Formation of carbon nanoscale elements of vacuum microelectronics by plasma treatment of SiC

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Abstract. The use of focused ion beams and atomic plasma chemical etching for forming an array of field emission structures on surface of SiC substrates is considered. SF6 was used as the fluorine-containing gas. Topology of formed elements was monitored using scanning electron microscopy method at Nova NanoLab 600. Dependences of geometric parameters of formed structures (topology of tip and its depth) on emission current were determined. Dependence of change in applied voltage and generated electric field of used to study probe on emission current density is also considered.

1. Introduction
Electronics has long and firmly come into our lives. We understand that she has fundamental limitations. Nevertheless, scientists had to do everything possible to make electronics work even faster and more efficiently. To do this, you need to use calculations, not electric current, but something else. Stimulating development requires not only complex calculations, but also consumer interest in faster, energy-efficient and “capacious” devices.

No, an acute question arises in implementation. Modern technologies are actively looking for new schematic solutions to the problems of the parties. However, all decisions rest on materials. At the moment, a number of new technological elements have already been opened for micro- and nanoelectronics [1-15]. All these problems are associated with new problems - it is necessary to explore the possibilities of creating devices based on these materials that affect the parameters of the formed working structures for the course of the rear processes. This fact allows you to update and give access to new discoveries and research. As, for example, for nitrogen carbide (SiC).

SiC is a promising material for micro- and nanoelectronics, and finds application in various manifestations, ranging from bulk MEMS structures to transistor elements. The instrumental output of SiC-based products largely depends on the Si or C side, which used with their distinctive physical and electrical parameters [16-23]. For each side, there are various technological methods for formation of structures, however, many of them either introduce significant damage to structural layers or require presence of additional dielectric layers to protect influence of substrate on the growth of working elements on SiC [24-35].

In this connection, development of formation technology of nanoscale emission structures based on SiC by focused ion beam and atomic plasma etching methods, a characteristic feature of which would be low influence of presence of bulk and structural defects in surface region of the substrate, is relevant.
2. Method
The studies are based on SiC substrates, surface of which was subjected to standard chemical cleaning processes. Initially, a frame of future nanoscale structure of a SiC-based field emitter was formed on surface of substrates using nanoscale profiling based on focused ion beams. For this, samples were placed in vacuum chamber of Nova NanoLab 600 module of focus ion beams and oriented in such a way that stream of accelerated ions fell on the substrate in the normal direction. During exposure to beams, working vacuum was maintained at a level of $1 \div 2 \times 10^{-4} \text{ Pa}$.

The next step was formation of a carbon nanoscale layer on the surface of array to reduce electron work function and start of electron emission. This process was carried out on basis of atomic layer etching in a fluoride plasma. SF$_6$ was used as a fluorine-containing gas, due to which it was possible to etch the surface layer of SiC. In this case, only Si was removed from their crystal lattice and a thin carbon layer was formed on the surface of the samples.

![Figure 1 (a, b). SEM-images of SiC surface with auto emission structures massive (a) and one pick element (b) based on graphene layer](image)

AFM images and current-voltage characteristics (CVC) of structures were obtained using Probe Nanolaboratory Ntegra (NT-MDT, Russia). SiC substrate was grounded, and a cantilever HA_HR with a W2C conducting coating was used. As result, 10 CVC at voltage from 5 to 20 V were obtained, and, according to the results, average CVC was built. Curves analysis was implemented using Origin 8.1 software. The AFM-image processing was performed using Image Analysis software.

3. Results and Discussion
At the end of experimental series of studies, an array of field emission structures was formed on surface of SiC substrate, as shown in figure 1. Thus, a technology was developed to obtain an array of emission structures with the possibility of varying the technological dimensions of the working elements. For further consideration, the structure with the best emission area in terms of the work function was selected, as shown in figure 1 (b).

The depth of 600 nm, the distance to the walls of the recess 470 nm at the place of emission, the size of the emission point 10-20 nm.
Figure 2 (a, b). Investigation structures, formed by FIB: (a) AFM-image; (b) cross-section profile along line on (a)

The element itself is recessed in a recess to a distance of 105 nm; this technique will allow the formation of a clear electron emission flux due to the limitation of the emission region.

Figure 3 (a, b). Analyzing of influence of high on emission current (a) and analyzing of influence of bias voltage on emission current (b)

These structures were used to analyze the operation of the emission current and the effect of the obtained geometric parameters on it. So, for example, on the structure from figure 1 (b), the dependences of the influence of the height of the formed elements on the emission current were constructed, as well as the analysis of the effect of the bias voltage on the emission current, as shown in figure 3.

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