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From continuous FC-CVD synthesis in the gas phase to direct deposition of CNT thin films – progress during 25 years

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Abstract:

The long route to develop continuous CNT synthesis and thin film manufacturing will be discussed. It started from combustion nanoparticle studies based on aerosol science and technology methods. Combustion processes generate many kinds of oxide and carbon based nanoparticles. Next step was the production of fullerene, metal (Au, Fe, Cu) as well as metal oxide (TiO2, FexOy, CuxOy) crystalline nanoparticles via gas phase chemical vapor deposition, i.e. via aerosol synthesis of materials using laminar flow reactors. SWCNTs were formed for the first time when studying Cu ands CuxOy nanoparticle synthesis using copper acac as the precursor in nitrogen carrier gas. When introducing CO to reduce copper oxide nanoparticles, some CNTs as well hollow carbon nano-onions were formed. The next step was to use physical evaporation as well as ferrocene decomposition to produce Fe nanoparticles and CO as the carbon source. In the aerosol science, it is a common method to collect particles from the gas phase via surface filtration. Accordingly, the CNT films were collected onto a filter surface after the reactor gas had cooled to ambient temperature. When the CNTs are long and clean enough, the CNT film can be press-transferred from the filter surface to any substrate to make a CNT film [1]. When the substrate has an open area, free-standing CNT films can be directly manufactured [2]. Alternatively, CNTs can be directly deposited onto a desired substrate via thermophoretic as well as via electric field induced deposition methods. The film thickness can be controlled via the collection time as well as via the concentration of the CNTs in the FC-CVD synthesis reactor gas. The CNT film conductivity when normalized by the light absorption increases with increasing nanotube length and decreasing the bundle diameter [3]. As no post synthesis purification, i.e. sonication and surfactant addition is neededand pristine CNTs will produce the film, state-of-the-art conductivity, uniform films with the sheet resistance below 25 ohms/sq at 90 % transmittance have been manufactured [4]. Freestanding CNT films find applications in e.g. EUV lithography and laser inspection of wafers.

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Reference:

[1] E.I. Kauppinen et al. NanoLetters 10, 4349-4355 (2010)
[2] E.I. Kauppinen et al. ACS Nano 5, 3214-3221 (2011).
[3] E.I. Kauppinen et al. Carbon 103, 228-235 (2016).
[4] E.I. Kauppinen, I. Jeon et al. Adv. Funct. Mater. 33, 2213374 (2023).

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