Screening effect in matrix graphene / SiC planar field emitters

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Abstract. The paper describes simulation of matrix field emission nanostructures on the basis of graphene on a semi-insulating silicon carbide. The planar spike-type field emission cathodes were measured. The electric field distribution in an interelectrode gap of the emission structure was obtained. The models take into account the distance between cathode tops. Screening effect condition was detected in planar field emission structure and a way of eliminating was proposed.

1. Introduction
The unique properties of graphene films contribute to their implementation in different areas of nanotechnology and development of electronics [1-6]. Special attention should be paid to the substrate material for the practical application of graphene in nanoelectronics. Silicon carbide is perfect for this purpose. This material has high thermal conductivity, stability in a wide range of temperatures and radiation, the possibility of graphene growth on the entire surface of the wafer by thermal decomposition of silicon carbide in a vacuum [7-13].

A promising direction in the application of graphene films is a field-emission micro and nanoelectronics, [14-17]. The disadvantage of the existing field emission cathodes is the instability of field-emission current due to local overheating, adsorption and desorption of residual gas molecules, ion bombardment of the cathode [18, 19]. Increased resistance to destructive factors is inherent to field emission cathodes based on carbon materials [20].

The stability of field emission cathodes is largely determined by the uniformity of the field strength distribution in the interelectrode gap. Several studies have shown that the emission from the cathode surface is not uniform at high field strengths. Even the "ring effect" is detected on the emission image at pre-breakdown state [21-23]. The nature of this phenomenon is still poorly understood and most likely due to the heterogeneity of the field strength distribution.

One of the factors affecting the emission uniformity is the emergence of the screening effect in matrix field emission structures [24-30]. The emission heterogeneity in matrix structures can lead to varying luminescence intensity of individual sections in the field emission display. Therefore, the identification of factors affecting the field distribution between the cathode and anode in the matrix nanoscale structures is an urgent task of field emission vacuum nanoelectronics.

The object of studying is detection of the screening effect in the matrix nanoscale field emission structures with planar spike-type cathodes on the basis of semi-insulating silicon carbide with graphene films.
2. Design
Spike, blade, film, face and matrix field emission cathodes based on these structures are used to obtain sufficient electric field to the electron emission. Spike-type of field emission cathodes have the greatest curvature of the surface. They allow obtaining high values of the electric field which are required for the start of emission. An important task is the development of energy-efficient nanoscale field emission structures with low threshold field emission [31-33].

Application of the matrix field emission cathodes allows high amperage which is proportional to the number of cathodes in the array. Consequently, it is necessary to have the maximum number of emitters per unit area. However, limiting the number of emitters is determined by the influence of screening effect.

Planar spike-type emitter is used as a single element of the matrix in our work. Previous studies of planar emitters have shown that such a structure has a high-gain and low-threshold voltage [34]. General view of a planar matrix-type field emission structure shown in Figure 1.

![Figure 1](image1.png)

**Figure 1.** Model of planar matrix field emission structure based on graphene films on a semi-insulating silicon carbide. The dimensions are in nanometers.

3. Simulation and results
Simulation of structural parameters of field emission structures can reduce the labor intensity and reduce the cost of their production and studies [30, 35, 36]. Three-dimensional simulation of the distribution of the electric field strength was performed with the boundary conditions: on the border of the cathode - \( U_c = \text{const} \); on the border of the anode - \( U_a = \text{const} \); on the border of emission of the cell - \( U_e = 0 \). Simulation parameters are shown in Table 1. These values are based on experimental models and simulation of single emitters.

The simulation showed that the electric field reaches values of the order of \( 10^9 \) V/m at a voltage of 10 V. At the same time, the heterogeneity of the field distribution appears along a top of field emission cathodes (Figure 2).
Table 1. Simulation parameters.

| Parameter                                         | Symbol | Value  |
|---------------------------------------------------|--------|--------|
| Distance between the field emission cathode top  | L      | 100 - 1000 nm |
| Angle of lateral surface relative to the central axis | α      | 5°     |
| Rounding-off radius of the cathode top            | r      | 10 nm  |
| Number of graphene layers                         | n      | 10     |
| Interelectrode distance                           | d      | 15 nm  |
| Height of the cathode                             | h      | 1 µm   |
| Potential difference                              | U      | 10 V   |

Figure 2. The screening effect in a planar matrix field emission structure: (a) distribution of the electric field strength at 200 nm distance between the centers of emitters; (b) distribution of the electric field strength along the top of emitters.
It was suggested to gradually increase the distance between the centers of emitters for reduction of the screening effect. As a result, it was found that the screening effect was absent in considered structure at a distance between the centers of field emission cathodes of 700 nm or more. Figure 4 shows the distribution of the electric field along the planar field emission cathodes, where screening effect is absent.

![Figure 3. Absence of the screening effect in a planar matrix field emission structure: (a) distribution of the electric field strength at 700 nm distance between the centers of emitters; (b) distribution of the electric field strength along the top of emitters](image)
4. Conclusions
Simulation allowed us to obtain the distribution of the electric field in the planar matrix field emission structure based on graphene films on a semi-insulating silicon carbide. The value of the field strength corresponds to a spike-type of field emission nanoscale structures [30, 35, 36]. The dependence of electric field strength on the X coordinate showed that the field strength in the edges of emitters exceeds the value of the central emitters at short distance between the emitters. Increasing the distance contributed to the uniformity of the field at each emitter. It was revealed that screening effect is absent when the distance between the emitters is 700 nm and more. These results correlate with the results for the vertical type matrix graphene / SiC field emission nanostructures [30]. However, more distance between the emitters is required for the planar structures. This can be explained by the fact that the lateral surface of the planar structures contributes more to the emission compared to vertical structures. Additional design changes of individual planar emitters can reduce the distance between the emitters while maintaining homogeneity of the field.

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