EFFECTS OF ELECTRON-IRRADIATION ON ELECTRICAL PROPERTIES OF AgCa/Si SCHOTTKY DIODES

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1. Introduction

The radiation plays a very negative role in the semiconductor devices functionality, mainly when particular semiconductor devices are exposed to an extreme type of radiation. Formation of the particular electrically active radiation defects is accompanied by a presence of the deep energy levels inside of the semiconductor forbidden gap, increasing in the density of generation-recombination traps at the surface and bulk of semiconductor, decreasing in the lifetime charge carriers, reducing in free charge carriers mobility [1,2].

The most frequently used semiconductor with a barrier structure is called the Schottky diode. Formation of the radiation-induced defects acts on some electrical parameters of the Schottky diodes. As a consequence of the formation of particular radiation-induced defects in a bulk semiconductor and as well as at the metal-semiconductor interface, the leakage current increases, the value of breakdown voltage and contact potential is reducing and the voltage dependent shape of current and capacity is changing, as well.

Recently, the attention is paid to a new knowledge which emerged after the high-energy electrons irradiation of the Schottky diodes prepared on the progressive GaN materials [3] and organic materials [4].

This contribution presents the results of the current-voltage I-V and the capacitance-voltage C-V measurement on the Schottky diodes with the AgCa gate on the silicon n-type substrate. The Si substrate was irradiated by 5 MeV electrons with a different dose value before the Schottky diode preparation.

2. Experiment

The Si substrates, doped by As (resistivity of 0.003 Ωcm), with the thickness of 650 μm were used for the experiment. The epitaxial layer with the thickness of 2.8 μm was doped by phoshorus (resistivity of 0.2 Ωcm). Such as prepared the bare Si n-type substrates were subsequently irradiated by 5 MeV high energy electrons with a different dose value and divided into four branches: (A1-50kGy, A2-100kGy, A3-500kGy, A4-1000kGy). The sample without irradiation is depicted as A0.

On the such as prepared samples were performed the Schottky contacts by a standard evaporation technique. The gate consists of the 20 nm thickness of Ca layer and 100 nm thickness of Ag top layer. The gates with the different areas were prepared lithographically by the MESA etching technique. The back-side Al ohmic contact with the thickness of 200 nm was prepared by a standard evaporation procedure.

Each of samples was measured from 8 to 10 times. The measurement was performed on the structures with the gate contact area of 100x100 μm.

The *C-V* and *I-V* characteristics were measured using Hewlet Packard 4280A and Agilent 4155C equipment, respectively.

3. Results and discussion

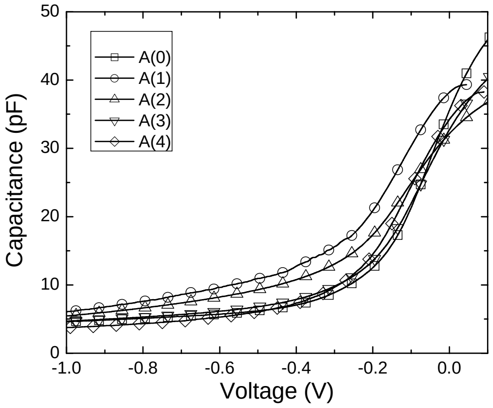

Fig. 1 *The C-V curves not irradiated (A0) and irradiated samples*

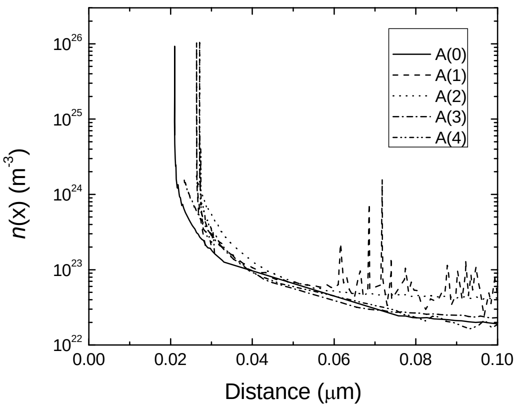

Fig. 2 *The deep doping profile of free charge carriers*

In Fig.1 are illustrated the measured *C-V* curves of the Schottky structures. The slope of these *C-V* curves was changed after irradiation with the dependence on the particular dose. The higher dose, the “worse” slope of the *C-V* curves. On the other hand, the reciprocal dependence between the shape of the *C-V* curves and corresponding value of dose was not observed.

It was observed a standard difference between C_{max} and C_{min} value of the *C-V* curves at the 1MHz measuring signal. The doping profile of free charge carriers was calculated from the *C-V* curve (Fig. 2). No significant dependence was indicated between the dose magnitude and the change of the doping profile n(x), as can be seen in Fig.2. Neglecting some side conditions within the calculation formula the measured samples showed the homogeneous profile of shallow impurities n(x) ÷ $1{,}6\times10^{22}$ m^{-3}. From the data of the capacitance measurement was calculated the value of Schottky barrier, $V_{bi} = 0{,}57$ V.

The results of current- voltage measurement are illustrated in Fig.3.

It can be seen a relatively large current in the reverse direction compared to forward one on the current-voltage characteristics. Probably it is due to some effects which can be summarized as follow: technological processes quality of the Schottky structure preparation, influence of the surface traps and influence of the edge effects on the leakage current.

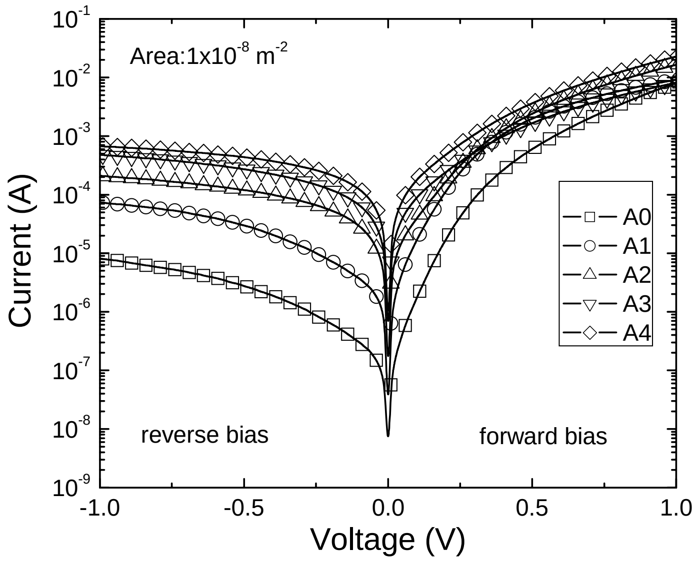

Fig. 3 *The forward and reverse I-V measured curves of the Schottky structures.*

From the point of view our experiment it was relevant to analyze the effect of the radiation-induced defects on a character of the current flow through the Schottky barrier in a forward direction.

It is evident from our experimental results that from point of view the preparation of Schottky contact on the high doped Si n-type substrate it was prepared the acceptable barrier structure quality with the AgCa gate which can be applied for silicon technology.

In the first step of the *I-V* curves forms evaluation it can be confirmed that introduction of the high energy electrons radiation-induced defects increases the current value in a reverse direction. With an increase in the value of the radiation dose increases the value of the forward current.

The total forward current flowing through the Schottky barrier consists of the thermo-emission part of current I_{te}, generation-recombination part of current I_{gr}, tunneling current I_t and leakage part of current, which is influenced by the series resistant R_s and the resistant R_L, which represents some inhomogenity and interface traps.

The total current through the Schottky barrier can be expressed as follow:

$$I = \sum_{i=1}^{4} I_i = I_{teo}\left[\exp\left(\frac{q(V_a - IR_s)}{kT}\right) - 1\right] + I_{gro}\left[\exp\left(\frac{q(V_a - IR_s)}{2kT}\right) - 1\right] + I_{to}\left[\exp\left(\frac{q(V_a - IR_s)}{E_0}\right) - 1\right] + \frac{V_a - IR_s}{R_L} \tag{3.1}$$

Comparing the shape of the *I-V* dependence of the unexposed sample A0 (see Fig.4) in forward direction it can be seen the linear tendency of the dominant thermo-emission part of current at the lower voltage values. Provided that exists only the termo-emission part of current (ideality factor n=1), the contact potential reached the value of V_{bi} = 0,65 V.

The linear shape of current is not stable and changes with the increase in radiation-induced defects. It is influenced mainly by an increase of the current parts I_{gr} and I_t (Fig.5).

By means of the analysis of particular flow processes of the charge carriers and total form of the current I_{tot} results that the tunneling process prevails and it is a dominant process which is responsible for the increase in the forward current value at lower voltages.

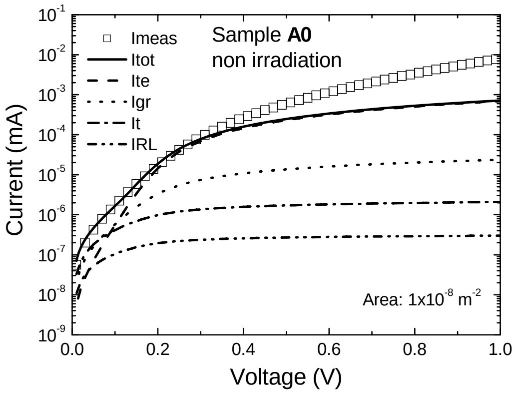

Fig.4 *Simulation of the I-V curve of not irradiated sample*

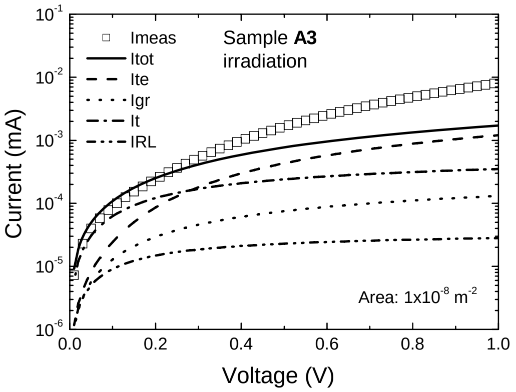

Fig.5 *Simulation of the I-V curve of irradiated sample*

Increase in the deviation value of the simulated current flow versus the measured current at the forward applied voltage V_a > 0,4 V (see Fig.4 and Fig.5) is due to the used model which does not reflect some real measurement conditions. These ones are connected with the prevalent negative edge effects of the leakage current.

4. Conclusion

The Schottky diodes with the silicon substrates were used to analyze the effect of 5 MeV electrons irradiation producing the radiation-induced defects.

The original access to the Schottky barrier preparation with the Ca gate on the n-type silicon was applied. Thereby, were formed a very proper conditions to the investigation of the effect of electron irradiation and radiation induced defects on some electrical parameters of the Schottky diodes.

The shapes of the capacitance-voltage *C-V* a current-voltage *I-V* curves were significantly changed under increasing in the value of radiation dose. By means of the simulation of the Schottky current flow processes was observed the dominant influence of charge carriers tunneling caused by the radiation-induced defects.

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