

Emission Enhancement by Surface Modification of Reticulated Vitreous Carbon (RVC)

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Irradiation by means of laser and ion treatment has been shown to modify the surface of various forms of carbon. Reticulated Vitreous Carbon (RVC) is of particular interest because it requires a lower field for the onset of field emission as compared to graphite and provides a higher emission current density than diamond due to a greater number of available carriers. In the current study, Argon ion radiation, applied through a shadow mask, is used to induce modifications at the surface of RVC in an effort to improve field emissive properties. Carbon Nanotube (CNT) self-assembly has been achieved by similar treatment of graphitic pastes [1]. Preliminary samples, systematically irradiated under varying conditions of beam energy, plasma density and duration, display a marked improvement in I-V characteristics for field emissivity over non-irradiated samples. As seen in Figure 1, taking the extraction field as associated with the field emission current equaling 0.1 μA , non-irradiated samples began emitting at an extraction field of roughly 4.0 $\text{V}/\mu\text{m}$ while Argon treated samples were measured to emit at extraction field values as low as 1.3 $\text{V}/\mu\text{m}$. This improvement, we believe, is due to the induced modifications in sp^2 - and sp^3 -bonds as well as in the formation of geometrically advantageous emission sources such as cones, whiskers and CNTs at the surface of the RVC.

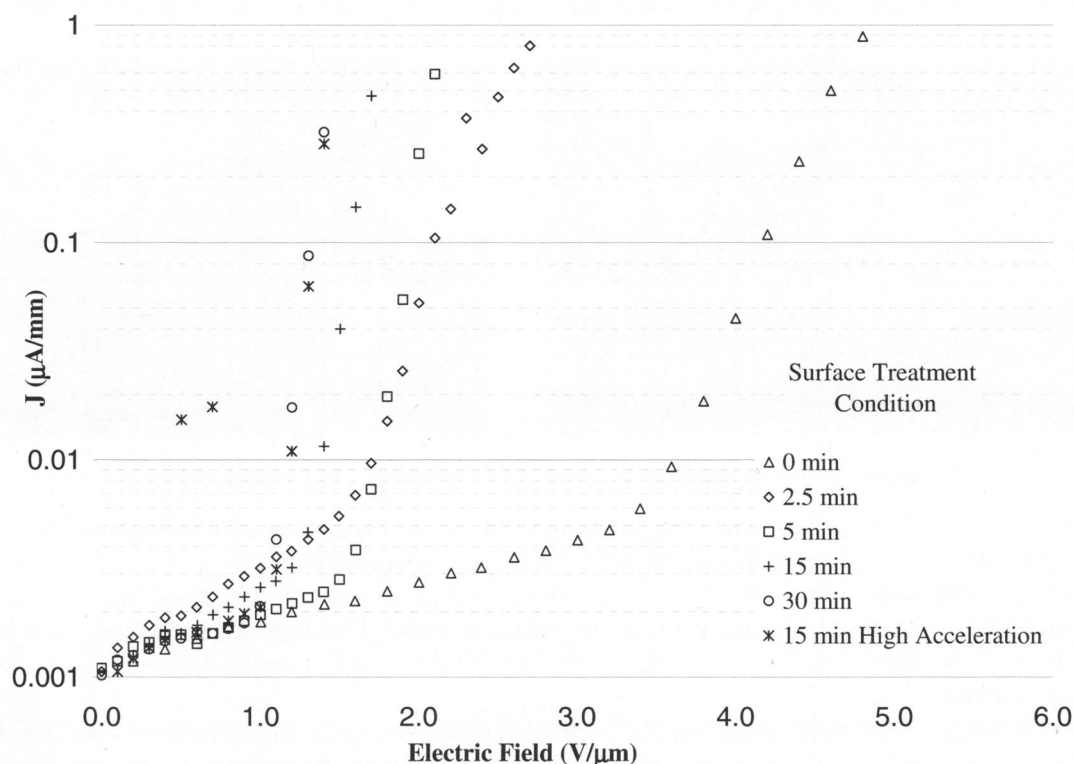


Figure 1 Semilog J-E curves of RVC samples, surface-treated under various conditions.

Although many surface-modifying degrees of freedom exist, for this work, the conditions considered are irradiation time, Argon plasma density and Argon ion beam energy. The plasma density and energy conditions were controlled by means of varying the Argon ion beam current and voltage, respectively. Following surface modification, the cathodes were placed a distance, $d=2\text{mm}$ away from a cathodoluminescent (CL) phosphor coated anode screen (see **Figure 2(a.)**) and measured for I-V characteristics at pressures near 1×10^{-6} torr.

Uniformity of emission was explored using the CL phosphor screen. By creating favorable emission sites away from the sample edges, the uniformity of emission over the cathode surface was greatly improved, as seen by comparison of the non-treated cathode, **Figure 2(b.)**, and the Argon treated sample in **Figure 2(c.)** The discrete areas of emission in **Figure 2c** are due to irradiation through a shadow mask array of openings.

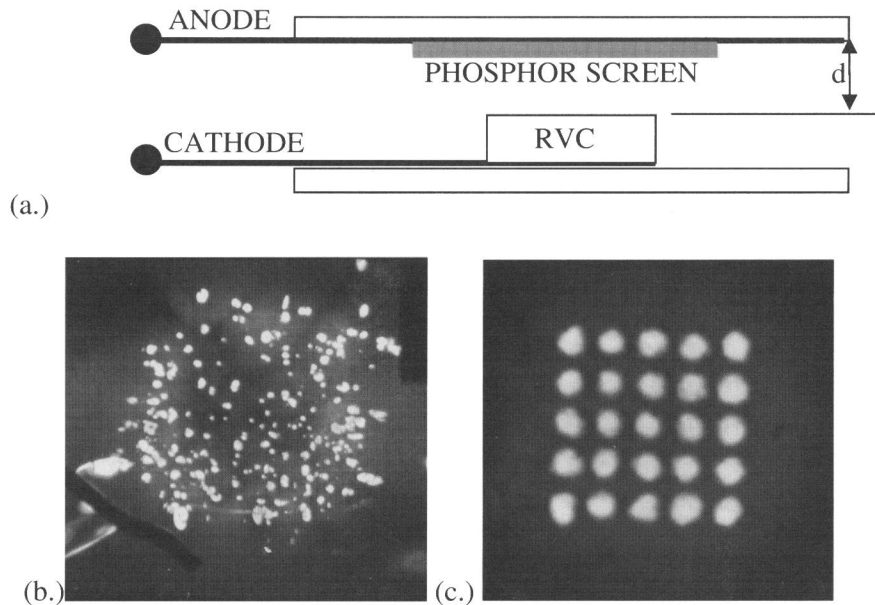


Figure 2 Illumination of a cathodoluminescent phosphor screen due to field emission from (a.) non-treated and (b.) Argon ion surface-treated, 1 cm^2 , RVC cathodes. Emission array in (c.) consists of a 5×5 array of 0.5 mm diameter emission spots, spaced 1 mm apart.

Scanning Electron Microscopy (SEM) and Raman techniques were used in determining and characterizing variations in surface features and bond structure of the material. SEM images, **Figure 3** of the irradiated samples show various morphologies present on the surface, including clusters and carbon nanotubes.

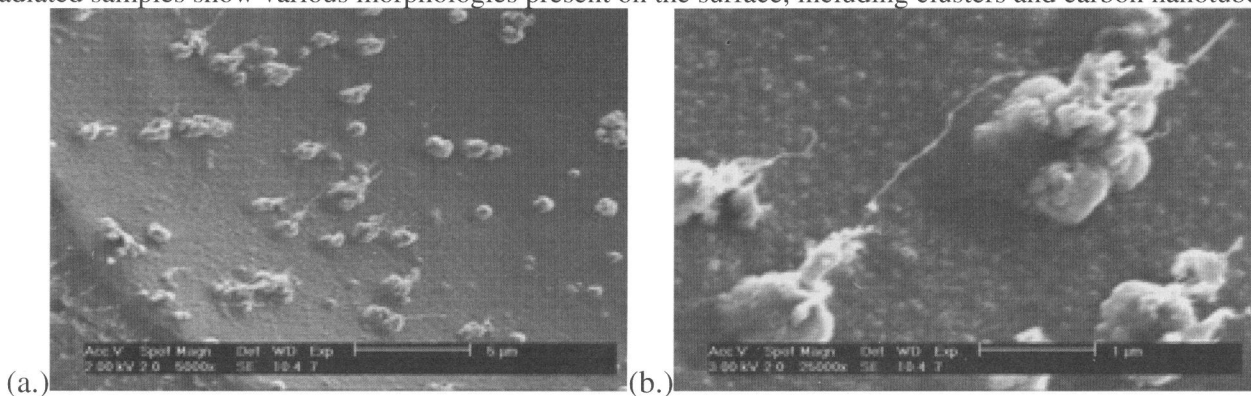


Figure 3 Emission sites of treated RVC as seen at (a.) 5 kx and (b.) 25 kx .

Self-assembly of nanotubes occurs at the apex of the formed carbon clusters as seen in **Figure 3b** at a magnification of 25 kx . These structures act as field-enhanced emission sites.

Raman spectroscopy was performed on all samples and preliminary results have shown shifts in D and G bands which reflect the clustering of carbon at the surface and possibly suggest the changing of bond structure type at the surface. Nuclear Magnetic Resonance (NMR) spectroscopy will be used to verify any change in bond nature.

In summary, surface modification of RVC under various conditions of Argon ion irradiation has been used to create self-assembled, emission-favorable sites. Emission characteristics of treated samples demonstrate marked improvement over non-irradiated samples, possibly due to changes in the types of bond present at the surface.

References:

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3. M.M Cao, R.J. Chacon and C.E. Hunt, "A Field Emission Light Source using a Reticulated Vitreous Carbon (RVC) Cathode and Cathodoluminescent Phosphors", submitted to *IEEE Trans. Industr. Appl.*, 2006.