Metallic Carbon Nanotubes for Nanoelectronic Interconnects

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It was realized, in recent years, that one of the stumbling blocks for miniaturization of microelectronic chips could be "interconnects." Interconnects link millions of transistors on the chip for efficient communication among all of the components. The International Technology Roadmap for Semiconductors identified five challenges for interconnect development, and two of them depend on materials: 1) new materials to meet conductivity requirements and reduce dielectric permittivity; and 2) three-dimensional (3-D) control of interconnect features to achieve circuit performance and reliability. The Johnson Space Center (JSC) Applied Nanotechnology Team is investigating the use of single-wall carbon nanotubes (SWCNTs) to replace these interconnects and is part of the State of Texas' Alliance for Nanoelectronics, comprising a range of industry, academic, and government institutions.

SWCNTs have very high electrical conductivity and the "armchair" tubes have been considered as "quantum conductors" with metallic properties and superior current-carrying capacity compared to copper. Also, nanotube interconnects can function as efficient heat pipes because of superior anisotropic thermal conductivity (better than diamond along the tube axis). It is possible to have 3-D interconnect structure using carbon nanotube forests.

An important step toward achieving these goals is to produce "type-specific" tubes, preferably armchair tubes. There was some earlier work on a small-scale production of semi-conducting tubes using plasma-enhanced Chemical Vapor Deposition (CVD). In a recent work, semi-conducting tubes have been formed in a CVD synthesis using silica-supported Cobalt catalysts. It is speculated that by controlling the size and surface preparation of the precursor catalyst nanoparticles, one can control the type of carbon nanotubes grown and thereby control the electrical properties.

The current work is based on a collaborative effort (Quantum Conductor Project) started in 2005 between Rice University and NASA-JSC to grow armchair tubes using the laser production method. It is noted from earlier experiments that certain conditions in laser production seem to produce an abundance of armchair tubes. It is speculated that this occurs when the laser-produced plume and the active material are exposed to several cycles of laser shots ("refried-beans"). Recently, some tests were conducted to achieve this condition by zero-flow, and the preliminary results indicate enhancement of armchair tubes. The results from the chirality determination by nano-beam electron diffraction of the samples collected from different regions of the flow-tube under "zero-flow" are shown in figures 1 and 2.

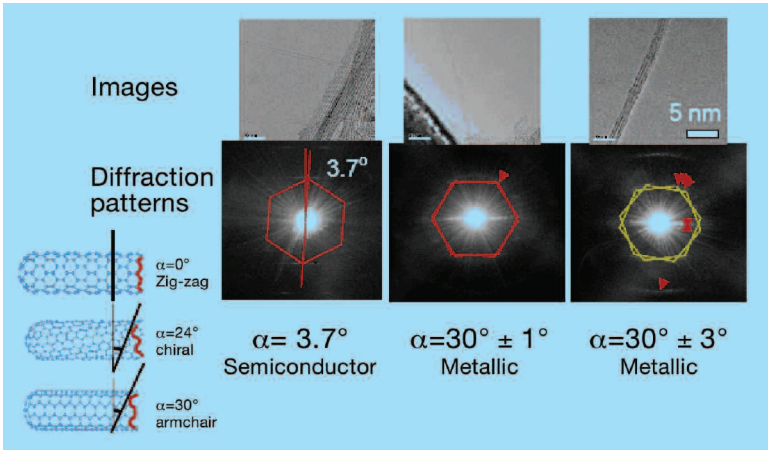

Fig. 1. *TEM images and e-diffraction patterns of armchair quantum-wire (AQW) samples, the second image has two tubes and the third image has three tubes.*

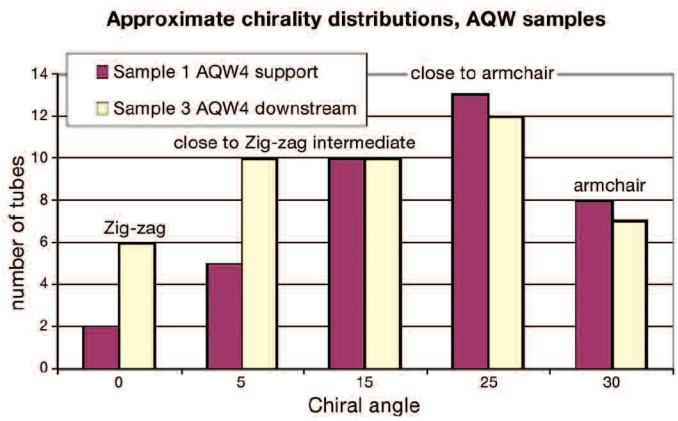

Fig. 2. Results from electron diffraction of samples from "zero-flow" condition.

These preliminary results indicate increased amounts of armchair tubes in the "zero-flow" condition. Further enhancement can be achieved by modifications of the laser setup to perform the "refried-beans" concept. One such configuration is shown in figure 3. This modification will divert the flow through another inner tube where a third laser will radiate the slow-moving plume reactants. Experiments are in progress in evaluating the material produced under different flow conditions mimicking different stages of "refried-beans." Efforts are also underway to improve methods to separate the metallic tubes from the rest of carbon nanotube material.

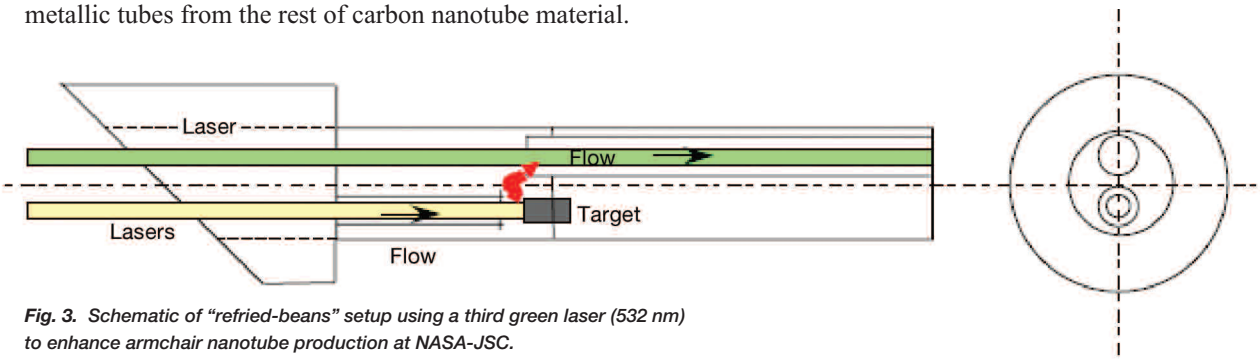

Fig. 3. Schematic of "refried-beans" setup using a third green laser (532 nm) to enhance armchair nanotube production at NASA-JSC.