Analysis of temperature effect on I-V characteristics of silicon (npn) emitter-base junctions.

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The current through silicon emitter-base (npn) junctions is measured for forward and reverse polarizations. The I-V characteristics are presented for unirradiated samples at different temperatures. For forward bias, we have studied the reverse saturation current (I_S), the series resistance (R_S) and the ideality factor (n) as function of temperature. The temperature effect is more consistent with the generation current from the space charge region. For reverse polarization, we have studied Ln ($I_R/T^{1/2}$) as function of the reciprocal temperature and we found 0.29 eV for the activation energy which is in good agreement with the result obtained from electroluminescence (EL) spectra.

Keywords: Si junctions, Temperature effect, I-V characteristics, ideality factor, Series resistance, activation energy.

I-Introduction

With the increasing uses of nuclear, satellites and aeronautics, the extensive studies concerning the development of semiconductor devices which can operate normally in different environment have been undertaken. The study of the temperature effect on the electronic components in the corrosive conditions becomes necessary to ensure their correct operation and their reliability. Several works studying the temperature induced damage in bipolar Si devices, which can easily be integrated, have been carried out [1-2].The purpose of this work is the analysis of I-V characteristics as function of temperature. Our I-V measurements were taken at the genie electronic of physics department of Sherbrooke University in Canada.

II-Theory

The silicon emitter-base transistors bipolar (npn) 2N2219A manufactured and commercialized by ST Microelectronics were used in this work. The I-V characteristics measurements are taken by a parametric analyzer controlled by a computer connected by IEEE bus. In order to analyse the current-voltage characteristics of our samples, we first describe the current components involved in the total junction current. For forward polarization, five components are involved in silicon junction. They are respectively, bulk diffusion current which has its origin from the neutral region, bulk generation-recombination current originating in the depletion region, surface diffusion, surface generation-recombination and tunnel effect. Our junctions are well passivated by SiO_2 and consequently we can neglect the surface effect. The silicon is an indirect band gap semiconductor for which the band gap energy is included between 1.08 eV and 1.17eV. Consequently, the tunnel contribution can be neglected. Then, the total current is equal to the sum of two components which is defined, by taking into account of the resistivity due to different regions which constitute the junction (emitter, base and Ohmic contact), as follows [3]:

$$I = I_S\left[exp(\frac{q(V-R_S I)}{nkT}) - 1\right] \quad (1)$$

Where I_S is the reverse saturation current, R_S is the series resistance, n is the ideality factor, q is the electron charge, T is the absolute temperature and k is the Boltzmann's constant. The measure of n depends on which current component is dominated in a specific operating regime.

For reverse polarization, the main current component is the generation from the deep centres (tunnel effect is negligible). It depends on the temperature and the applied voltage and it is defined [3]:

$$I_R \propto \sqrt{T}\sqrt{V_R}exp\left(-\frac{E_a}{kT}\right)exp\left(CV_R\right) \quad (2)$$

Where V_R is the reverse applied voltage, T is the absolute temperature, k is the Boltzmann's constant, E_a is the activation energy and C is a constant which depends on the semiconductor.

III-Experimental results

III-1-Electroluminescence spectra

Figure 1 shows the EL spectra of silicon emitter-base (npn) bipolar junctions for forward and reverse polarization for unirradiated samples. The electroluminescence (EL) spectra are acquired at 307 K and modelled by the Gaussian profiles. For forward bias, we notice that, EL maximum intensity of structure noted (a) is located at 1.0923±0.0001 eV. This value is approximately equal to the bulk silicon band gap energy at 307K and it is in good agreement with those present in the literature which varies typically between 1.08 eV and 1.17 eV. For reverse polarization, we note that the spectrum contains two structures (b) and (c). It appears that (b) is broader and more intense than (c) and its behaviour is not Gaussian. Consequently several defects can be implied in this structure. Its EL maximum intensity is occurred at 0.8064±0.0004 eV. On the one hand, the structure (b) can be due to a band-impurity recombination for which the impurity ionization energy is equal to 0.2859±0.0005 eV. On the other hand, It was reported that copper (Cu) in silicon site gives rise to a donor state whose ionization energy is about 0.24 eV below the conduction band [8]. Similarly, when Boron replaces Si, B_{Si} is an

acceptor state whose energy is 46 meV above the valence band [4]. Indeed, the signal which corresponds to the Copper-Boron will be located at 0.8063±0.0005 eV. Then, the structure (b) can also be attributed to donor-acceptor recombination in which Cu and B are involved. The origin of copper in our samples remains unknown. The structure (c) is located at 1.62eV.

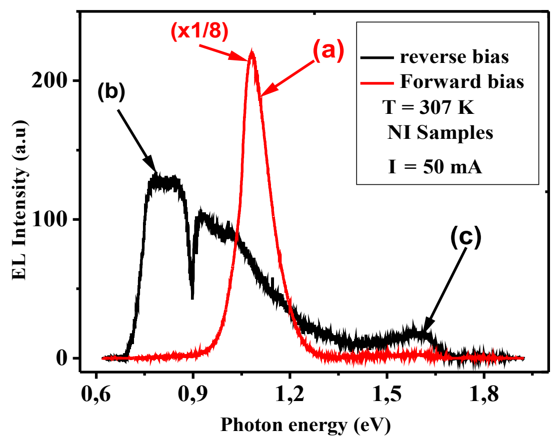

Figure 1: Electroluminescence intensity as function of photon energy at 307K for forward and reverse polarization (I=50 mA) of unirradiated silicon (npn) emitter-base junction.

III-2-Forward polarization

Figure 2 shows the linear and semilog plot I-V characteristics of unirradiated silicon (npn) emitter-base junctions for forward polarization at different temperatures. We notice that the current is approximately null for the voltage smaller than 0.7V and the knee voltage varies as function of the temperature. We can also see that, the current increases as function of temperature for a constant voltage. The experimental results are fitted by equation (1) for which I_S, n and R_S are the fitting parameters. We extract these parameters as function of temperature for unirradiated samples. One established method to determine the defect energy is to study the saturation current (I_S) as function of temperature. Its

temperature dependence is defined as follows [2]:

$$I_S = A\,exp\left(\frac{-E_a}{kT}\right) \qquad (3)$$

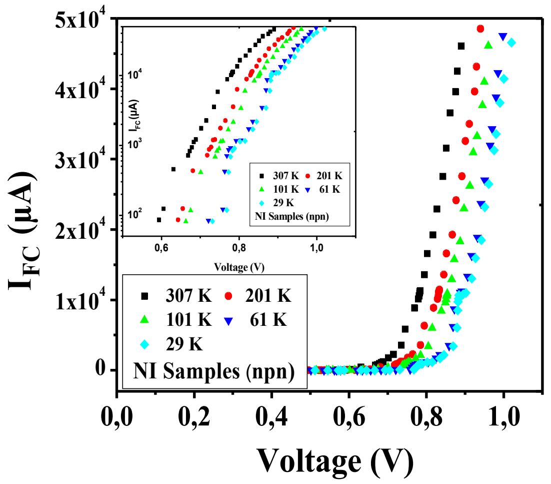

Figure2: The temperature effect on linear and semilog plot I-V characteristics of silicon (npn) emitter-base for forward polarization. NI means: The sample is not irradiated

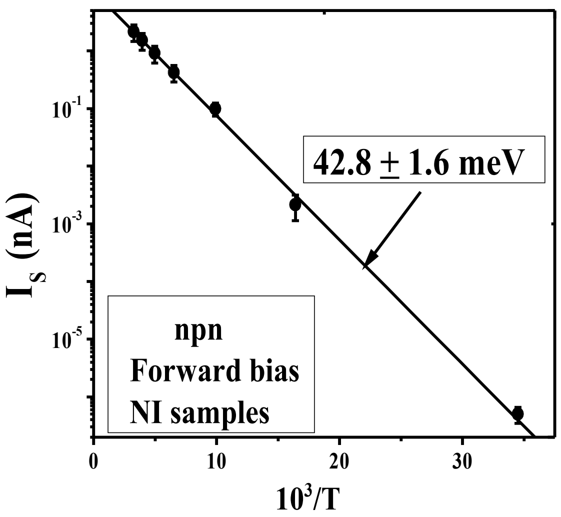

Figure3: The saturation current as function of reciprocal temperature for unirradiated sample for silicon (npn) emitter-base junction.

Where A is a proportionality factor which may have power low temperature dependence; however, since A is a prefactor to an exponential term, its temperature variation in the temperature range studied is usually negligible. The experimental results of the temperature effect on saturation current are shown on figure 3. The activation energy obtained from the fitting procedure is 42.8 ± 1.6 meV. It was found previously that, when phosphorus (P) replaces Si, P_{Si} gives rise to a donor state whose energy lies at about 44 meV below the conduction band [4]. Then, the activation energy corresponds probably the phosphorus in the silicon site. From figure 4, we note that when the temperature decreases, the series resistance (R_S) increases. This behaviour corresponds to the freezing of the carriers in the regions N and P of the junction. The temperature dependence of the ideality factor (n) is illustrated on figure 4. We notice that n decreases as function of temperature; it is equal to 1.78±0.02 at 29 K and 1.18±0.01 at 307 K. This behaviour shows that the diffusion current and the generation-recombination current intervene in the conduction transport mechanism. At low temperature, the conduction mechanism is dominated by the recombination component. When the temperature increases, n decreases and consequently the conduction mechanism becomes increasingly assured by the diffusion component.

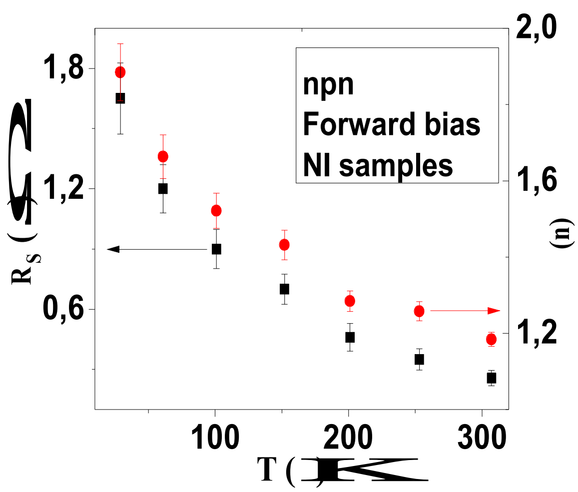

Figure 4: The series resistance and the ideality factor as function of temperature for unirradiated sample for silicon (npn) emitter-base junction.

III-3-Reverse polarization

Figure 5 illustrates the temperature effect on I-V characteristics for unirradiated samples for reverse polarization. We notice that the current

is approximately null for the voltage smaller than 7.2V and the knee voltage varies as function of the temperature. The knee voltage is equal to 7.2V at 307K and 8.3V at 29K. It appears that the current increases when the temperature increases which is characteristic of the generation mechanism from the deep centres. The characterization of these defects is carried out by the temperature dependence of the reverse current given by equation (2) for a constant voltage. The experimental results of Ln ($I_R/T^{1/2}$) as function of the reciprocal temperature are shown on figure 6. The activation energy obtained from this procedure is 0.296± 0.013 eV for 9V and 0.282± 0.019 eV for 8V.

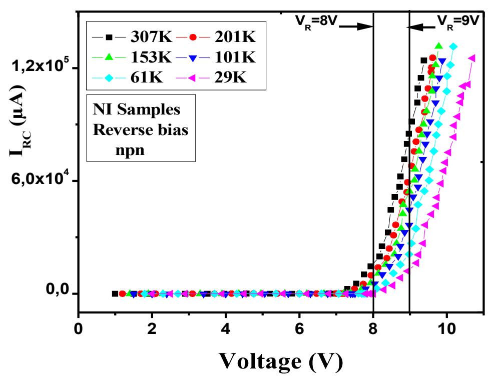

Figure 5: The reverse bias I-V characteristics of silicon (npn) emitter-base for unirradiated sample at different temperature.

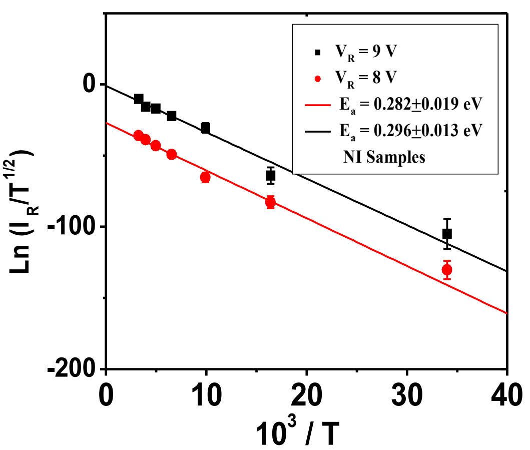

Figure 6: The Arrhenius plot of Ln($I/T^{1/2}$) as function of the reciprocal temperature of bulk silicon (npn) emitter-base junction for two values of the reverse voltage. Solid lines show the fitting result.

IV-Discussion

It is known that, the diffusion is the conduction mechanism dominating at room temperature. When the temperature decreases the series resistance (R_S) increases. This effect is due mainly to the trapping of the charge carriers and consequently the diffusion current for which the origin is the junction neutral zone becomes reduced. From the temperature dependence of n, it appears that n decreases as function of the temperature but the factor (nkT/e) increases. This behaviour shows that the carrier's generation is the dominating effect when the temperature increases. This effect is illustrated on figure 2 for which the current increases as function of temperature for a constant voltage. It is well known that the saturation current depends of n_i^2 and n_i (intrinsic density) for bulk diffusion current and bulk recombination current respectively [5]. The temperature dependence of the intrinsic density (n_i) is given by $T^{3/2}\exp(-E_g/2kT)$ [6]. In the temperature range studied, the temperature dependence of the fist term ($T^{3/2}$) is dominated by that of the second. From I_S temperature dependence, we have obtained 42.8 ± 1.6 meV for the activation energy. Then, this later which is different to $E_g/2$ indicates that the saturation current is independent of the intrinsic density (n_i) qnd depends strongly of the doping. The activation energy (E_a) is approximately equal to the phosphorous ionization energy [4] which is the silicon doping. For reverse polarization, the Arrhenius plot of Ln($I_R/T^{1/2}$) as function of the reciprocal temperature gives us an activation energy equal to 0.29 eV . This value is approximately equal to the energy of the defect involved in the EL signal situated at 0.8064±0.0004 eV [7]. We can suggest two assumptions for the defect position. If the generation is carried out in the region N, then the implied defect is situated at 0.29 eV below the conduction band. If the generation is carried out in the region P then, the defect is located at 0.29 eV above the valence band (VB). The temperature dependence of reverse current shows that the generation current is the dominating component. Consequently, the first assumption is the most probable.

Conclusion

The effect of temperature on I-V characteristics of silicon (npn) emitter-base junction has been investigated. We have shown that the temperature effect is more consistent with the generation current from deep centres. The activation energy (42.8meV) obtained for forward bias indicates that the saturation current depends of the doping rather than the intrinsic density. For reverse bias, the same result is obtained for the defect energy (0.29 eV) from EL and I-V studies.

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