Electron Emission from Nano- and Micro-Engineered Materials Relevant to Electric Propulsion

IEPC-2013-390

Presented at the 33rd International Electric Propulsion Conference,
The George Washington University • Washington, D.C. • USA
October 6 – 10, 2013

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Abstract: Micro-engineered materials with surface architecture were proposed for the reduction of secondary electron emission, which is unwanted phenomenon for various plasma applications, including Hall thrusters. In this paper, possible electron field emission effects from nano- and micro-engineered materials relevant to plasma thrusters, including but not limited to Hall thrusters, and cathode applications are investigated. As an example, we studied these effects using different doped and non-doped ultrananocrystalline diamond coatings. The results of these studies suggest that for engineered materials with surface architecture at nano and micro scales proposed for operation on plasma thrusters, electron field emission should not be an issue as long as characteristic features of these materials are much smaller than the sheath size.

I. Introduction

Micro-and nano-engineered materials are predicted to have a small secondary electron emission (SEE) because their micro cavities should trap emitted electrons. Low SEE properties of these materials can be useful for various plasma applications including, Hall thrusters [1]. It was previously demonstrated that the use of, for example, carbon velvet as the channel wall material for a Hall thruster can lead to dramatic improvements of insulating properties of magnetized thruster plasma allowing to reach significant dc electric fields of ~ 1kV/cm. Very recent measurements of SEE yield from a carbon velvet demonstrated a significantly smaller SEE yield from this engineered material as compared to graphite material (Fig. 1, [2]) and boron nitride [3]. These results were obtained using an experimental setup for SEE measurements at PPPL [3].

One of the main concerns in the application of materials with engineered surfaces is that their complex surface architecture, including non-uniformities formed by, for example, fiber cavities could create conditions for field enhancement leading to electron field emission at sufficient large electric fields. For thruster applications, such strong electric fields could occur for high discharge voltage operation, which are required, for example, for high Isp applications. Then, for plasma-wall interaction processes, the field emission could act similarly to SEE, i.e. reducing thermal and electrical insulating properties of the plasma-wall sheath. In fact, we observed electron field emission from the carbon velvet materials in our previous works [1]. The analysis of these results showed that field emission from carbon velvet can take place from protrusive fibers (5 μm diam, ~1000-2000 μm length and inter-fiber spacing of ~ 20 μm) due to field enhancement.

In this paper, we focus on possible electron field emission from engineered materials with surface architecture. As an example, we studied these effects using nitrogen incorporated and undoped ultrananocrystalline diamond

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(UNCD) coatings. Structural features of these materials (grain size is several nm, but surface roughness can be up to several tens of nm) are smaller than typical micro-engineered velvet materials (~ several micron diameter of fibers), but they are known to have exceptional field emission properties and even considered for cold cathode applications [4].

II. Plasma-Immersion Experiments with Ultrananocrystalline Diamond Coatings

To evaluate the field emission ability of UNCD materials in the plasma, samples of different grain size with and without dopant additions (usually nitrogen) were immersed in LTPX plasma using a specially designed holder (Fig. 2). A wafer with UNCD coating was attached to one side of the holder, while the other side of the holder had a probe-collector made from aluminum. The probe and material samples have comparable cross-sectional area of their plasma-facing sides. Moreover, the probe and the sample are electrically isolated and therefore, can be biased independently. The holder can be moved radially and rotated to expose test sample or probe sides to the plasma. By biasing the plasma-facing side of the holder with respect to the plasma, the current, which is carried by collected and emitted (field emission, secondary electron emission or thermionic emission) charge particles was measured. The main result of these experiments is that there was no appreciable effect of electron field emission from the nano-engineered materials. Fig. 2b illustrates this result for UNCD material. For negative bias voltages of below the floating potential, the current values for the UNCD are not larger than the current measured for the aluminum probe-collector. This result may be explained by a relatively low electric field at the UNCD surface facing the plasma in these experiments, which are relevant to operating conditions of Hall thrusters. From plasma measurements, an average electric field between the UNCD and the sheath edge does not exceed 2 V/µm. This is a few times less than the electric field threshold at which a strong field emission from UNCD was reported for vacuum experiments earlier [6]. In addition, because of screening from closely spaced grains and because of the larger sheath ~ 10^2 µm compared to the grain size, the field enhancement is negligible and cannot support the field emission from the UNCD materials under plasma presence [7]. These results and our previous results obtained for carbon velvet [1] imply that for nano and micro-engineered materials proposed for operation on plasma thrusters, electron field emission should not be an issue as long as characteristic features of these materials are much smaller than the sheath size..

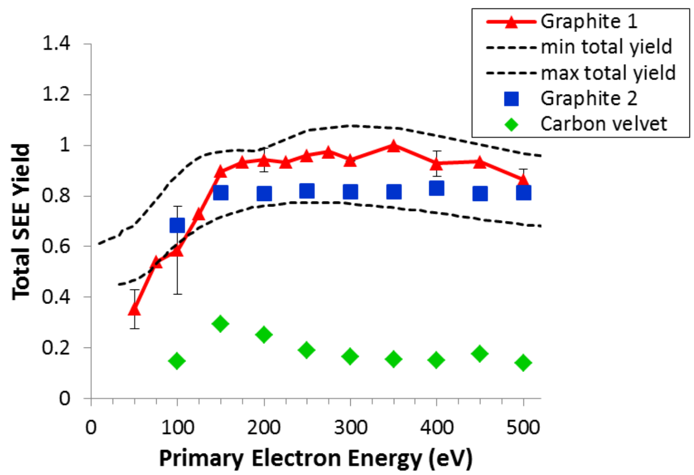

Figure 1. A comparison of the total secondary electron emission yield from graphite and carbon velvet materials. Graphite 1 and Graphite 2 are samples made from the same Poco graphite material. The results for Graphite 1 were obtained using a new PPPL setup for measurements of SEE based on Auger electron spectroscopy [5]. The dashed lines show the range of values for SEE yield from graphite deduced from data available in the literature [5]. SEE yield from Graphite 2 and carbon velvet was measured using the setup described in Ref. [3].

III. Summary

We reported preliminary results of measurements of secondary electron emission properties for micro-engineered materials. These results corroborated our previous hypothesis that for example, carbon velvet material have much smaller secondary electron emission yield as compared to, for example, graphite and boron nitride. In addition, we demonstrated that for engineered materials with surface architecture at nano and micro scales proposed for operation on plasma thrusters, electron field emission should not be an issue as long as characteristic features of these materials are much smaller than the sheath size.

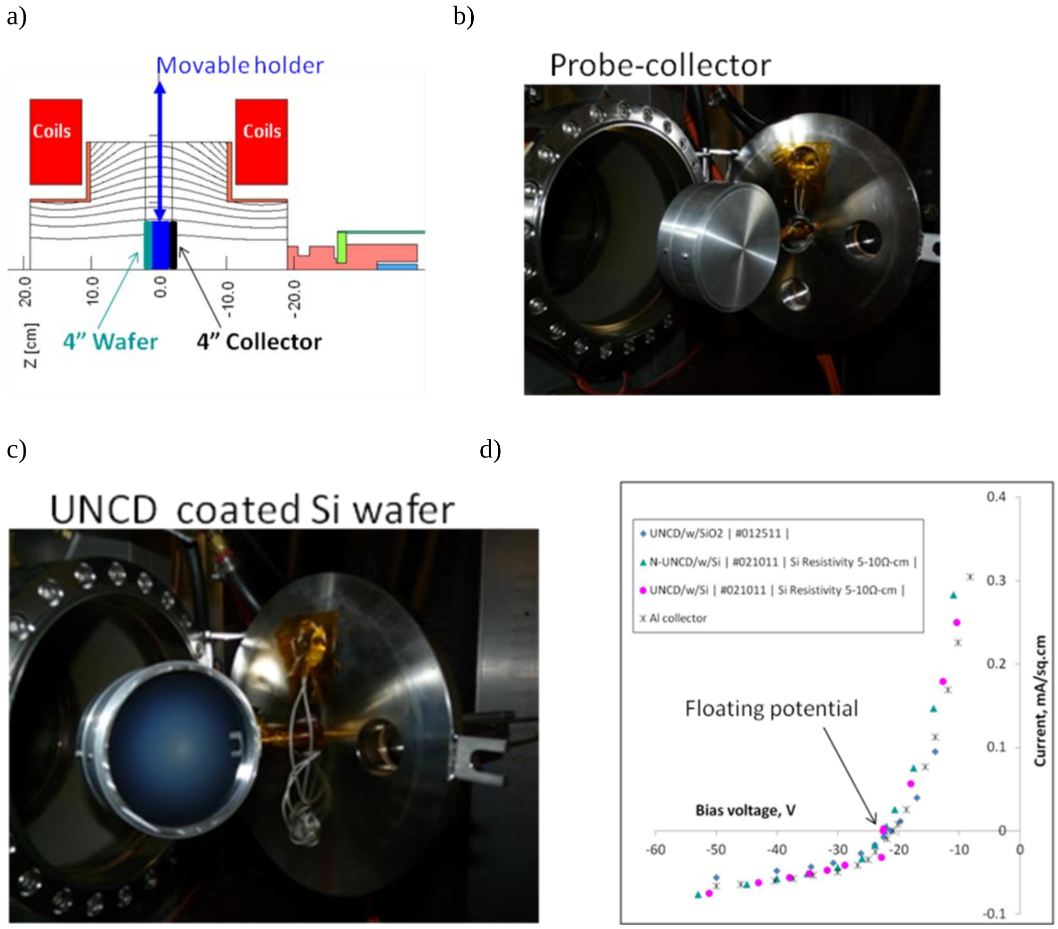

Fig. 2 Experiments with plasma immersed nano-engineered materials: a) Movable holder for immersion of the material samples in the low temperature plasma, b) 4” diameter probe-collector for measurement of plasma fluxes to the test materials, c) micro-engineered material – ultrananocrystalline diamond coating on 4” diameter Silicon wafer d) voltage-current characteristics of biased probe collector and wafers with different UNCD coatings (with and without Nitrogen dopant, different thickness etc.).

Acknowledgments

The authors wish to thank Alex Merzhevskiy for technical assistance. This work was supported by the AFOSR.

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