Water Vapor and Carbon Nanotubes

Controlling fabrication, improving yield and reducing contamination using RainMaker HS

For repeatable and reliable CNT fabrication, tools are needed to control whether CNT are single or multi-wall, straight or bent, long or short, and clean or dirty. Water vapor addition to the process turns out to be the main 'control knob' for all of these processes. Precise delivery of water vapor will determine what the CNT looks like, what the yield is, and how contaminant free the structure is. Water vapor is both the gas pedal and the steering wheel for CNT fabrication.

Length

Water vapor is used to control the growth of CNT and remove contamination post growth. The formation of the carbon nanotube takes place at the catalyst site as the carbon is incorporated into the structure. However not all the carbon is used and some deposits as amorphous carbon and chokes off the reaction at the catalyst site. By adding a small amount of water vapor, the catalyst is kept free of debris and able to continue converting the carbon source in the CNT structures.

A small amount of water vapor introduced into the reaction chamber can combust the amorphous carbon, converting it into CO2 which can then be purged from the chamber. Removal of the amorphous carbon allows the reaction to continue.

Structure of CNT

The ability of CNT to branch or turn has been attributed to catalyst particles contacting the assembly end of the CNT far from the CNT substrate. These particles can be removed by the addition of water vapor. In addition, water vapor was shown to change the growth structure from multi-walled to single wall. Metallic species are the sites for bends and branches of CNT. Addition of water vapor can react with metallic species to volatize and remove them.

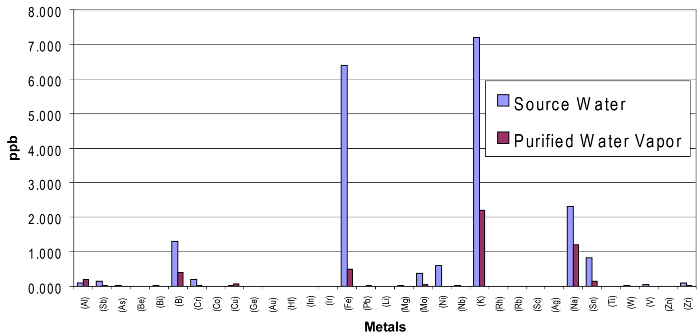

Figure 1: Tests using the RainMaker Humidification System to remove contaminants reveal a reduction of 75% for metals.

Contamination of metals and amorphous carbon

Single-walled nanotubes grown with water vapor are clean and free from amorphous carbon and metal particles.

Continuity of tube wall

While small additions of water speed up the assembly process by keeping the catalyst site free, adding more water leads to breaks in the CNT walls. This leads to more perforations in the tubular structure, which is beneficial for applications such as hydrogen adsorption. Further addition ceases the process.

Post CVD Cleaning

Once the tubes have been constructed, remaining amorphous carbon and metallic contaminants need to be removed by weak oxidizers. Standard processes using O2, non-specifically attacked the entire structure leading to CNT degradation. Generic semiconductor approaches such as SC1/SC2 cleaning or use of halogenated gases leads to non-specific degradation of the CNT. These and other aggressive wet cleaning technologies lead to large chemical usage and waste stream generation. The use of water vapor at temperatures above 200˚C attacks only the amorphous carbon debris and metallic contaminants.

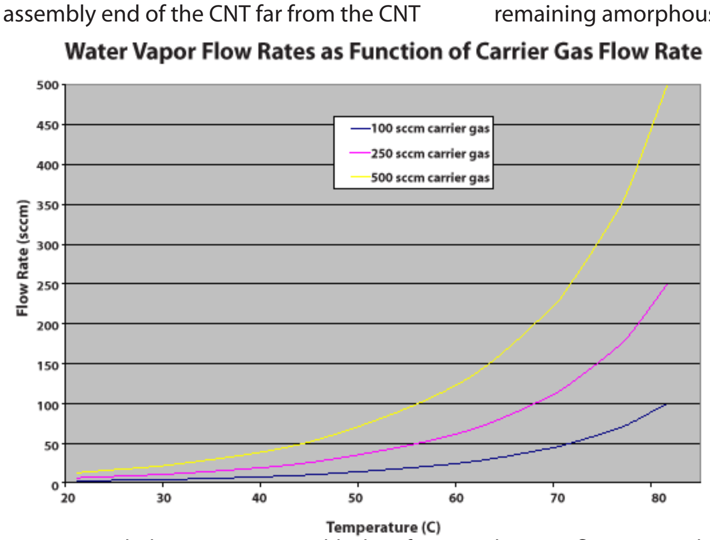

Figure 2: With the RHS, you can add a lot of water relative to flow rate and control water vapor for a specific flow rate by adjusting temperature.

RainMaker Humidification System

The RainMaker Humidification System delivers water vapor into both atmospheric and vacuum process, which otherwise eliminates many alternatives for delivery of water vapor. No other technique can take industrial grade DI water and convert it directly in a single pass to the ultrapure degassed water vapor needed for CNT fabrication. RASIRC technology is the only water purification that can separate oxygen from water vapor and deliver ultrapure steam under precise control to the process.

About RASIRC

RASIRC focuses on cutting-edge applications where the ability to deliver ultrapure steam is critical to film performance. RASIRC product lines, including the RASIRC Steamer direct water vapor delivery system and the RainMaker Humidification System, are designed to provide ultrapure water vapor precisely to critical processes. These safe and low cost techniques are appropriate for applications that include CNT, photovoltaic cells, MEMS, and semiconductor.

RASIRC®

www.rasirc.com

(858) 259-1220 • info@rasirc.com

11760 Sorrento Valley Road, Suite E

San Diego, CA 92121