INFLUENCE OF SCANDIUM ON THE EMISSIVE PROPERTIES OF SILICON AUTOEMITTERS

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We study the influence of scandium (Sc) on the emissive properties of the matrix of silicon Si autoemitters in superhigh vacuum. It is shown that the presence of Sc affects significantly the absolute value of the emission current and its stability in time. Moreover, this influence can be positive or negative depending on the amount of Sc on the surface. The results of experimental studies testify to the existence of an optimum of the amount of Sc on the specimen surface under study which is characterized by a maximum emissive ability and a high stability of the emission current. The growth of the emissive ability of Si autoemitters in the presence of Sc is explained by the creation of a complex chemical compound on their surface, which favors a decrease in the total work function of a specimen.

1. Introduction

The technology using the phenomenon of a field or cold emission is one of the promising methods to visualize the information and attracts a great attention in the world [1—4]. The mechanism of the creation of images in devices of such a type is somewhat similar to that in devices constructed on the basis of cathode-ray tubes (CRTs). In both cases, the image is formed by a layer covered by a luminophor that fluoresces under the action of an electron beam. The main difference consists in the method of derivation of this electron beam. In CRTs, three heated cathodes forming three beams of electrons which successively scan a panel covered by a luminophor layer are used. As for the devices on the basis of the field emission, they contain a great number of electron sources (several thousands) that are located behind each element of the screen, and each element is controlled independently of others.

Due to the specific features of the phenomenon underlying the basis of the operation of devices of such a type, their main advantages are significantly smaller geometric sizes and the lower energy consumption as compared to those of CRTs. The advantages include also the absence of a flickering and a distortion of images.

The main element of devices on the basis of the field emission phenomenon is a field emitter or autoemitter. Its parameters (a material and a composition of the surface, the autoemission current density, working voltage, and the resistance to poor vacuum conditions) define the resulting characteristics of a ready-made device (the resolving power, brightness, contrast, etc.). Therefore, a lot of studies, whose goal is the optimization of the above-mentioned parameters of autoemitters, is carried out in the world.

In this work, we present the results of studies of the dependence of the emissive ability of Si autoemitters on the amount of Sc sprayed on their surface. The choice of namely Sc is conditioned, first, by its wide utilization for the improvement of the emissive characteristics of powerful thermoemitters (in particular, dispensing ones [5—7]). Secondly, the Sc—O/W system attracts the enhanced attention now from the side of researchers, because it is very perspective as a Schottky emitter [8—10].

2. Experimental Procedure

The experimental studies were performed in the working chamber of a high-vacuum setup with oil-free evacuation.

The pressure of residual gases in a chamber was measured with the help of an ionization vacuometer VI-14 with a Bayard—Alpert manometric transformer and was at most 5×10^{-9} Torr during the experiment.

The positioning of a specimen was realized with the help of a high-vacuum manipulator with four degrees of freedom.

In the studies, we used a matrix of autoemitters that was produced from boron-alloyed silicon (ρ=1 Ω/cm) by the method of plasmochemical etching. The matrix was 5×5 mm in size and contained about 2.5×10^5 autoemitters. Each emitter had the form of a tetragonal pyramid with edges of the base of 10 μm in length. The curvature radius of a tip was $\sim$ 10 nm. To perform the high-temperature purification of the matrix surface from contaminants, we positioned the matrix on a resistive heater.

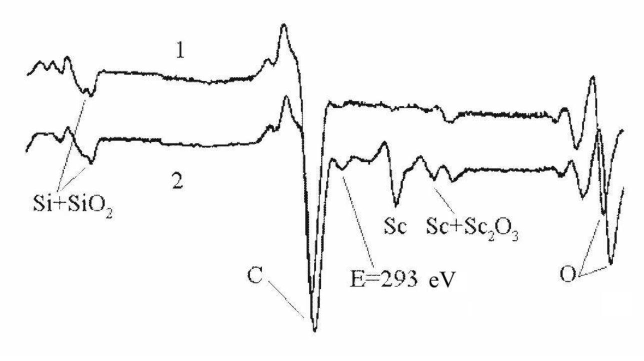

Fig. 1. Auger-spectra corresponding to the specimen surface prior to the spraying of Sc (*1*) and after the spraying of 1/12 ML of Sc (*2*)

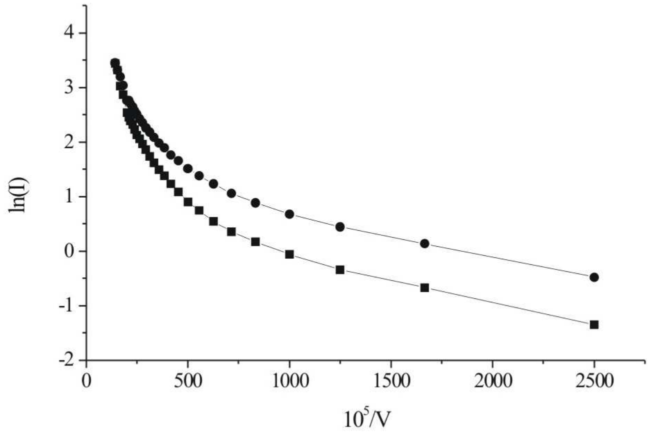

Fig. 2. VACs of the specimen without Sc and with sprayed Sc

In the analysis of the composition of the specimen surface, we applied a serial Auger-spectrometer 09 IOS-3 with an analyzer of the "cylindrical mirror" type. During the study, the surface of specimens was observed on a TV display, and we were able to choose the necessary sections for our studies.

The deposition of Sc on the specimen surface was carried out by a molecular beam emitted by a relevant source in the form of a tube which was made of a refractory metal and filled by metallic Sc. The source of Sc was heated by the electron bombardment.

Before the start of the experiment, the source of Sc was calibrated with the purpose to determine the duration of the spraying of a monolayer (ML). The calibration consisted in the gradual spraying of Sc on the surface of a tungsten monocrystal [edge (110)] with the further recording of Auger-spectra and the measurement of a change in the work function of such a system by the method of contact potential difference (CPD) in the Andersen version.

The volt-ampere characteristics (VAC) of a specimen were measured in the stationary mode in the diode system with a plane anode. The anode was produced of Mo, had 2×2 cm in size, and was degassed by the electron bombardment prior to the measurement of each characteristic. The distance between the specimen and the anode was 1 mm in the course of studies. Thus, the electric field strength near the specimen surface was $4\times10^5 - 7\times10^6$ V/cm, according to our estimates.

3. Results of Studies and Their Discussion

Upon the execution of the experimental studies, Sc was successively deposited on the specimen surface by 1/12 ML.

In Fig. 1, we present two successively recorded Auger-spectra which illustrate a change in the composition of the specimen surface after the spraying of 1/12 ML of Sc. It is seen that the Auger-lines appear in the spectrum which correspond to the main transition in a Sc atom (E=336 eV), the transition with participation of valence band electrons (E=363 eV), and the interatomic transition in Sc oxide (E=357 eV). In addition, it is clearly seen that the main Auger-lines which are characteristic of oxygen (E=504 eV) and carbon (E=272 eV) changed their energy position by 7 and 3 eV, respectively, and the Auger-line with the energy E = 293 eV appeared. In this case, the positions of the Auger-lines characteristic of Si oxide (E=83 eV) and pure Si (E=93 eV) remained practically the same. Such a behavior of the Auger- lines of oxygen and carbon in the presence of Sc can testify to the formation of a complex chemical compound with participation of Sc, C, and O on the specimen surface. In Fig. 2, we give the VAC corresponding to this composition of the surface in the Fowler—Nordheim coordinates.

The derived results allow us to assume that the creation of a complex multicomponent compound on the specimen surface, which leads to a decrease in the total work function of the system, can be a reason for the increase in the emission current upon the spraying of 1/12 ML of Sc.

The further spraying of Sc was performed also by 1/12 ML.

We can qualitatively explain the course of VACs at the given strengths of the electric field by assuming that the autoemission occurs from the conduction band without degeneration of the semiconductor [12]. At the same time, it is worth noting that this assumption is

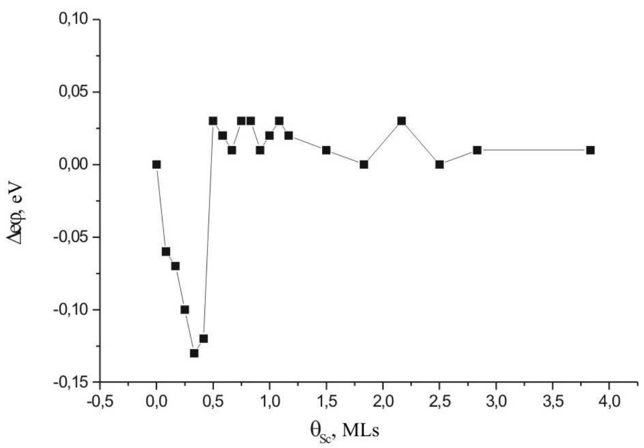

Fig. 3. Absolute change of the work function of the autocathodes—Sc system versus the amount of Sc

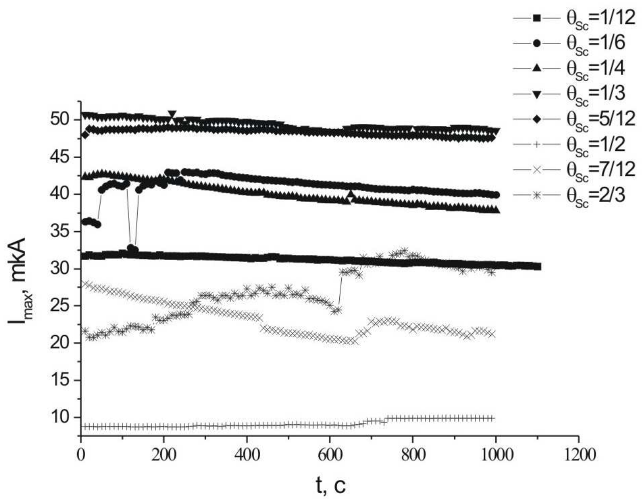

Fig. 4. Stability of the maximum autoemissive current of specimens as a function of the amount of Sc on their surfaces versus time

not correct upon a significant increase in the electric field strength. Therefore, in the further analysis, we carried out the numerical calculations of a change in the work function of the autocathodes—Sc system by using only the low-field sections of real VACs of the specimens in the frame of the Fowler—Nordheim theory of autoelectronic emission.

The calculation was carried out with the use of the Fowler—Nordheim relation

$$j = \frac{e^3E^2}{8\pi h\varphi t^2\left(y\right)} \times \exp\left\{-\frac{8\pi\sqrt{2m}\varphi^{3/2}}{3heE}\nu\left(y\right)\right\}, \qquad (1)$$

where φ is the work function of electrons, and $\nu(y)$ and $t(y)$ are the elliptic Nordheim functions of the argument $y = \sqrt{e^3E}/\varphi$ [11]. In a certain approximation, we present the Nordheim functions as

$$t^2\left(y\right) = 1.1, \nu\left(y\right) = 0.95 - y^2. \qquad (2)$$

This leads to a considerable simplification of relation (1):

$$j = C_1 \times \frac{E^2}{\varphi} \times \exp\left\{\frac{C_2}{\sqrt{\varphi}}\right\} \times \exp\left\{-\frac{C_3\varphi^{3/2}}{E}\right\}, \qquad (3)$$

where j is the autoemission current density (A/cm^2), E is the electric field strength (V/cm), φ is the work function of electrons (eV), and C_1=1.5×10$^{-6}\Omega^{-1}$, C_2=10.4 V$^{1/2}$, C_3=6.44×10^7 V$^{-1/2}\cdot$ cm^{-1} are constants. In the calculations, we took into account the dependence of the work function on the electric field strength at the expense of the Schottky effect:

$$\varphi = \varphi_0 - C_4\sqrt{E}, \qquad (4)$$

where C_4=3.79×10^4 V$^{1/2}\cdot$cm$^{1/2}$ is a constant, and φ_0 is the value of the work function for the matrix of Si autoemitters in the zero external electric field. It was measured by the method of CPD and is equal to 5.05 eV.

The calculated behavior of the absolute change of the work function is presented in Fig. 3.

As seen in Fig. 3, the greatest change in the work function of the system under study (0.15 eV) is observed, when the amount of Sc on the surface is equal to 1/3 ML. The absolute value of the work function of the specimen for such a coating by Sc, namely 4.9 eV, supported our assumption that electrons are emitted from the conduction band under a small (∼ 0.5 eV) deflection of the bands.

The nonmonotonous behavior of this dependence indicates that Sc affects actively the emissive ability of Si autocathodes. But, depending on its amount, this element can improve or deteriorate the emissive ability. In addition, it is seen that there exists the optimum of the amount of Sc which is characterized by a high absolute value of the emission current.

We carried out the additional studies of the stability of the emission current of the specimens as a function of the amount of Sc on their surface (Fig. 4).

The comparative analysis of the derived results showed that the best stability of the emission current in time at an anodic voltage of at most 700 V is observed for the amounts of Sc on the specimen surface which correspond to the optimum.

4. Conclusions

In view of the derived experimental results concerning the influence of Sc on the emissive properties of Si autocathodes, we may state that

— Sc affects actively the emissive ability of Si autocathodes and can increase or decrease the activity of the cathodes, which depends on its amount on the specimen surface;

— there exists the optimum of the activity of autocathodes, which is characterized by a high emission current and a high stability of the current in time at a constant anodic voltage, as a function of the amount of Sc on their surfaces;

— the growth of the emission current of Si autocathodes in the presence of Sc is explained by the creation of a complex multicomponent compound on the basis of the oxides of Sc and Si on their surfaces, which favors a decrease in the total work function of specimens.

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ВПЛИВ СКАНДІЮ НА ЕМІСІЙНІ ВЛАСТИВОСТІ КРЕМНІЄВИХ АВТОЕМІТЕРІВ

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Р е з ю м е

Досліджено вплив скандію на емісійні властивості матриці кремнієвих автоемітерів у надвисокому вакуумі. Показано, що присутність скандію помітно впливає як на абсолютне значення струму емісії, так і на його стабільність у часі, причому в залежності від його кількості на поверхні вплив може бути як позитивним, так і негативним. Результати експериментальних досліджень свідчать про існування оптимальної кількості скандію на поверхні досліджуваного зразка. Останній в цьому випадку характеризується максимальною емісійною здатністю та високою стабільністю струму емісії. Зростання емісійної здатності кремнієвих автоемітерів у присутності скандію пояснюється утворенням на їх поверхні складної хімічної сполуки, що сприяє зниженню загальної роботи виходу зразка.