INFLUENCE of 5 MeV ELECTRON IRRADIATION ON GALVANOMAGNETIC PARAMETERS OF SEMI-INSULATING GaAs

***P. Boháček*[1]*, B. Zaťko*[1]*, A. Šagátová*[2,3]*, P. Hybler*[3]*, M. Sekáčová*[1]**

[1]*Institute of Electrical Engineering, Slovak Academy of Sciences, Dúbravská cesta 9,*
841 04 Bratislava, Slovakia,
[2]*Faculty of Electrical Engineering and Information Technology, Slovak University of*
Technology, Ilkovičova 3, 812 19 Bratislava, Slovakia,
[3]*University Centre of Electron Accelerators, Slovak Medical University, Ku kyselke 497,*
911 06 Trenčín, Slovakia

E-mail: pavol.bohacek@savba.sk

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1. Introduction

High-energy electron irradiation has been employed to study primary defects (vacancies, interstitials, and, sometimes, anti-sites) in many metal and semiconductor materials [1]. Typically, the electron energy necessary to displace an atom will be a few hundred keV; thus, the common choice of 5 MeV irradiation will produce only a few displacements (simple intrinsic point defects like vacancies, anti-sites, and interstitials in the lattice) and no massive damage. All these intrinsic defects are electrically active and their presence will modify the Fermi level and also the lifetime of the free carriers. The defects created by electron irradiation in semiconducting GaAs and particularly their electrical properties have been studied before [2]. Several studies have demonstrated, that the formation of anti-site defects during the electron irradiation of semi-insulating (SI) GaAs takes place with high introduction rates, e. g. [3]. This interest largely stems from the fact that the most important native defect in SI GaAs, the EL2 defect, is related to the arsenic anti-site. Recently, the influence of 5 MeV electron low dose irradiation on the electrical and spectrometric properties of a SI GaAs Schottky barrier detectors was reported [4]. However, studies of galvanomagnetic parameters of electron irradiated SI GaAs are rare.

We report on the conductivity and Hall effect measurements at temperature 400 K and 300 K performed on SI GaAs samples before and after high energy electron irradiation. The obtained results of resistivity, Hall coefficient, electron Hall mobility, and electron Hall concentration in the samples investigated are compared and analysed.

2. Technology and experimental details

To analyze the effect of electron irradiation in undoped SI GaAs, we use a set of samples issued from the same wafer. The experimental samples were prepared from the bulk un-doped SI GaAs 2 inch wafer grown by the vertical gradient freeze (VGF) method (producer CMK Ltd., Žarnovica, Slovakia) with (100) crystallographic orientation and dislocation density less than 5000 cm^{-2}. The wafer was polished by the producer from both sides down to (230 ±5) μm. Electrical contacts in the corners of square shaped samples (8 × 8) mm^2 were prepared by rubbing Ga + In euthectic alloy into the surface of the sample at room temperature, and their ohmic behaviour was confirmed by the measurement of current-voltage characteristics. Precise DC measurements were carried out with the samples in the dark at temperature 400 K and 300 K, using the electrometer Keithley 6517A controlled by personal computer. The probe station was thermally adjustable with stability of temperature ±0.2 K. The temperature was measured by the thermocouple Cu-constantan. The conductivity, and Hall effect measurements by van der Pauw method were used to obtain the conductivity σ_0, the low magnetic field (B = 0.4 T) Hall coefficient R_{H0}, electron Hall mobility $\mu_H = \sigma_0 \times$ abs(R_{H0}) and electron Hall concentration $n_H = 1$ / abs(e × R_{H0}) before and after each exposition the samples to electrons; e is the elementary charge. Before electrical measurements the samples were chemically etched in a solution of $3H_2SO_4$:$1H_2O_2$:$1H_2O$ for 3 min., rinsed in deionised water and subsequently were treated in HCl to avoid undesired oxides and again rinsed in deionised water. The described wet treatment was done at room temperature. Two samples (labeled 1B and 3B) were irradiated at room temperature from the top side (where new electrodes for conductivity and Hall measurements were prepared after each irradiation) with 5 MeV electrons in pulsed beam (3.5 μs pulse duration) using a linear accelerator UELR 5-1S. Samples were placed on a PCB (Printed Circuit Board) support laid on a 1 cm thick aluminum board during the experiment. The distance between the sample and the foil of accelerator exit window was 95 cm. Identical samples were irradiated in static regime by equal total dose at first 1 kGy, afterwards again 1 kGy, then 2 kGy, 4 kGy, 8 kGy, 8 kGy, 16 kGy, 16 kGy, 16 kGy, and 16 kGy (10 steps) but by different dose rates: 20 kGy/h (sample 1B), 40 kGy/h (sample 3B). The different dose rates were obtained by changing the electron beam repetition rate 10 Hz to 20 Hz maintaining the beam scanning frequency (0.25 Hz) and the beam scanning width (40 cm) of electron accelerator. The dose was measured using B3 radiochromic films with a diameter of 1 cm evaluated by Spectrophotometer GENESYS 20. Verification of the dose delivered to sample was performed with RISO polystyrene calorimeters.

3. Results and discussion

The samples 1B and 3B before exposed to high energy electrons exhibited measured resistivity ($1/\sigma_0$) 1.92×10^7 Ωcm and 1.89×10^7 Ωcm, and Hall mobility 6960 cm^2/Vs and 6940 cm^2/Vs at 300 K, respectively. The conductivity mechanism of the samples was found to be single carrier (electron) dominated, due to low values of resistivity (below 4×10^8 Ωcm at room temperature). The mixed conductivity analysis was not needed to calculate the true electron parameters [5].

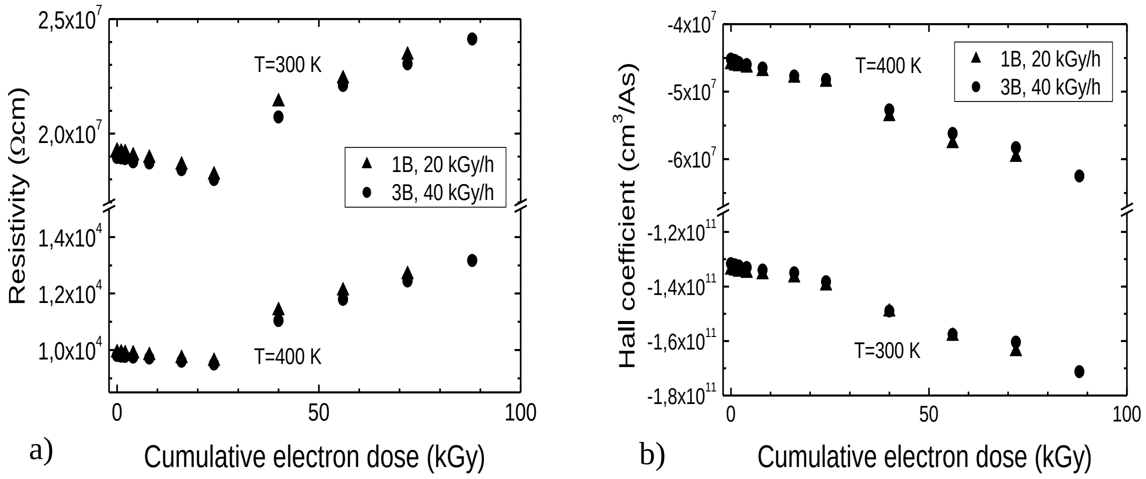

Fig. 1. Resistivity (a) and Hall coefficient (b) versus cumulative electron dose for irradiated samples obtained from measurements at 400 K and 300 K, respectively.

Resistivity versus cumulative electron dose for irradiated samples 1B and 3B obtained from measurements at 400 K and 300 K is plotted in Fig. 1a. At first, the resistivity slightly decreases with increasing cumulative electron dose of 24 kGy because the electron Hall concentration also decreases with increasing cumulative electron dose as can be seen in Fig. 2b. Afterward measured values of the resistivities were raised to 2.34×10^7 Ωcm and 2.41×10^7 Ωcm at 300 K for samples 1B and 3B, irradiated with the cumulative electron dose of 72 kGy and 88 kGy, respectively. This can be explained by creation of point defects like vacancies, anti-sites, and interstitials caused by electron irradiation [2].

The dependence of Hall coefficient on the cumulative electron dose for irradiated samples 1B and 3B obtained from measurements at 400 K and 300 K is depicted in Fig. 1b. As well as the resistivity, Hall coefficient also slightly decreases with increasing cumulative electron dose. At the cumulative electron dose of 72 kGy and 88 kGy the obtained values of Hall coefficient were decreased to -1.64×10^{11} cm^3/As and -1.71×10^{11} cm^3/As at 300 K for samples 1B and 3B, respectively in comparison to values -1.34×10^{11} cm^3/As and -1.32×10^{11} cm^3/As before electron irradiation.

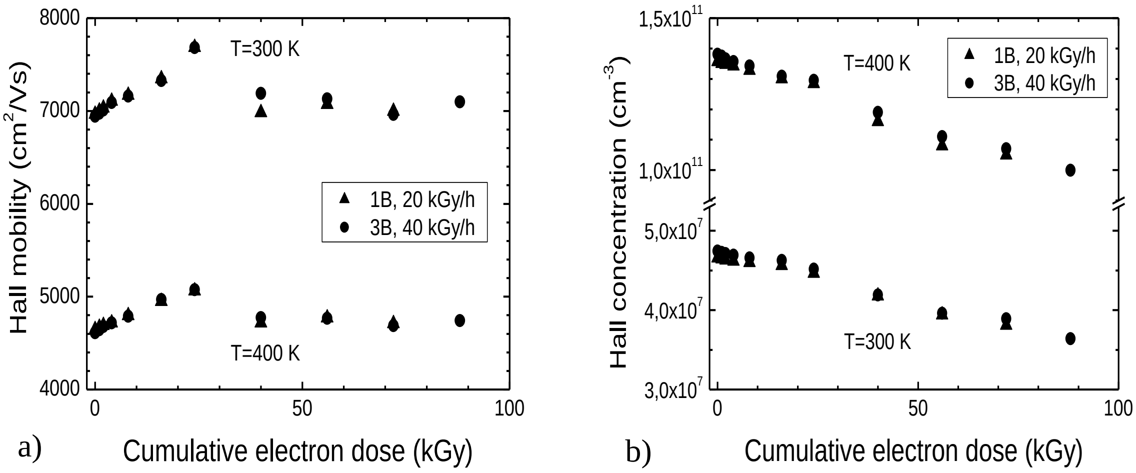

Fig. 2. The electron Hall mobility (a) and the electron Hall concentration (b) versus cumulative electron dose for irradiated samples obtained from measurements at 400 K and 300 K, respectively.

The dependence of electron Hall mobility on the cumulative electron dose for irradiated samples 1B and 3B obtained from measurements at 400 K and 300 K is plotted in Fig. 2a. It is very interesting, that the electron Hall mobility increased to about 7680 cm^2/Vs at 300 K for both samples irradiated with the cumulative electron dose of 24 kGy. This is caused by increasing of numerical value of Hall coefficient and decreasing the resistivity with rising of cumulative electron dose irradiation to 24 kGy. Then the electron Hall mobility decreased to about 7000 cm^2/Vs with rising of cumulative electron dose to 88 kGy.

The electron Hall concentration versus cumulative electron dose for irradiated samples 1B and 3B obtained from measurements at 400 K and 300 K is plotted in Fig. 2b. It can be seen that the electron Hall concentration was lowered roughly linear from 4.7×10^7 cm^{-3} for both samples before electron irradiation to 3.7×10^7 cm^{-3} at 300 K after irradiation with the cumulative electron dose of 88 kGy. Our experimental results indicate that the dependencies of galvanomagnetic parameters of electron irradiated SI GaAs on cumulative electron dose are qualitative similar at 300 K and 400 K.

No influence of higher dose rate electron irradiation in samples investigated was observed.

4. Conclusion

We have investigated and analyzed results of galvanomagnetic measurements versus cumulative electron dose and temperature on bulk VGF SI GaAs irradiated by 5 MeV electrons. Also different dose rate (20 and 40 kGy/h) was applied on samples. The resistivity and the electron Hall concentration slightly decrease with increasing cumulative electron dose irradiation from 1 kGy up to 88 kGy. This can be explained by creation of point defects like vacancies, anti-sites, and interstitials caused by electron irradiation. Numerical value of Hall coefficient increases linear with increasing cumulative electron dose. Electron Hall mobility as a ratio of Hall coefficient and resistivity increases with increasing cumulative electron dose to 24 kGy. Then the electron Hall mobility decreased to about 7000 cm^2/Vs with rising of cumulative electron dose to 88 kGy.

Experimental results on electron irradiated SI GaAs can be very useful to predict the performance, reliability, and radiation resistance to a high flux of ionizing particles. In order to better understand the above effect more detailed theoretical and experimental investigations will be carried out.

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