Review of Laser Ablation Process for Single Wall Carbon Nanotube Production

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Abstract

Different types of lasers are now routinely used to prepare single wall carbon nanotubes (SWCNTs). The original method developed by researchers at Rice University utilized a "double pulse laser oven" process. A graphite target containing about 1 atomic percent of metal catalysts is ablated inside a 1473K oven using laser pulses (10 ns pulse width) in slow flowing argon. Two YAG lasers with a green pulse (532 nm) followed by an IR pulse (1064 nm) with a 50 ns delay are used for ablation. This set up produced single wall carbon nanotube material with about 70% purity having a diameter distribution peaked around 1.4 nm. The impurities consist of fullerenes, metal catalyst clusters (10 to 100 nm diameter) and amorphous carbon. The rate of production with the initial set up was about 60 mg per hour with 10Hz laser systems.

Several researchers have used variations of the lasers to improve the rate, consistency and study effects of different process parameters on the quality and quantity of SWCNTs. These variations include one to three YAG laser systems (Green, Green and IR), different pulse widths (nano to microseconds as well as continuous) and different laser wavelengths (Alexandrite, CO, CO_2, free electron lasers in the near to far infrared). It is noted that yield from the single laser (Green or IR) systems is only a fraction of the two laser systems. The yield seemed to scale up with the repetition rate of the laser systems (10 to 60 Hz) and depended on the beam uniformity and quality of the laser pulses. The shift to longer wavelength lasers (free electron, CO and CO_2) did not improve the quality, but increased the rate of production because these lasers are either continuous (CW) or high repetition rate pulses (kHz to MHz). The average power and the peak power of the lasers seem to influence the yields. Very high peak powers (MW/cm^2) are noted to increase ablation of bigger particles with reduced yields of SWCNTs. Increased average powers seem to help the conversion of the carbon from target into vapor phase to improve formation of nanotubes. The use of CW far infrared lasers reduced the need for the oven, at the expense of controlled ablation.

Some of these variations are tried with different combinations and concentrations of metal catalysts (Nickel with Cobalt, Iron, Palladium and Platinum) different buffer gases (e.g. Helium); with different oven temperatures (Room temperature to 1473K); under different flow conditions (1 to 1000 kPa) and even different porosities of the graphite targets. It is to be noted that the original Cobalt and Nickel combination worked best, possibly because of improved carbonization with stable crystalline phases. The mean diameter and yield seemed to increase with increasing oven temperatures. Thermal conductivity of the buffer gas and flow conditions dictate the quality as well as quantity of the SWCNTs. Faster flows, lower pressures and heavier gasses seem to increase the yields.

This review will attempt to cover all these variations and their relative merits. Possible growth mechanisms under these different conditions will also be discussed.