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RELIABILITY FOR SELECTION OF MICROELECTRONIC DEVICES

Wahiba TAZIBT[1, 2], Pierre MIALHE[2]
[1]Department of physique, University of Bejaïa A. Mira, Algeria
[2]ELIAUS, University of Perpignan Via Domitia, 66860 PERPIGNAN Cedex, France.

Invited article

Abstract

A study of the reliability of commercial electronic components is presented. The method is based on numerical analysis performed on the emitter-base junction experimental current-voltage curves to extract junction characteristics and their evolutions after ageing steps. The sensitivity of their variations to degradation processes is considered to introduce parameters for reliability evaluation. An evolution of reliability along ageing is quantified.

Keywords: junction, quality, parameter, reliability, selection.

I. INTRODUCTION

High performance microelectronics large-scale integrated circuits results from advanced technology in the field of low size devices, which allows a higher commutation speed, good quality of transmission and low energy consumption. The international market requires new applications in the fields of telecommunications, telephony, game specific devices, image processing and drives the development of nanotechnology for the realisation of new devices. Structures on a molecular scale in these new technologies emerge. In addition to the conditions of performances, the consumer requires information concerning reliability of new manufactured systems and it is now the responsibility of the scientists to inform the public and both commercial and political professionals. This lecture gives an overview of current research work along the past decade (2000 - 2010) concerning reliability of electronics devices, together with some results obtained in our laboratory.

The interest carried in the notion of microelectronic reliability devices has strongly increased [1-8] during last years. A component or an integrated circuit is reliable when it can work during a long time without any modification of its electric characteristics. Thus, a prediction of device reliability could be given only in relation with operating conditions and for possible specific external constraints. An estimation of reliability requires knowledge about the structure of the devices, their characteristics and the manufacturing processes..

During current operations, ageing effects are generally observed which modify device performances. They are related to induce defects of structure [8] and also to interactions with an aggressive external environment for example radiative phenomena [6, 7]. The reliability problems also result from effects of miniaturization creating intense electric fields which produce energetic carriers interacting with the crystalline lattice [5-13]. Until now, the techniques used for quality evaluation are purely mathematical, based on statistical studies [14-18]. Simulation tools give predictions, probabilities for failure mechanisms and are concerned by device lifetime. They do not consider failure processes.

The method presented, which consists on evaluation of device reliability, is based on an experimental study. This work introduces a link between reliability of microelectronic devices, characteristics of an n-p junction, and a threshold voltage which delimitates low and high injection operations. The aim of this work is to describe all the measurements to be made in order to be able to manage evaluations of reliability indicators of microelectronic devices.
In this work, we consider the evolution of the operation of junction in a microelectronic component. The junction being subjected to electric constraints, we characterize its evolution from the study of its current-voltage I (V) characteristics. Our method is based on the modelling of experimental current-voltage characteristics of the emitter –base junction of transistors. Junction parameters are introduced which allow discussing the charge transport related to structure and operating conditions. Operations are related to low or high injection considerations. Results point out that the increase of the ideality factor of a junction is a sign of degradation of the structure of devices, and the decrease of the transition voltage is a sign of the degradation of the phenomena of transport which take place in the junction [8, 19-21].

II. EXPERIMENT AND METHOD

Physical parameters of the emitter-base junction were extracted from a theoretical description of the experimental I (V) characteristics. The description was obtained by using well established diode models by the following equation:

$$I = \frac{V - R_s I}{R_{sh}} + I_{01}\left(\exp\left(\frac{q}{kT}(V - R_s I)\right) - 1\right) + I_{02}\left(\exp\left(\frac{q}{nkT}(V - R_s I)\right) - 1\right) \quad (1)$$

The five characteristic parameters (R_s, R_{sh}, I_{01}, I_{02}, and n) are related to the carrier transport processes, the physical structure, and the junction proprieties.
V_T=kT/q is the thermal voltage, Rs is the series resistance introduced to take into account the power losses, R_{sh} the shunt resistance which takes into account the leakage current, I_{01} and I_{02} are the junction reverse saturation currents. I_{01} corresponds to the reverse diffusion-recombination phenomena in the quasi-neutral region of the structure and I_{02} is the reverse recombination current in the space-region of the junction and at interfaces of semiconductor layers [19].

Parameter n is the ideality factor which is determined so as it leads to a superposition of the theoretical curve (graph of function I (V) given by Eq (1)) with the experimental curve. It expresses the deviation between ideal and real behaviours. Several theories related the values of n with the physical transport phenomena. According to the diffusion theory of Shockley [20] based on the minority carrier diffusion, the value n=1 is associated with the ideal junction. By considering the phenomena of generation-recombination in the space charge region and assuming that the energy level of the recombination traps is located at the intrinsic Fermi level, the ideality factor should equal 2. Values of the ideality factor greater than unity [8, 20-25] indicate low quality junctions.
No analytic expression has been explicitly obtained relating values of ideality factor to the physical transport carrier phenomena. Various distributions of recombination centres [24] can be activated depending on the structure of the junction that leads variations of the ideality factor, series resistance and of the recombination current in the space charge region of the junction.

An accelerated electrical ageing of npn transistors have been performed in order to evaluate quality and reliability of the microelectronic components. The devices over studied were bipolar transistors on current sale, and have been selected with similar technological characteristics; they will be referred as "standard bipolar transistors. We searched for this experiment suitable stress conditions so as to accelerate the electrical aging. The electrical stress was performed by reverse biasing the emitter-base junction with a voltage V = -12 V, close to the breakdown voltage value and the collector was in open condition. The reversed current intensity, 200 mA, was higher than the saturation current.

The current-voltage measurements were made through an experimental set-up including a computer acquisition system using a Keithley 2400 SMU (source measurement unit) driven through an IEEE interface. With this experiment, 100 current-voltage data points of the emitter-base junction I(V) characteristic were obtained and stored in the form of files. The files were treated by our software [26] using the double exponential models (DEM) so as to extract physical parameters, from a theoretical description of the experimental current-voltage characteristic I (V).

The transition voltage V_{tr} is introduced via model of the junction I (V) characteristics, based on carrier transport phenomena and taking in consideration the carrier concentrations in each region when an external bias is applied to the junction. The transition voltage delimitates low and high injection operating conditions. It is taken as the bias value at the intercept of two linear regions of semi-log forward bias I (V) characteristics [8, 21], and measured at every step of the ageing experiment.

III. DEGRADATION OF THE DEVICE

After each minutes of the applied stress, we performed the acquisition of the I (V) characteristic of the emitter–base junction and the values of the junction parameters were extracted together with the measurement of the transition voltage V_{th}. Figures 1-4 display the results which show the gradual and large evolutions of the parameters all along a nine minutes stress time.

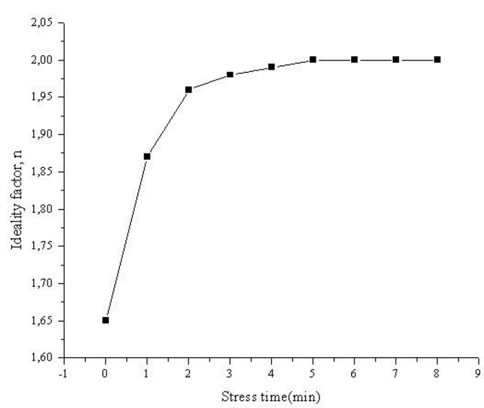

Figure 1: The ideality factor of the emitter–base junction of a standard bipolar transistor as a function of the stress duration (reverse junction bias).

Figure 1 shows the variation of the ideality factor of the emitter- base junction of a standard bipolar transistor according to the stress duration. The ideality factor increases during the first three minutes of the applied stress, and stabilizes at a value n=2 when increasing the duration of the stress until nine minutes.

The growth of the ideality factor is interpreted by an increase of the defects density engendered by the hot carriers. The electric field in the space region is intense and it accelerates the charge carriers which create interface states and traps in the structure material and at interfaces. The junction is degraded and these processes decrease the reliability of the transistor. The stabilization of the increase of the ideality factor is related to the saturation of these defects creations which are linked to the break of weak bonds of silicon by hot carriers.

The value n=2 points out that high injection effects appear in the base of the junction which modify the carrier transport processes.

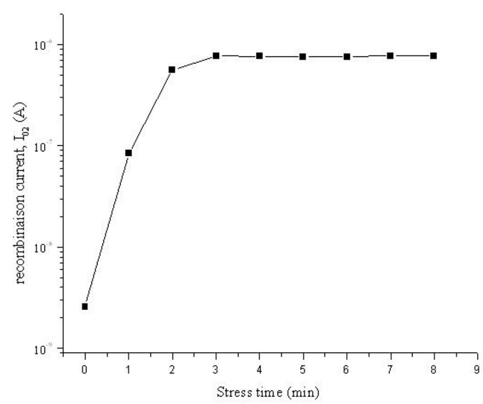

Figure 2: The reverse recombination current of the emitter–base junction of a standard bipolar transistor as a function of the stress duration (reverse junction bias).

Figure 2 shows also a saturation of the increase of the junction reverse recombination current. The variation is globally from 10^{-9}A before stressing the device to10^{7}A at the end of the stress duration. This result leads to introduce a localisation of the defects close to the space charge region that implies a removal process which increases the density of defects in a located area.

The recombination current follows the same evolution as that of the ideality factor that is a confirmation of the interpretation introduced in order to describe the ideality factor measurements. A rate of degradation of the junction could be defined by a graphical evaluation of $\Delta n / \Delta t$.

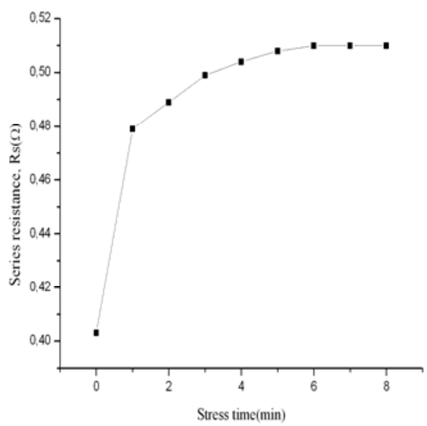

Figure 3: The series resistance of the emitter–base junction of a standard bipolar transistor as a function of the stress duration (reverse junction bias).

Figure 3 shows that the series resistance increases quickly during the first three minutes of the ageing experiments, then continues to increase less quickly to stabilize at the end of the stress. It shows that operating conditions of the transistor are degraded.

The increase of the series resistance is due to the decrease of carrier mobility and is dependent on the effective base doping level. The continuation of the degradation is a consequence of high injection effects [21] which maintain a high density of minority carriers in the base, close to the space charge region. A rate of degradation of the junction could be defined by a graphical evaluation of $\Delta R_s / \Delta t$.

The evolution of operating conditions could be discussed from measurements of the transition voltage V_{tr}. At each step of the experiment, the I(V) characteristic of the junction is acquired and a software leads to determine V_{tr} from the log (I) against V curve.

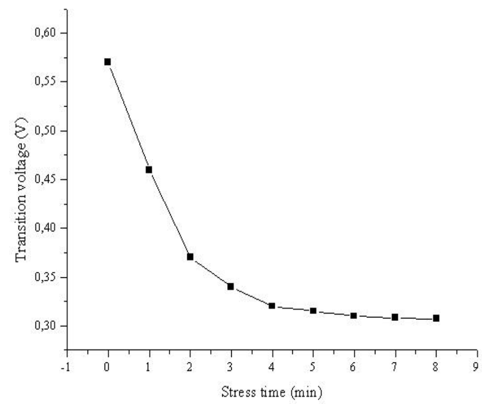

Figure 4: The transition voltage of the emitter–base junction of a standard bipolar transistor as a function of the stress duration (reverse junction bias).

Figure 4 displays the diminution of the transition potential. It shows that the conditions of high injection are obtained for very low values of the junction polarisation since V_{tr} decreases from 54 mV before stress until 37 mV after 3 minutes of stress duration.

The slow decrease of the transition potential during the second phase of degradation (for duration higher than 3 minutes), is correlated with the variations of the series resistance, that confirms the modification of operating conditions of the device. The initial fast degradation concerns interactions of hot carriers and modifications of crystal structure.

The device degradation observed in this study of bipolar transistors operating with extreme conditions of polarisation conditions is believed to be dominated by induced bulk and interface states. The gradual increase of the space charge reverse current of the emitter-base junction is correlated to the organisation, close to the junction, of a layer which is characterised by a high density of crystal defects. A removal process of traps is then considered which leads to the observed saturation effects. It is confirmed by the fast decrease of the transition voltage during the initial phase of the degradation which is an indication of high injection effects at the junction. It implies modification of charges transport processes and a large increase [21] of minority carrier density in the defect layer.

IV. RELIABILITY

A reliability prediction is concerned by device failures which are induced by selected applications and operative conditions. Device failures involved a combination of several physical mechanisms related to degradation processes and the scientist has to identify and to describe the dominant failure mechanisms. Tests are performed, depending on the physical phenomena which induce a dominant failure, and introduce indicative parameters linked to each degradation process.

This work considers mechanisms for hot carriers injection and introduces the rates of variations of the ideality factor and of the series resistance of the junction, together with the transition voltage.

A model for quantifying reliability of bipolar transistors selected for power applications or commutation controls, must take into account degradations of both the structural properties and the operating conditions which have been identified as dominant failures.

Figures 5 and 6 display the variations of the transition voltage against respectively the ideality factor and the series resistance of the emitter-base junction.

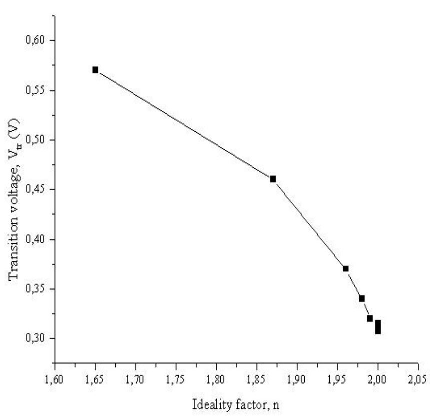

Figure 5: The transition voltage of the emitter–base junction of a standard bipolar transistor as a function of the ideality factor during the ageing experiment.

Figure 5, shows that the variation of the ideality factor is bound to the variation of the transition voltage. The gradient RF = $\left|\frac{dV_{tr}}{dn}\right|$ has been measured from figure 5, and appears as an indicator for reliability evaluation of the devices junction. It introduces an evaluation of the reliability of the component. This parameter is linked to the effects of degradation of the junction structure and to the effects of degradation of the operating conditions.

The experimental results give a value of RF = 0.5 V during the first two minutes of stress duration, and a value of RF = 1.1V for the second phase of the degradation processes.

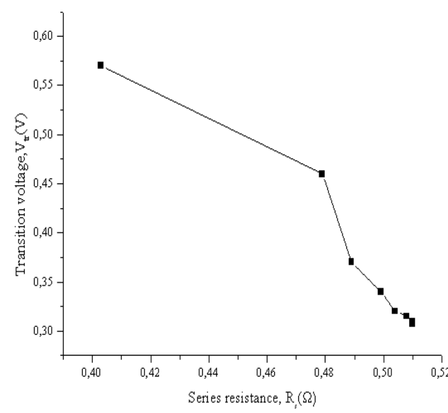

Figure 6: The transition voltage of the emitter–base junction of a standard bipolar transistor as a function of the series resistance during the ageing experiment.

We can calculate the gradient VR $=\left|\frac{dV_{tr}}{dR_s}\right|$, measured through a time interval from Fig.6. This gradient is related simultaneously to structural degradation of the junctions and to the degradation of operating conditions. The experimental results for the initial 4 min of ageing experiments give mean values of VR = 2.39 A and 3 A at the end of the ageing experiment. These results show that the values of VR reflect the existence of two phases, the second phase being characterized by a lower reliability than the initial phase.

Parameters RF and VR can be determined from experimental measurements, which are easy to perform since they imply only measurements of I-V characteristics of a junction.

V. CONCLUSION

A detailed experiment for studying ageing of bipolar transistors has been performed. Electrical stress was applied to the transistors with an emitter-base reverse current. A gradual and large evolution of the junction characteristics have been measured all along the experiment. Two rates of degradation, Δn / Δt and ΔRs / Δt, respectively of the quality factor "n" and of the series resistance "Rs" have been introduced. Linked to define operative conditions, they introduced a way to follow structural and operating ageing effects induced on the performance of the active part of the electronic device.

The determination of the transition potential values leads to points out that high injection effects appear at low values of the junction bias for the degraded device.

We introduced parameters RF = $\left|\frac{dV_{tr}}{dn}\right|$ and VR = $\left|\frac{dV_{tr}}{dR_s}\right|$ for reliability evaluations.

Parameter RF is linked to the effects of degradation of the junction structure, and to the effects of degradation of the operating conditions.

Parameter VR is an indicator of reliability since it is related to degradation processes. The evolution of parameter VR, along technological industrial processes, introduces a quality control.

These results are of importance, because they bring to light the relation between the reliability of the devices, the structural properties and the operating conditions. The values of parameter RF and VR are indicative of the reliability of components.

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