Extreme Brightness: Reaching the Ultimate Limits of the Electron Beam

J. D. Jarvis, B. Ivanov, J. L. Kohler, C. A. Brau
Dept. of Physics and Astronomy, Vanderbilt University, Nashville, TN
jonathan.d.jarvis@vanderbilt.edu
N. Ghosh, W.-P. Kang, J. L. Davidson
Dept. of Electrical and Computer Eng., Vanderbilt University, Nashville, TN

We report recent results from field emission microscopy studies of multiwall carbon nanotubes (MWCNT) and from energy spectrum measurements of beams from diamond field emitters (DFE). As expected, resonant tunneling through adsorbed species on the emitter surface is an important and sometimes dominant effect. For diamond emitters our observations include order-of-magnitude emission enhancement without spectral broadening, complex spectral structure, and sensitivity of that structure to the applied electric field. For carbon nanotubes we have observed electron beams from individual adsorbates which are estimated to approach the maximum beam brightness allowed by Pauli exclusion. We suggest the use of highly polarizable small molecules on covalent-carbon field emitters for the production of electron beams with unprecedented, and perhaps quantum limited, brightness.

The development of CNTs as field emitters for the purposes of microscopy, lithography, radiation generation, and display production has been a protracted endeavor. Working in their favor, CNTs have excellent emission stability, high activation energy for thermal migration, excellent current throughput capacity, and a high degree of chemical inertness. Not surprisingly, these properties extend to other covalent-carbon structures such as CVD diamond field emitters. DFEs have shown great promise as high-brightness electron-beam sources in recent years [1,2]. One of the more exciting revelations regarding CNTs and DFEs has been the realization that resonant tunneling through adsorbed species can be exploited for the generation of multi-microamp-level beams with perfect transverse coherence [2].

For resonant tunneling through a single molecule the electron source size is on the order of the electron wavelength. Estimates of the transverse momentum spread of the resulting electron beams suggest that the transverse emittance is Heisenberg limited. Such beams have been produced using single atom tungsten, or single atom noble-metal field emitters, however the relatively weak binding of the metal atoms has limited the total current that can be extracted to the sub-microamp regime. In this paper we will discuss our efforts to generate, stabilize, and characterize, multi-microamp beams from individual molecules on CNTs, such as the one shown in Figure 1.

[1] J. D. Jarvis, H. L. Andrews, C. A. Brau, B. K. Choi, J. Davidson, W. -P. Kang, Y. -M. Wong, J. Vac. Sci. Technol. B **27**, 5, pp. 2264-2269 (2009)
[2] J. D. Jarvis, H. L. Andrews, B. Ivanov, C. L. Stewart, N. de Jonge, E. C. Heeres, W. Kang, Y. M. Wong, J. L. Davidson, C. A. Brau, , J. Appl. Phys. **108**, 094322 (2010)

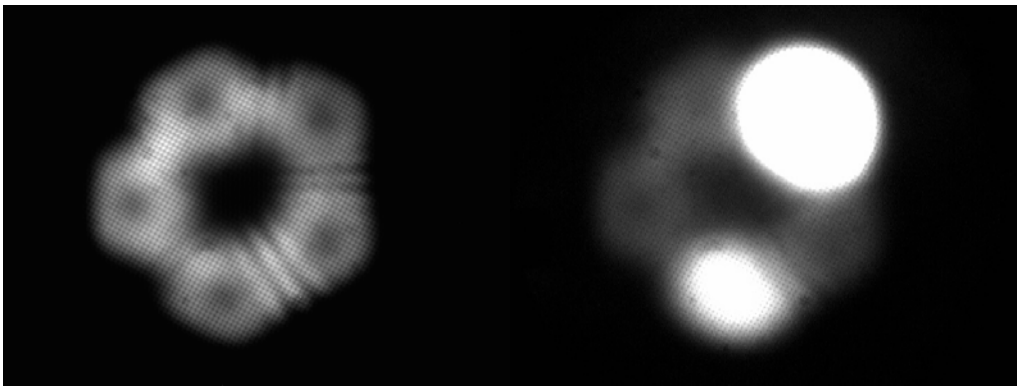

Figure 1: A clean, closed-cap MWCNT serves as an excellent testbed for the examination of single molecule electron sources. Left: field emission micrograph of a clean MWCNT, clearly dominated by the pentagonal dislocations on the emitter surface. Right: a 1-μA beam originating from a single molecule, likely CO_2 or N_2 (bottom pentagon), and a 10-μA beam originating from a single, unknown molecule (upper right pentagon).