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Determination Of The Effect Of The Gradient Pressure Field On A Varicap-Based Schottky Diode

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ABSTRACT: The volt-farada dependence of a varicape made on the basis of a Schottky barrier subjected to comprehensive hydrostatic compression up to 6 kBar is considered, as well as capacitance variations from the voltage as the frequency increases from 44 Hz to 150 kHz. A strong dependence of the barrier parameters on the shape of the impurity distribution profile and on the applied pressure is shown. It is established that holding the varicap within 12 minutes under a pressure of 6 kBar leads to an increase in its sensitivity.

I. INTRODUCTION

In modern microelectronics, layered heterogeneous structures of the metal-insulator-semiconductor (MIS) type are widely used. They form the basis of most discrete semiconductor devices and integrated circuits. Therefore, the actual task of microelectronics is to improve the parameters and characteristics of semiconductor MIS devices and elements of integrated circuits.There are various ways to solve this problem, including improving methods for manufacturing dielectric films, improving the quality of the interface between a semiconductor and a dielectric film, using new, more promising materials that are suitable for use in thin-film state and making it possible to expand the functionality of instruments.

The most widely used dielectric in the manufacture of MIS structures is currently silicon dioxide, since it is the natural oxide of the semiconductor substrate, which forms the basis of most semiconductor devices and elements of integrated circuits. In modern devices of semiconductor microelectronics, the active instrument area is a very thin semiconductor layer, a near-surface region, or a boundary between two media.MIS structures are convenient test objects, both for controlling technological processes, and for elucidating the mechanisms of electronic processes occurring in the nearsurface layers of a semiconductor and a dielectric under various external influences [1].

One of such MIS devices as test objects are electric capacitors with a capacitance controlled by the applied voltage - varicaps [2,3].

Varicaps based ona MIS system can be used in electronic devices of the RF and microwave ranges [4] to control the frequency and phase of an alternating signal, as well as for frequency multiplication. At present, the basic element of microwave phase shifters is the p-i-n-diode [5]. The development of a varicap on the basis of the MIS system for these purposes provides the principal possibility of reducing the control power. Despite the wide variety of existing designs of varicaps based on Schottky diodes, p-n junctions, metal-insulator-semiconductor structures, each of them has various drawbacks and limitations.

II. DESCRIPTION AND RESULTS OF THE RESEARCH

When creating varicaps for more efficient operation, the condition of non-uniformity of the volt-farad characteristic [69] is necessary. To obtain a sufficiently large unevenness of the characteristic, a sharp profile of the impurity distribution concentration in the base region is used. A predetermined impurity concentration profile is obtained using epitaxial growth processes. However, it is known that a baric effect on both the original semiconductor substrate and the formed Schottky barrier leads to a change in the impurity distribution [10], which can be used in the manufacture of varicaps.

An important property of barrier capacitance of varicaps is its practical lack of inertia. The change in the barrier capacitance of a MIS structure with Schottky barriers with a change in the applied voltage is due to the displacement of the main charge carriers in the regions adjacent to the barrier layer. The rate of this process is very high, since the exchange-charge time in this case is determined by the Maxwell relaxation time $\tau_M = \frac{\varepsilon\varepsilon_0}{qn\mu}$ where is $\varepsilon\varepsilon_0$dielectric permeability, q is the electron charge, n is the electron concentration, and μ is their mobility. 10^{-14} s. For silicon, this value is approximately five times greater. For example, for GaAs, n = 10^{17} cm^{-3} This means that varicaps must remain operational even in the submillimeter range (at frequencies up to 10^{12}Hz higher) [11] In this paper we consider the current-voltage dependence of the Schottky barrier, for the case when the impurity concentration in a semiconductor substrate varies according to the law $\boldsymbol{n(x)=n_0/x^2+a}$

where $\boldsymbol{n_0}$ is the impurity concentration in the semiconductor at the interface with the metal, a is the constant, and x is the coordinate reckoned from the metal-semiconductor interface into the depth of the semiconductor. Using the Poisson equation and the dependence of the density of the space charge on x, we obtain:

$$\frac{d^2\varphi}{dx} = -\frac{en_0}{\varepsilon\varepsilon_0}\frac{1}{x^2+a^2} \qquad (1)$$

After integration over the coordinate, we have:

$$\frac{d\varphi}{dx} = -\frac{en_0}{\varepsilon\varepsilon_0}\frac{\arctan\left(\frac{x}{a}\right)}{a} + c_1 \qquad (2)$$

To find the constant in equation (2), we use the following boundary conditions

$$x = L, \frac{d\varphi}{dx} = 0, \qquad \varphi = 0; \quad x = 0, \ \varphi = \varphi_{K,} \frac{d\varphi}{dx} = 0,$$

where is the contact potential difference between the metal and the semiconductor. Using these boundary conditions, we get the value:

$$c_1 = -\frac{en_0}{\varepsilon\varepsilon_0}\frac{\arctan\left(\frac{L}{a}\right)}{a} \qquad (3)$$

Substituting expression (3) into equation (2), we obtain:

$$\frac{d\varphi}{dx} = -\frac{en_0}{\varepsilon\varepsilon_0}\frac{\arctan\left(\frac{x}{a}\right)}{a} + \frac{en_0}{\varepsilon\varepsilon_0}\frac{\arctan\left(\frac{L}{a}\right)}{a} \qquad (4)$$

After integrating expression (4) with respect to the coordinate, we have:

$$\varphi(x) = -\frac{en_0}{\varepsilon\varepsilon_0}\frac{x\cdot\arctan\left(\frac{L}{a}\right) - x\cdot\arctan\left(\frac{x}{a}\right)}{a} + \frac{en_0}{\varepsilon\varepsilon_0}\frac{\ln\left[1+\left(\frac{x^2}{a^2}\right)\right]}{2} + c_2 \qquad (5)$$

After determining the constant C_2

$$c_2 = -\frac{en_0}{\varepsilon\varepsilon_0}\frac{\ln\left[1+\left(\frac{L^2}{a^2}\right)\right]}{2} \qquad (6)$$

we have:

$$\varphi(x) = -\frac{en_0}{\varepsilon\varepsilon_0}\frac{x\cdot\arctan\left(\frac{L}{a}\right) - x\cdot\arctan\left(\frac{x}{a}\right)}{a} + \frac{en_0}{\varepsilon\varepsilon_0}\frac{\ln\left[1+\left(\frac{x^2}{a^2}\right)\right] - \ln\left[1+\left(\frac{L^2}{a^2}\right)\right]}{2} \qquad (7)$$

and then we find the depth of penetration of the electric field into the semiconductor

$$L = \left\{a\left[\exp\left(-\frac{2\varepsilon\varepsilon_0(\varphi_K+U)}{en_0}\right) - 1\right]\right\}^{\frac{1}{2}} \qquad (8)$$

It is seen from the expression obtained that the dependence L = L (U) differs significantly from that calculated for the uniform distribution of the impurity [6,7].

Considering the capacitance of the metal-semiconductor contact in the flat-capacitor approximation, we find the dependence of the capacity of the Schottky diode on the applied voltage (Figure 1) for different values of the parameter a ($2 \cdot 10^{-6}$, $4 \cdot 10^{-6}$, $6 \cdot 10^{-6}$, $8 \cdot 10^{-6}$).

From the dependence shown in Fig. 1, it can be seen that the calculated voltage-voltage characteristic constructed for an Schottky diode of the Au-nSi type varies greatly depending on the value of the parameter a. When creating a varicap, in order to increase the efficiency of their operation, the condition of unevenness of the volt-farad characteristic [8] is necessary.

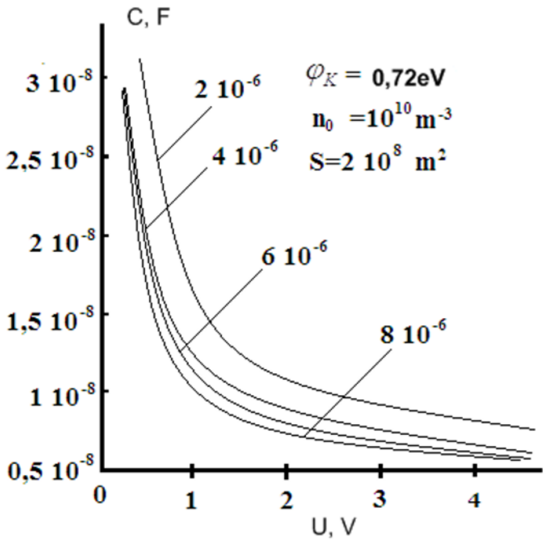

Fig.1. Calculated C-U dependences for the Schottky diode for various values of the parameter a

Indeed, one of the characteristic parameters of the varicap is its sensitivity:

$$S = \frac{dC}{C}\frac{U}{dU}\frac{1}{(n+2)} \qquad (9)$$

Here, n is the exponent in the expression $N(x) = N_0x_n$, which describes the impurity distribution over the thickness of the space-charge region of the semiconductor.

It is seen from the relation (9) that the larger the value of S, the greater the change in capacitance C under the applied alternating voltage U. Figure 2 shows the experimental volt-farad (averaged over 5 samples) dependences of a diode of the Au-nSi type made on the basis of a semiconductor n is the type of conductivity. The solid dependence corresponds to the calculated current-voltage characteristic given in Fig. 1 for the parameter $a = 8 \cdot 10^{-6}$.

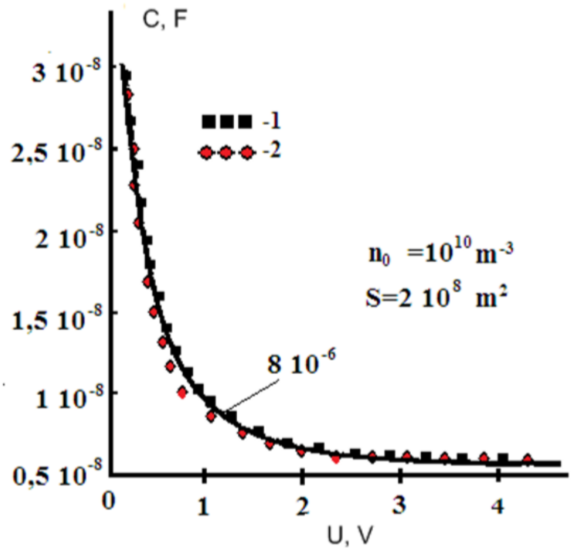

Fig.2. Experimental C-U dependences for the Schottky diode: 1- control diodes; 2 - diodes exposed to a pressure of 6 kBar

It can be seen that the experimental dependence (1) is in good agreement with the calculated dependence, which confirms the validity of the impurity distribution used in calculating the law. Dependence (2) corresponds to the structure subjected to the all-round compression at a pressure of 6 kBar with an exposure of 12 minutes.

It can be seen that after the action of the pressure, the voltage-voltage characteristic (in the applied voltage range 0.5-1.5 V) shifts to the left, which agrees well with the data of [10]. Such a shift in the characteristic leads to an increase in the value of dC / dU in this region and to an increase in the varicap sensitivity.

Then, using the method of isothermal relaxation of the capacitance, the concentration and energy spectrum of the deep centers were determined. It is established that in all Schottky barriers made on the basis of structures subjected to and not subjected to pressure, charge exchange of the center with an ionization energy of Ec-0.4-0.03 eV with a concentration of $Nr = 3 \times 10^{12}$ cm^{-3} is observed.Moreover, before the increase in the pressure, the concentration of the detected center changes insignificantly. Consequently, the observed changes in the varicap parameters are due to a decrease in the density of states localized at the semiconductor-glass interface. Figure 3 shows the frequency characteristics of the manufactured varicape, measured in the dark at a temperature of 21 ° C, subjected to a pressure of 4 kBar.

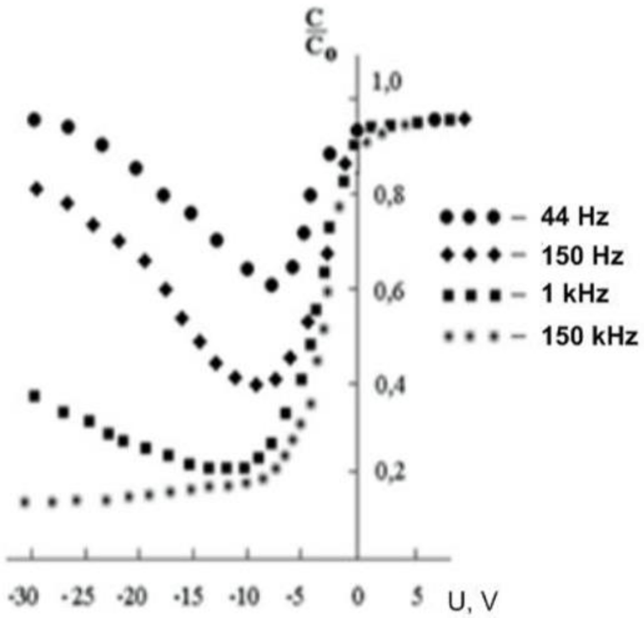

Fig. 3. Frequency characteristics of the manufactured varicap.

As can be seen, from Figure 3, the steepness of capacitance change from voltage as the frequency increases from 44Hz to 150kHz substantially increases and reaches a maximum value at 150 kHz. The operating voltage range is in the range from zero to 7 volts.

III. CONCLUSION

The dependences of the Schottky barrier capacity on the voltage for a gradient distribution of impurities in the base region are considered. It is shown that as the gradient increases, the steepness of the capacitance change - the varicap sensitivity increases. At the same time, under the influence of a comprehensive pressure, the sensitivity of the Schottky barrier also increases. In this case, the deformation causes a rearrangement of the defective structure of the interface between the Si-glass and a change in the spatial and energy distribution of the surface defects, which leads to an increase in the capacitance sensitivity to the voltage change.

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