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Original article

Some features of the thermoelectric properties of the “metal-carbon film” junction

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ABSTRACT Carbon films were obtained by magnetron sputtering of graphite in an argon atmosphere on various metal substrates. As a result, a “metal-semiconductor” junction is formed due to the fact that the temperature dependence of the film resistance is of a semiconductor nature. The current-voltage characteristics of the junction were studied at various ambient temperatures, and the degradation of its electrical properties over time was discovered.

KEYWORDS carbon films, metal-semiconductor contact, thermoelectric properties

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1. Introduction

The development of electronics is accompanied by creation of new technologies and semiconductor materials that can increase the efficiency and reliability of electronic devices. Recently, semiconductor carbon materials have been actively studied [1–4], which often have more outstanding properties than classical semiconductors and are of interest as materials for micro- and nanoelectronic products. Although silicon and gallium arsenide still remain the dominant semiconductor materials, the traditional silicon platform no longer meets many modern requirements, and increasingly, researchers are citing carbon as a potential replacement in certain niches. Due to the huge variety of allotropic forms (for example, graphene and similar structures), this material has considerable potential of applications in many fields, but it is of particular interest for electronics due to the higher mobility and, consequently, high speed, of charge carriers. Allotropic modifications differ by the structure of their crystal lattices, which affect the conductive properties of the material. For example, sp^2-hybridized carbon conducts electricity well, but sp^3-hybridized carbon does not. Therefore, depending on the ratio of carbon atoms with different types of hybridization, electrical properties can vary from semi-metallic (like graphite) to dielectric (like diamond). Thus, under certain conditions, carbon combines dielectric, conductor and semiconductor properties. It makes this material unique. Many researchers predict the possibility of implementing the idea of all-carbon high-speed nanoelectronics in the future [4, 5].

IT is known that the oldest practical semiconductor device is a metal-semiconductor contact. Such contact junctions are widely used in electronics and have the unique properties that allow one to create efficient devices and instruments. However, the mechanisms of current transfer in such structures remain incompletely studied, and, for example, it is not clear due to which reason, the Schottky barrier irreversibly transforms into an ohmic contact [6]. In connection with the above, a rather urgent task is to study the metal-carbon transition (where carbon exhibits semiconductor properties), which can demonstrate interesting contact phenomena.

This work examines some of the electrical properties of such a contact junction depending on the ambient temperature, as well as changes in such properties over time.

2. Experimental technique

Samples for the research were obtained by magnetron sputtering of graphite in an argon atmosphere. Carbon films were deposited on substrates made of dielectric (cover glass) and various metals (titanium, steel, niobium, etc.) [7]. Plasma was created using a planar DC magnetron with a flat cathode and an annular anode. The conditions for deposition of samples on all types of substrates were the same: the gas pressure in the chamber was 150 mTorr, the film growth time was 40 min, the substrate temperature was 350°C, and the magnetron current was 40 mA.

The electrical properties of the obtained samples were studied using the resistometric method in a heat chamber in the range from ∼20°C to 150°C. To eliminate the influence of a highly conductive metal substrate the transverse conductivity was measured using a two-probe method in films deposited on a glass substrate. Longitudinal conductivity (along the direction of the film growth) was measured at the contact junction in the “metal substrate–carbon film–measuring contact” structure. The temperature dependences of the carbon films resistance and the current-voltage characteristics (CVC) of the “metal-carbon film” contact transition at different temperatures were studied. To study the processes of temporary degradation of the contact junction, the current-voltage characteristics of the samples were remeasured 15–20 months after the samples were obtained, in order to evaluate changes in the characteristics.

3. Main results and discussion

As shown in [7], the temperature dependence of film resistance has classical semiconductor character - the resistance decreases with the temperature increasing. Thus, it is obvious that as a result of the work, the "metal-semiconductor" contact junction was obtained (where the semiconductor is the carbon film), which is the subject of this study. Let us consider some features of such contacts at different temperatures.

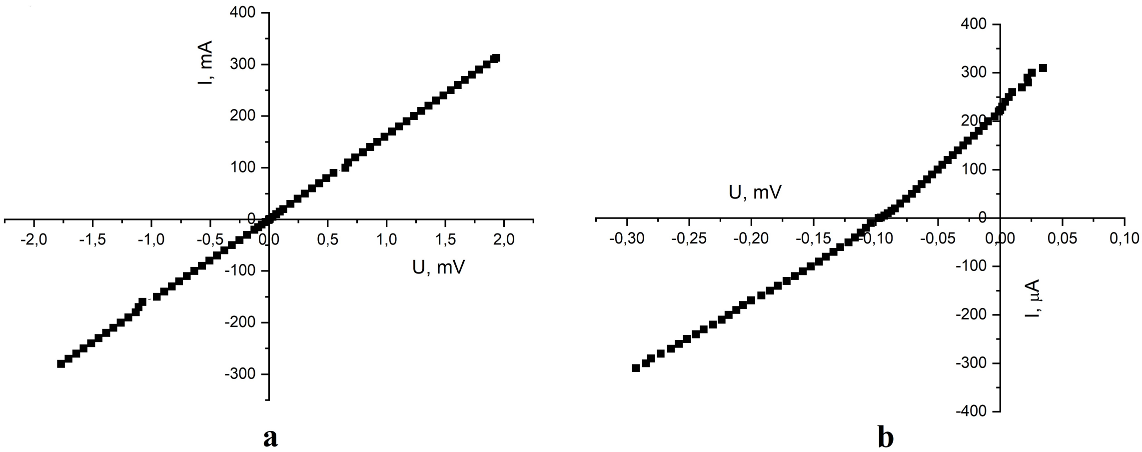

FIG. 1. Current-voltage characteristics of the "niobium-carbon" contact at room temperature (a) and when heated to 100°C (b)

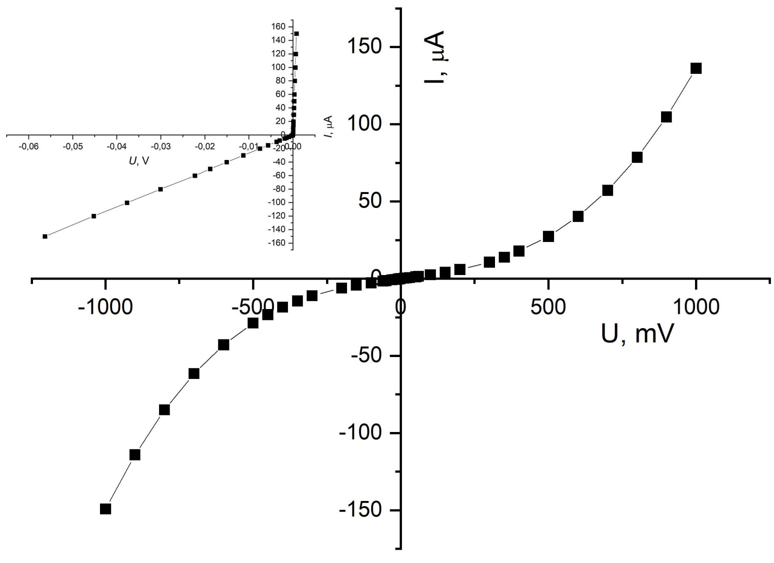

FIG. 2. Current-voltage characteristics of the titanium-carbon contact after 18 months from the moment the sample was obtained (the inset shows the original sample CVC)

Fig. 1 shows the current-voltage characteristics of the "niobium-carbon" contact at room temperature and under heating. It can be seen that the current-voltage characteristics have a symmetrical linear dependence, characteristic for ohmic contact. It is known that in such contacts, there are electric fields caused by the contact potential difference between the materials (which differ by the value of the work function) that make up the junction. The potential distribution in the semiconductor material of the "metal-semiconductor" contact can influence significantly on the current-voltage characteristics and current flow mechanisms of such junctions. In particular, in Fig. 1(b), a small contact potential difference is observed when the junction is heated to 100°C. This property may be interesting in some applied fields, correspondingly, further researches in this direction are perspective.

The current-voltage characteristics of titanium-carbon contact junction obtained some time ago (more than a year) were also re-examined. The initial contact transition, as shown in [7], demonstrated an asymmetrical nonlinear current-voltage characteristics (see inset in Fig. 2) and had the rectifying properties of a "metal-semiconductor" junction with a potential Schottky barrier, which goes into the open state at very low voltage values (about tens of microvolts). From Fig. 2, it is clear that the current-voltage characteristics of the same junction, approximately 18 months after the initial measurements, is noticeably different and has a symmetrical nonlinear dependence (also characteristic for ohmic contact). Thus, certain degradation processes have been detected in the material over time (probably due to the adsorption of atmospheric gases into the carbon film structure). As a result, the structure with a rectifying Schottky barrier undergoes irreversible changes and goes into ohmic contact (see also [6, 8]).

4. Conclusion

Studies of the thermoelectric properties of metal-carbon film junctions demonstrate a dependence characteristic for ohmic contact and the presence of a contact potential difference when the junction is heated. It is also shown that over time, the electrical characteristics and parameters of such contacts can change: the junction with the Schottky barrier degrades and the rectifying properties observed earlier disappear.

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Conflict of interest: the authors declare no conflict of interest.