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INVESTIGATION OF THE ROLE OF METAL IN NON-ALLOY METAL-SEMICONDUCTOR (Si) CONTACT

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Abstract. In the paper is shown that the metal is a more active partner in Schottky diodes (SD) based on metal-semiconductor contact (MSC) from the series of semiconductor devices. It is shown the structural inhomogeneity of the interface, as a result of which the MSC as a parallel connection of numerous subdiodes having different parameters. To reveal the inhomogeneity of the metal on the properties of the MSC, the dependence of the barrier height of Schottky diodes on the contact area was investigated. It was assumed that in the case of a contact of a single-crystal semiconductor with a polycrystalline metal, the degree of inhomogeneity and accordingly, the number of subcontacts grow with increasing area.

Keywords: *Metal-semiconductor contact, Schottky diodes, barrier height, interface, complex systems.*

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1. Introduction

In recent years, interest in stady of the Schottky diodes based on metal-semiconductor contact and electrophysical processes between metal and semiconductor has increased significantly (Bulyarskiy *et al.*, 2023; Ali *et al.*, 2020; Akın *et al.*, 2019; Askerov *et al.*, 2017). Thus, research and experimental results in the field of metal-semiconductor contact physics led to the development of the different approaches to this field. The most important feature of the contact boundary of the metal-semiconductor contact is its formation between the substrate and the thin layer (Sze, 1980; Sistani *et al.*, 2018; Patra *et al.*, 2017).

It is known that in almost all cases the real surface of metal layers has a granular structure and therefore the work function of the metal depends on the coordinates of the surface (for example, the maximum difference in output work for different points of the polycrystalline layer of pure wolfram reaches 1eV). The polycrystalline nature of the metal contact makes the contact boundary of the MSC non-uniform on the metal side. Such heterogeneity is due to various surface defects: dislocations and oxide layers of different thicknesses (Askerov, 2017; Hudait & Krupanidhi, 2001).

Another source of MSC homogenity is peripheral homogenity and homogenity resulting from physico-chemical processes occurring at the border of touch. In this regard, the study of the effect of various technological and design facts on the electrophysical

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properties of SD is of great scientific and practical importance (Afandiyeva *et al.*, 2018; Khannaa *et al.,* 2011; Cheng & Wang, 2009).

On the other hand, when the contact area is very small (in the order of the size of the metal layer), the probability of a non-uniform contact boundary increases.

The monocrystalline, amorphous or polycrystalline structure of the metal layer plays an important role in changing the contact properties and electrophysical parameters. It is known that it is more expedient to use single-crystal layered structures to obtain a quality diode with ideal properties. Diffusion transport in monocrystalline layers occurs even at very low temperatures. The creation of such a layer ensures the homogeneity of the tactile boundary. That is why the study of the properties of metal-semiconductor contacts with a single crystal metal layer, the study of their electrophysical properties is always relevant, of great scientific and practical importance. Significant advances have been made in the study of the electrophysical parameters of silicon diodes based on Schottky shielded metal-semiconductor contacts (Askerov *et al.,* 2018; Lu *et al.,* 2019; Lee *et al.,* 2019).

In Schottky diodes, the amorphous metal layer is often used to ensure uniformity of the touch boundary. This is due to the fact that it is technologically difficult to obtain a monocrystalline layer that creates a homogeneous touch boundary. When the metal layer has a polycrystalline structure, the touch boundary cannot be homogeneous (Sze, 1980; Askerov, 2017).

2. Materials and Methods

The contacts studied in the paper are made with planar technology used in the manufacture of small-field diodes and have different geometric dimensions within a matrix as a result of a single technological process. During the described technological process, 14 diodes (areas in the range of (($(1\div14)x10^{-6}cm^2$) were created on the chip (Figure 1).

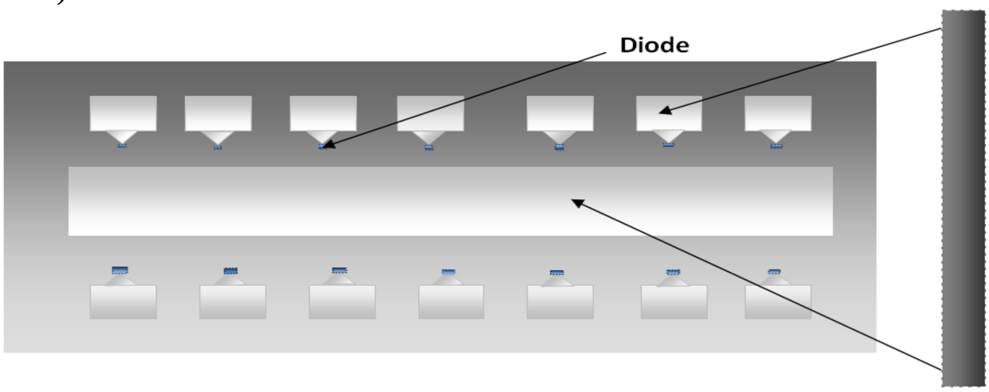

Figure 1. The structure of the fabricated chip

The choice of botton silicon (111) as a semiconductor bottom is due to the smaller output in this direction (110). On the other hand, there are deformed hexagonal voids in this direction of silicon. This, in turn, can affect the parameters of the metal-semiconductor contact-based device (for example, the presence of load-carrying mechanisms) (Sze, 1980; Askerov, 2017; Afandiyeva *et al.*, 2018).

From a technological point of view, the polycrystalline structural alloy by magnetron dusting has a granular structure and the processes occurring in small volumes

- microstructures testify to the existence of new properties From this point of view, one of the main tasks is to study the properties of Schottky diodes with a polycrystalline metal layer and to expand the field of application in modern instrumentation - radio engineering, microelectronics.

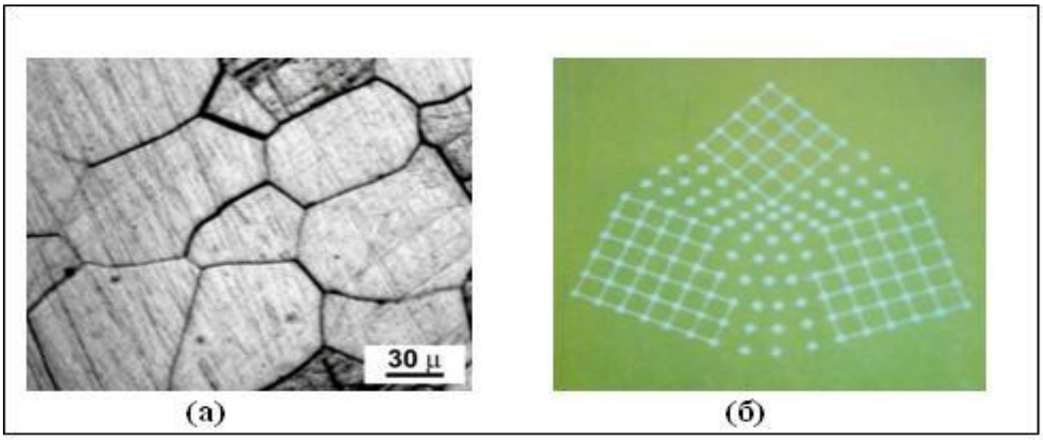

Figure 2. Microstructure of polycrystalline metal at micron (a) and atomic (b) levels

Aluminum and Al containing 1% Si were used to obtain the standard silisum of counting based on polycrystalline structural metal. Al, Al + 1% Si and subsequent processes lead to the creation of a polycrystalline structural layer. It remains the most common material for metallization of integrated circuits in a number of its convenient qualities: simplicity and convenience of applying a layer, the ability to form various images, high cross-country ability, good qualities, as well as simplicity and cheapness. The application of Si layer to the Si board was carried out by the method of sputtering the magnetron.

3. Experimental part

The article analyzes the results obtained during the study of polycrystalline metal layer Al-TiCu / n-Si and Al / n-Si Schottky diodes.

Al-TiCu / n-Si Schottky diodes were obtained by magnetron sputtering on single-crystal silicon wafers with phosphorus-added resistance $0{,}7\ Om \times cm$ and a thickness of 3.5 μm (111).

Two cathode-targets: titanium and Cu are used by magnetron sputtering to obtain the alloy from the layer. At this time, the vacuum pressure in the working chamber is in order of $10^{-4} Tor$. Ar gas was used as the working gas. The preheating temperature of the layer used as a substrate $(200 \div 250)C^{o}$, the heating time is (2÷3) minutes. Depending on the condensation conditions and the technological environment, the $Ti_x Cu_{100-x}$ alloy-layer is obtained in different structures. A sample for the formation of a thin metal layer alloy is prepared in a working-experimental chamber.

The mixture is obtained within three hundred seconds. A metal layer is created. Subsequently, it is required to improve the adhesion of the semiconductor layer and obtain a more uniform metal-semiconductor metal-semiconductor separation boundary within 300 seconds. For this, the sample is thermally processed in the working chamber when the temperature is $T=150^{0}C$.

Considering the sputtering coefficients of Ti and Cu the areas of copper and titanium in the total area of the target were calculated

$$\frac{N_{Ti}}{N_{Cu}} = \frac{9}{1}$$

After obtaining layers with different components, X-ray structural analysis was performed (Figure 3). As can be seen from the figure, only the $Ti_{0,5}Cu_{0,5}$ alloy layer has an amorphous structure, while the remaining layers have a polycrystalline structure.

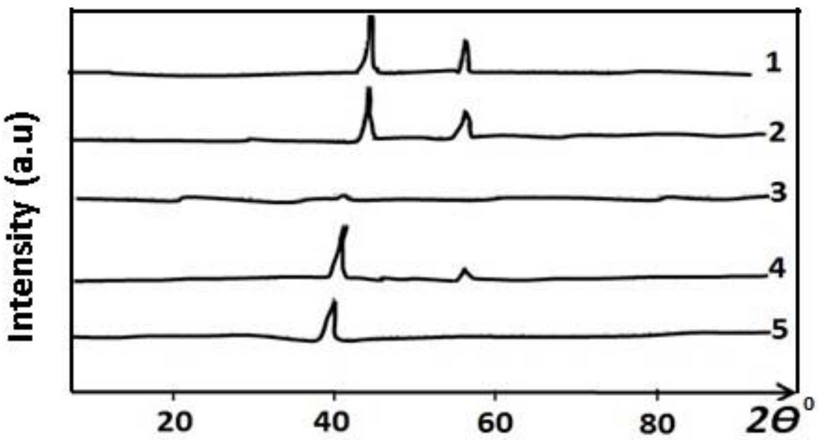

Figure 3. X-ray of Ti_xCu_{1-x} alloy
1- x=0,1; **2**- x=0,3; **3**- x=0,5; **4**- x=0,91; **5**- x=1

This conclusion is based on the clear expression of the series of maxima and minima in the crystals. This means that in addition to the correct arrangement of nearby atoms, we can also talk about the existence of a distant order. Thus, it is possible to draw coordinates in crystals in such a way that the distance between the atoms is much larger than the size of the elementary nucleus.

It is possible to assume that in the case of MSC microstructural diversity of metal plays an important role in the processes occurring in contact. As shown in previous works, in the case of MSC can be represented as a parallel connection of many discrete discrete contacts (Cheng & Wang, 2009; Eshqurbonov & Safarova, 2023; Asadullayeva *et al.*, 2023).

It is not difficult to state that in this case the behavior of the contact should depend on the number of parallel subcontacts, as well as on their individual parameters.

In the case of a two-diode contact, according to (Askerov *et al.*, 2020) the height of the barrier is expressed by the formula:

$$\overline{\Phi} = \frac{\Phi_1 S_1 + \Phi_2 S_2}{S_1 + S_2} = \omega_1 \Phi_1 + \omega_2 \Phi_2 = \sum_{i=1}^{n} \omega_i \Phi_i.$$

Here $\overline{\Phi}$ is a surface-averaged barrier height; Φ_1 and S_1 the height of the barrier and the area of the first and Φ_2 and S_2 is the height of the barrier and the area of the second diode; ω_1 and ω_2 are relative areas of the subdiodes, correspondingly. As can be seen from formula, the height of the barrier of the inhomogeneous contact $\overline{\Phi}$ depends on the relative area of the sub-diodes and their height of the barriers.

4. Results and Discussion

To check the validity of this assumption, the dependence of the barrier height of Al-n/ Si (111) of the Schottky diodes on the contact area (Askerov, 2017; Askerov *et al.*, 2018), which is shown in Figure 4, was studied. As can be seen from the figure, with an increase in the area of the diodes, the barrier heights Φ_B grow. Obviously, with an increase in the contact area, the number of subdiodes that form a common contact and have different parameters increases.

It seems that the polycrystallinity of the metal changes the homogeneous contact into the inhomogeneous one. The presence of the dependence $\Phi_B(S)$ indirectly proves the influence of the metal microstructure on the properties of the Schottky diodes. We believe that with an increase in the area of the diodes, the complexity of the system increases.

Therefore, the properties of the inhomogeneous contact should be very different from the properties of a homogeneous one, as follows from the theory of complex systems (Loskutov & Mikhailov, 2007; Holovatch *et al.,* 2017; Askerov *et al.,* 2020). According to that theory, each interface of the MSC is individual with its own non-repeatable parameters. So, there are no two identical Schottky diodes made of a specific metal and semiconductor.

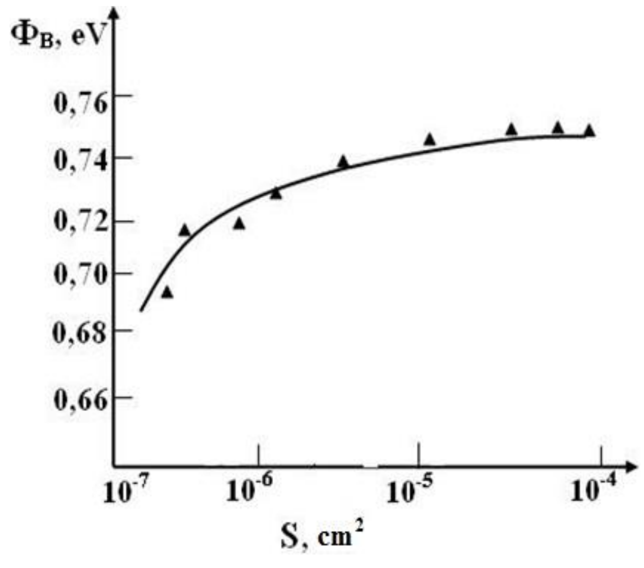

Figure 4. Dependence of the height of the Al-n Si (111) of the Schottky diodes barrier on the contact area

The role of the metal in the operation of the Schottky diode is revealed and it is shown that metal is the more active partner of the MSC than a semiconductor. The reason for the discrepancy between the values of the barrier height of the same diode structures, obtained by different authors, is explained by the structural diversity of the interface. Each interface of a specific metal with a specific semiconductor is individual and unique.

It is concluded that the observed dependence $\Phi_B(S)$ is the effect of the inhomogeneity of the interface initiated by the metal partner of the metal-semiconductor contact. The results obtained are explained from the standpoint of the inhomogeneous MSC model, which represents the contact as a complex system, consisting of the parallel connection of numerous elementary, discrete and homogeneous contacts.

5. Conclusion

The micro-contacts of the real MSC are in the electrical contact and electrical interaction with each other. The study and analysis of the electrophysical properties of real MSC, consisting of a set of micro-contacts with certain geometric dimensions, parallel joints and the height of potential fences with different electrical interactions, is quite interesting and relevant.

The result of this work is to determine the activity of the metal by physical and chemical processes occurring at the contact boundary of metal-semiconductor contacts.

In this work, the Schottky diode is considered as a complex system and the results obtained are discussed in the light of the theory of the complex system.

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