Single-walled carbon nanotubes: from synthesis to applications

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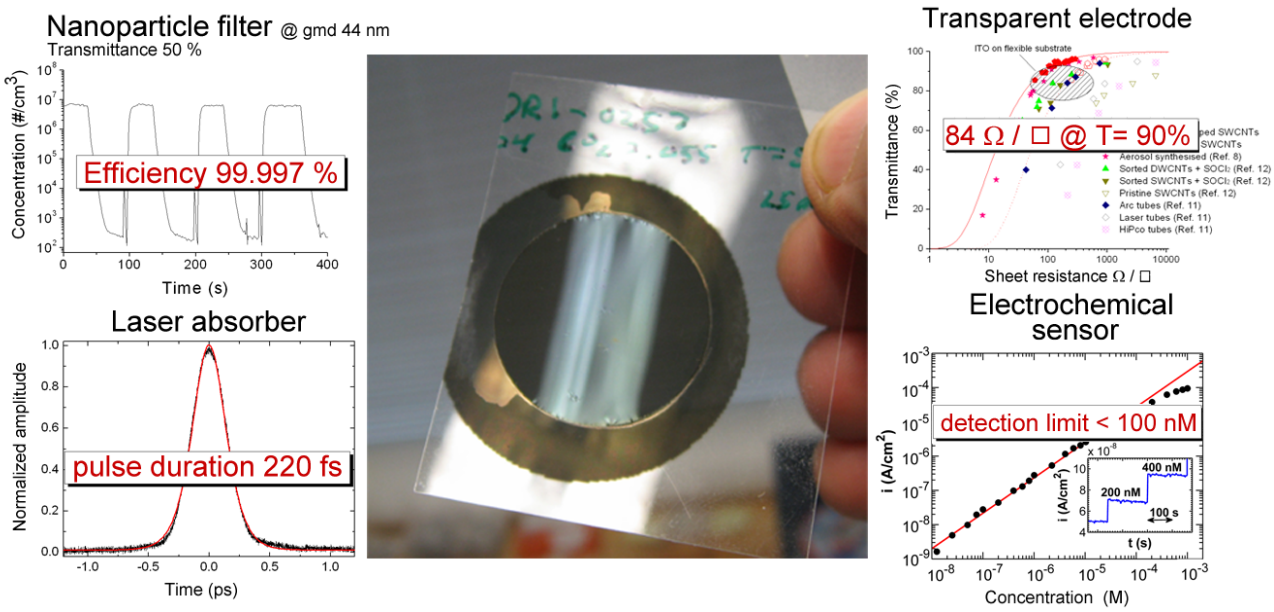

Multifuctnional Free-Standing SWCNT Film.

Carbon nanotubes (CNTs) are a unique family of materials exhibiting diverse useful chemical and physical properties. The CNTs and especially single-walled CNTs (SWCNTs) were found to have exceptional mechanical, thermal and electronic properties. Among different routes to synthesize SWCNTs, an aerosol CVD method is one of the most promising. This method allows growing high quality and cleaning SWCNTs with certain diameters and lengths. CNTs can be easily deposited onto practically any substrate, including temperature nontolerant polymers, so that time-consuming steps of CNT purification from the catalyst and support, dispersion and deposition processes are avoided. Supplementary advantages of the aerosol method are possibilities to on-line control of the CNT quality and separate individual and bundled CNTs. This continuous aerosol CVD process is one of the most promising and powerful methods for the high-yield synthesis at controlled conditions. (Nasibulin & Shandakov, 2010)

This paper reviews the latest results obtained by two different aerosol synthesis methods elaborated in our group. In the first method, catalyst particles were produced by evaporating catalyst material from resistively heated Fe wire (a hot wire generator, HWG method) (Nasibulin *et al.*, 2005). The second method is based on ferrocene vapor decomposition in carbon monoxide atmosphere (Moisala *et al.*, 2006).

We report the investigations of the mechanism of single-walled carbon nanotube formation (Anisimov *et al.*, 2010; Nasibulin *et al.*, 2006) and charging of CNTs in the gas phase due to the bundling process (Nasibulin *et al.*, 2008). The paper also discusses the discovery and growth mechanism of a novel hybrid material, NanoBuds (Nasibulin *et al.*, 2007), SWCNTs with covalently attached fullerenes.

Direct integration of the CNTs produced by the aerosol methods into different applications, especially for high-performance flexible electronics, is discussed. (Kaskela *et al.*, 2010; Sun *et al.*, 2013; Sun *et al.*, 2011). Produced SWCNT/polyethylene composite films have exhibited excellent optical and electrical properties as well as high mechanical flexibility. It was found that the electrical conductivity of the SWCNT films could be significantly improved by ethanol densification and chemical doping. SWCNT/polyethylene thin films demonstrated excellent cold electron field emission properties. We have fabricated state-of-the-art key components from the same single component multifunctional SWNT material for several high-impact application areas: high efficiency nanoparticle filters with a figure of merit of 147 Pa^{-1}, transparent and conductive electrodes with a sheet resistance of 84 Ω/□ and a transmittance of 90%, electrochemical sensors with extremely low detection limits below 100 nM, and polymer-free saturable absorbers for ultrafast femtosecond lasers.

Wide application potential of our SWCNT films is demonstrated by successful energy applications in photovoltaic devices (Aitola *et al.*, 2013; Cui *et al.*, 2014) and supercapacitors.

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