



# Synthesis and Field Emission Properties of Carbon Nanostructures

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## Abstract

This dissertation focuses on developing carbon nanostructures for application as the electron emissive material in novel back-gated triode field emission devices. The synthesis, characterization, and field emission properties of carbon nanostructures, including 1-D carbon nanofibers (CNF), 2-D carbon nanosheets (CNS), and chromium oxide coated carbon nanosheets (CrOx-CNS), are presented in this work.

First, we have fabricated aligned carbon nanofiber based back-gated triode field emission devices and confirmed the validation of these devices. 1-D carbon nanofibers were directly synthesized on blank TiW substrates using direct current plasma enhanced chemical vapor deposition. It was found that the morphology of carbon nanofibers could be tuned from spaghetti-like to aligned nanofibers by adjusting the applied plasma power. Field emission properties of spaghetti-like and aligned carbon nanofibers on blank TiW substrates were studied using the cartridge holder assembly. Results demonstrated that spaghetti-like carbon nanofibers had better field emission performance than aligned carbon nanofibers. However, the electrostatic simulation of the triode device demonstrated that aligned carbon nanofibers could yield the best device performance.

Second, we have demonstrated that carbon nanosheets, a 2-D carbon nanostructure developed by our group, were a competitive electron emissive material for application as the cold cathode in vacuum microelectronic devices. Carbon nanosheets were synthesized on a variety of substrates, without the need for catalysts, by radio frequency plasma enhanced chemical vapor deposition. Materials characterization results revealed that carbon nanosheets consisting of vertically oriented ultra-thin graphitic sheets terminating with 1-3 graphene layers were hundreds of nanometers in length and height but less than 4 nm in thickness. By using the diode holder assembly, field emission properties of carbon nanosheets were studied from a broad perspective, including turn-on and threshold field, maximum total current, emission lifetime and stability, and emission uniformity. The result revealed that the threshold field of nanosheets ranged from 3.5 to 5.2 V/ $\mu\text{m}$ , which was in the same range as 1-D carbon nanotubes and 3-D diamond. Moreover, the lifetime of nanosheets showed milliampere current emission (1.5 mA in a dc mode and 13 mA in a slow pulse mode) for hundreds of hours without significant current degradation after the conditioning process. However, the emission uniformity of nanosheets were quite poor due to the existence of hot runners during PEEM and FEEM observations. Further, the effectiveness of carbon nanosheet based back-gated triode field emission device was briefly introduced.

Third, we have also demonstrated that the emission uniformity of nanosheets could be improved by incorporating a thin chromium oxide coating. The chromium oxide coated carbon nanosheets were fabricated by vacuum evaporating thin chromium films on carbon nanosheets and sequentially exposing them to the atmosphere. The stoichiometry of the oxide was estimated to be 0.37, very close to Cr<sub>2</sub>O<sub>3</sub>. PEEM and FEEM observations showed excellent emission uniformity of chromium oxide coated carbon nanosheets. Moreover, field emission properties of chromium oxide coated carbon nanosheets were dependent on the coating thickness. The enhanced field emission performance could be expected from chromium oxide coated carbon nanosheets with an appropriate thickness (from 1.5 nm to 15 nm).

