Lawrence Berkeley National Laboratory
Recent Work

Title
Theoretical Electron Mobility/Temperature Dependencies as Functions of Carrier Concentration and Compensation Ratio

Permalink
https://escholarship.org/uc/item/31q4q1wn

Author
Walukiewicz, W.

Publication Date
1996-04-29
Theoretical Electron Mobility/
Temperature Dependencies as
Functions of Carrier Concentration
and Compensation Ratio

W. Walukiewicz
Materials Sciences Division

April 1996
To be published as
a chapter in
EMIS Datareview Series,
J.L. Sears, Ed.,
The Institute of Electrical Engineers,
Stevenage, UK, 1996
DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.
Theoretical Electron Mobility/Temperature Dependencies as Functions of Carrier Concentration and Compensation Ratio

W. Walukiewicz

Materials Sciences Division
Ernest Orlando Lawrence Berkeley National Laboratory
University of California
Berkeley, California 94720

April 1996

This work was supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Materials Sciences Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF0098.
Theoretical Electron Mobility/Temperature Dependencies as Functions of Carrier Concentration and Compensation Ratio

W. Walukiewicz

A. INTRODUCTION

Electron mobility is one of the most commonly measured semiconductor characteristics. The mobility is determined by the momentum randomizing scattering processes. These dominant processes can be divided into two groups: intrinsic effects which include acoustic and optical phonon scattering and a number of extrinsic effects including ionized impurities, neutral impurities, dislocations and other extended defects. The maximum mobility that can be achieved at a given temperature is called the phonon mobility limit and is determined by the intrinsic scattering processes. Since the material parameters are known, the temperature dependence of the phonon mobility limit is now quite well established in GaAs[1- 4]. A deviation of the actual mobility from the phonon mobility limit can thus be considered a measure of the strength of extrinsic scattering processes.

In doped material, the most important extrinsic scattering mechanism is the ionized impurity scattering. Since the scattering rate by an isolated charged impurity center can be easily calculated, a measurement of the electron mobility can be used to evaluate the total concentration of ionized impurities in the sample [2-8]. In most instances, for practical purposes, the theoretical electron mobility is presented as a function of the electron concentration and the compensation ratio $\theta$ which is defined as the ratio of the concentration of
compensating acceptors to the concentration of shallow donors, $N_A/N_D$. The functions have been calculated for both room and liquid nitrogen temperature and are routinely presented in the form of graphs [2-6] and/or tables [7,8].

**B. THEORETICAL ELECTRON MOBILITIES**

In this review the theoretical electron drift mobilities as functions of the ratio of the total ionized impurity concentration to the electron concentration, $N_{imp}/n$, are presented in form of graphs and, in a limited electron concentration range are also approximated by analytic expressions. They provide an easy method for determination of the total concentration of charged impurities from the measured values of the mobility $\mu$ and the electron concentration $n$. Fig. 1(a) and (b) show calculated drift electron mobilities at 300 K [6] and 77 K [7] using a variational method [9]. The total ionized impurity concentration is related to the electron concentration $n$ and the compensation ratio $\theta$ through the equation,

$$N_{imp} = n(1+\theta)/(1-\theta) \quad (1)$$

The calculated values were obtained assuming that there is no spatial correlation between impurities in the samples [10,11]. Also multiple scattering [10,11] and effects of macroscopic inhomogenities [12] were ignored in these calculations.

Use of such graphs for the determination of the total impurity concentration is not always easy as in general it requires interpolation between the curves corresponding to different electron concentrations. In a limited concentration range it is possible to obtain an analytic expression approximating the theoretically calculated functions relating the total ionized impurity concentration.
with electron mobility and electron concentration. The expression has a following general form,

\[ N_{\text{imp}} = n f(n) \mu g(n) \]  \hspace{1cm} (2)

where \( n \) and \( N_{\text{imp}} \) are, respectively, the free electron and the ionized impurity concentration in \( \text{m}^{-3} \), and \( \mu \) is the mobility in \( \text{m}^2/\text{Vs} \). For the room temperature mobility the functions \( f(n) \) and \( g(n) \) can be approximated by,

\[ f(n) = -0.41 + 4.1 \times 10^{-2} \log(n) \]  \hspace{1cm} (3)

\[ g(n) = -4.808 \times 10^{4} n^{-0.2546} \]  \hspace{1cm} (4)

Eqns. 2 to 4 provide a good approximation only for electron concentrations \( n > 10^{23} \text{ m}^{-3} \) i.e. in the range where the room temperature mobility is significantly affected by the ionized impurity scattering. Determination of the impurity concentration in lightly doped GaAs requires measurements at low temperatures at which the mobility is more sensitive to the ionized impurity scattering. For very lightly doped GaAs with electron concentrations in the range \( 10^{20} \text{ m}^{-3} \leq n \leq 3 \times 10^{21} \text{ m}^{-3} \) the ionized impurity concentration can be obtained from the mobility and electron concentration measurements at 77 K. Again \( N_{\text{imp}} \) can be obtained from Eqn. 2 with the functions \( f \) and \( g \) given by

\[ f(n) = 2.46 \times 10^{28} n^{-1.2817} \]  \hspace{1cm} (5)

\[ g(n) = -3855.9 n^{-0.1609} \]  \hspace{1cm} (6)
The above phenomenological formulae are approximate and can be used only for rough estimates of the ionized impurity concentrations. It should be also noted that, in general, the use of experimental mobilities to determine the ionized impurity concentration has to be treated with great caution and can be applied only to a homogenous material with a low density of extended structural defects.

C. CONCLUSIONS

Theoretical room and liquid nitrogen temperature electron mobilities are presented as functions of free electron and ionized impurity concentration. The curves and/or the formulae provide a convenient method to assess the total concentration of ionized impurities from the experimentally measured carrier concentration and the electron mobility.

REFERENCES


Figure Caption

Figure 1  Calculated room (a) and liquid nitrogen (b) temperature electron mobilities as functions of the concentration ratio \(N_{\text{imp}}/n\). Electron concentration \(n\) is a parameter for the different curves.
(a) GaAs 300 K

Electron mobility (m^2/Vs)

$\frac{N_{\text{imp}}}{n}$

$N_{\text{imp}} = 10^{21} \text{ m}^{-3}$

$10^{22}$

$10^{23}$

$10^{24}$
(b) GaAs 77 K

Electron mobility (m²/V·s)

Concentration ratio, \( N_{imp} / n \)

\( n = 10^{20} \text{ m}^{-3} \)

10^{-2} \quad 10^{-1} \quad 10^{0} \quad 10^{1} \quad 10^{2} \quad 10^{3} \quad 10^{4}