Ultra-clean carbon nanotube electron guns for use in space

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Reliable mass spectrometers developed for spaceflight instruments could benefit future terrestrial applications.

Interest in carbon nanotubes (CNTs) for field-emission applications has been growing due to their low operating voltages and power consumption. For the same reasons, spaceflight instrument developers recognize the appeal of CNT sources for in-situ tools, such as an electron-impact ionization mass spectrometer (MS).¹

A robust, high-performance MS could enable missions for which a long and reliable lifetime is important, such as a long-duration Mars rover, entry probes to the giant gas planets, or to study the upper atmosphere of Venus, Mars, Titan, or a cometary coma. Previously, we have shown that CNT cathodes exhibit favorable power consumption, but their lifetime is diminished by the use of polymeric assembly materials.^{2,3} Here, we report on efforts to improve the reliability of a modular CNT electron gun for use in mass spectrometry.

In an electron-impact MS, an electron beam ionizes a sample gas through momentum transfer and the ions can then be analyzed using electromagnetic fields. Instrument sensitivity is in part determined by the number of electrons and how efficiently they ionize the sample. As a result, a high-performance electron gun must generate at least microamps of current at the low energies (70–100eV) that are most efficient for ionization.

For use in spaceflight, the electron gun must possess maximum reliability but minimum contamination, and only the cleanest construction materials should be used. Previously, we found that CNT emission can persist for hundreds of hours, but the polymers used were likely to be detrimental to the instrument's lifetime.

Our new ultra-clean approach will provide the MS with a low background signal and low pressure in the cathode vicinity for a longer lifetime. Using patterning, etching, bonding, and alignment micro-fabrication protocols, we have constructed a highly redundant array of CNT towers that are

Figure 1. (a) Patterned micron-scale CNT emitter array bonded to extraction grid. (b) Microamps of current are produced at low extraction voltage. Fowler-Nordheim tunneling describes the extraction of electrons from the carbon nanotube using an electric field. J = current density. E = Electric field. K values are constants.

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Figure 2. CNT cathode integrated with silicon lens elements. Inset image shows that the electron gun interfaces to the MS via metal shielding at the output.

precisely aligned with a closely spaced extraction grid to achieve emission at the low voltages required, as shown in Figure 1.

Other groups have fabricated CNT emitters and the grid using a single substrate^{4,5} or micro electromechanical systems (MEMS) pop-up techniques.⁶ We integrate a prefabricated CNT array and grid using a low-temperature process. One advantage is that the CNTs are patterned and grown under ideal conditions before mating to the grid, and the high-quality CNTs remain as-grown and unaffected by grid integration. Moreover, our procedure is compatible with other emitters.

We have recently packaged the cathode-grid component with electrostatic lenses into a complete electron gun, as pictured in Figure 2. Testing has revealed that this design produces microamps of current between 150 and 200V, a four-fold improvement over previous cathodes. To achieve our target voltage of 100V we will reduce cathode-grid spacing, but our approach makes this straightforward.

Our modular, ultra-clean CNT electron gun design is capable of producing microamps of current at the low voltages demanded by electron-impact ionization MS. After further testing and development, we expect improvements to emitter lifetime, ionization efficiency, and reduced background signal, as compared to previous prototypes. We intend to use our findings to guide future modifications to the MS design for further enhanced sensitivity, reliability, and performance in terrestrial and space-based instruments.

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