Short Communication

Features of Ion-Electronic Emission from Surface of Semiconductors

A. Kurochka[1], A. Sergienko[1], S. Kurochka[1], V. Kolybelkin[2], S.G. Emelyanov[3], E.V. Yakushko[1], L.M. Chervjakov[3]

[1] *National University of Science and Technology "MISIS" (MISIS), 4, Leninskiy Pr., Moscow, Russia*
[2] *Research and production corporation "Istok", 2A, Vokzalnaya Str., Fryazino, Moscow Region, Russia*
[3] *Southwest State University, 94, 50 let Oktyabrya, 305040 Kursk, Russia*

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The results of the research value of the current of the secondary electrons in the ion-beam etching of various semiconductors. Shows the setup and electrical circuit of the experiment. An experimental study to determine the dependence of the current of the secondary electrons from the band gap Eg and the height of the potential barrier (electron affinity) $e\chi$. It is shown that in the conditions of ion-beam etching of the semiconductor is the penetration of the electric field, which leads to a shift of the energy levels of electrons in the surface layer. Found that the ion-electronic signal emission silicon *n*-type is higher than the *p*-type silicon.

Keywords: Ion-electronic emission, Ion-beam etching, Secondary electron current, Autoelectronic emission, Electron affinity, Space charge region.

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1. INTRODUCTION

Using the integral signal of ion-electronic emission control processes of ion-beam etching and reactive ion beam etching during the formation of semiconductor structures is very important [1]. Convincing explanation of the mechanism of electronic emission from the surface of semiconductors in terms of ion-beam etching is missing. In [2], the current value of the secondary electrons from the surface of semiconductors during ion-beam etching is determined by three factors: the energy transferred to the electron by the ion beam, the number of electrons that have received extra energy and escape probability of secondary electron in a vacuum.

It is also necessary to consider the impact of such important semiconductor materials, such as the band gap E_g, which determines the value of the product of the equilibrium concentration of charge carriers ($n_0 \cdot p_0$) at a certain temperature and the height of the potential barrier (electron affinity) $e\chi$ characterizing the probability of the electron in a vacuum.

2. EXPERIMENTAL SECTION

In the course of the work carried out experimental studies to determine the dependence of the current of the secondary electrons from the band gap, the potential barrier height and the type of conductivity of various semiconductors in reactive ion-beam etching.

Block diagram of the experimental setup and electrical circuit of the experiment are shown in Fig. 1 and 2, respectively [3].

Table 1 shows the experimental values of the current of secondary electrons Ise, reference data $e\chi$ and E_g for some semiconductors [4].

Clearly pronounced dependence of the current of secondary electrons on the parameters E_g and $e\chi$ not established that exemplified by the current of secondary electrons depending on the width of the band gap (Fig. 3).

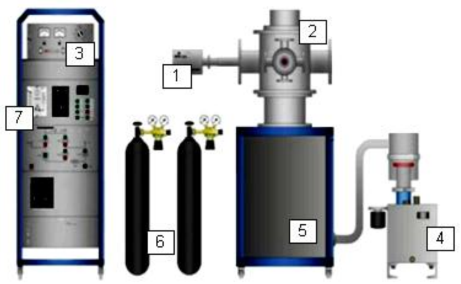

Fig. 1 – Block diagram of the experimental setup: 1 – ion source, 2 – vacuum chamber, 3 – power supply, 4 – backing pump, 5 – diffusion pump, 6 – gas bottles, 7 – automatic inlet system

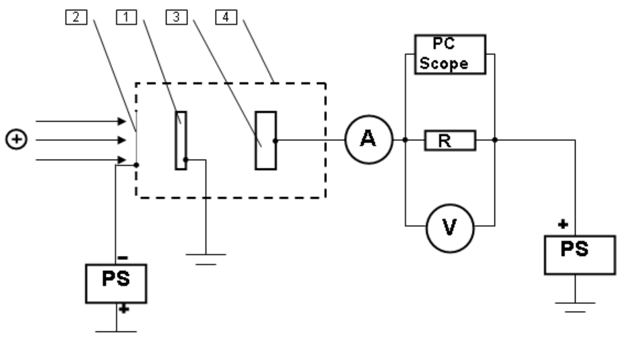

Fig. 2 – Electrical scheme of the experiment: 1 – sample, 2 – metal grid, 3 – electron receiver, 4 – metal container with a diaphragm

Table 1 – Experimental values *Ise*, the parameters E_g and $e\chi$ for some semiconductors

Material	*Ise*, μA	E_g, eV	$e\chi$, eV
Ge	18	0,67	0,5
Si	22	1,1	0,7
GaAs	4	1,43	0,9
GaP	8	2,24	1,1
SiC	17	3	1,2

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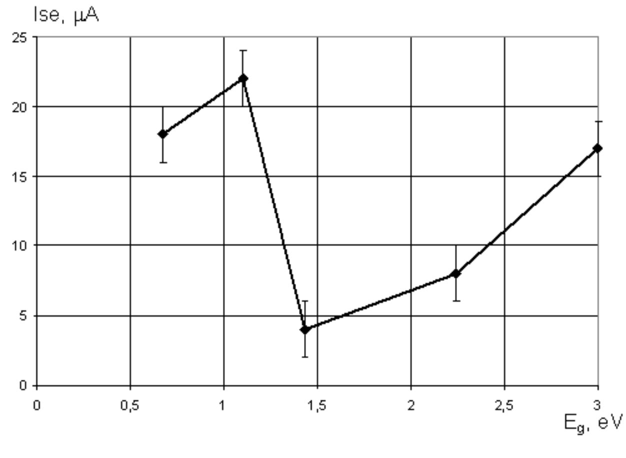

Fig. 3 – The dependence of the current of secondary electrons from Ise semiconductor band gap E_g

Regarding the mechanism of release of electrons in a vacuum can expect secondary emission through a two-step mechanism involving free electrons: excited electron is transferred directly to the Fermi level, freed after his departure level, is engaged in the conduction band electrons with the transfer of the released energy to another electron, which goes into the vacuum (Auger effect).

Is accessed directly transition into the vacuum electrons of system: ion-target atom as a result of direct excitation by the energy acquired in the collision of particles.

To clarify the mechanism of electronic emission from the surface of the semiconductor measured the integral signal electronic emission by etching the n-type silicon and p-type in a mixture of gases: Ar (80 %) and CF_4 (20 %). Ise graphics depending on the etching time t for these materials are presented in Fig. 4.

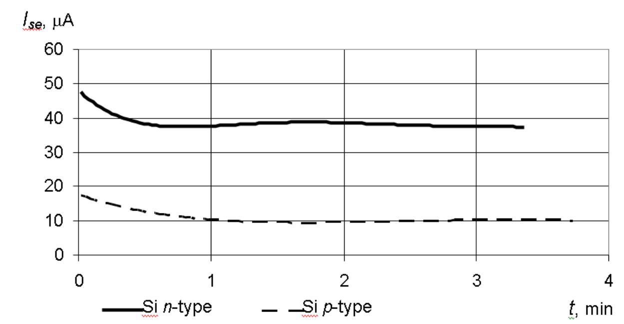

Fig. 4 – Dependence of current *Ise* secondary electrons from the etching time *t* etching *n*-type silicon and *p*-type in a mixture of gases: Ar (80 %) and CF_4 (20 %)

Ise value for *n*-Si is higher than the *p*-Si. This excess is explained as follows.

The surface is one of the main defects in three-dimensional crystal structure. Breakage of chemical bonds at the surface leads to a change in the coordination sphere of the surface atoms and rehybridization their valence orbitals. In all practical aspects used in surface physics model uniform surface, wherein all the physical properties are uniform in the plane (x, y) and all the changes of physical parameters occur in the direction normal to this plane (along axis z).

The general approach to the problem of electronic properties of both volume and the surface area is based on the band theory.

In this theory, considered that the appearance of the surface does not change the structure of the energy bands of delocalized over the entire crystal states, arise only new surface electronic states, which are localized at the interface and are able to capture charge. In view of electrical neutrality of the crystal as a whole in its surface region accumulates compensating charge of opposite sign – a region of space charge region [5].

In addition, disturbance of electroneutrality the near-surface region can occur under the influence of an external electric field. Induced on the surface of the treated by ions material positively charged penetrate some distance into the crystal. Space charge region "shields" electrically neutral crystal volume on the external field. The depth of penetration of the electric field l_d is given by [6]:

$$l_d = \sqrt{\frac{\varepsilon\varepsilon_0 kT}{q^2(n_0 + p_0)}}\,, \qquad (1)$$

where n_0, p_0 – the equilibrium concentrations of electrons and holes in the volume;
ε_0 – permittivity of free space;
ε – permittivity of the semiconductor;
q – the electron charge;
k – Boltzmann constant;
T – temperature.

The depth of shielding depends on the concentration of free carriers. If for metal ($n_i = \ldots 10^{22}$ cm^{-3}) Debye length is 0,1 nm, that for the silicon with intrinsic conductivity ($n_i = 1{,}5\cdot 10^{10}$ cm^{-3}) – $l_d \approx 25$ μm, for silicon *n*-type ($n_0 = 10^{15}$ cm^{-3}) – $l_d = 0{,}13$ μm.

Field penetration into the semiconductor leads firstly to the uncertainty of the forces acting on the electrons at the surface of the crystal and, secondly, to the shift of the energy levels of electrons in the surface layer down (in the case of electronic emission).

In terms of ion bombardment of the surface at the accumulation of positive charge in the n-type semiconductor creates a mode of enrichment, in which the majority carriers (electrons) are attracted to the surface and form a thin layer of high concentration of free charge carriers.

Thus, conditions are created for the emergence of an additional component of the integral signal of the emission current - autoelectronic emission.

Currently there is no complete physical theory of semiconductor autoelectronic emission. Complexity autoelectronic emission phenomenon in the case of semiconductors is that unlike metals in which the electrons are emitted only from the conduction band, for semiconductors electron source can be valence band, electrons are generated by impact ionization.

In these conditions, the concentration of free electrons in the surface layer at the boundary with the vacuum defined by Boltzmann [7]:

$$n = n_o \exp\left(\frac{\Delta R}{kT}\right), \qquad (2)$$

where ΔR – the value of the band bending.

3. CONCLUSIONS

Investigated the dependence of current of secondary electrons from the band gap E_g and the height of the potential barrier (electron affinity) $e\chi$. Clearly pronounced dependence of the current is not established.

With ion-beam etching, there is a shift energy levels of electrons in the surface layer. Equilibrium concentration n_0 electrons in *p*-type semiconductor is much less than in n-type semiconductor. This accounts for the lower value of the integral signal of electronic emission from the surface of *p*-Si.

Thus, the mechanism of ion-electronic emission from the semiconductor surface in the ion-beam etching can be divided into three components:

– emission involving electrons of the conduction band;

– emission through direct transfer of electrons of the ion-atom;

– autoelectronic emission under the influence of the surface potential.

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