Contribution ID: **21** Type: **Poster**

Carbon-based materials for cathode neutralizers in electric propulsion

Thursday, 2 March 2017 16:00 (1h 15m)

Neutralizer cathodes used as electron sources represent a key component of electric propulsion (EP) systems for spacecrafts. In EP systems such as electric propulsion thrusters, ion engines and hall thrusters, a positive ion beam is ejected at high speed to produce thrust. Over time, the ion beam expands and becomes fuzzy for the space charge formation that reduces the thrust and causes arcing and back-ion bombardment that damage onboard instruments. Thus, neutralizer cathodes are needed to obtain an electron emission current equal or greater than the ion beam, so to maintain ion beam neutralization and restore spacecraft charge balance.
Typically, neutralizer cathodes utilized in Hall thrusters [1] are hollow cathodes that are not suitable for satellite stations because they require a limited number of ignition cycles and a long heating time for each ignition. For this reason, field emission (FE) cathodes with Spindt geometry [2] are presently considered as alternative to hollow cathodes. However, Spindt type cathodes made of microfabricated Mo [3] and Si [4] tips are predicted to malfunction in a simulated thruster environment due to the excessive ion-sputter damage.
Recently, innovative carbon-based materials, such as carbon nanotubes arrays [5, 6] and thin films of nanocrystalline graphite [7], are tested as field emitters featuring a current density of 1 A/cm2 and an ion-sputter resistance higher than that of Mo and Si. Among carbon-based materials, diamond exhibits superior chemical and physical properties, such as high hardness, corrosion resistivity, chemical inertness and excellent photo-, thermo- and field-electron emission. This, thanks to its negative electron affinity if the surface is hydrogenated and low work function if it is doped.
In this contribution a number of emissive measurements of nanocrystalline diamond (NCD) and N-doped diamond films produced by the microwave plasma enhanced chemical vapor deposition (MWPECVD) technique starting, respectively, from CH4-H2-Ar and CH4-H2-N2 gas mixtures, and of nanodiamond (ND) layers deposited by the pulsed spray technique using nanoparticles of about 250 nm dispersed in solvents, are illustrated.
The NCD films were grown at different values of the deposition temperature that affects the shape and size of grains and, as a consequence, the fraction volume of grain boundaries with the amount of incorporated hydrogen that modulates the surface electron affinity. The NCD films grown at the highest deposition temperature featured the highest photo- and thermoionic emission currents [8].
The N-doped diamond films were produced by using variable N percentages, i.e. 0, 0.2, 0.5, 1, 3.5, 5 and 6 %, to the CH4-H2 gas mixture. The quantum efficiency (QE) of photocathodes was assessed in the UV range from 140 to 210 nm for all samples, before and after plasma treatments in pure H2 and H2-N2 (25-75%) plasmas. Both the hydrogenated and hydro-nitrogenated films showed an enhancement of the QE up to 38% at 140 nm, with respect to the untreated aged ones [9].
Two types of ND powders with particle size of about 250 nm and having different sp2 (graphite phase) and sp3 (diamond phase) C contents were examined. The photoemission results showed that the QE values depended on the type of NDs. In particular, the rich-graphite ND layers are more photoemitting (QE=47% at 140 nm, [10-12]) than the rich-diamond ones, for both as-received and hydrogenated ND powders. The values obtained represent the highest QE achieved by diamond-based devices in the current literature, and encourage the application of these films and layers as neutralizer cathodes in small aerospace thrusters.

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Session Classification: poster (continued)