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STUDY AND ANALISYS OF DEGRADATION PROCESSES IN THE ELECTRONIC EQUIPMENT OPERATING AT KOZLODUY NPP

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The electronic equipment for control and monitoring of different systems on Units 5 and 6 of Kozloduy NPP has been studies for identification of degradation processes, occurring during its long use under the conditions of monitored radiation background in accordance with the radiation safety norms for the plant. For this purpose operating electronic units have been selected, and active components, such as diodes, transistors and integrated circuits, have been disassembled and their main parameters have been measured. By comparison with the parameters of the same components from non-operated equipment, it has been found out that some changes occur which may impact the functionality of the electronic equipment. The most sensitive factor for the diodes is the ideality factor β and for the transistors these are the current transfer constant h_{21} and the collector current $I_{\kappa o}$. A theoretical model has been developed by means of which the equipment lifetime forecast can be made depending on the duration and intensity of the operation.

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1. Introduction

The most important parameter of all semi-conductor elements, built on the basis of barrier structures (p-n junctions, hetero-junctions, “metal-semiconductor” junction, “metal-dielectric” junction or combinations there of) is the ideality factor **β.** It is extremely sensitive to any degradation processes in diode and transistor components and its quantitative values guarantee with high precision whether the electronic components have entered the ageing phase or are in normal functioning condition. Using this factor an experiment was made to study and analyze the electronic equipment, operating for a long time at Kozloduy NPP under conditions of monitored radiation background in accordance with the radiation safety norms. A selection of an electronic system was made, from which a number of units, operating in continuous load mode with a mark-to-space ratio close to one, was selected. Out of these units selected samples of the boards were disassembled, while keeping their mechanical integrity and functionality. This procedure was applied simultaneously for similar electronic equipment which:

- has not been in operation at all before the experiment;
- has not completed its full design operation time as per manufacturer’s instructions (5-6 years);
- has been in operation by the time of this experiment.

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2. Experimental

The electric parameters of the three groups of samples were measured and analyzed using the theoretical model. The model is based on the formation of shunt areas in the p-n junctions of diodes and transistors being in long operation, which change their current-voltage characteristics and the characteristics of the remaining current, accordingly. The main reasons for shunt areas formation are considered to be diffusion and accumulation of residual impurities on the dislocation defects, arising in the process of technological composition of the active semi-conductor structure of the diodes and transistors. Two types of dislocations are assumed in the model: linear and non-conformity dislocations. The former cross the p-n junction and have their origin from the semiconductor substrate or from non-conformity dislocations, arising in the interface area of the basic semiconductor substrate and the inverse epitaxial layer. Both types of dislocations accumulate foreign (impurity) atoms but the linear dislocations contribute to development of shunt channels, while the non-conformity dislocations result in development of clusters or compound complexes. The model with linear dislocations is demonstrated in Fig. 1. Part of these appears on the surface of the active semiconductor structure, composed of a substrate and an epitaxial or diffusion layer over it, while the other part of the dislocations remains closed in the interface area and is regarded as space defects, appearing as micro-pores. As a whole both types of defects form a unified dislocation grid in the semiconductor structure, whose parameters are determined by the crystal growth conditions. Under the impact of the electric field, applied on the p-n junction and its internal temperature in the course of operation accelerated diffusion of foreign atoms takes place (most frequently copper atoms due to their small covalent radius) in the so formed dislocation grid. Three typical cases are presented in Fig. 1.

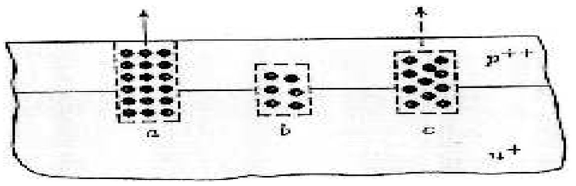

Fig. 1. Possible models of structural defects in the **p-n** junction area, resulting from degradation processes.

The first case (a) results from accumulation of foreign atoms on the dislocation defects which appear on the surface of the layer thus forming directly shunt areas.
The second case (b) results from accumulation of relatively small quantities of residual atoms on closed defects, thus forming cluster, which does not cause directly a shunt effect. The third case (c) occurs, when large amounts of impurities accumulated on such a closed defect cause high mechanical stress on the grid and as a result the closed defect enlarges up to the point of egression on the free surface of the epitaxial layer. The occurrence of shunt channels and clusters, creating deep energy levels in the forbidden zone affects most strongly the current-voltage characteristic of the p-n junction and more specifically the $\boldsymbol{\beta}$ factor (ideality factor) in the equation:

$$I = I_0 e^{(qU / \beta kT)} \tag{1}$$

The change of the ideality factor is illustrated by the change of the slope of the current-voltage characteristic of the p-n junction and respectively the change of the current parameters of the ordinary diode, formed on its basis. As regards a bipolar transistor, based on two p-n junctions (emitter and collector ones) the current of the collector junction $\boldsymbol{I}ko$, current transfer constant $\boldsymbol{h}21$, as well as the steepness of the family of current-voltage characteristics are most strongly affected. This degradation phenomenon can be explained with the model, based on the modification of the space charge trapped at the p-n junction due to generation of shunt areas after accumulation of foreign atoms on dislocation defects. The space charge in a mono-dimensional version together with the shunt area is shown in Fig. 2. The ideality factor of such p-n junction is given by the expression:

$$\beta I = \{2[b + ch(\varpi / L)]\}(b-1)^{-1} \quad (2)$$

where ***ω*=*xn*+*xp*** is the width of the space charge, ***L*** is the diffusion length of the carriers, ***b*** is the ratio between the mobility of the electrons and holes.

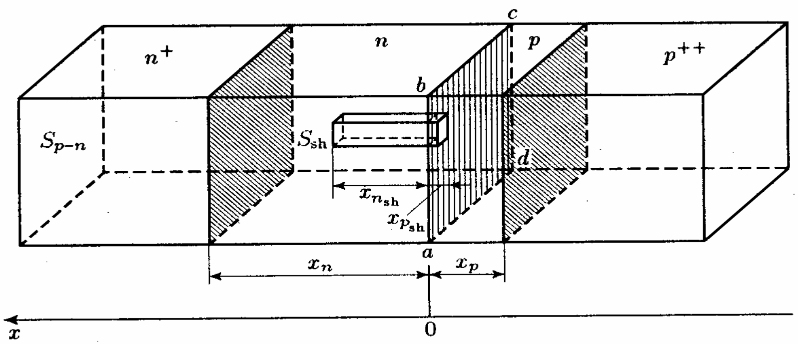

Fig. 2. Mono-dimensional model of a shunt area.

This formula allows quantitative evaluation of the current flowing through the p-n junction (respectively the diode current shifted in forward direction or the collector current). If the ratio between the width of the space charge regions of the p-n junction and the diffusion length of the carriers tends to zero, then the ideality factor assumes values below 2. This case corresponds to the normal condition of the p-n junction, when there is no generation of shunt areas in the space charge region and deep impurity levels in the forbidden gap or their concentration is very low.

The generation of shunt areas and deep levels in considerable concentrations, affecting current parameters of the diode and transistor increases the ideality factor above 2. In this case the ratio between the width of the space charge region and diffusion length becomes higher than zero due to the increased length of the space charge.

3. Results

On the basis of this theoretical model a lifetime forecast is made for the diodes and transistors from a given board, as part of the electronic equipment, and thereupon a decision is made regarding its operation extension or replacement.

Translated into practice this means that:

(1) Boards of electronic equipment are selected (three sets of the same electronic equipment, out of which one set has not been in operation at all, while the other two have operated for a different periods of time).

(2) Using the sampling method several identical diodes and transistors are disassembled from each set.

(3) For the diodes the ideality factor is measured, and for the transistor transfer constant by current is measured. If the ideality factor is less than 2 and the transfer constant by current has changed to not more than 25%, then a decision can be made to extend the lifetime, provided both diodes and transistors meet these conditions.

(4) In case these conditions are not met a straight line is constructed via three points and its continuation is extrapolated, keeping the resulting slope.

(5) A graphics is constructed with the following coordinates:
   (a) the abscise being the time in operation
   (b) the ordinate being the measured parameter (ideality factor and transfer constant by current).

(6) The approximation will show the time period whereupon the subject parameter will exceed the defined limit and based on this a decision could be made regarding the extension of lifetime of given electronic equipment or its replacement with a new one from the spare parts reserve.

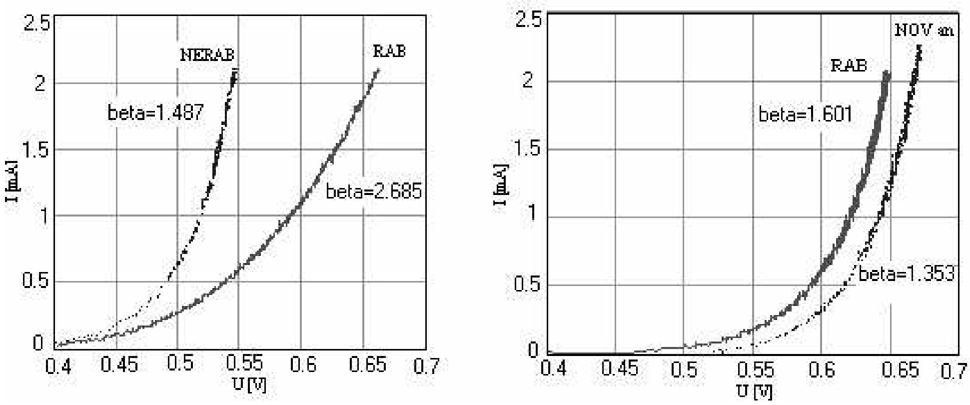

Fig. 3 (a) Current-voltage characteristics of diode **КД 105:** non-operated (upper curve) and long Operation of about 10 years (lower curve); (b) Same for diode **Д223Б** in operation for about 6 years.

Fig. 3(a) presents the current-voltage characteristics of one operated and one non-operated diodes of **КД 105В** type from the electronic unit БЛП 1-У, where from the ideality factor for the former is determined to be β = 2.685 and for the latter β = 1.487. This means that in the sample that has been in operation degradation processes have occurred, related to the changed ratio between the diffusion and recombination components of the diode current, with a slight domination of the latter. The overall current significantly decreases thus changing the functionality of the unit. Fig. 3(b) represents the current-voltage characteristics of two types of diodes, disassembled from two electronic units: <ПБР-2М>, having been in operation for 6 years (diode Д223 В) and <БЛП-1У>, having been in operation for 10 years (diode КД105 В). According to the model for the β factor, the lifetime of the first diode has not expired.

Fig. 4(a),(b). presents the modification of h_{21} for transistor КТ310 2Б and the base current for transistor КТ315В from unit БУЗ-У, being in operation for 10 years. This modification exceeds the admissible limits, therefore replacement is required.

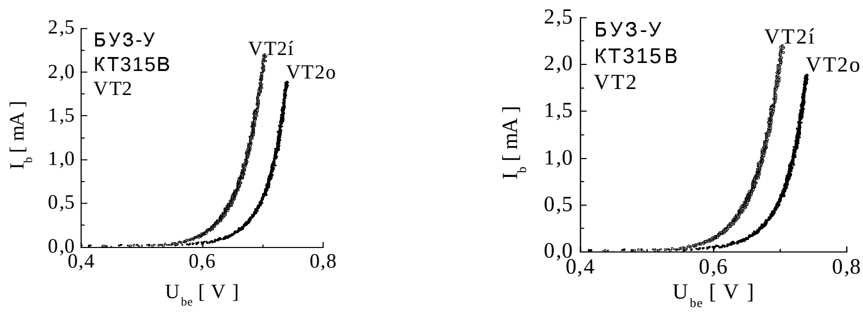

Fig. 4(a). Static transfer constant by current $\mathbf{h_{21}}$ of a non-operated (upper curve) and of an operated for 10 years (lower curve) transistor **КТ310 2Б;** (b) Base current $\mathbf{I_b}$ of a non-operated (upper curve) and operated for 10 years (lower curve) **КТ315В.**

In conclusion, it has been demonstrated in this study that the theoretical model developed [1] allows a forecast to be made for the equipment lifetime depending on the duration and intensity of its operation.

References

[1] A. S. Popov, Phys. Stat. Solidi (a) **81**, 669 (1984).