RECENT ADVANCES ON N-DOPED CARBON NANOTUBES: APPLICATIONS AND BIOCOMPATIBILITY

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By doping carbon nanotubes it is possible to alter significantly the electronic, mechanical and chemical properties of the tubes. This possibility opens up new avenues in the production of nanomaterials with desired properties using different dopants. Therefore, the controlled production of N-doped carbon nanotubes will be discussed. The field emission properties of doped tubes, their use as gas sensors or protein immobilizers will also be discussed. It will be also demonstrated that Ag and Au particles could be easily anchored on the surface of N-doped nanotubes. Possible mechanisms will be discussed.

We will present the first results related to the fabrication of CN_x nanotube–polystyrene (PS) composites, which were produced by a novel polymerization technique using a "grafting from" route using Nitroxide Mediated Radical Polymerization (NMRP) and atomic transfer radical polymerization (ATRP). We demonstrate using HRTEM and EELS that the tube material was covalently bonded to the PS chains, thus forming brush-like structures. These polymerized CN_x nanotubes form uniform dispersions in organic solvents. The results are novel and constitute will results in further developments related to the chemistry of CN_x nanotubes and fabrication of novel polymer composites.

Finally, the bio-applications of CN_x nanotubes will be discussed in detail. In particular, comparative toxicological studies of CN_x MWNTs and pure carbon multi-walled nanotubes (MWNTs) on mice reveal that CN_x tubes appear to be far less harmful. For example, using extreme high doses of CN_x nanotubes (e.g. 5mg/kg), no lethal effects were observed on the mice, which is in contrast to previous reports using MWNTs or SWNTs. Interestingly, pure MWNTs appeared to be lethal at all doses tested for intratracheal instilation, whereas CN_x MWNTs were not.

We also carried out a detailed cell viability study with amoeba and different types of nanotubes: pure carbon MWNTs and N-doped MWNTs. We found that when the cells were incubated with CN_x MWNTs, they survived and even proliferated at all doses tested. In contrast, most of the amebas' population died after 8 hs of incubation with undoped MWCNTs. Therefore, we believe that CN_x nanotubes are more biocompatible when compared to undoped nanotubes (either single- or multi-walled).

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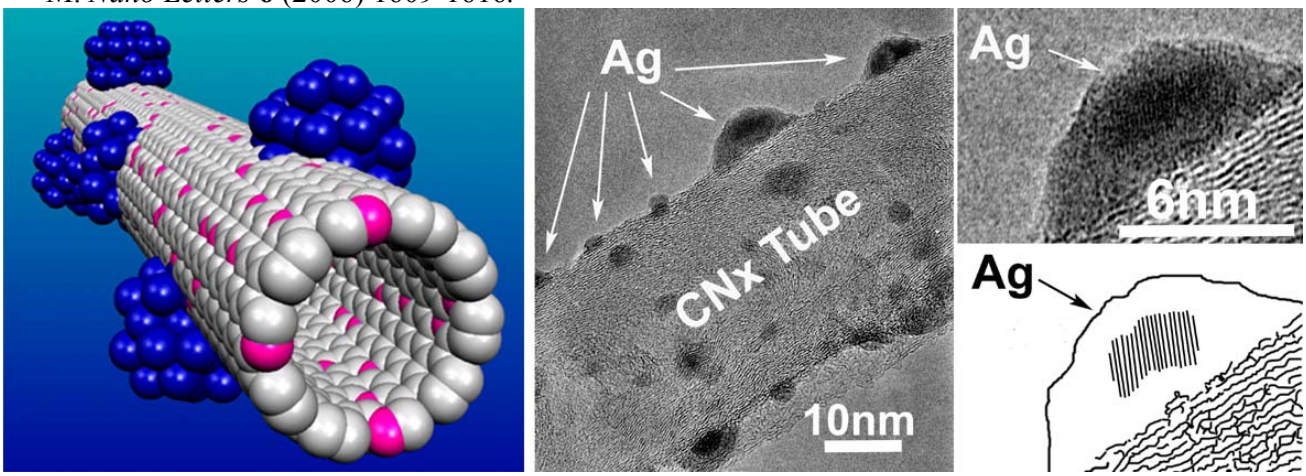

Fig. 1 HRTEM images of Ag-nanoparticles deposited on N-doped and undoped carbon nanotubes: **(a)** Ag-nanoparticles (2-5 nm in diameter) deposited on CN_xMWNTs. The image reveals a nanotube bundle which is uniformly coated with Ag-nanoparticles, and **(b)** Ag nanoparticles (10-20 nm in diameter) poorly coating carbon MWNTs (undoped); the latter sample was produced by the reduction of $AgNO_3$ in DMF in presence of MWCNTs. Note the clear absence of Ag-nanoparticles covering the undoped material.

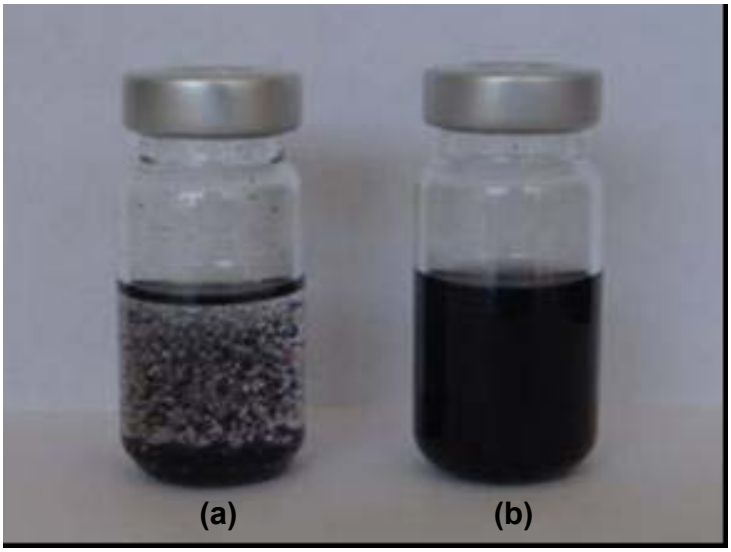

Fig. 2 Vials containing CN_x tubes grafted with polystyrene (PS). There are clear differences in organic solvents (i.e. toluene) between (a) physical blend of PS and CN_x tubes, and (b) PS-CN_x tubes polymerized in-situ.

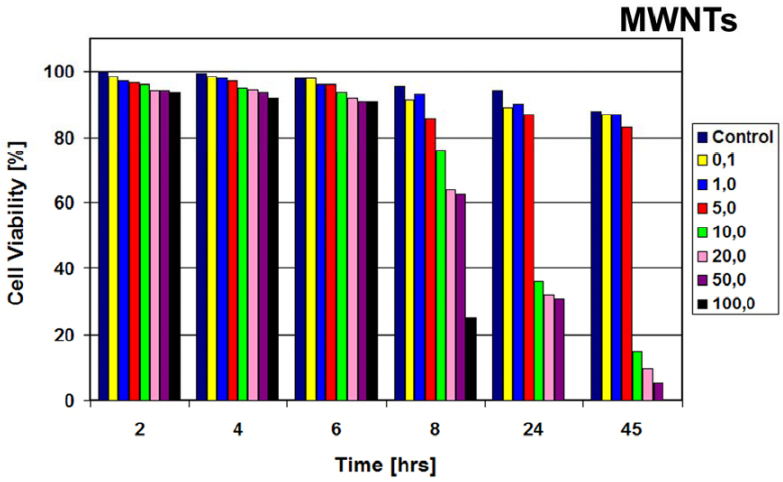

Fig. 3 Cell viability of *Entamoeba histolytica* trophozoites incubated with different concentrations of undoped MWCNTs evaluated at the indicated times.

Mauricio Terrones

Mauricio Terrones is a native of Mexico City born in 1968, obtained his B.Sc. degree in Engineering Physics at Universidad Iberoamericana (1992, Mexico City). He received the highest grade point average (GPA) award and the highest recognition for his B.Sc. Thesis ("Mención Honorífica"). In that year, he was also awarded a Medal for being one of the best students of México (a recognition given by the Mexican President). After lecturing at Universidad Iberamericana for two years, in 1993 he was awarded a Fulbright fellowship to carry out doctoral studies in the USA. However, he did not take this fellowship and preferred to travel to the UK and work for a Ph.D. with Prof. Harold W. Kroto (Nobel Prize Winner in Chemistry 1996). He pursued his graduate studies fully sponsored by CONACYT-Mexico. In 1997, he obtained his doctorate degree and started to work as a postdoctoral research fellow at the University of Sussex. After a postdoctoral year, funded by the Materials Research Laboratory (UC-Santa Barbara) and the Royal Society, he was appointed Research Fellow at the Fullerene Science Centre and was funded by the Royal Society.

In 1999, Mauricio Terrones returned to Mexico and became a faculty member as Assistant Professor "category A", at the Institute of Physics –UNAM (Mexico). In 1999, he was also awarded an Alexander von Humboldt Fellowship to carry out research at the Max-Planck-Institut für Metallforschung in Stuttgart (Germany). In April 2001, he became full Professor (category "C") at the Instituto Potosino de Investigación Científica y Tecnológica (IPICYT). Mauricio Terrones has co-authored more than 185 publications in prestigious international journals such as *Nature (3), Science (4), Nature Nanotechnology (1), Physical Review Letters (9), Nano Letters (18), Chemical Physics Letters (35), Annual Reviews of Materials Research (1), Advanced Materials (6), International Materials Reviews (1), etc.* He has been awarded the UNESCO Javed Husain Prize for Young Scientists and received the Albert Einstein Medal in November 2001 for his numerous contributions in Carbon Nanoscience and Nanotechnology. In 2001, he also received the National Prize for Chemistry in Mexico for his work on Carbon Nanoscience. His work has also been recognized by various agencies and Magazines in Mexico (e.g. Mexican Achievers 2004, Top 30 outstanding young people by "Revista Expansión", Outstanding Young Mexicans by "Revista Dia Siete", etc). In 2005, he received the José Antonio Villaseñor prize (a recognition given by the State government of San Luis Potosí) for his contribution to the production of N-doped carbon nanotubes and his applications. In that year, he was also awarded the TWAS prize (given by the Academy of Sciences for the Developing World) in Engineering for his outstanding contributions to the synthesis and characterization of novel carbon-based nano-materials. Mauricio Terrones is the youngest scientist ever to win a TWAS Prize. In 2005, we was elected member of the TWAS. In April 2006, he was awarded by UNAM the "Fernando Alba" medal for his outstanding contributions to experimental physics.

The scientific impact and quality of his publications has given him more than 4250 independent citations (without auto-citations) in international journals and books. In addition, he has co-edited a special issue on *Nanoscience and Nanotechnology of Carbon* that was published in November 2004 by Philosophical Transactions (The Royal Society). He has also written 8 book chapters, 2 independent reviews, 19 articles in conference proceedings and 6 miscellaneous publications. He has presented his research in more than 90 international conferences. The average impact factor of his publications is *>4*, according to the Institute for Scientific information 1998. He has been invited to present his research in more than 60 international conferences (*i.e.* England, Austria, USA, Hungary, Belgium, Argentina, Brazil, Chile, Korea, Germany, Japan, etc.) devoted to nanotubes.

Mauricio Terrones is one of the most productive scientists in Mexico, and has closely participated in the creation of the first Fullerene and Nanotube Laboratory in Mexico (Departamento de Física Aplicada y Tecnología Avanzada, UNAM). He has set-up the new Nanoscience Laboratory at IPICYT and is now leader of the National Laboratory for Nanoscience and Nanotechnology Research (LINAN), recently approved by CONACYT-Mexico.