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Effect of pressure on the characteristics of Schottky barrier diodes made of overcompensated semiconductor

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Abstract. We studied the effect of uniform compression on characteristics of Au–*n*-Si Schottky barrier diodes made of overcompensated semiconductor. It is shown that overcompensation is caused by formation of structural defects owing to thermal treatment of the initial silicon wafers.

Keywords: Schottky barrier diode, overcompensated semiconductor, structural defect.

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1. Introduction

The metal–semiconductor structures (Schottky barrier diodes, SBDs) are extensively used in microelectronics, both as separate devices and components of most of the modern semiconductor devices and integrated circuits [1]. At the same time, the discrete SBDs serve as convenient object to investigate how the properties of semiconductor materials vary under external actions [2-5]. This is due to relative easiness of diode fabrication and unambiguity in interpretation of results.

Here we present the results of experimental investigation of the pressure effect on characteristics of SBDs made of overcompensated semiconductor.

2. Objects and methods of investigation

The initial material was crystalline *n*-silicon КЭФ-200 of crystallographic orientation ⟨100⟩. The wafers were subjected to thermal treatment at the temperature 1250 °C for 2 hours followed with rapid cooling (>200 °C/min). The SBDs to be studied were made using vacuum deposition of gold onto the silicon wafer surface. The metal contact area was $7.1\times10^{-2}\,\text{cm}^2$. Some diodes were subjected to uniform compression (pressure up to 4 kbar) using a plant “Гидростат” ЛГ – 16 .

3. Results and discussion

The variation of diode parameters was monitored by measuring dark $C-V$ curves that were measured with the bridge compensation method at a frequency of 150 kHz. The diode temperature was stabilized in the course of measurements with the accuracy better than 0.5 °C.

The measurements showed that the diode capacitance depended only weakly on the voltage applied and decreased to the value of geometrical one, C_g, at cooling down to −80 °C. Shown in Fig. 1 are the temperature dependences of capacitance (*1*) and conductance (*2*) for a diode measured using parallel equivalent circuit at the reverse voltage 4 V. According to the theory [6-8], such a behavior of capacitance and presence of a peak in the temperature dependence of diode conductance indicate overcompensation of the diode base region. In this case, the interrelation $N_a > N_m$ between the concentrations of deep acceptor centers, N_a, and shallow donor centers, N_m, is obeyed.

By using the assumptions proposed in [6] and the equivalent circuit of diode made of an overcompensated semiconductor [8], one can obtain the following expression:

$$1.15\lg A = 2.3\lg\left(\frac{\omega\varepsilon d}{q\mu_n N_m}\right) + \frac{E_c - E_a}{kT}. \quad (1)$$

Here $A = \left(C^{-1} - C_b^{-1}\right)/\left(C_g^{-1} - C^{-1}\right)$, C is the capacitance measured, $C_b(C_g)$ – diode barrier (geometrical) capacitance, E_c – energy of the conduction band bottom, E_a – activation energy for compensating impurity, ω – cyclic frequency, ε – semiconductor permittivity, μ_n – majority charge carrier mobility and d – non-dimensional parameter.

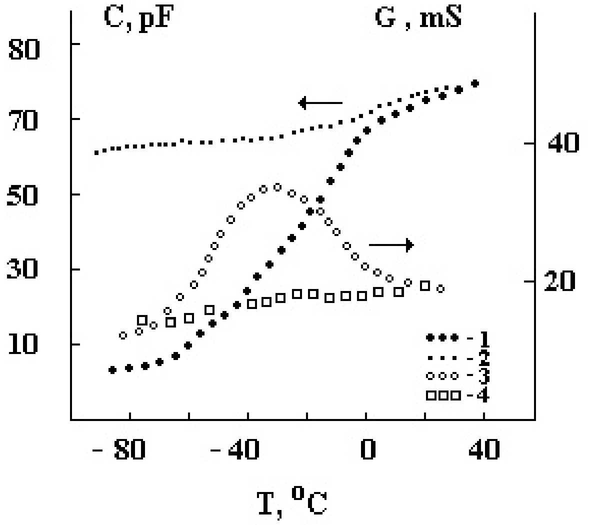

Fig. 1. Temperature dependences of capacitance (*1*) and conductance (*2*) for an SBD before (*1*, *2*) and after (*3*, *4*) action of pressure.

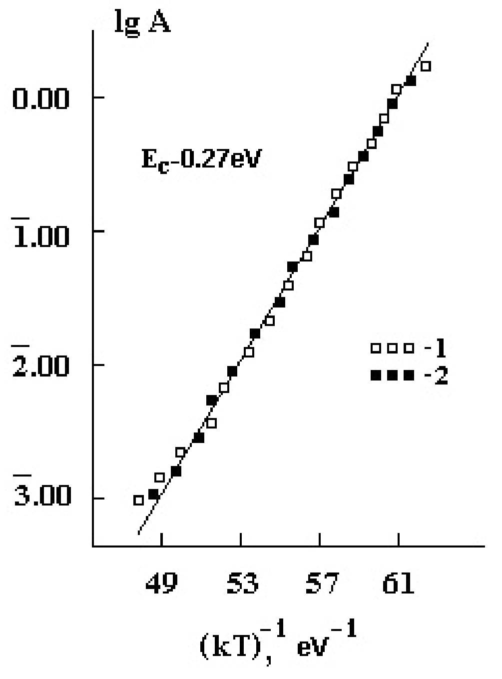

Fig. 2. Temperature dependence of the parameter *A* for two (*1*, *2*) SBDs. The full curve is similar dependence according to [7].

Disregarding the temperature dependence of the parameter $(\omega\tau_0 d)$ (i.e., temperature dependence of the majority charge carrier mobility), one can determine the activation energy for compensating deep centers from the tangent of the curve (*1*) slope. Shown in Fig. 2 are the temperature dependences of the parameter *A* for two of the diodes studied. The energy level of the compensating center determined from the above temperature dependences is (E_c–0.27) ± 0.03 eV.

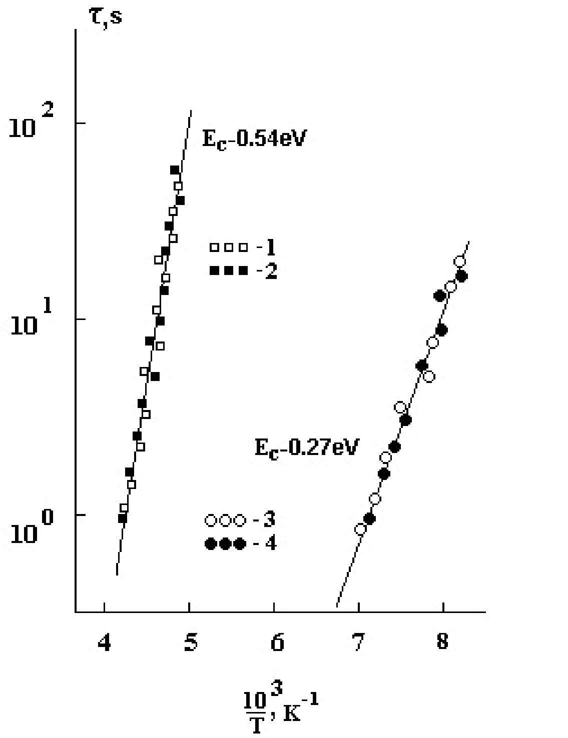

Fig. 3. Temperature dependences of the time constant of relaxation for two (*1*, *3* and *2*, *4*) SBDs subjected to the pressure 4 kbar. The full curves are $\tau(T)$ dependences according to [7].

All the diodes that have been subjected to uniform compression (pressure up to 1–4 kbar, interval of 1 kbar, held for 10 min in each interval) demonstrated weakening of temperature dependence of capacitance and progressive smoothing of the peak in the temperature dependence of conductance. As the pressure grew up to 4 kbar, the temperature dependence of capacitance became comparable with that of diffusion potential (see Fig. 1, curves 3 and 4). Such behavior of the diode capacitance indicates removal of compensation and breaking of the condition $N_m > N_a$. The check measurements using the method of isothermic capacitance relaxation [8, 9] (that can be applied if $N_m > N_a$) showed that recharge of deep levels with energy values (E_c–0.27) ± 0.03 eV and (E_c–0.54) ± 0.03 eV occurs in the diodes that have been subjected to action of 4 kbar pressure. The temperature dependences of the time constant of relaxation for two SBDs subjected to the pressure 4 kbar are presented in Fig. 3. A comparison of the dependences obtained by us with those given in [7, 8] showed very good agreement, i.e., in [7, 8] as well as in our case recharge of identical [9] centers was observed.

4. Conclusions

Taking into account that the diodes described in [7] were made using boron diffusion while in our case the silicon wafers were subjected to similar thermal treatments only, one can draw the following conclusions. The centers that have been observed in our diodes are of the same nature as those described in [7, 8]. Action of pressure does not change the center structure: the capture cross-section for the majority charge carriers does not vary under action of pressure. This conclusion follows from the fact that the dependences $\tau(T)$ for diodes are the same at compensation as well as in its absence. Subjection to pressure leads to reduction of the center concentration only.

Action of pressure on the structures with impurity centers in the semiconductor bulk led to change of the impurity concentration profile [10]. We did not observe the above effect in our diodes. Therefore, one can conclude that the centers observed by us are structural defects of semiconductor that appear owing to its rapid cooling.

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