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RELIABILITY OF MICROELECTRONIC DEVICES FROM EMITTER-BASE JUNCTION CHARACTERIZATION

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ABSTRACT

The current-voltage characteristics of microelectronic devices are used to compare commercial components. A double exponential model (VDEM) introduces physical parameters to characterise the junction properties of bipolar transistor.

The method leads to differentiate the high and low power operating modes of devices and shows that values of the junction parameters can be associated with each manufacture and related to quality and reliability control.

KEY WORDS

Quality, reliability, characterisation, microelectronic.

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INTRODUCTION

The development of new technologies for electronic devices must answer to the most important requirements of the markets which are performance and evaluation of quality and reliability [1, 2]. High reliability is an indication for operating during a long duration without modification of electrical characteristics.

The major cause of the performance degradations is the generation of hot carriers by the high electric field at the junction [3-7].

Degradations are related to the structure of defects induced by the operating conditions [6], but also to interaction with aggressive external medium for example radiative phenomena [8].

Many works have been published concerning the properties of materials and of interfaces, to qualify the component; they can be presented in four categories:
- Studies of the structure defects, native or induced by degradation processes, creation of structure defects and their interactions with carriers [6, 9].
- The evolution of the junction properties during specific operations [10, 11].
- The origins of noise [12].
- The research of physical indicators which are related to the structure and which evolve during operation [13-15].

Different methods of devices characterisation have been considered, they generally consider parameters which are related to operating conditions.Parameter extraction from performance measurements have been performed using semiconductor models [16-18].

This work proposes to show that the operating modes of commercial bipolar transistors can be differentiated by a determination of the parameters of the emitter-base junction. The processes of recombination of carriers are discussed from the analysis of I(V) characteristics and the analysis lead to consider quality and reliability of the components.

METHOD

The method is based on a numerical analysis of the experimental current-voltage I(V) curves of the emitter-base junction [18]. The mathematical VDEM model (variable double exponential model) of the silicon I(V) junction current, given by Eq. (1), has obtained [19] the total current as the sum of three contributions to the junction current:
(i) a leakage current which introduces series (R_s) and shunt (R_{sh}) resistances,
(ii) the diffusion component with the reverse saturation current I_{01},
(iii) the recombination component which introduces the junction ideality factor (n) and the reverse recombination current I_{02}.

This model introduces five parameters R_s, R_{sh}, n, I_{01} and I_{02} which are dependent on the structure of the junction and are considered as characteristic parameters since they are linked to carrier transport processes, physical structure and junction properties.

The I(V) characteristic of a junction can then be described from the I(V) graph of the equation:

$$I = \frac{V - R_S I}{R_{sh}} + I_{01}\left[\exp\left(\frac{1}{V_T}\left(V - R_S I\right)\right) - 1\right] + I_{02}\left[\exp\left(\frac{1}{nV_T}\left(V - R_S I\right)\right) - 1\right] \qquad (1)$$

where $V_T = kT/q$ is the thermal voltage.

R_s and R_{sh} are strongly related to the structure such as geometry, doping, interface. I_{01} correspond to the reverse diffusion-recombination phenomena in the quasi-neutral region of the structure. I_{02} to the reverse recombination current in the space region of the junction and at metal-semiconductors or oxide-semiconductors interfaces. The ideality factor, n, it is an empirical parameter. Values of n greater then unity are related to carrier recombination via traps [20], and the increase in values of n is related with an increase in the reverse current I_{02}.

The VDEM model separates electronic diffusion phenomena in the quasi-neutral regions of the junction, from recombination processes. For this method, these five parameters are extracted from a theoretical [18] description of the experimental I(V) characteristics with the graph of Eq. (1).

RESULTS AND DISCUSSION

The experimental set-up includes a computer driver acquisition system, a specifically conceived software YAKA [18] which extracts parameters R_s, R_{sh}, n, I_{01}, I_{02} from the I(V) junction characteristic data.

The devices were commercial n-p-n transistors from several companies and had been selected with similar technological characteristics.
For each company, devices were considered from different manufacturers which are generally localised in different countries.
For each transistor, the emitter-base current voltage characteristic had been acquired, for different operative conditions, in the form of a file of one hundred data points, and stored for modelling analysis.
Parameters were then extracted from each file. More than ninety transistors have been measured.
For each experiment, we have considered the highest value of the measured load current, Irg, as a reference for the power operating conditions.
Low Irg values (Irg < 35 mA) indicate low injection current and great values (Irg > 50 mA) define high power operations.

The typical evolutions of the junction parameters n, I_{01}, I_{02} and Rs vs Irg are represented in figures 1-4 with results obtained for TIP41C commercial transistors. These results point out that the parameters of the emitter-base junction of bipolar transistors are dependent on the operating conditions. The reverse recombination current increases with the intensity of the load current (Fig. 2), it is correlated with the increase of the ideality factor (Fig.1). These higher than unity ideality factor values [13, 19] indicate recombination processes at interfaces and in the space charge region. The increase, observed in Fig. 2, of the recombination current with Irg points out an increase of trap efficiencies for high values of the load current, that means for high power operations. Further, the decrease of the series resistance (Fig. 3) for high power operating conditions is an indication of an evolution of the carrier transport processes. The increase of the reversed I_{01} component (Fig. 4) follows the increase of the injection level.

It can then be inferred that this characterisation method enables to differentiate various operating processes of bipolar transistors. These experiments have been performed with more than fifty commercial transistors. For a lot of devices, junction parameters are not dependent on operating conditions.

Table 1 and Table 2 represent respectively the physical junction parameters: n, I_{02} and R_s of the emitter-base junction of two transistors coming from two different manufacturers (references BC548 and 2SC2240).

Results were obtained for two different operations, with low power (Table 1), then at high power conditions (Table 2).

Table 1: Emitter-base junction parameters (low intensity current)

	n	I_{02} (A)	$R_s(\Omega)$
BC548	1.41	$2.36\ 10^{-12}$	3.028
2SC2240	1.74	$3.63\ 10^{-10}$	0.717

Table 2: Emitter-base junction parameters (high power).

	n	I_{02} (A)	$R_s(\Omega)$
BC548	1.34	$6.52\ 10^{-13}$	1.513
2SC2240	1.47	$1.84\ 10^{-11}$	0.769

An operation with low intensity was considered in order to study the recombination phenomena. The indications of the values of R_s and I_{02} allows showing that the losses by recombination (strong values of I_{02}) are not connected to the ohmic losses. By comparing the data of the two tables for the same transistor an evolution of the parameters is observed when comparing the two operation conditions for transistor 2SC2240. The ideality factor decreases at high power; at low intensity the diffusion current is low and the large value of the ideality factor is an indication of active recombination traps. It is not the case for transistor BC548 for which the reverse recombination current is low in all operating conditions.

Then, these results show that the ideality factor values give an indication of quality and of reliability since ageing studies [15] showed that the degradation of the parameters are generally consequences of an increase in density of recombination centres. Such results lead to introduce a systematic study of junction parameters of commercial devices before an evaluation of technological processes.

Figure 5 and figure 6 display the values of the ideality factors and of the series resistance of the emitter-base junction of transistors obtained from eight manufactures. For these measurements, the software was organised to compute the parameters values of each transistors for more than 20 low power operating conditions including very low injected currents, then to determine, for each manufacturer, the values found for the best description [18] of the experimental junction I(V) curve; these values are reported on Fig. 5 and Fig. 6. The values of the ideality factor of the samples are differing from one company to another and are also related to manufacture and these results show that they could be considered as a signature of the companies' process. The values of the series resistance differ also from one manufacturer to another and are related to the doping level of the layer and to the structure of metal semiconductor interface.

CONCLUSION

The method used to extract physical parameters is a powerful method for microelectronics device characterization; it allows to introduce selection of devices with higher reliability for specific applications**.** The ideality factor appears as a sensitive parameter for quality characterisation of junction. Devices reliability and quality may be discussed depending upon technological processes.

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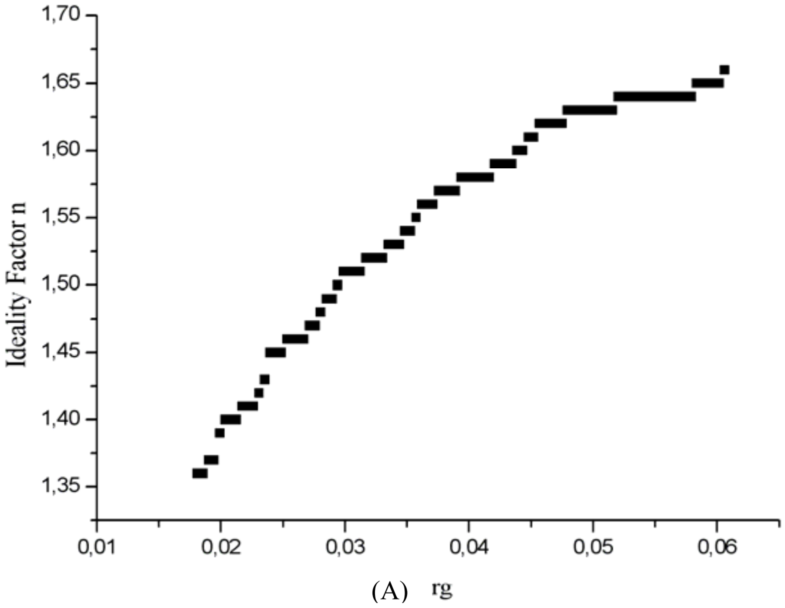


Fig.1: Variation of the junction ideality factor vs the highest value Irg of the load current intensity for each I(V) characteristic.

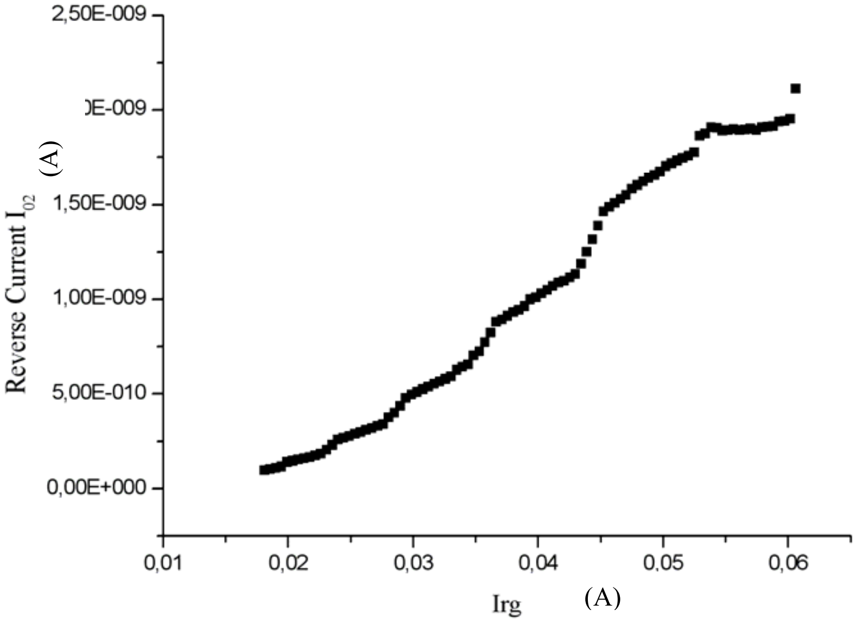
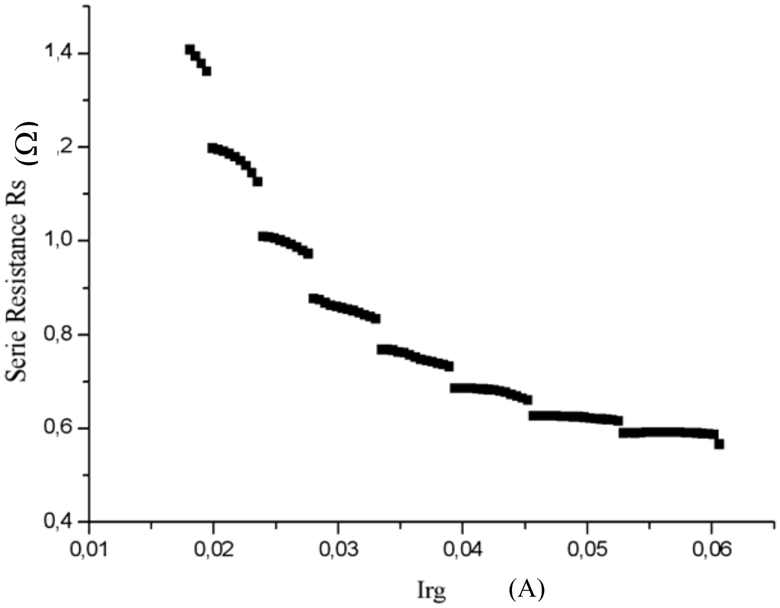


Fig.2: Variation of the reverse recombination current vs the highest value Irg of the load current intensity for each I(V) characteristic.



Fig;3: Variation of the junction series resistance vs the highest value Irg of the load current intensity for each I(V) characteristic

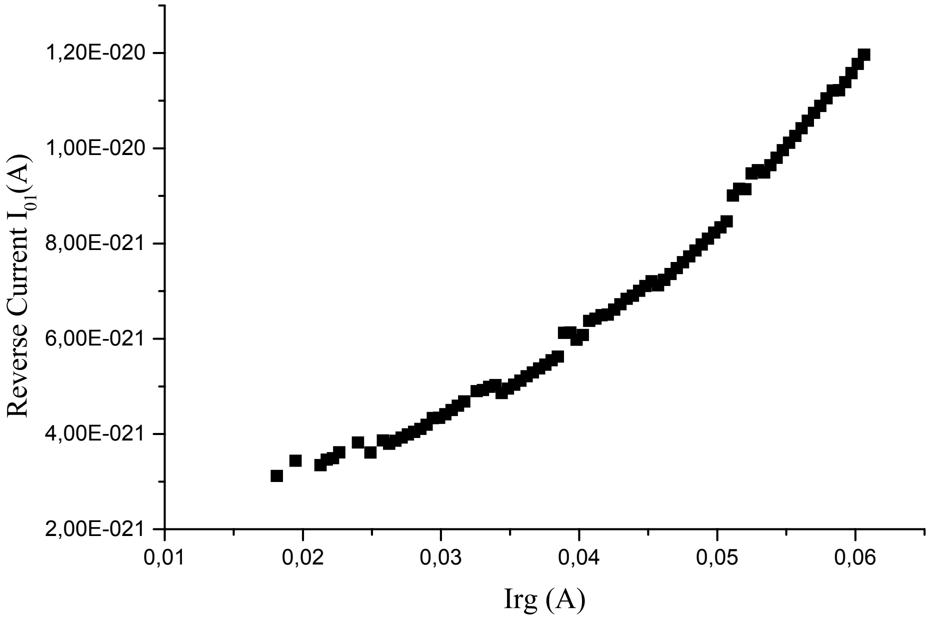


Fig.4: Variation of the reverse diffusion component of the current vs the highest value Irg of the load current intensity for each I(V) characteristic.

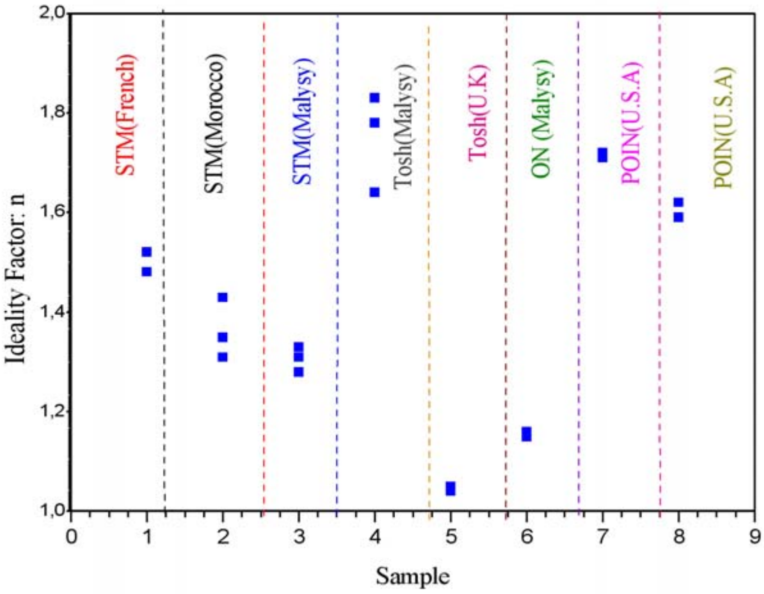


Fig.5: The ideality factor of the emitter-base junction of commercial transistors from different companies and for some manufactures.

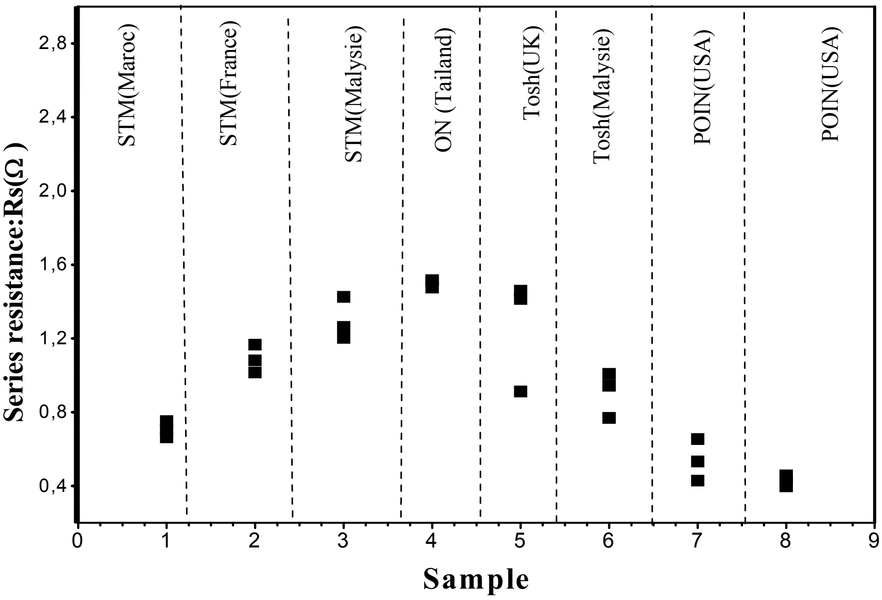


Fig.6: The series resistance of the emitter-base junction of commercial transistors from different companies and for some manufactures.