Physical Parameters for Reliability Evaluation

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Abstract—This paper presents ageing experiments controlled by the evolution of junction parameters. The deterioration of the device is related to high injection effects which modified the transport mechanisms in the space charge region of the junction. Physical phenomena linked to the degradation of junction parameters that affect the devices reliability are reported and discussed. We have used the method based on numerical analysis of experimental current-voltage characteristic of the junction, in order to extract the electrical parameters. The simultaneous follow-up of the evolutions of the series resistance and of the transition voltage allow us to introduce a new parameter for reliability evaluation.

Keywords—High injection, junction, parameters, reliability

I. INTRODUCTION

THE tendency, today, is to make more complex electronic circuits by integrating as many, possible, transistors with less dimensionality and with less or at least the same cost, and less material [1]. The development of new devices increases with a vertiginous speed, gives place to serious problems of performance. To improve the performances and the quality of electronic devices, the performance must be included as parameter in order to estimate and to take into account during the development and manufacturing of new material or electronic device.

In the microelectronics field, published works are often concerned with the identification of mechanisms leading to failures. The structures are not only observed at the end of manufacturing but they are also observed during the aging tests, by application of several constraints, like: radiation exposure [2]-[10], electrical stress [11]-[20], and thermal fluctuations [21]-[24]. The constraints chosen are: high temperature, strong current density, high voltage, and high irradiation dose. These constraints accelerate the processes that induce the degradation of electronic devices, or lead eventually to their damage. By addressing a full analysis of the evolution of the electronic devices characteristics under the previously mentioned constraints [11], will help us to understand and obtain a quantitative and qualitative data on the performance and the aging processes of these devices.

Actually, the research on the devices performance is at the embryonic stage. The most of the published works are focused on the estimation of the life time of electronic devices.

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This estimation is made by using mathematical, statistical or numerical models [25]-[28], and on the prediction of the degradation mechanisms. Recently, Plumbridge *et al* [29] analyzed the most known mechanical problems found in the industry of the microelectronic devices. They are due to the miniaturization and to the greatest number of soldered interconnections, as common defect and likely modes of failure, for example thermo-mechanical fatigue of soldered interconnections, creep failures, and micro-structural instability [29].

Numerous searchers have addressed a detailed study on the various mechanisms which affects the performance and the performance of several kinds of electronic devices [30]-[33]. They have shown that the presence of hydrogen and hydrogenous species remains as a serious problem [31]. Vendrame *e al* [32] and Borgarino *et al* [33]. Gave an overview of most important degradation mechanisms that can occur in poly-silicon bipolar transistor.

In our work, we aim to address a new and a deeper insight into the performance quantification by considering the high injection effects. We study the impacts of high injection effects on the conditions operating mechanisms, to allow the prediction of damages responsible for the performance and performance degradation of electronic devices. We introduce a new parameter for performance evaluation of devices from measurements concerning local degradation at the junction and carrier transport processes.

At the moment, and to our knowledge, no concluding studies were made on the performance quantification and no parameter was proposed to study the junction quality of electronic devices.

II. EXPERIMENTAL DETAILS

To investigate and quantify the performance of electronic devices, we have made experiments using the commercial NPN bipolar transistors, coming from various manufacturers. We have performed electrical measures to follow the degradation process related to the evolution of the structural parameters and to the operating conditions by analyzing the modifications of the junction parameters.

All (I-V) measurements were performed at room temperature using a Keithley 2400 SMU (source measurement unit) which is interfaced to a computer for data acquisition. The obtained results were treated by PARADI software [34] available in our laboratory, in order to extract the structural junction parameters (n, R_s, I_{02}). This is made by means of the double exponential model (VDEM), which leads to a description of the experimental I(V) curve from the graph of (1).

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$$I = \frac{\left(V - R_s I\right)}{R_{sh}} + I_{01} \exp\left[\left(\frac{q}{kT}\left(V - R_s I\right)\right) - 1\right] + \quad (1)$$

$$I_{02} \exp\left[\left(\frac{q}{AkT}\left(V - R_s I\right)\right) - 1\right]$$

This model allow us to distinguish between the electronic diffusion-recombination phenomena in the quasi neutral region of the junction (variation as: $I_{01}\exp\left[\left(\frac{q}{kT}\left(V - R_s I\right)\right) - 1\right]$) from the surface and space charge region recombination current (variation as: $I_{02}\exp\left[\left(\frac{q}{AkT}\left(V - R_s I\right)\right) - 1\right]$).

Where A is the junction ideality factor; R_s indicates the series resistance, I_{01} is the diffusion-recombination current in the bulk of the junction, and I_{02} corresponds to recombination current in the space charge region of the junction and at layer interfaces.

The ideality factor, A, is an empirical factor introduced to allow us a better fitting of the theoretical data with respect to the experimental data. The study made by EL-Tahchi *et al* (2000) using the PC1D software [35], have shown the existence of a strong dependence of this parameter on the structural properties of the junction [36].

The ideality factor varies with the position of the energy levels of the recombination centers, in the space charge region, it reaches a maximal value, when the levels of the recombination centers coincide with the intrinsic Fermi level, and the Shockley-Read-Hall recombination rate (SRH) becomes maximal.

An accelerated ageing has been performed on the NPN transistor type 2SC3467, by injecting a strong current intensities of 250 mA in the emitter-base junction polarized in inverse, with reverse bias V= -12V, while the collector was not connected during the stress. The purpose, here, is to obtain more important damages in short times.

The durations of the electric constraints application were chosen in a way that two consecutive periods of stress have an important action on the measured parameters. It is very important to make several tests before application of the electrical stress to choose the best compromise between a fast ageing and a greater risk of breakdown of the junction.

After raising the fresh characteristics, we measured the curve (I-V) at each step with an accumulated stress time of 60s, 120 s…, 480s. The voltage and the current are kept constant by the source Keithley 2400 along every period of stress. The stress is interrupted between two periods of ageing in order to be able to make the data acquisition which are necessary for analysis. The most important parameters studied are compared before and after aging. Examples of typical values obtained with studied bipolar transistors are presented in table1.

Parameter	Fresh transistor	After 480s stress time
Ideality factor: A	1,3	1,92
Recombination current : I_{02}	$8,669.10^{-13}$ A	$2,41.10^{-7}$ A
Series resistance: Rs	$0,788\ \Omega$	$2,086\ \Omega$

The parameters I_{02}, A, Rs, are very pertinent to study the properties linked to carriers transport processes, since their values are sensitive to the applied constraint.

The increase of the ideality factor to values close to A=2 in the short time of 8 min is an indication of high injection effects [39].

III. PARAMETERS INDICATOR OF PERFORMANCE

To estimate experimentally the performance of electronic components, and in order to link it to the physical parameters of the junction, we followed the evolution of the measured parameters as function of the stress time.
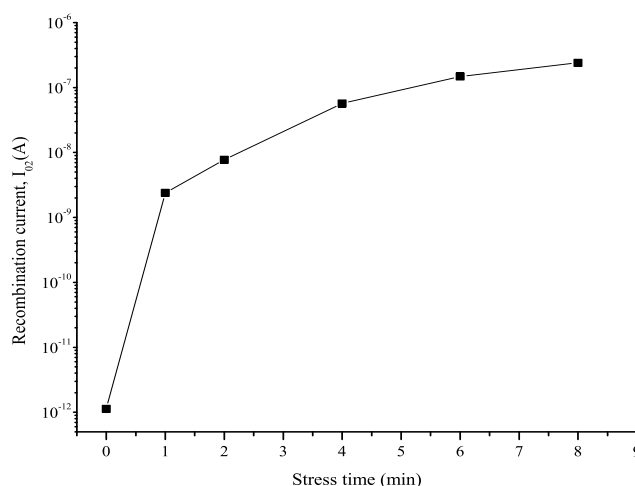

Fig. 1 The recombination current of the emitter-base junction as function of the stress duration

In the Fig1, we present the evolution of the recombination current, I_{02}, as a function of the stress time. It shows the increase of recombination current of the emitter-base junction with the stress duration.

I_{02} increases strongly during the first 4 minutes of stress time, then it continues to increase slowly and stabilizes to the value $I_{02}= 2,41.10^{-7}$A .The stress applied on bipolar transistor in hot carrier injection configuration has create interface states and other defects affecting their performance, by activating chemical reactions, and displacing atoms in the crystal lattice of the junction devices.

Several types of defects are enumerated by various authors; most of them are dedicated to the role of the hydrogen and

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hydrogen species in the defects formation [30]-[33]. The quick stabilization of I_{02} is an indication of the stabilisation of the conduction mechanisms modification, correlated to the high injection effects [35],[37], which appear when the excess of the minority carrier density increases and becomes comparable to the thermal equilibrium value of the majority carrier density. Thus, the fundamental physical processes of carrier transport in the junction are modified.
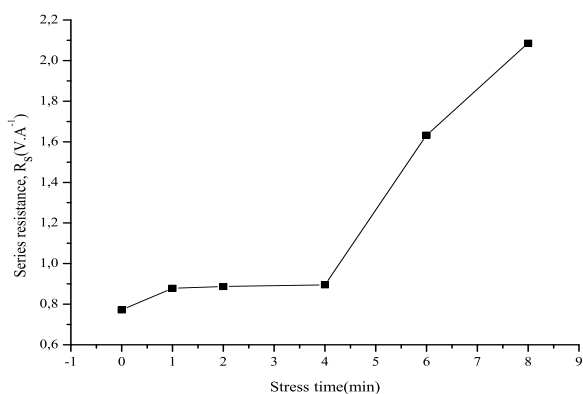

Fig. 2 The series resistance as a function of time stressing

The fig 2 shows, that during the first 4 minutes, series resistance remains stable, and then increases very quickly to reach the value of 2,086Ω. The increases of the series resistance is due to the reduced carrier mobility, and to the decrease of the base apparent doping provoked by the electrical stress, as consequence, conditions operating are degraded. Effectively, the carrier transport phenomena are modified after 4 minutes of stress time, by the high injection effects due to the insertion of a new defects layer in the base close to the space charge region [36], characterized by an apparent doping value lower than the base doping [37]-[39], it extends mainly in the p region [37].
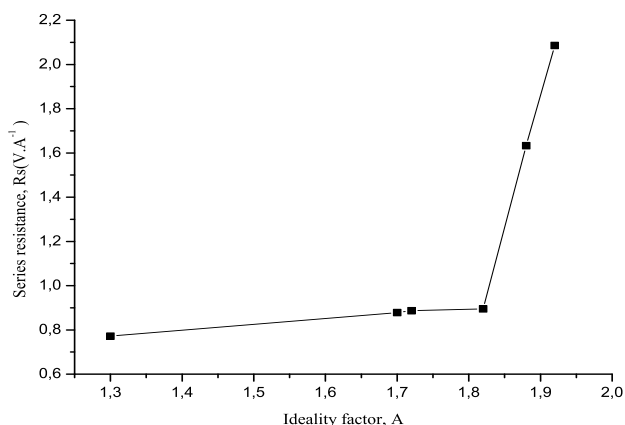

Fig. 3 The series resistance vs ideality factor of the emitter-base junction during the stress experiment

The fig 3 shows the correlation between variations of the series resistance and the ideality factor. We notice two different parts on the curve, the first one which goes from 0 min to 4min stress time is related to the structure degradation, and the second one which goes from 4min to 8 min stress time is related to the high injection effects.

We have introduced the parameter $RA = \left| \dfrac{dRs}{dA} \right|$, which is a parameter indicator of performance to estimate the process ascendancy of the degradation of the functioning conditions of the junction. It takes into account simultaneously the structural and operating conditions degradation. Effectively, the ideality factor is related to the structural properties of the junction and the series resistance is related to the transport process and to the carrier concentration of the junction.

The experimental results for the first 4 min of stress duration give a mean value of performance indicator parameter, RA, of 0.236Ω, and the value 11.91Ω for the last step when the high injection effects appears. After a while of application of the electrical stress, the degradation continues to increase, thanks to the high injection phenomena which plays a crucial role in the evolution of the degradation process [40]-[42].

IV. CONCLUSION

In this paper, we have investigated and presented the problems of the high injection effects on the electronic devices performance. We have proposed a new parameter $RA = \left| \dfrac{dRs}{dA} \right|$ of the performance evaluation based on the study of the high injection phenomena.

Our results establishes a direct measure of the degradation caused by high injection effects; related to the level of minority carrier concentration obtained in the base. We have shown that for the studied transistors, the operating conditions degradation is the dominating process, and high injection effects mask the process of the creation of the structural defects. This behavior is indicated by the variation of the, proposed, performance parametersr, RA.

The series resistances and the ideality factor increase with the decreasing the base doping due to the high injections effects.

The determination of the performance via the physical junction parameters introduces an innovative and powerful method for the characterization of the microelectronic devices.

It is very suited to apply this method, in the field of the microelectronics industry, to control the quality, and to improve the operating conditions for high performance requirements.

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