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Modelling of the Influence of a Pointed Field Emission Cathode Design from the Silicon Carbide with Graphene Film on the Electric Field Strength

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Abstract. Graphene film on silicon carbide is considered to be promising material for high-frequency vacuum nano-electronics. However, the possibility of graphene application in this area is still poorly understood. We have carried out the simulation of the electric field distribution in inter-electrode gap of the anode-cathode system pointed field emission cathode based on silicon carbide with graphene film on its surface subject to the rounding-off radius of the top, interelectrode gap, height and cathode forming half-angle of the cone opening by the finite element method. The influence of constructional parameters on the electric field strength in the test structure was analyzed. It is shown that the values of rounding-off radius of the cone point and inter-electrode distance has the biggest influence on the electric field in the investigated structure. Changing of the height and cathode forming half-angle of the cone opening does not lead to a significant increase or decrease of the electric field value.

Introduction

Currently, the research of field emission cathodes made of silicon and carbon materials: silicon carbide, diamond-like films, nano-diamond, nanotubes, fullerenes and glassy carbon, graphene films obtained by different methods and on different substrates is carried out intensively [1-7]. Interest to this research stems from the fact that for the above materials a number of promising heavy-current field emission devices can create for different purposes: microwave devices, electron multipliers, photo emissive amplifiers, field emission displays, micro- and nano-sensors, high-speed switching devices [8, 9]. Emitters based on monolithic carbon substrates using laser radiation to form microstructures and subsequent ion-plasma treatment to pointing emitters are developed in order to increase the emission current density, the stability of pointed field emission cathodes. Another important sphere of emission electronics is the development of matrix pointed emitters fabricated by using ion-plasma deposition and technologies of microstructures local etching, as well as focused ion beams [10, 11].

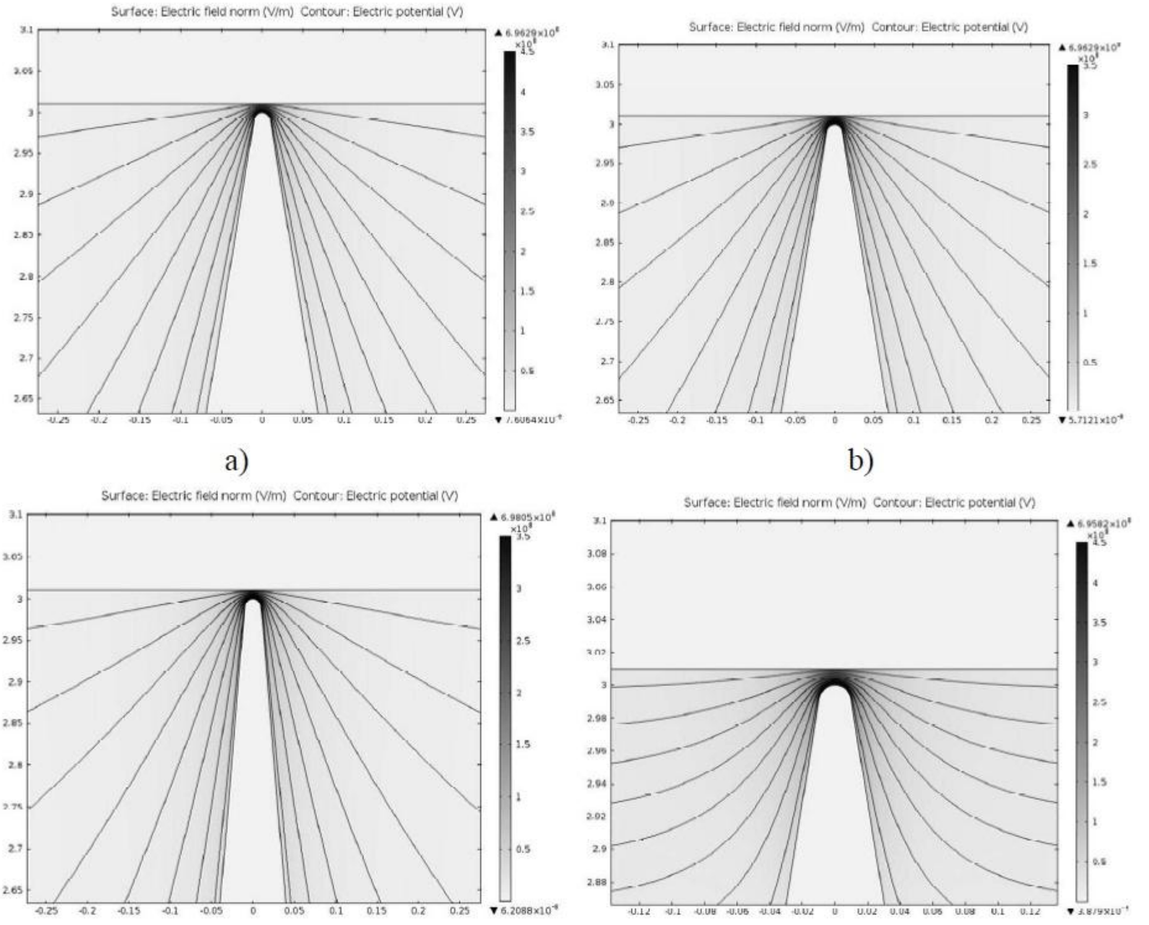
Many research of the carbon nanotubes array dedicated to the simulation of the emission characteristics. Individual nanotube has high aspect ratio and unique mechanical and electrical properties. The main drawback of carbon nanotubes is poor adhesion to the substrate. Graphene is obtained by sublimation of silicon carbide in vacuum deprived this disadvantage due to the fact that in this case the graphene is a natural continuation of the silicon carbide crystal lattice [12-18].

Field emission cathodes in devices operate at electric field strength of about 10^7 V/cm^2. This imposes a number of requirements to the matrix of the emitter: ensure uniformity of emission over the entire area of the matrix, higher liquid limit materials and high adhesion of structured films to a substrate.

Further technological factors constructional parameters (the height, the distance between the cathode and the anode, cathode-forming angle of the cone opening, rounding-off radius of the top) have a significant impact on the emission characteristics. Currently, the degree of this influence was still poorly understood. This is because the analysis region has a complicated geometry with a small size (from 5 nm), and the field strength near the emission region (top cathode) is rapidly changing. Therefore, the study of the electric field strength in the inter-electrode space of emission structures based on silicon carbide with graphene film on the surface is an urgent task [19, 20].

Modeling

In this paper, the modeling of the electric field distribution in the anode-cathode system inter-electrode gap was carried out. Finite element method was chosen to increase the accuracy of the electric field strength calculations in the inter-electrode gap. Adaptive meshing algorithm was used to reduce the error of the solution. Finite element mesh is strongly concentrated in the neighborhood of the field emission cathode top. This permitted to describe the complex geometry of the nanometer emission structures more exactly. The simulation parameters were geometric dimensions of field emission cell: *h* – height of the cathode; *R* – inter-electrode spacing; α - cathode forming half-angle of the cone opening; *r* - rounding-off radius of the top. Properties of the material, which a field emission cathode was manufactured, were set. Potential on the boundary of field emission cell = 0 V.



a) b)

c) d)

Fig. 1 The electric field distribution in the emission structure: 1a - at rounding-off radius of the cone point $r = 10$ nm; 1b – at inter-electrode distance $R = 10$ nm, 1c - at cathode forming half-angle of the cone opening $\alpha = 5$ °, 1d - at height of a field emission cathode $h = 0.2$ μm.

Simulation of the electrostatic field distribution in the inter-electrode gap was used to determine the electric field strength dependence of the rounding-off radius of the cathode top at $r = 5$ - 30 nm, height of the cathode $h = 3$ μm, the potential difference $U = 4$V, inter-electrode distance $R = 10$ nm, and cathode forming half-angle of the cone opening $\alpha = 10$ °. Fig. 1a shows the electric field distribution in the emission structure at $r = 10$ nm.

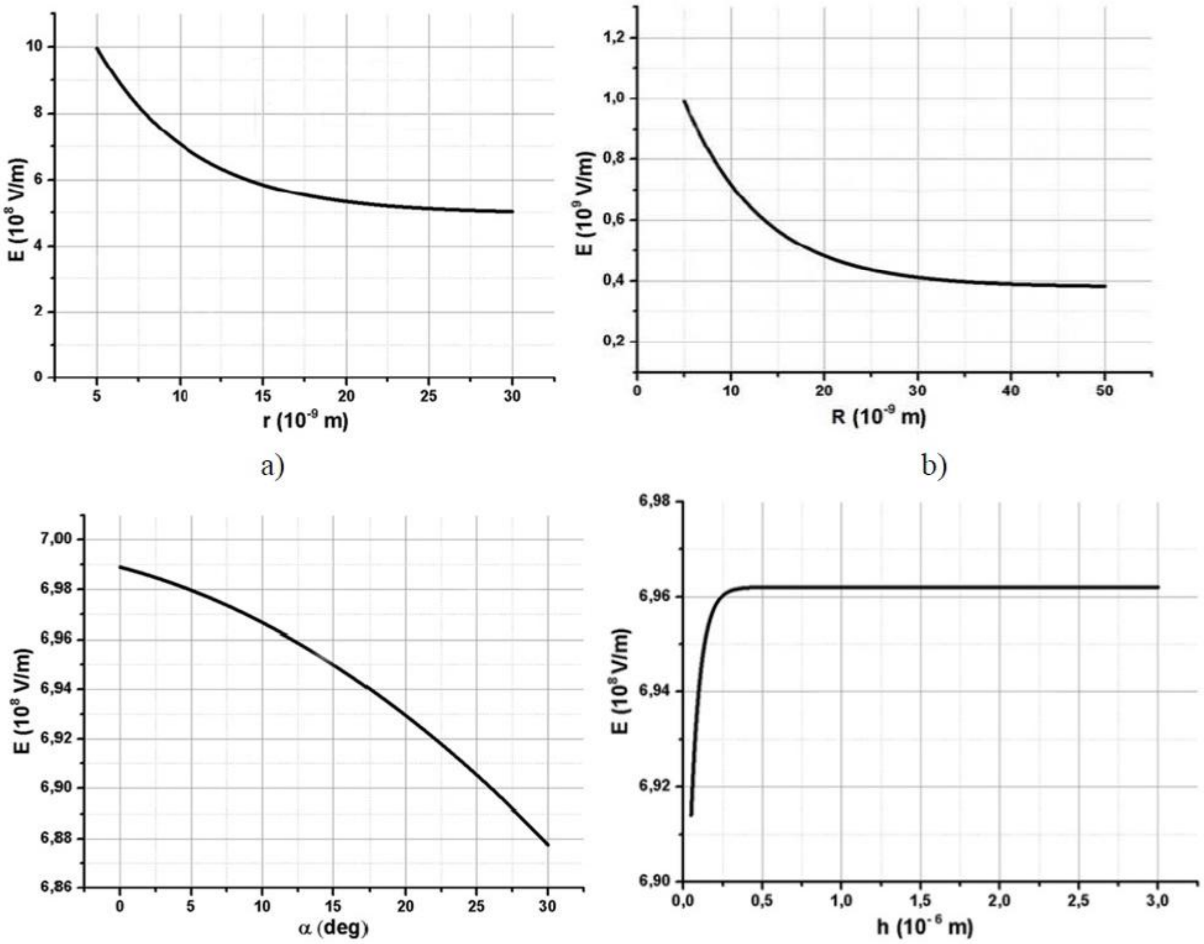
Simulation of the electrostatic field distribution in the inter-electrode gap was used to determine the electric field strength dependence of the distance between the electrodes with the values R = 5-50 nm. Fig. 1b shows the electric field distribution in the emission structure at R = 10 nm.

It is known that one of the important parameters influencing on a properties of the field emission cathodes and emissions as a whole, is the aspect ratio, i.e. the ratio of the height to the base of the cathode. For pointed field emission cathode the height and the cathode forming half-angle of the cone opening has a significant impact on the aspect ratio. Simulation of the electrostatic field distribution in the inter-electrode gap was used to determine the electric field strength dependence of the cathode forming half-angle of the cone opening with the values α = 0-30 °, r = 10 nm, U = 4V, R = 10 nm, h = 3 µm. Fig. 1c shows the electric field distribution in the emission structure at α = 5 °.

Simulation of the electrostatic field distribution in the electrode gap was used to determine the electric field dependence of the height of field emission cathode with different values h = 50 nm–3 mm, r = 10 nm, U = 4V, R = 10 nm, α = 10 °. Fig. 1d shows the electric field distribution in the emission structure at h = 0.2 µm.

Analysis of the Results

Electric field strength dependence on the geometric parameters of the investigated structure were calculated on the basis of simulation results.



a) b)

c) d)

Fig. 2 The electric field strength dependence on: a) the rounding-off radius of the cathode top; b) the cathode forming half-angle of the cone opening; c) the distance between electrodes in the emission structure; d) the height of a field emission cathode.

Fig. 2a shows the electric field strength dependence on the rounding-off radius of the field emission cathode top, which shows that at $r > 20$ nm, the field strength is reduced by half and varies slightly with increasing of parameter r.

Fig. 2b shows the electric field strength dependence on the inter-electrode spacing, which shows that the field gain factor is reduced with increase an inter-electrode gap, but electric field strength is calculated as for a plane-parallel capacitor.

Fig. 2c shows that the field strength is weakly dependent on the angle of the cone opening. When the angle was changed on 30° field, strength changed only on 1.7%. This can be explained by the fact that at a sufficiently low value of the inter-electrode distance ($R << h$ and $R << r$) no effect of the field shielding.

Simulation results were a plot of the electric field strength on the height of field emission cathode (Fig. 2d). After analyzing the results of the simulation, we see that when $h >> R$ field strength weakly depends on height of the field emission cathode, with $h \geq R$ field strength begins to depend on height of the field emission cathode. This can be explained by the appearance of the field shielding effect from substrate on which the point of the cathode is formed.

Conclusion

Analysis of the results shows that electric field strength in the emission region does not depend on the height h and weakly depends on the cathode forming half-angle of the cone opening α in micro-nanosized emission structures with cathodes in the form of the point when an inter-electrode distance R is much smaller than the height of a field emission cathode h. Hence, the electric field strength depends strongly enough only on the rounding-off radius of the cathode top and inter-electrode spacing when $R << h$. Therefore, to improve the stability and uniformity of the emission current in the matrix systems of the micro-nanosized pointed cathodes is necessary to optimize the design taking into account the rounding-off radius of the cone top, the height of a pointed emitter, inter-electrode spacing and the cathode forming half-angle of the cone opening.

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