Eight International Conference on Science and Application of Nanotubes – NT07: a report

24th – 29th June, 2007
Ouro Preto – Brazil

The International Conference on Science and Application of Nanotubes (NT), that took place in Ouro Preto, from the 24th to 29th June, was a place of interaction of a global community, having 370 participants (240 participants from all over the world besides the 130 Brazilian scientists and students). Its program also included some of the Brazilian and Minas Gerais culture, in special the most genuine baroque which is present in the old Gold Capital, namely the 18th century's. The Japanese, Korean, Chinese, North and Latin American as well as European participants might not have expected such lively nights after an intense scientific program. But the "invisible colleges" – places where those groups fraternize unpretentiously – have been present in the sociological literature about the scientific-academic community. They are cafes, bars, squares and also congresses where colleagues from different areas and subjects interact themselves, learn secrets, exchange addresses, reinforce and renew convictions, terms, values, try cooperation, begin friendship.

As it is an international community, those moments are unique in order to promote an approach that, so far, had been restricted to e-mail exchange and distance identification of myths and characters that proudly and healthily compete to make knowledge advance. On the other hand, conferences like NT07 show a high percentage of young participants, not only physicists, but also chemists, engineers and people from the biological field, standing out and leading a significant number of projects on this world of technological and scientific research boundary.

Professor Mildred S. Dresselhaus, one of the twelve "*Institute Professors*" in the Massachusetts Institute of Technology (MIT), says about the need to talk to the young, to get their opinion. They are more optimists and linked to what is promising and update in relation to scientific research.

For Professor Marcos Pimenta (Federal University of Minas Gerais – UFMG/Brazil), the coordinator of the Brazilian Network on Carbon Nanotube Research (www.fisica.ufc.br/redenano/) and also one of the coordinators of NT07, one of the roles fulfilled by the NT is to give the students from the host country the opportunity to directly interact with the most significant people and subjects in the area. "It would have been impossible to reach this public if the event had occurred out of Brazil".

Professor David Tomanek from Michigan State University, USA, is the one who made the NT conferences come true and also the co-organizer of all editions. He explains that since the first edition (NT99), which he thought would be the only one, the idea was to promote a democratic event where the focus is on the active people, not on "important" people. "The most important thing in the conference is the direct communication among the participants." Tomanek reinforces that the

informality spirit is a facilitator to communication. He shows his name tag: “Look! No ‘professor’ or ‘doctor’ ...First name: ...David!” The elimination of the title helps to break barriers and helps the interaction between students and scientists. At the end of the meeting, Pimenta invites Tomanek to give prizes to the students who had made questions during the NT.

A large increase of publications about carbon nanotubes (CNTs) - there were 5,000 scientific articles only in 2006 – mirrors the dynamism of the field. The context justifies the organization of an event that must “cover everything that is going on in the area, from theory to application, from synthesis to medicine and eletronics”, mentions Tomanek. Having the conference without any parallel activity seems to be the right thing to do. In the NT conferences, people participate in every session. Some posters are selected to be presented and people are chosen daily to make a general presentation of one section of posters that will be explained individually, by their authors, in the exhibition room.

The proposal is praised by a Brazilian researcher who is tired of conferences with monotonous sessions, when a number of authors have, each one, few minutes to show their results in *power point*. “It is very frustrating to the one that is presenting and little productive and boring to the ones who watch it”.

Besides the participation spirit, Tomanek calls attention to another characteristic of the NT conference. “We want to promote, to advertise the excellent groups that are not well known. This surprises both the international groups and the own countries where the conference takes place. We make conferences where there are active, recognized groups. We are not looking for beautiful, famous cities.”

At the closing of the Conference in Ouro Preto (a place that was chosen by the group from Belo Horizonte), the coordination of the next edition of the conference presents a picture of the reality of production and scientific interaction that qualifies France, the National Center of Scientific Research (CNRS) and the University of Montpellier to hold and organize the NT08. The ritual reinforces the tradition of making the conferences of carbon nanotubes at places that are really active in the field and it also reminds every national research community that it is necessary to make the best of oneself in order to have recognition.

Factors for Country development

David Tomanek mentions another intention of the conference. “Since the carbon nanotube rush started in 1991, we needed a central event that helped us educate the government about good opportunities” about CNT applications. Afterwards, “in the US, if there is no application there is no money.”

Marcos Pimenta says that an event like the NT07 helps to promote, in the international community, the quality of research groups that belong to *not listened* countries like Brazil. The fact that Brazilian research has become an international reference in the area brings fruitful results to the national researchers. One of them is “to provide more interest from the referees that assess Brazilian works in

international journals". Besides that, "the conference is a place to set partnerships, which allow possibilities of cooperation. In the interaction of CNTs with biomedical use, for example, foreign guests got surprised with the techniques developed here and research groups from other countries may have been convinced of the benefits of cooperating with the best Brazilian groups".

Professor Glaura Goulart Silva (Chemistry Department – UFMG, Brazil) notices that there is a great opportunity for countries like Brazil in the current moment for the development of carbon nanotubes research. "The NT07 shows that both the CNT preparation work and the material that will be part of CNTs with its varied characteristics constitute a science that is just beginning. The investigation of materials and arrangements based in carbon nanotubes is still at an early stage and Brazil, for having outstanding groups in the area, has the rare chance to follow its development in the same way as more advanced countries".

This evaluation is reinforced by another aspect, according to Professor Ado Jorio (UFMG, Brazil), one of the coordinators of both, the NT07 and the 1st International Forum in Metrology, Standardization and Industrial Quality of Nanotubes, one of the two *satellite conferences* that took place in Rio de Janeiro two days before the opening of NT07. Jorio states that the National Institute of Metrology, Industrial Normalization and Quality (Inmetro, Brazil) is getting itself structured constructing laboratories, which are similar to the ones belonging to the best universities in the country. Brazil will be able to certificate its CNT products as soon as we begin exporting them. According to Jorio, the country shouldn't wait for ideal conditions of production in order to start structuring a nanomaterial quality monitoring and standardization system. "To do nanometrology today is a matter of basic science. It has been like this in the past 10 to 20 years. The manipulation of carbon nanotubes is a complex task and that may cause an alteration to its proprieties. To reach a precise control, metrology must be *together with* science".

Jorio explains that the current electronic microscopes don't have the necessary calibration to deal with CNTs". The fact is "that great quantities of CNTs of multiple walls are being produced internationally, but, in general, there is no control of purity". If Inmetro is able to recruit qualified labor to the new task, it will be able to reach the same standard of North American institutions like NIST [National Institute of Standards and Technology] and NASA [National Aeronautics and Space Administration]. According to Jorio, the satellite conference of metrology showed that these institutions are still in a too basic level, working to establish protocols and standards or percentages of purity relative to the CNTs. In other words, the moment is good for an objective and deep structuring of Brazilian nanometrology. The fast and increasing advances in quality in the production of CNTs also justify the investment as the necessary condition to follow the changes and provide the necessary orientation to companies that want to join the club of nanotube manufacturers.

Origins, material and synthesis

In a state which is marked by mine-metallurgic tradition (Ouro Preto is in the heart of the main mining state in Brazil, Minas Gerais), the reason why many research groups in CNTs are associated to metallurgy departments of academic and scientific institutions in different places can not be avoided. “In Brazil”, Professor Glaura Goulart Silva explains that “the active groups of the area usually belong to the Physics and Chemistry departments”. Marcos Pimenta reminds that “the materials science is very recent and it was born in several places in the world, in Metallurgic Engineering departments. After that, materials like carbon fiber, plastic and ceramics joined the scenario, bringing new possibilities of application, challenge and elaboration to engineering”.

About the NT07, it was agreed that there is an advance in the CNT synthesis methods and in the diversity of the material presented. Mario Romero-Ortega, chemical engineer and Professor of Neurology and Biomedical Engineering (University of Texas Southwestern Medical Center, USA), highlights that the production of different types of CNTs and their composites is a great service offered by the ones that work with synthesis to the development of science and application of CNTs.

Romero argues that people working with synthesis should not “compete for a product, but to work using synergy, searching for diversity in production”, that can be tested in different applications, by different research groups.” The researcher is an enthusiast of the structuring of cooperation networks as a way to eliminate the local disadvantages of this or that group.

The chemist Aldo Zarbin (Federal University of Paraná – UFPR, Brazil) has also noticed a considerable advance in synthesis and functionalization (introduction of chemical groups that change the characteristics of CNT, turning them more soluble, conductive, biocompatible, etc.) in the NT07. “Those two fronts have really evolved. It is impossible to think about applications without the beginning material, that is, the carbon nanotube, with adequate properties. NT07 shows that the chemical methods are, in this respect, much ahead from others”.

The biggest challenge is to synthesize nanotubes with high purity, homogeneity, quantity and low price. Zarbin observes that NT07 presented “great contributions about some of those aspects in an isolated way or, in the most, associate with a second aspect “- for instance, homogeneity and purity or quantity and price. There is, thus, a good way to go in order to synthesize, with good results in the four aspects, simultaneously.

Another point seen in NT07, according to Marcos Pimenta, is that the so called CVD (*Chemical Vapor Deposition)* method for CNT growth*,* especially with the use of alcohol as start material, is dominating the works on CNTs synthesis.

Professor Ernesto Joselevich, from Weizmann Institute of Science (Israel), points out the studies presented by the group led by Professor Alan Windle from Cambridge University (UK), as one of the works which impressed him as the most technologically promising at the Ouro Preto Conference. Windle is drawing the tubes straight from the CVD reactor, which allows him to produce fibers of unlimited sizes.

Joselevich calls attention to two types of NT organization: nanotubes vertically aligned to the substrate, that will make it possible to produce field emission devices for monitor screens; and horizontally aligned to the surface, type of NT position favorable to nanocircuit assembly. According to Joselevich, the growth of CNTs in an organized way has been possible due to the use of electric fields or gas jet. Another technique, that he has been working with, is the use of an epitaxial substrate – a surface on which nanotube grow in an organized way_– and it is obtained from a diagonal cut on a crystal in such way that the surface gets steps in atomic scale. The combination of those atomic steps with electric fields allows the structuring of nanotubes in grid shape and in other different architectures.

Although there is market and technology demand for the CNT industrial production – especially polymeric composites –, Zarbin says that few people in Brazil work with synthesis. He cites the Material Chemistry Laboratory from UFPR (Paraná), the lab from USP in Ribeirão Preto, and the group led by Luiz Orlando Ladeira and Rodrigo Lacerda from UFMG, in Belo Horizonte. “The group from UFMG is the only one turned to large scale growth and it has already achieved a pre-industrial level of production”.

Electronics

In areas such as electronics, the Indian Professor Pulickel Ajayan (Rensselaer Polytechnic Institute – Troy, USA) says that maybe countries like India and Brazil would need a larger economic and technological strength than the one they currently have in order to be more competitive. For him, the companies and governments will invest their money in areas where each country can offer more benefits. In case of India, Ajayan thinks that those areas are environment, medical science and alternative energy.

At NT07 there was no disagreement about the Table (cf. attached) presented by professor Ajayan about the development and industrial application of CNTs on the next years. On the Table, the development of electronics based on carbon nanotubes is a distant reality.

Marcus Freitag, IBM physicist and researcher, does not believe on the substitution of silicon technology in short and average terms. He believes that “we can reach faster results with nanowires, that can be made of different elements and then result in different types of electrical connections. The advan\ages of the CNTs, though, are the fact that they are much smaller and more resistant and they also

have excellent electrical transport properties, much better than silicon or any nanowire".

"It is not possible to imagine the nanotube substituting all the present functions in a chip", explains Freitag. "We are at a point to understand how the CNTs could be used as electro-optical device in a reduced circuit of transistors. We have already built an important circuit, a ring oscillator, comprising 10 transistors made in the same nanotube". Freitag explains that it was necessary to build the transistors in the same nanotube so they would have similar characteristics. "That oscillator operates under a frequency of 80 Mega Hertz (MHz) [one MHz is equivalent to a million oscillations per second]. This value is still very low, but the theoretical limit in nanotubes will be in Tera Hertz [1 THZ = 1,000,000 MHz], a frequency band out of silicon possibility". Marcus Freitag studies the properties of light emission by transistors made of semiconductor carbon nanotubes. As those transistors are bipolar [they can conduct electrical current with both positive and negative charges] there is light emission depending on the operation conditions. This light can be used for optical communication in a nanoscopic scale. The electronic and optical communication between transistors through nanotubes is, therefore, one of the main targets of Freitag's activities at IBM.

Both physicists Antonio Gomes de Souza Filho (Federal University of Ceará – UFC) and Eduardo Barros (currently taking his post-doc at Tohoku University in Japan) led a research presented at NT07, which also appeared in Professor Dresselhaus's report as an important challenge to be faced in relation to the double wall carbon nanotube (DWCNT) photophysical properties and their possible applications. The work reports the behavior of this kind of nanotubes, with inner and outer nanotubes, respectively, metallic (M) and semiconductor(S), or vice-versa, submitted to chemical treatment with gases or liquid – in this case bromine gas and sulfuric acid to dope the nanotubes. "We are still investigating the basic principles", says Barros. "If we know how the chemical treatment produces the electrical charge transfer between the internal and external structures of the DWCNT, we will be able to understand how to control their electronic properties". The next step is to understand the same situation with the double wall nanotubes with the M-M and S-S configurations. Barros believes that the possibility of constructing double wall nanotubes, like coaxial nanocables, represents an interesting perspective of electronic application, but still far to be solved by the nanoengineering.

According to the physicist, the carbon nanotubes will be able to play another important role for electronic circuits, that is to substitute the material used in cooler's production, that prevent the transistors, which work under high temperature, to melt. As the current coolers are heavier and take a considerable space in the circuits, its substitution by others made with CNT polymers, with more efficient thermal properties, will allow the assembly of smaller and lighter electronic equipment.

Although there is still much to do in the application of CNT in electronics, Marcos Pimenta sums up: “We are in the Silicon Age today, but maybe the Carbon Age is on its way”.

Graphene

Professor Dresselhaus also points out in the report presented at the end of the Conference that Graphene is a hot topic that is now expanding rapidly, first in theory and now also in the experimental field. For the coming year we might expect the growth at the interface between Graphene and the CNTs. Barros and Pimenta are fascinated by the subject because of both the exceptional electronic properties and by the possible applications in nanotechnology of these materials. Barros mentions that 400 theoretical works on Graphene and only 20 experimental ones were published in 2006, showing that there is still a long way to go.

Biomedicine and Pharmacology

Another hot spot of the science and application of carbon nanotubes is its interaction with biology, medicine and pharmacology. Significant advances and perspectives that may represent great progress in the treatment of diseases like cancer were shown at the NT07.

Not long ago, there was a fear that the CNTs had toxic properties, which caused great resistance among medical community regarding its use for health treatment. What is being observed now, however, does not confirm those fears.

The CNTs biocompatibility has revealed singular properties for its utilization in the gene silencing, in the drug delivering and also as biosensors and biocomposites. Luiz Orlando Ladeira (UFMG) sees that biocompatibility as the most promising area appearing at the NT07 conference. “The nanotube supplies a friendly support for cell growth”. Regarding the gene silencing, Ladeira informs that the CNT can be used to carry a segment of RNA, that stops the order of protein synthesis in cells with pathological properties, for instance.

One of the secrets of the application of carbon nanotubes in therapeutic activities is its utilization as isolated nanotubes. What it is observed in several environments is that nanotubes tend to agglomerate themselves, forming larger bundles. In this case, their passage through the cell, without causing any harm, is not viable. The recent discoveries about the CNTs functionalization creates the conditions for them to become dispersible (that is, not to join together) in water. This reinforces the potential of its biocompatible use.

Professor Mario-Romero Ortega fast drove his research to the interaction of cells with carbon nanotubes after working with Professor Ray Baughman (Nano-Technical Institute, Texas University, USA), who started offering support in CNTs for cell growth. His experiments with CNTs had been unfruitful so far because the supports he worked with were manufactured in such way that the nanotubes either dispersed or containing toxic residue from the catalyst used for NT growth were

harming the cells. Romero-Ortega noticed that the manufacturing process, considering the level of purity and the way to prepare the nets of nanotubes, were decisive for the results.

Nowadays he has been working with the use of carbon nanotubes to nerve regeneration and bets that the CNTs will improve the quality of the transmission of information for bionic functions, that is, they will work as connectors between brain activity and human body organs (nerve terminations on the skin, hands, arms, etc), that have, for instance, to be restored or reactivated. Romero-Ortega thinks that carbon nanotube biocompatibility will really ease this kind of interface.

Professor Kostas Kostarelos, a chemical engineer from the Pharmacy School of London University, talks about some advantages of carbon nanotubes in treating diseases. “We observed that the nanotubes penetrate the cell and are excreted easily through urine in rats. This means that they won’t be accumulated by human being organs”, opposite to what may happen to, for instance, round shaped medicamentual nanomaterials. “One of our challenges is to discover how to keep the composites with CNTs inside the human body for long term treatments”. Kostarelos mentions that the medication being used recently in cancer treatment kills not only the cancerous cells but also the healthy ones. As the production of molecules with properties to identify and attack only the cancerous cell succeeds, the efficiency of therapies will minimize the suffering of the patients, a very important aspect concerning the success of the treatment. Once again, CNTs can be used to carry not only medication, but also the molecules or chemical groups that can identify the injured cells.

This perspective, according to Kostarelos, also drives to the simultaneous use of biosensors and medicamentual composites. Professors Rodrigo Lacerda and Luiz Orlando Ladeira, from UFMG, believe that the first carbon nanotube products in biomedicine will be the ones applied to diagnoses. Lacerda forecasts advances that allow the immediate detection of illnesses like dengue (illness transmitted by the mosquito *Aedes Aegipty*), whose current methods take more than two weeks for having its diagnoses produced. The results for public health seem to be obvious. The work coordinated by Ladeira and Lacerda has deepened its application potential through partnerships with the laboratory of Biological Science Institute from UFMG.

Right now, Lacerda is testing (*in vivo)* the carbon nanotube biocomposite with collagen, developed by the Nanomaterial Laboratory (Physics Department/ UFMG), to be applied in bone reconstruction. According to the analyses of mechanical, thermal and biological properties, it is believed that the product gathers the properties to substitute titanium and hidroxiapatite powder which are, currently, the most applied materials in tissue engineering to restore skin, cartilage and bones.

The NT08

Professor David Tomanek prefers not to foretell anything about NT08. “There will be surprises next year. The last year we knew little about graphene and didn’t know anything about the experiments and applications with blood and about Lacerda”.

What is known about NT08 is what has been presented by its organizers Annick Loiseau (LEM, Châtillon), Jean-Louis Sauvajol (LCVN, Montpellier) – from France – and Jean-Christophe Charlier (PCPB, Louvain), from Belgium.

Montpellier is an agreeable town, with significant historical - cultural heritage and good gastronomic and wine tradition. The tutorial presentations will be centered in electronic microscopy, phonons, electronic transport and CNT devices. The themes chosen for the satellite conferences are Metrology, Modeling and Nanobiology. For more information check www.cnrs-imn.fr/NT08, www.cnrs-imn.fr/GDRE NanoE and http://nanotube.msu.edu/nt08.

At the end of NT07, professor Dresselhaus started her tutorial defying the participants present in Ouro Preto. She said that the NT08 organizers would give more emphasis to the fundamental scientific aspects of CNTs and invited all to work intensively on the next twelve months.

Professors Hélio Chacham (UFMG), one of the coordinators of the satellite conference about the CNTs theory (that took place in Rio de Janeiro too) and Marcos Pimenta were interviewed in different moments, but both agree that the research in carbon nanotubes science “is getting more mature” (Chacham). According to Pimenta, the basic research has already played most of its role on revealing the carbon nanotube properties. Chacham explains that the CNT “behaves like a uni-dimensional crystal. It is an atomic scale wire and, at the same time, it is perfectly periodical, which gives it unique properties in relation to other materials”. These crystalline properties are essential for the nanotubes to work as sensors – so that they can become *smart materials”*.

Chacham confirms that NT07 is a strongly experimental conference and that it stood out for the great number of works turned to technology applied to production. The theory similarly follows the trend to explain the CNTs applications.

To paraphrase Professor Ado Jorio, the science to be shown in Montpellier about the nature of nanometrologic work must be, therefore, *stuck* to technology. And some tasks have already been identified: “The effects of the defects in the optical and electronic properties and in the structural stability” of the CNTs as well as the nanotube *spintronics* [magnetic materials electronics] must be better explored both experimentally and theoretically, proposes Mildred Dresselhaus among other conclusions.