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DEGRADATION OF A LIGHT EMITTING SILICON JUNCTION OF A BIPOLAR TRANSISTOR

N. Toufik, F. Pélanchon and P. Mialhe

LP2A, Université de Perpignan, 52 avenue de Villeneuve, 66860 Perpignan Cedex, France, email: toufik@univ-perp.fr, Tel: +33 4 68 66 17 98, Fax: +33 4 68 66 17 49.

Abstract: The variations of the current-voltage characteristics of a light emitting silicon junction of a bipolar transistor is monitored for the first time along an experiment performed at high constant reverse current. The evolutions of the parameters show the effects of degradation processes which are correlated with induced high injection effects and the changes in the avalanche generated light emission. The analysis introduces an induced low doping defect layer where an inversion of carrier populations appears, which provides an interpretation of both localisation of previously described long term light emission and variations of measured parameters

Keywords: Silicon, Bipolar transistor, Ageing, Junction parameters, Light emission.

1. Introduction

The evolution of the degradation of bipolar transistors biased in avalanche breakdown have been previously described [1-5] and induced hot carrier effects has been established. The characterisation has been obtained from the evaluations of the degradation of the current gain, and of the modifications of the junction breakdown voltage including measurements of their evolutions as a function of stress time. An emission of visible light, due to avalanche hot carriers, along the emitter-base junction has been monitored [6, 7]; the light intensity has been obtained non uniform and changes in the localisation of light emission during the measurements has been discussed. Future prospects for silicon-based optoelectronic developments [7-9] require a long term emission stability and enhancing radiative efficiency, both effects being related to carriers transport properties in the device.

This work describes and analyses the variations of the junction parameters of the emitter-base junction of a bipolar transistor during a hot carrier injection at high constant reverse current. This study is of interest since the photon emission has been observed located along the length of the emitter base junction [6] and the emission stability is related to the evolutions of the junction parameters, as a function of time. A model for the description of degradation mechanisms introduces a defect layer where carrier population inversion provides an interpretation of these effects.

2. Experimental procedure and results

The experimental procedure has been described previously [10]. The devices used in this study were Commercial n+-p-n epitaxial planar silicon bipolar transistors [Motorola 2N2222A]. The reverse-biased of the emitter-base junction was performed in avalanche breakdown, with the collector contact floating. Bias in avalanche conditions was performed with a 40 mA reverse current applied for intervals which durations were geometrically increased from 15s to 900h. Under these conditions the variations of light emission intensity and localisation have been previously described [6]. In this work, after each interval, the reverse bias was interrupted to allow acquisitions of the I-V characteristics of the forward emitter-base junction.

The junction characteristic can be described by the implicit I(V) equation [11]:

$$I = \frac{V - R_s I}{R_{sh}} + I_{od}[\exp(\frac{q}{kT}(V - R_s I)) - 1] + I_{or}[\exp(\frac{q}{nkT}(V - R_s I) - 1] \qquad (1)$$

which introduces the junction parameters R_s, R_{sh}, n, I_{od} and I_{or}, related to physical processes;

R_s and R_{sh} are the series and shunt resistances, n is the ideality factor, I_{or} corresponds to the recombination current in the space charge region of the junction and I_{od} is the diffusion-recombination current in the bulk of the junction [10, 11]. The value $n=1$ characterize an ideal junction, an increase of n implies carrier recombination via traps and the value $n=2$ is associated [12-14] with space charge region (SCR) recombination processes (low bias) and with high injection effects at higher bias.

The parameters of the emitter-base junction n, I_{or}, I_{od}, R_s, R_{sh} were extracted from the forward I-V characteristics, by the means of the PARADI software [15] in order to describe the hot electron induced degradation effects.
Experimental results in Fig. 1-3 show the evolutions of the forward I-V characteristic and of the emitter-base junction parameters I_{or} and R_s during a 900 hours stress duration performed by the application of a reverse bias in avalanche conditions with a 40 mA reverse current. The main results concern the evolutions of the I(V) characteristic of the emitter-base junction (Fig. 1). A significant degradation appears with a decrease of the slope of the middle bias part which is described by an increase of the ideality factor, n , until the value 2.

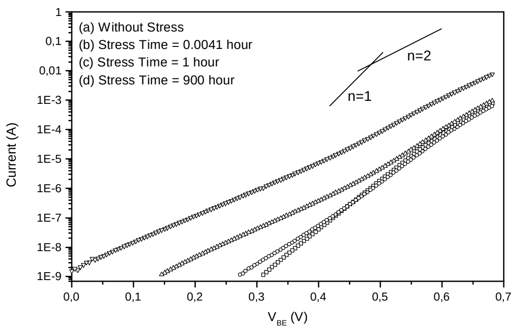

Figure 1 : Variation of the I-V characteristics for different stress times

Large variations are obtained during the first stage of the process. Such results point out that beyond the first fifty seconds of the initial fast variations, a continuous small increase of the degradation occurs for the junction parameters I_{or} (Fig. 2) and R_s (Fig. 3) during a period of 500 hours then followed by a third period characterized by a saturation effect for I_{or} degradation and by an increase of the degradation rate of the series resistance, indicating a new degradation process throughout this period.

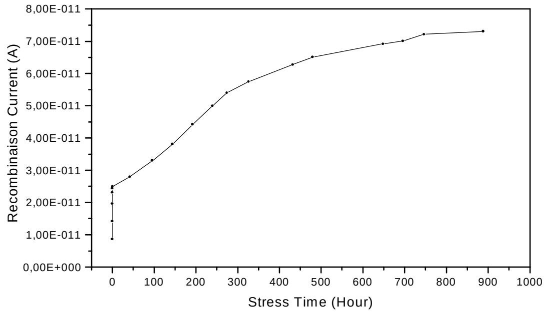

Figure 2 : Evolution of the recombination current versus the stress time

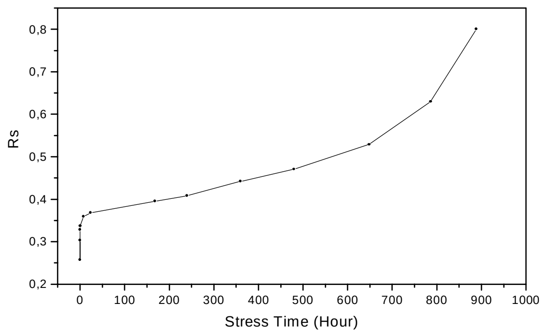

Figure 3 : Evolution of the series resistance with time during the stress time

Theses two periods introduced by the differentiation of the evolutions of junction parameters during stress correspond to the observed changes of the light emission [6] which has been observed all along the entire junction before it concentrated into localised junction sites. This observation relates the light emitting process to hot carriers interactions.

3. **Discussion**

Under an applied reverse bias, the degradation of silicon junctions is generally attributed to hot carrier injection along the junction [2, 3]. In the vicinity of the SCR, electrons and holes are accelerated by the intense electric field and their energies become high enough to generate active defects [16], to break crystalline bonds [6, 7] and to penetrate into the oxide above the SCR by tunnel effect. These multiple carrier interactions contribute to induce local degradations of semiconductor layers and of interfaces, which are creation of complexes, activation of bulk and interface defects and breakdown of crystalline bonds.
Hot carriers can break Si-H and SiO-H bonds and free [4, 6] H^+ ions resulting from hydrogen introduced during the thermal oxidation. These H^+ ions migrate through the oxide-silicon interface under the influence of the negative bias of the base contact. They can then combine with ionised boron atoms and form neutral B-H complexes. This process has been considered to discuss the changes

[6, 7] in light emission during the stress. The initial degradation of the junction parameters is mainly due to the B-H complexes creation. A defect zone appears, beginning at the SCR, which spreads towards the base contact close to the oxide-silicon interface. In this silicon layer, the apparent doping concentration decreases since the concentration of B-H complexes increases. It results in an increase of the local resistivity [17, 18] that causes the observed (Fig. 3) series resistance increase. This mechanism has been considered and shown [7] to be consistent with the increase of the breakdown voltage with the coalescence of light emission observed at long stress time.

The increase of the series resistance during the third period, then with the saturation of the recombination current degradation, is significative of a modification the crystalline structure. The defect zone is transformed as a consequence of breaks of bonds between boron and silicon atoms by hot carriers that lowers more the doping concentration. This result is confirms by the analysis [14] of the middle voltage part of the long term stressed I(V) characteristic of the emitter base junction (Fig. 1) which determines the value 2 for the junction ideality factor which is an indication of an effect of high injection with an inversed population of carriers. This result points out the creation of a low doping degraded layer near the junction with low values of the breakdown voltage, leading to the localisation of high light intensity peaks.

4. **Conclusion**

The variations of the parameters of the emitter-base junction of a bipolar transistor have been measured as a function of time during a hot carrier stress performed at high constant reverse current. They are related to previously described changes in the localisation of avalanche generated light emission. It shows that the evolution of the structure of the junction is not quantifies by recombination parameters. Degradation effects are considered as the results of competitive mechanisms which introduce the formation of a defect layer located close to the space charge region and characterised by a low doping value, where high injection effects appear in normal operative conditions. High injection results from an inversion of carrier populations in the defect layer, which is related to the localisation of previously observed high peaks of light intensity.

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