ION-BEAM MORPHOLOGICAL CONDITIONING OF CARBON FIELD EMISSION CATHODE SURFACES

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Abstract: Square-cm samples of bulk graphite, reticulated vitreous carbon, and paste graphite film have been evaluated for field-emission properties both before and after surface modification using a novel Ar-ion flood bombardment method. The Ar-ion treatment results in a change in surface morphology of the emission cathode which physically resembles results of emission treatments using lasers or other heat sources, as well as results obtained using current or voltage stress treatment methods. Emission properties become more uniform, exhibit less noise, and, in the best cases, match results seen from carbon nanotubes or ultra-nanocrystalline diamond cathodes. The results demonstrate a method for obtaining large total currents at optimal extraction voltages, from large-area, low-cost cathodes. This method is useful for applications, such as field-emission lamps and x-ray tubes, which do not require nanofabricated cathode structures.

Various forms of graphitic and diamond-like surfaces have been investigated for some time as potential field-emission cathode materials for vacuum microelectronics. Some of these, such as carbon nanotubes and ultra-nanocrystalline diamond, have demonstrated substantial emission at comparatively low extraction fields. Other materials, which may be lower cost or more readily manufacturable, such as bulk and paste graphite, reticulated vitreous carbon (RVC), and PAN fibers, although perceived as having great potential for robust large-area, high-current cathodes, do not demonstrate comparably low-field operation without undergoing substantial "training", either through voltage or current stressing, or surface-morphology conditioning with high-energy sources, such as pulse-mode lasers [1]. These treatments have proven to be either time-consuming, unwieldy, or damaging to the cathode. We report here a new, low-cost surface conditioning method for use with inexpensive bulk or paste graphite, RVC, or other glassy carbon forms, which overcomes the deficiencies of field-training or laser conditioning methods, but results in comparable electron extraction performance seen with carbon nanotubes and ultra-nanocrystalline diamond [2].

We report the use of excited flood-ion Ar irradiation on several carbon cathode types, including bulk and paste graphite, molded and machined RVC, and bulk vitreous carbon. The bulk graphite and vitreous carbon samples were machined flat and smooth from commercial stock. The paste samples, which represent the most cost-effective approach, utilize a graphite suspension in an expellable binder [3]. The film samples used were deposited, by screening methods, onto conductive substrates at room temperature, and baked at 150°C for 30m in air. Graphite paste surface morphology and field-emission characteristics, of untreated (as-deposited) samples, is consistent with results found from untreated bulk graphite. The RVC samples were made from pyrolized foamed phenolic.

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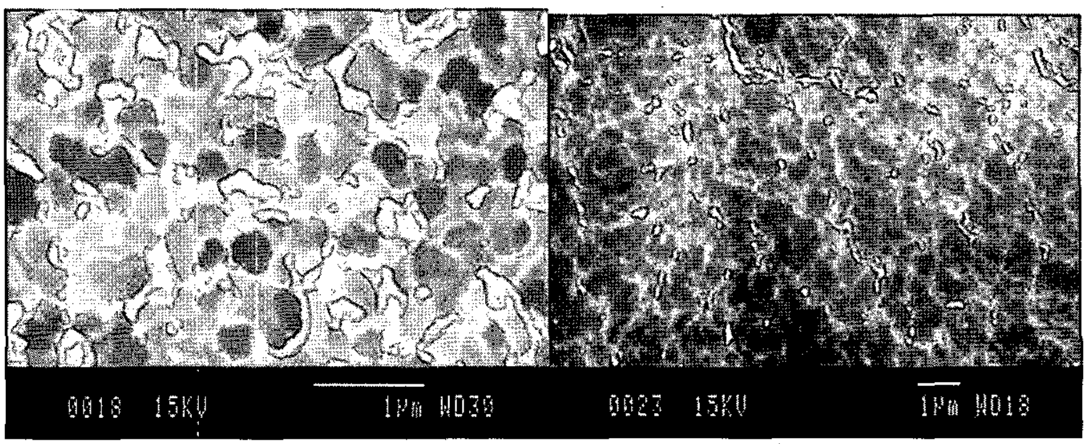
Field-emission measurements from the cathode samples were initially made before any ion treatment. Each sample was subsequently subjected to ion-bombardment. The process is undertaken in medium vacuum for a few minutes; therefore, this is consistent with the requirements of high throughput for manufacturing. The energies are maintained in a range which modifies the cathode surface to emulate the morphology resultant from voltage or current stressing, but does not significantly sputter or reshape the cathode on a macroscopic scale (such as seen using laser treatment.) An example of the change in surface morphology is readily seen comparing Fig.s 1 (a) and (b), which are comparable SEM images of a RVC portion, before (a) and after (b) surface treatment. It is noteworthy that although the microscopic surface morphology changes substantially (resulting in the formation of countless nanoscopic individual emission sites), such as what is seen through other carbon training methods, the macroscopic surface remains unaltered. This differs substantially from results obtained using lasers or other heat sources.



(a) (b)

Figure 1: Samples of RVC cathode, before (a) and after (b) surface treatment

Measurements were made at approximately $5x10^{-7}$ Torr base pressures, using both stainless steel and P22 phosphor anodes (for imaging emission uniformity.) Untreated bulk and paste graphite samples emit at unstable, high extraction fields; these results are consistent with past results obtained by many others. Untreated RVC samples emit substantially better, as expected; but these exhibit unacceptable levels of noise and non-uniformity in emission (over the surface area.) All samples showed improved uniformity of emission and lower extraction field after flood Ar-ion bombardment treatment. Notably, the paste samples have the more controllable results. It is believed this is because the thickness of the film (and the resistance of the layer) is easily, and precisely, variable. These samples are most-easily optimized for emission characteristics. The resulting cathodes emit in the 1-2 V/μm range, depending on the substrate type and extent of irradiation. These results are comparable to the best emissive surfaces produced by other, more costly methods [1], or using less robust materials.

[1] A. G. Chakhovskoi, C. E. Hunt, et al., *Proc. of IVMC-2001*, p. 263, IEEE Press
[2] M. Hajra, C. E. Hunt, et al., *J. Appl. Phys.*, **94**, 4079 (2003)
[3] US Patent #6,409,567