method of calculation for estimating the drift mobility from PL spectra was developed. The procedure was verified with data from literature obtaining a good agreement between the calculated and measured experimental values of the drift mobility. The estimation of the drift mobility was done for \( n \)-type conductivity samples. Different scattering mechanisms were taking into account to obtain a good agreement between the estimated values and the experimental ones. The difference between the estimated and measured values of mobility was approximately 5%.

With the help of the method it was calculated the total drift mobility for nine samples of GaAsInP from PL spectra at 300 K and for 10 samples at 77 K.

References