IOPscience iopscience.iop.org

Home Search Collections Journals About Contact us My IOPscience

Hall emf features in bipolar media

This article has been downloaded from IOPscience. Please scroll down to see the full text article.

2000 J. Phys.: Condens. Matter 12 9163

(http://iopscience.iop.org/0953-8984/12/43/306)

View the table of contents for this issue, or go to the journal homepage for more

Download details:
IP Address: 171.66.16.221
The article was downloaded on 16/05/2010 at 06:56

Please note that terms and conditions apply.

J. Phys.: Condens. Matter **12** (2000) 9163–9166. Printed in the UK PII: S0953-8984(00)14274-2

Hall emf features in bipolar media

A Konin and R Raguotis

Semiconductor Physics Institute, Goštauto 11, 2600 Vilnius, Lithuania

Received 26 May 2000, in final form 31 August 2000

Abstract. An expression for the Hall electromotive force (emf) in a bipolar bounded semiconductor sample is obtained by taking into account both volume and surface recombination rates. It is shown that the Hall emf value has non-linear dependence on the sample thickness. The Hall emf value also depends significantly on the surface parameters, such as surface recombination rates and surface conductivity of carriers.

1. Introduction

It has been shown [1] that the determination of the thermo-electromotive force (emf) in bipolar semiconductor samples differs in principle from the monopolar semiconductor case. The theoretical model [1] generalized in [2] shows that the thermo-emf depends on the surface semiconductor parameters in any size sample of semiconductors.

Although the thermo-emf arises under the influence of the thermodynamic 'external force' and the Hall emf arises under the influence of the Lorenz force, the common scheme [1] is valid for the determination of the emf of any nature. So, we expect the revealing of the Hall emf dependence on the same surface parameters as in [2]. We note that the dependences of thermoelectric and Hall currents [3] on semiconductor volume parameters are different. Thermo-current is proportional to the thermo-emf coefficient while the Hall current is proportional to the carrier's mobility. Therefore, different dependences of the thermo-emf and the Hall emf on the volume and surface semiconductor parameters can be expected.

The goal of this present work is to find an expression for the Hall emf in a finite semiconductor, taking into account surface parameters.

2. Theory

Let us treat the semiconductor sample as having parallelepiped form ($-a \leqslant x \leqslant a$, $-b \leqslant y \leqslant b$, $-d \leqslant z \leqslant d$) and $a \ll b, d$. We assume that the external electric field E is applied along the y-axis and the external weak magnetic field B is applied along the z-axis.

The distributions of carrier densities and potential are obtained from the equations [2]

$$\frac{1}{e}\frac{\mathrm{d}j_n^x}{\mathrm{d}x} - \frac{\Delta n}{\tau_n} = 0 \qquad \frac{1}{e}\frac{\mathrm{d}j_p^x}{\mathrm{d}x} + \frac{\Delta p}{\tau_p} = 0 \tag{1}$$

$$\frac{\mathrm{d}^2\varphi}{\mathrm{d}x^2} = \frac{e}{\varepsilon\varepsilon_0}(\Delta n - \Delta p) \tag{2}$$

0953-8984/00/439163+04$30.00 © 2000 IOP Publishing Ltd

and from the boundary conditions [1, 2]

$$\frac{1}{e}j_n^x\bigg|_{x=\pm a} = \mp S_n^{\pm}\Delta n|_{x=\pm a}$$

$$\frac{1}{e}j_p^x\bigg|_{x=\pm a} = \pm S_p^{\pm}\Delta p|_{x=\pm a} \tag{3}$$

$$\frac{1}{e}(\xi_p^{\pm}\Delta F_p - \xi_n^{\pm}\Delta F_n)|_{x=\pm a} = (\xi_n^{\pm} + \xi_p^{\pm})(\varphi_{\pm} - \varphi)|_{x=\pm a}. \tag{4}$$

Here j_n^x and j_p^x are the electron and hole current densities, Δn and Δp are non-equilibrium electron and hole densities, $\tau_{n,p}$ is the lifetime of electrons and holes, φ is electrostatic potential, ε is the electrical permittivity, ε_0 is the vacuum permittivity, $S_{n,p}^{\pm}$ are the surface recombination rates (SRRs), $\xi_{n,p}^{\pm} = \lim_{x\to\pm a}\sigma_{n,p}$ are the surface conductivities of electrons and holes [1], $\Delta F_{n,p}$ is the variation of chemical potential of electrons and holes caused by the deviation of their densities from the equilibrium one

$$\Delta F_n = kT\ln(1 + \Delta n/n_0) \qquad \Delta F_p = kT\ln(1 + \Delta p/p_0)$$

n_0, p_0 are equilibrium densities of carriers, $\varphi_+ = \varphi(a+0)$, $\varphi_- = \varphi(-a-0)$, e is hole charge and $2a$ is sample thickness.

The equations for currents take the form [3]

$$j_n^x = n\mu_n\left[\frac{kT}{n}\frac{\mathrm{d}\Delta n}{\mathrm{d}x} - e\frac{\mathrm{d}\varphi}{\mathrm{d}x} - eb_n\mu_n EB\right]$$

$$j_p^x = p\mu_p\left[-\frac{kT}{p}\frac{\mathrm{d}\Delta p}{\mathrm{d}x} - e\frac{\mathrm{d}\varphi}{\mathrm{d}x} - eb_p\mu_p EB\right]. \tag{5}$$

Here n, p are carrier densities, $n = n_0 + \Delta n$, $p = p_0 + \Delta p$, $\mu_{n,p}$ are electron and hole mobilities, T is the semiconductor temperature, k is the Boltzmann constant and $b_{n,p}$ is the Hall factor. In a non-degenerate semiconductor [4]

$$b_n = \frac{\Gamma(2q_n + 5/2)\Gamma(5/2)}{\Gamma(q_n + 5/2)} \qquad b_p = \frac{\Gamma(2q_p + 5/2)\Gamma(5/2)}{\Gamma(q_p + 5/2)}.$$

Here $\Gamma(\ldots)$ is the gamma function and $q_{n,p}$ is the parameter characterizing the carrier momentum relaxation mechanism [5]. Note that usually $b_n = b_p$.

We investigate the case of small carrier densities deviation from equilibrium $\Delta n \ll n_0$ and $\Delta p \ll p_0$. At the same time $\Delta F_n = kT\Delta n/n_0$ and $\Delta F_p = kT\Delta p/p_0$. In addition, for simplicity we assume that the boundary conditions are symmetrical: $S_n^+ = S_n^- = S_n$, $S_p^+ = S_p^- = S_p$, $\xi_n^+ = \xi_n^- = \xi_n$, $\xi_p^+ = \xi_p^- = \xi_p$.

Solving equations (1)–(4) we obtain for the Hall emf $\Delta\varphi_H = \varphi_+ - \varphi_-$:

$$\Delta\varphi_H = -D^{-1}2ab_n\mu_n EB[(1+\beta)(\nu_p - \chi\gamma^2\eta\theta\nu_n)\tanh u + (1+\theta)(1 - \chi\beta\gamma^2\eta) + (1+\chi\gamma)(\beta\gamma\eta - \theta)u^{-1}\tanh u] \tag{6}$$

where

$$D = (1+\theta)(1+\beta\gamma\eta) + (1+\beta)(\nu_p + \gamma\eta\theta\nu_n)\tanh u.$$

Here $\beta = p_0/n_0$, $\gamma = \mu_p/\mu_n$, $\eta = \tau_p/\tau_n$, $\chi = b_p/b_n$, $\theta = \xi_p/\xi_n$,

$$\lambda = \sqrt{\frac{kT\mu_n\mu_p\tau_n\tau_p(n_0 + p_0)}{e(n_0\mu_n\tau_n + p_0\mu_p\tau_p)}}$$

is the diffusion length, $\nu_{n,p} = S_{n,p}\tau_{n,p}/\lambda$ is the normalized SRR and $u = a/\lambda$ is the normalized sample thickness.

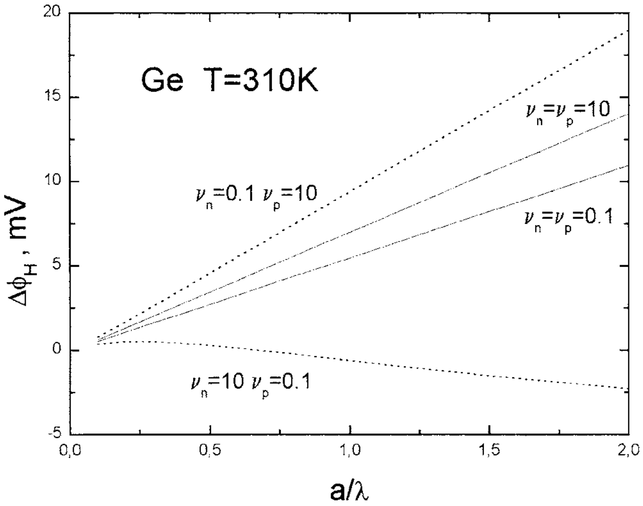

Figure 1. Hall emf in intrinsic Ge versus sample thickness for $\xi_n = 2\xi_p$ and for the various normalized SRR values $\nu_{n,p}$.

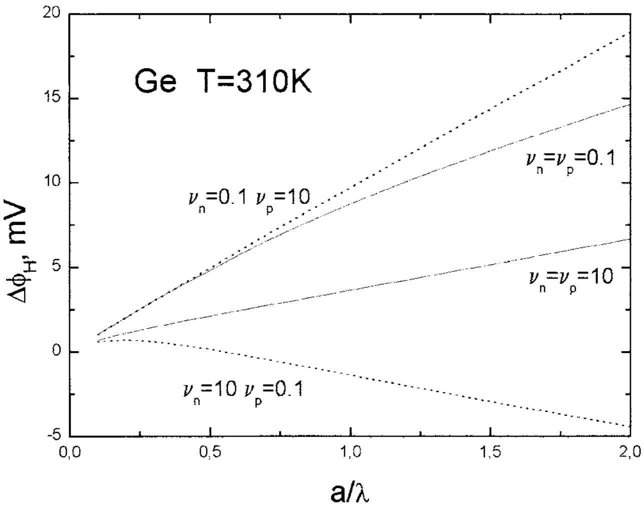

Figure 2. Hall emf in intrinsic Ge versus sample thickness for $\xi_p = 2\xi_n$ and for the various normalized SRR values $\nu_{n,p}$.

Equation (6) for the Hall emf is obtained assuming that diffusion length significantly exceeds the Debye length [2], that usually occurs. The same expression for the Hall emf is obtained from the common expression [1]

$$\Delta\varphi_H = \oint \left(\frac{\sigma_n}{e(\sigma_n + \sigma_p)} \frac{\mathrm{d}\Delta F_n}{\mathrm{d}x} - \frac{\sigma_p}{e(\sigma_n + \sigma_p)} \frac{\mathrm{d}\Delta F_p}{\mathrm{d}x} \right) \mathrm{d}l. \tag{7}$$

Here integration in the sample volume is performed by x from $-a$ to a, and $\sigma_n = en\mu_n$, $\sigma_p = ep\mu_p$.

3. Discussion of results

The Hall emf, as can be seen in equation (6), is not proportional to the sample thickness. Moreover, the Hall emf depends on volume and surface parameters and this dependence takes place in the sample of arbitrary thickness.

The dependence of the Hall emf $\Delta\varphi_H$ on normalized sample thickness a/λ is presented in figures 1 and 2 for the various normalized SRR values $\nu_{n,p}$ in intrinsic Ge at $T = 310$ K ($\lambda = 0.1$ cm, $\mu_n = 3800$ cm^2 V^{-1} s^{-1}, $\mu_p = 1800$ cm^2 V^{-1} s^{-1}). The electric field is equal to $E = 5$ V cm^{-1} and the magnetic field induction $B = -22$ mT. As seen in figures 1 and 2, the Hall emf depends strongly on the SRRs and even changes its sign to the opposite one. The non-linearity of the function $\Delta\varphi(u)$ depends on the surface conductivity ratio $\theta = \xi_p/\xi_n$ and its value is large in the case of $\xi_p = 2\xi_n$.

It is seen from the comparison of the Hall emf (equation (6)) with the expression of the thermo-emf [2], that their dependences on the volume and surface parameters are different. Therefore, the thermo-emf and the Hall emf, as well as the Dember and photomagnetic emf measurement on the same semiconductor sample, give the possibility to determine carrier surface conductivity and surface recombination rates. This is very important because, to the best of our knowledge, there are no methods for the determination of surface conductivity.

References

[1] Gurevich Yu G, Titov O Yu, Logvinov G N and Lyubimov O I 1995 *Phys. Rev.* B **51** 6999
[2] Konin A and Ragoutis R 1999 *Semicond. Sci. Technol.* **15** 229
[3] Konin A M, Rudaitis V G and Sashchuk A P 1990 *Liet. Fiz. Rink.* **30** 295
[4] Kireev P S 1969 *Semiconductor Physics* (Moscow: Vishaja Shola)
[5] Bass F G, Bochkov V S and Gurevich Yu G 1984 *Electrons and Phonons in Boundaried Semiconductors* (Moscow: Nauka)