Planar nanosized field emission cathodes on the basis of graphene/semi-insulating silicon carbide fabricated by focused ion beam

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Abstract. We investigate the field emission properties of planar graphene structures with nanosized interelectrode distance. The graphene was obtained by thermal decomposition of silicon carbide in vacuum. Planar field emission structures on the basis of graphene on semi-insulating SiC were fabricated by using focused ion beam. We have performed current-voltage measurement on graphene/SiC field emission cathodes. The planar field emission structures showed a threshold voltage less than 1 V.

1. Introduction

Approaching the technological limit of formation possibilities of modern integrated logic components promotes the scientific interest to field emission electronics. The main difficulties of practical realization are related to the large size and low durability of vacuum element, which mainly depends on the field emission cathode material. On-stream a field emission cathode device degrades under a number of destructive environmental influences.

Recently, many studies of field emission cathodes based on carbon materials have been published. The resistance to destructive factors, low threshold voltage and unique geometric dimensions of carbon nanomaterials make them attractive for field emission applications [1-4]. Graphene is one of carbon nanomaterials with high aspect ratio, small thickness and work function, excellent field emission, mechanical and thermal properties [5-10].

Methods of graphene preparation differ in their labor content, film size, imperfection, etc [11]. One of the methods is thermal decomposition of silicon carbide in vacuum [12, 13]. Thermal conductivity, radiation resistance of silicon carbide and opportunity of graphene growth on the entire surface make it progressive substrate for field emission devices, and graphene on silicon carbide is promising material for vacuum micro- and nanoelectronics [14-16].

The object of studying is development of manufacturing technology a planar field emission graphene/semiinsulating silicon carbide structure with nanoscale interelectrode distance and rounding-off radius of the top by gallium focused ion beams and investigation of its emission characteristics.

2. Design

The material and shape are important parameters of the field emission cathodes. Cathodes with high surface curvature are used for field emission. The cathodes in the shape of the tip, the blade and matrix structures are of the greatest interest. Previously, it was found that interelectrode spacing and rounding-off radius of the top having the greatest impact on the electric field strength [17]. It was determined that achievement of a field strength 10^9 V/m in nanoscale field emission structures is possible at a potential difference of less than 10 V. The small size of field emission cathode allows to create a compact matrix structure with a high current density [18].

Since graphene has the atomic thickness, fabrication of planar cathodes in the form of the tip on the basis of graphene proposed in this study. Schematic sketch the planar field emission structure shown on Figure 1.

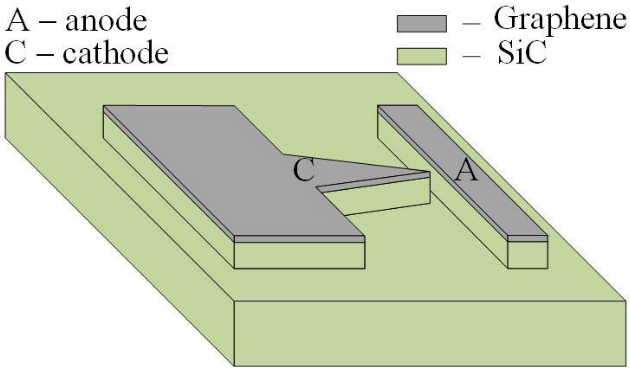


Figure 1. Schematic sketch of planar field emission structure on the basis of graphene on semiinsulating silicon carbide.

3. Experiment and results

Graphene was grown by thermal decomposition of silicon carbide in vacuum at a residual pressure of 10^{-3} Pa [13, 19, 20]. This method is characterized by obtaining high quality graphene large area with good adhesion to the substrate. Only the semiinsulating silicon carbide is required for fabricating planar field emission cathodes on the basis of graphene / SiC, because the cathode and the anode should not be shorted.

Precision maskless etching by gallium focused ion beam (FIB) was used to form the nanosized elements. In this case, FIB allows to form planar anode and cathode in a single technological cycle [21-25]. Other mask technology is more labor intensive, it requires the use of specialized templates, more time, additional photolithography operations and hinders the formation of nanosized elements based on graphene/SiC.

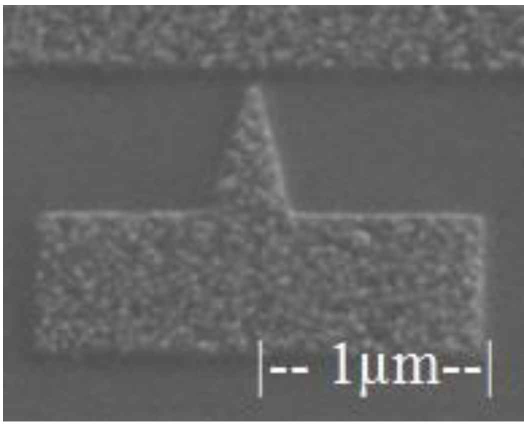
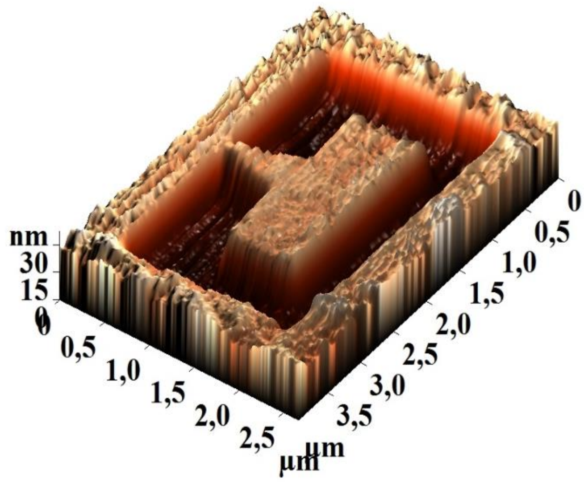
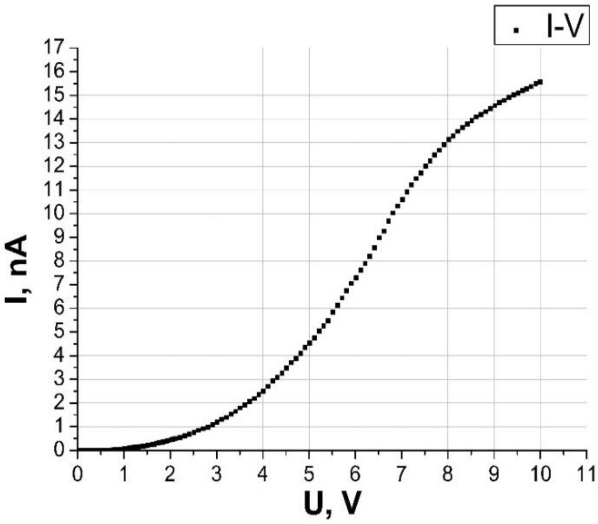


Figure 2. SEM image of planar field emission structure on the basis of graphene/SiC

In this study, the planar field emission structures were fabricated. SEM images of field emission structure (Figure 2) were obtained by using a scanning electron microscope "Nova NanoLab 600". SEM images show a planar field emission structures on the basis of graphene on semiinsulating SiC predetermined shape with 30 nm rounding-off radius of the top and 15 nm distance between the electrodes. Shape of field emission structure was determined by the need for the availability of the cathode and anode contact pads for subsequent measurement of current-voltage characteristics. Interelectrode distance was determined by the resolution of the etching equipment. Total etching time of the planar field emission structure was 2 min. 33 sec.



a)



b)

Figure 3. AFM-image of planar field emission graphene/semiinsulating SiC nanostructure (a) and their current-voltage characteristics (b)

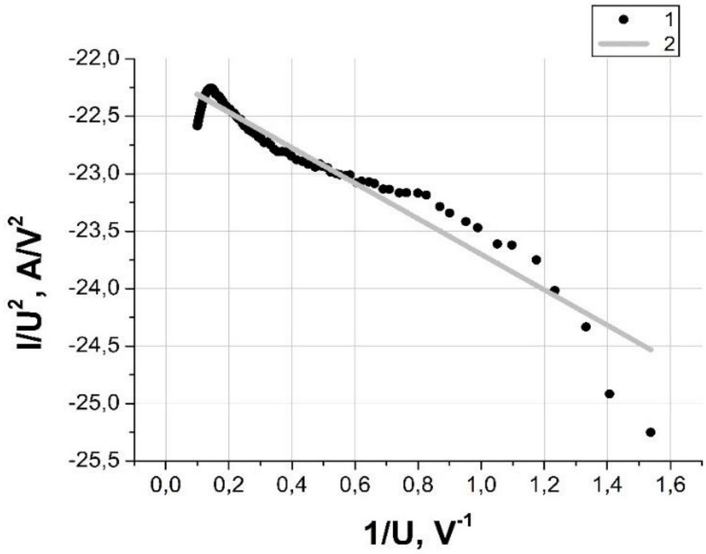


Figure 4. The current-voltage characteristics of planar field emission structure on the basis of graphene/SiC in Fowler–Nordheim coordinates: 1 – experimental data, 2 – approximation.

Structural studies and measurement of current-voltage characteristics was carried out by a scanning probe microscope "Ntegra Vita". AFM images have confirmed parameters of field emission structures and allowed to estimate etch depth, which was 30 nm (Figure 3a).

Measurements of current-voltage characteristics were carried out at standard pressure and a temperature of 23 °C in the voltage range of 0-10 V. The measurement result is shown on Figure 3b.

From the I-V dependence follows that the planar field emission structure is characterized by a threshold voltage of 0.5 V. The maximum current of 20 nA limited by instrumentation capability. I-V dependence in Fowler-Nordheim coordinates was plotted on the basis of experimental data (Figure 4). I-V dependence in Fowler-Nordheim coordinates confirms the field emission nature of planar nanoscale graphene on silicon carbide cathode.

4. Conclusions

The manufacture method of nanoscale planar field emission structures by using a gallium focused ion beam was shown. Forming modes of field emission structures on the basis of graphene on the semiinsulating silicon carbide are determined. The current-voltage characteristics of planar structures were obtained. Using of graphene as a material for planar field emission cathode with nanoscale interelectrode distance and rounding-off radius of the top allowed us to obtain electron emission at a low voltage of less than 1 V. This is significantly better results among nanocarbon field emission cathodes [26-28]. The results of current-voltage characteristics correlate with the results of field emission cathodes on the basis of graphene on SiC vertical type [6]. Low operating voltages can promote the using of nanoscale planar field emitters based on graphene on SiC in modern micro- and nanoelectronic devices.

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