Design features of matrix nanoscale pointed graphene/SiC field emission cathodes

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Abstract. The article describes the design features of the matrix nanoscale pointed field emission cathodes based on silicon carbide with a graphene film. The influence of the distance between electrodes, the distance between cathodes, the cathode height at the fixed values of the rounding-off radius of the top, the potential difference and the half-angle of the opening of cone forming the cathode is researched. The effective parameters of the matrix pointed field emission structure with nanoscale cathodes that provides homogeneity of the electrical field are determined.

1. Introduction

The interest to graphene electronics is growing every year [1-3]. Exceptional geometrical, electrical, mechanical and thermal properties of graphene expand the scope of its application [4-7]. One of the research areas of graphene is the field emission micro- and nanoelectronics [8, 9]. It is expected that the use of field emission devices will advance terahertz electronics.

The disadvantage of field emission cathode is the instability of field emission current due to the destruction of the emissive surface in strong electric fields. Ion bombardment, adsorption and desorption of residual gas molecules, local overheating can be reasons of destruction [10-12]. Field emission cathodes based on carbon materials are more resistant to destructive factors [13]. Silicon carbide has high thermal conductivity and is stable in a wide range of temperatures and radiation [14]. The method of thermal decomposition of silicon carbide in a vacuum permits to obtain graphene on the entire surface of the wafer. In this case, graphene is a natural continuation of the silicon carbide substrate [15]. As a result, the use of field emission cathodes based on silicon carbide with a graphene film will make it possible to create devices for operation in extreme, inaccessible to the solid-state electronics conditions.

Optimization of field emission cathodes structure is also important in engineering development along with a choice of material. There are pointed, edge, film and other constructions of field emission cathodes. Pointed cathodes are the most promising because they have the greatest curvature of the surface, which permits to obtain the necessary high values of the electric field strength for the start of the emission. The decrease of geometric dimensions of field emission cell to nanometer size contributes to lower operating voltage up to 2-3 orders of magnitude compared to modern characteristics of field emission devices [8, 16, 17].

The matrix of field emission cathodes is applied to increase the values of the field emission current. The value of field emission current is determined by the number of single cathodes in the matrix.

There is a limit on the maximum number of individual field emission cathodes per unit area related to reduction of electric field strength under the screening effect. The gain factor tends to 1 at extremely short distances between the cathodes in the matrix. Increasing the distance between the cathodes contributes to the rise of gain factor up to a value corresponding to the single cathode. Currently, the influence of screening effect in the matrix with nanoscale pointed field emission cathodes has not been studied sufficiently. The purpose of the work is the research of design and identification of the effective geometrical parameters of the matrix pointed nanoscale field emission cathodes based on silicon carbide with a graphene film on the surface.

2. Simulation
Simulation of the electric field strength distribution in the interelectrode space at different values of the cathode height (h), the distance between cathode (L) and the interelectrode distance (d) by the finite elements method with adaptive meshing algorithm was carried out to determine the effective parameters of matrix nanoscale pointed field emission cathodes based on silicon carbide with a film of graphene [18]. The choice of the design features of individual field emission cathodes was based on the theoretical and experimental studies [8, 19]. The general view of a matrix nanoscale pointed field emission cathode is shown in Figure 1, where K – the cathode, A – the anode, α - the half-angle of the opening of cone forming the cathode.
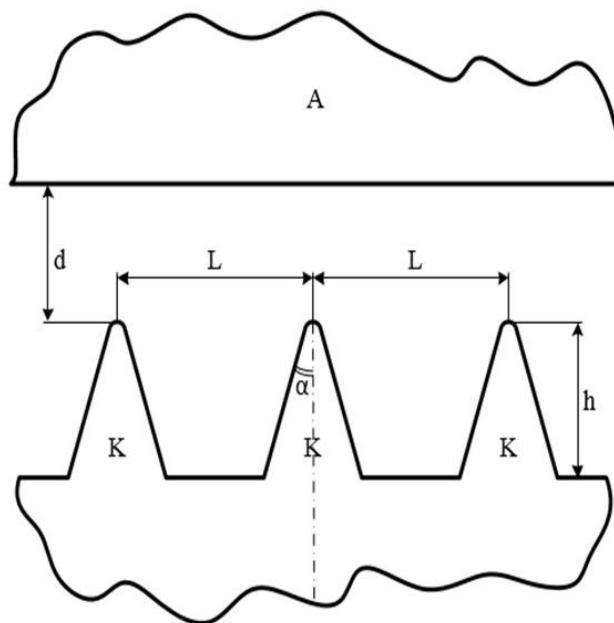

Figure 1. General view of a matrix pointed field emission cathode.

Table 1. Simulation parameters.

Parameter	Symbol	Value
Rounding-off radius of the field emission cathode top	r	10 nm
Half-angle of the opening of cone forming the cathode	α	10°
Potential difference	U	4 V
Interelectrode distance	d	10 - 50 nm
Height of the field emission cathode	h	50 nm - 3 μm
Distance between the field emission cathode top	L	50 - 500 nm

The values of the parameters which were used for the simulation of the electric field distribution in interelectrode gap are shown in Table 1. Wide range of the interelectrode distance, the distance between the field emission cathodes top and cathode height permitted to determine the effective parameters of the matrix field emission cell.

The main results of the simulation in the form of the electric field distribution in the interelectrode space with equipotential lines are presented in Figure 2.
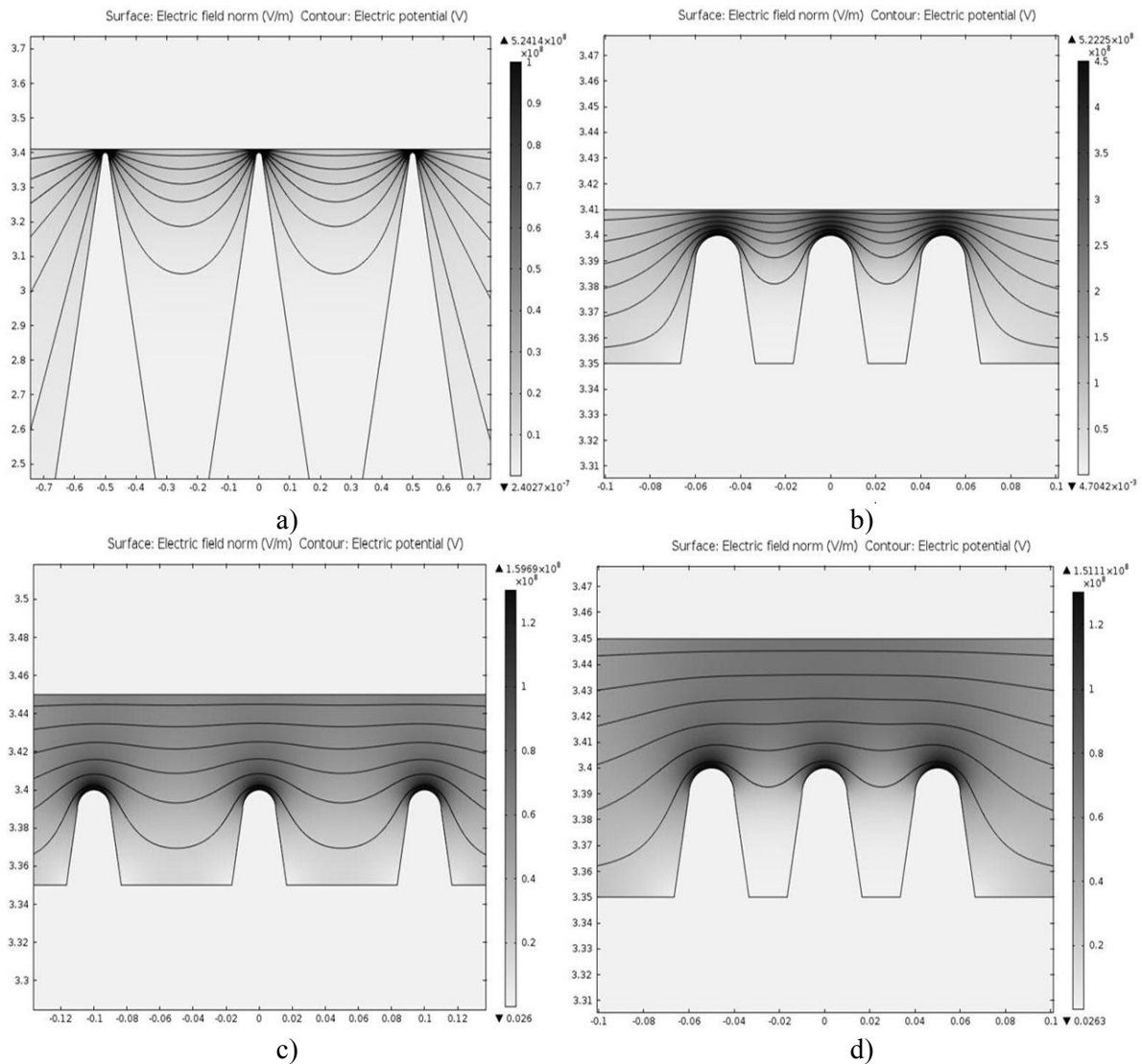

Figure 2. The simulation results of the matrix pointed field emission cathode at the parameters:
a) h = 3 μm, r = 10 nm, d = 10 nm, L = 500 nm; b) h = 50 nm, r = 10 nm, d = 10 nm, L = 50 nm;
c) h = 50 nm, r = 10 nm, d = 50 nm, L = 100 nm; d) h = 50 nm, r = 10 nm, d = 50 nm, L = 50 nm.

3. Results and Discussion
The dependences of the electric field strength on the x coordinate (along the cathodes) at fixed values of the potential difference, rounding-off radius of the field emission cathode top, the half-angle of the opening of cone forming the cathode and variables the parameters of the interelectrode distance, field emission cathode height and the distance between the cathodes tops were determined with the simulation results. The plots of the distribution of electric field strength along the matrix field

emission cathodes permitted to visually estimate the impact of screening effect or its absence (Figure 3). Figures 2 and 3 shows only the results that have practical importance and permit to draw conclusions about the impact of the specific parameters of the matrix field-emission cathodes on the electric field distribution. The obtained dependences showed a reduction of the electric field strength in the central cathodes due to the screening effect at high density of cathodes per unit area. This effect is becoming stronger with increasing the distance between electrodes. It was found that the emission from the substrate begins with small values of the field emission cathode height.
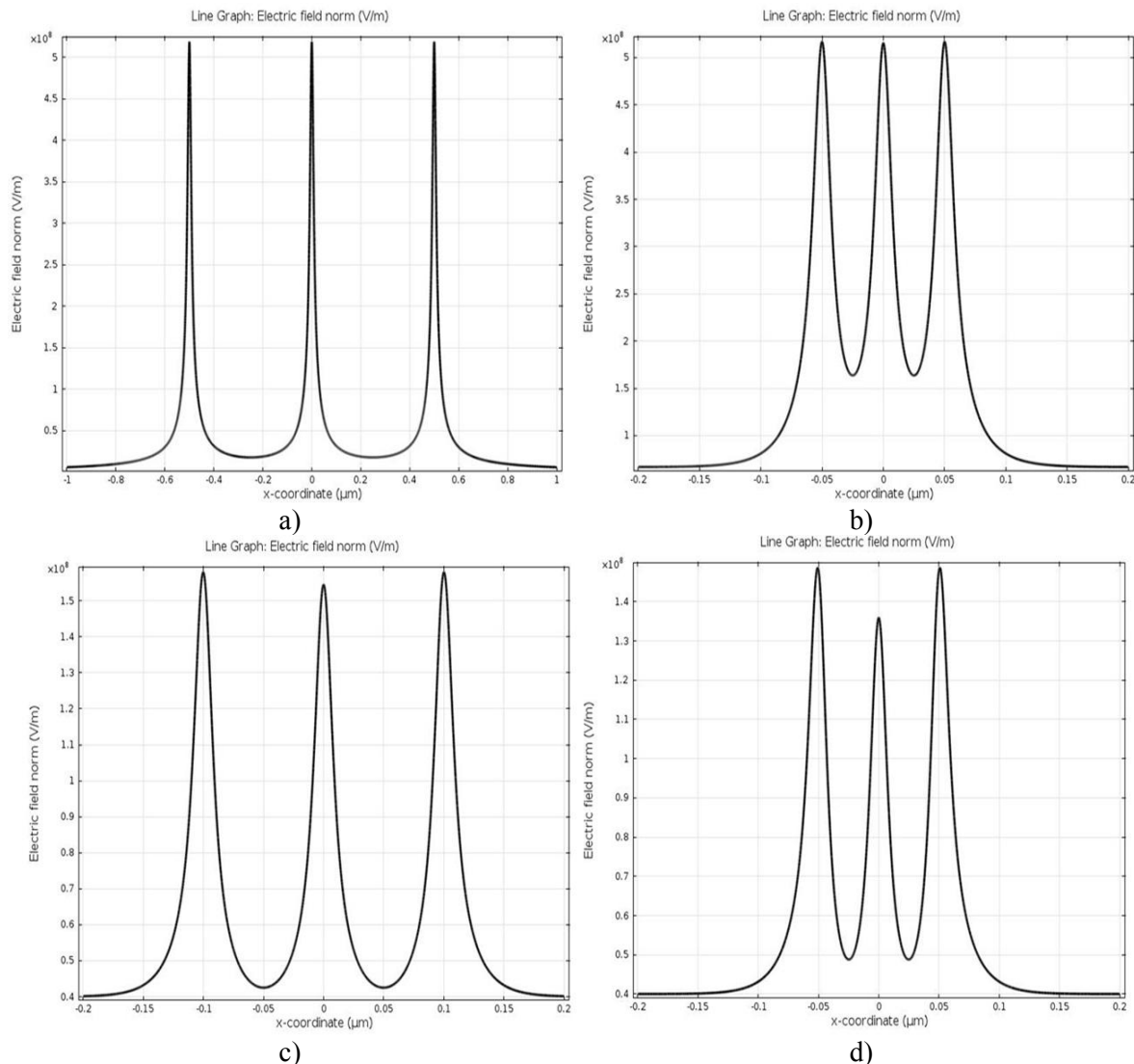

Figure 3. Electric field strength distribution along the field emission cathodes of different configurations:
a) h = 3 μm, r = 10 nm, d = 10 nm, L = 500 nm; b) h = 50 nm, r = 10 nm, d = 10 nm, L = 50 nm;
c) h = 50 nm, r = 10 nm, d = 50 nm, L = 100 nm; d) h = 50 nm, r = 10 nm, d = 50 nm, L = 50 nm.

4. Conclusions

The crucial factor of the number of field emission cathodes per unit area is the distance between their peaks. The simulation of the electric field distribution in the electrode gap of matrix field emission cell with nanosized pointed cathodes was carried out in this work. The simulation results shows that the screening effect in matrix nanoscale pointed field emission cathodes is low when the interelectrode

distance is much less than the distance between the cathodes and their height. The appearance of the screening effect is observed when the interelectrode distance, distance between the cathode and their heights are approximately equal. There is no screening effect on conditions that: d ≤ 0,5L and d ≤ 0,5h.

Acknowledgments

References

[1]   Novoselov K S, Geim A K, Morozov S V, Jiang D, Katsnelson M I, Grigorieva I V, Dubonos S V and Firsov A A 2005 *Nature* **438** 197
[2]   Arefinia Z and Asgari A 2015 *Solar Energy Materials and Solar Cells* **137** 146
[3]   Yue W, Jiang Sh, Xu Sh, Ma Y and Ba Ch 2015 *Sensors and Actuators B: Chemical* **214** 204
[4]   Lee C, Wei X, Kysar J W and Hone J 2008 *Science* **321** 385
[5]   Berger C, Song Z, Li X, Wu X, Brown N, Naud C, Mayou D, Li T, Hass J, Marchenkov A N, Conrad E H, First P N and de Heer W A 2006 *Science* **12** 1191
[6]   Ghosh S, Calizo I, Teweldebrhan D, Pokatilov E P, Nika D L, Balandin A A, Bao W, Miao F. and Lau C N 2008 *Applied Physics Letters* **92** 151911
[7]   Das Sarma S, Adam Sh, Hwang E H, and Rossi E 2011 *Reviews of Modern Physics* **83** 407
[8]   Konakova R V, Okhrimenko O B, Svetlichnyi A M, Ageev O A, Volkov E Yu, Kolomiytsev A S, Jityaev I L and Spiridonov O B 2015 *Semiconductors* **49** 1278
[9]   Okhrimenko O B, Konakova R V, Svetlichnyi A M, Spiridonov O B and Volkov E Yu 2012 *Nanosystems, Nanomaterials, Nanotechnologies* **10** 335
[10] Dyke W P, Charbonnier F M, Strayer R W, Floyd R L, Barbour J P and Trolan J K 1960 *Journal of Applied Physics* **31** 790
[11] Todokoro H, Saitou N and Yamamoto Sh 1982 *Japanese Journal of Applied Physics* **21** 1513
[12] Cui Y, Zhang X, Lei W, Di Y, Wang J and Yang X 2009 *Vacuum Electronics Conference, 2009. IVEC '09. IEEE International* 269
[13] Bormashov V S, Baturin A S, Nikolskiy K N, Tchesov R G and Sheshin E P 2007 *Surface and Interface Analysis* **39** 155
[14] Lebedev A A, Kozlovski V V, Strokan N B, Davydov D V, Ivanov A M, Strel'chuk A M and Yakimova R. 2002 *Semiconductors* **36** 1270
[15] Konakova R V, Kolomys O F, Okhrimenko O B, Strelchuk V V, Volkov E Yu, Grigoriev M N, Svetlichnyi A M and Spiridonov O B 2013 *Semiconductors* **47** 812
[16] Chen L, He H, Yu H, Cao Y, Lei D, Menggen Q, Wu Ch and Hu L 2014 *Journal of Alloys and Compounds* **610** 659
[17] Deng J H, Wang F J, Cheng L, Yu B, Li G Zh, Hou X G, Li D J and Cheng G A 2014 *Materials Letters* **124** 15
[18] Reddy J N 2005 *An Introduction to The Finite Element Method (Third Edition)* (New York: McGraw-Hill)
[19] Svetlichnyi A M, Ageev O A, Volkov E Yu, Jityaev I L and Dem'yanenko M V 2015 *Applied Mechanics and Materials* **752-753** 163