Nanocrystalline graphite : advanced field emission cathode material for a spacecraft neutralizer

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Abstract: The nanocrystalline graphite (NCG) is an advanced field emission cathode material has been assessed to introduce an alternative technology for carbon nanotube (CNT) cathodes as a source of electron beam in spacecraft neutralizers compensating the ionic charge of small electric propulsion (EP) thrusters plume. Important advantage of the NCG cathode material for use in neutralizers is its ability to withstand higher oxygen content in ambient gas. In particular NCG cathode readily survives the lasting operation in atmospheric air at pressure of 10^{-4} Torr without cathode emission degradation.

Nomenclature

CNT = carbon nanotube
NCG = nanocrystalline graphite
PECVD = plasma enhanced chemical vapor deposition

I. Introduction

SMALL research satellites Universitetsky Tatiana program supervised by Skobeltsyn Nuclear Physics Institute of Moscow State University (SINP MSU) is an optimal choice for testing of new concepts of instrumentation and tools as these microsatellites is providing of a orbital platform not only for basic science, but also for educational purposes[1]. Particularly, it is contemplated to deploy a prototype neutralizer cathode based on an advanced field emission material for durability testing in the satellite own ambient.

During recent decade the active efforts are being undertaken to develop improved thrusters for low-weight satellites where requirements on weight of the engine unit including propellant becomes crucial as the satellite mass decreases. Possible thruster options are broadly discussed elsewhere[2]. One of the most promising approaches is the minituarization of commonly used electric propulsion (EP) thrusters where the thrust is provided by a flow of ions accelerated with electrostatic grids what enables higher propellant utilization efficiency. However, this ionic flow inherently carries away a positive electric charge necessitating implementation of additional units to compensate this electrostatic charge, i.e. the neutralizers. The exhaustive survey of the neutralizer technologies, both commonly used and under development, was recently published[3]. Here one can just briefly mention the main problem facing the standard hollow discharge based neutralizers, i.e. high power consumption and fast degradation of thermionic cathodes and losses of working gas to maintain the hollow discharge e-beam. In case of microsattelites having tight

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payload restrictions and therefore limited power and propellant gas resources the field emission cathodes are the obvious substitute to be employed in neutralizers. Particularly, the carbon nanotube (CNT) based approaches are commonly considered to be the most appropriate ones and studied both theoretically and experimentally[4-7]. However the CNT cathodes suffer from long term instability and limited life in oxygen containing atmosphere typical for low-orbit applications[8].

II. Nanocrystalline graphite cathode characterization

To properly address these challenges the proprietary nanocrystalline graphite (NCG) is proposed for use in neutralizers. Nanocrystalline graphite (NCG) have been recognized as an advanced field emission cathode material that is superior the CNTs by all key performances, such as maximal field emission current density, durability in higher ambient gas pressure, service life[9-10].

Structurally the NCG film comprises the predominantly vertically oriented graphite planes of varying thickness forming a micro ribs pattern as shown in the Fig. 1. The graphite planes essentially are the multilayer graphene walls. Atop of them some quantity of carbon whiskers comprising the graphene nanoribbons, nanowires and carbon nanotubes grow and determine the very high electron emission performances[11-12].

A. Nanocrystalline graphite film fabrication

The NCG material is produced in form of thin films grown by plasma enhanced CVD noncatalytic process either on a conductive or dielectric substrate in a dc glow discharge in mixture of hydrogen and methane on substrates placed on anode. To implement this process a special PECVD reactor tool is used to produce simultaneously up to six NCG coated substrates. Important that each cathode-anode assembly of the reactor is electrically decoupled thus enabling individual control of each NCG film fabrication.

Pressure of working mixture during deposition process gradually varies from the moment of discharge initiation and finally increases up to 200 Torr. Methane concentration is 3%-8%. Hydrogen serves as a carrier gas with flow rate of 2-3 l/h. Substrate temperature during process typically is 900-1000°C. Duration of NCG films deposition is typically 25-30 min.

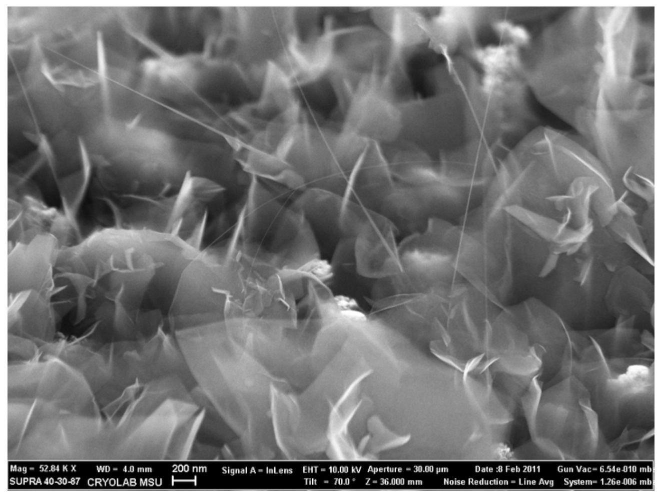

Figure 1. SEM image of the NCG film.

The CVD synthesis is adjusted to enable self-organizing of the film growth to produce NCG film in a quite regular mesh-like pattern formed by vertical graphene nanowalls. Location of emitting carbon whiskers is essentially follows the ribs of the pattern thus providing their self-organized separation and enabling absence of electrostatic shielding of emission centers. Additionally, the super-texturing of cathode substrates[13] allows further improving of the cathode performances. It results in higher and more stable electron emission[14].

B. Cathode design and testing arrangements

Field emission cathode is designed as a vacuum triode comprising control grid made of the 30 micron tungsten wire and positioned at a distance of normally ~100 microns from NCG film. The detailed views of the electrode system assembly design and field emission cathode unit are shown in the Fig.2. Most of the tests have been performed using the electrode system assembly placed into special testing setup comprising the vacuum chamber equipped with gas supplies, pumps and all necessary instrumentation and controls.

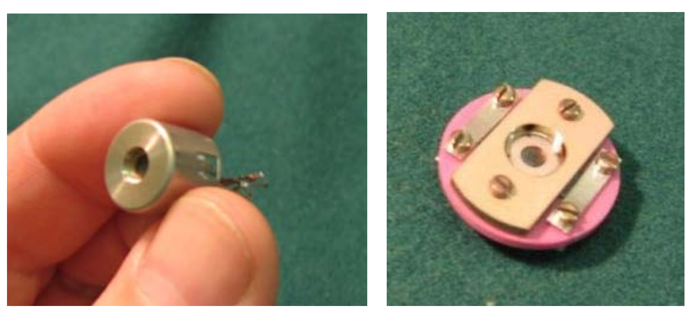

Figure 2. NCG field emission cathode (left photo) and electrode system assembly (right photo).

C. Performances

The extended lifetime measurement of the NCG cathode were performed in high vacuum conditions where the adverse effect of bombardment on the field emission area by residual gas ions is minimized to reveal the inherent stability of the NCG material. To enable this test the cathode assembly was sealed into the gettered vacuum tube. Testing was performed in the emission current stabilization mode. The specially designed power supply is used to maintain the preset value of the emission current via adjusting the anode voltage. For the reported NCG field emission cathode sample the emission current is 1.4 mA. The corresponding temporal behavior of the extracting voltage is shown in the Fig. 3. Actually this test has not ever been terminated and lifetime figures continue being updated continuously. Variation of voltage required to maintain the emission current is a measure of the cathode long time stability. Important to note the absence of anode voltage increasing with time as it commonly observed for CNT cathodes.

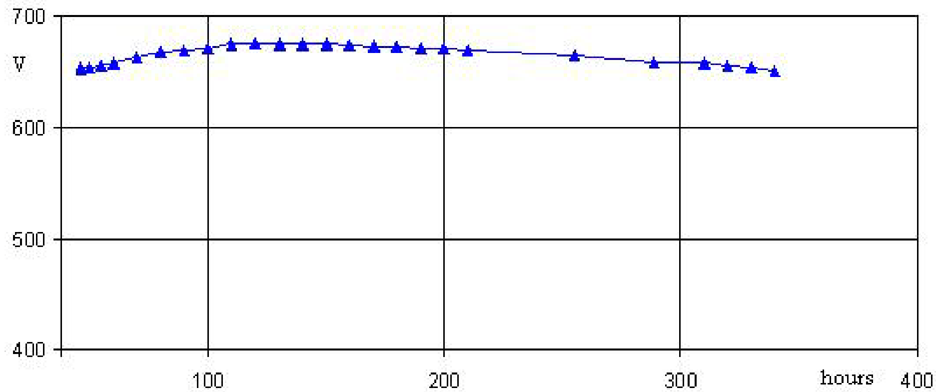

Figure 3. Field emission stability test at current stabilized at 1.4 mA.

Another unique and important advantage of the NCG cathode material for use in neutralizers operating in low orbit micro satellites is its ability to withstand the higher oxygen content in ambient gas.

The measurements were carried out in the testing setup. Typical temporal behavior of the emission current is shown in the Fig. 4. One can see that the emission current stabilized at 0.3 mA (emission area is 0.08 cm^2) readily survives the lasting operation in atmospheric air at pressure of 10^{-4} Torr without any cathode emission degradation detected.

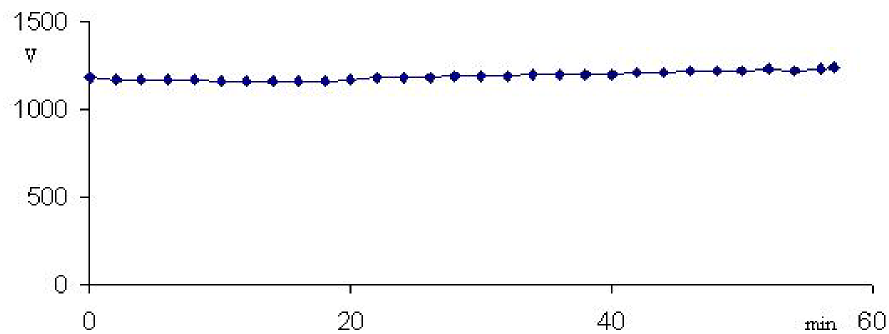

Figure 4. Field emission stability test in air at pressure of 10^{-4} Torr.

III. Conclusion

A durable field emission material named nanocrystalline graphite was proved as an advanced cathode material to be employed in ionic charge neutralizers for small EP thrusters including low orbit micro satellites. Program of additional testing of the NCG field emission cathodes is underway with final stage contemplating durability orbital tests inboard of the future Universitetsky Tatyana educational and research micro satellites.

Acknowledgments

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