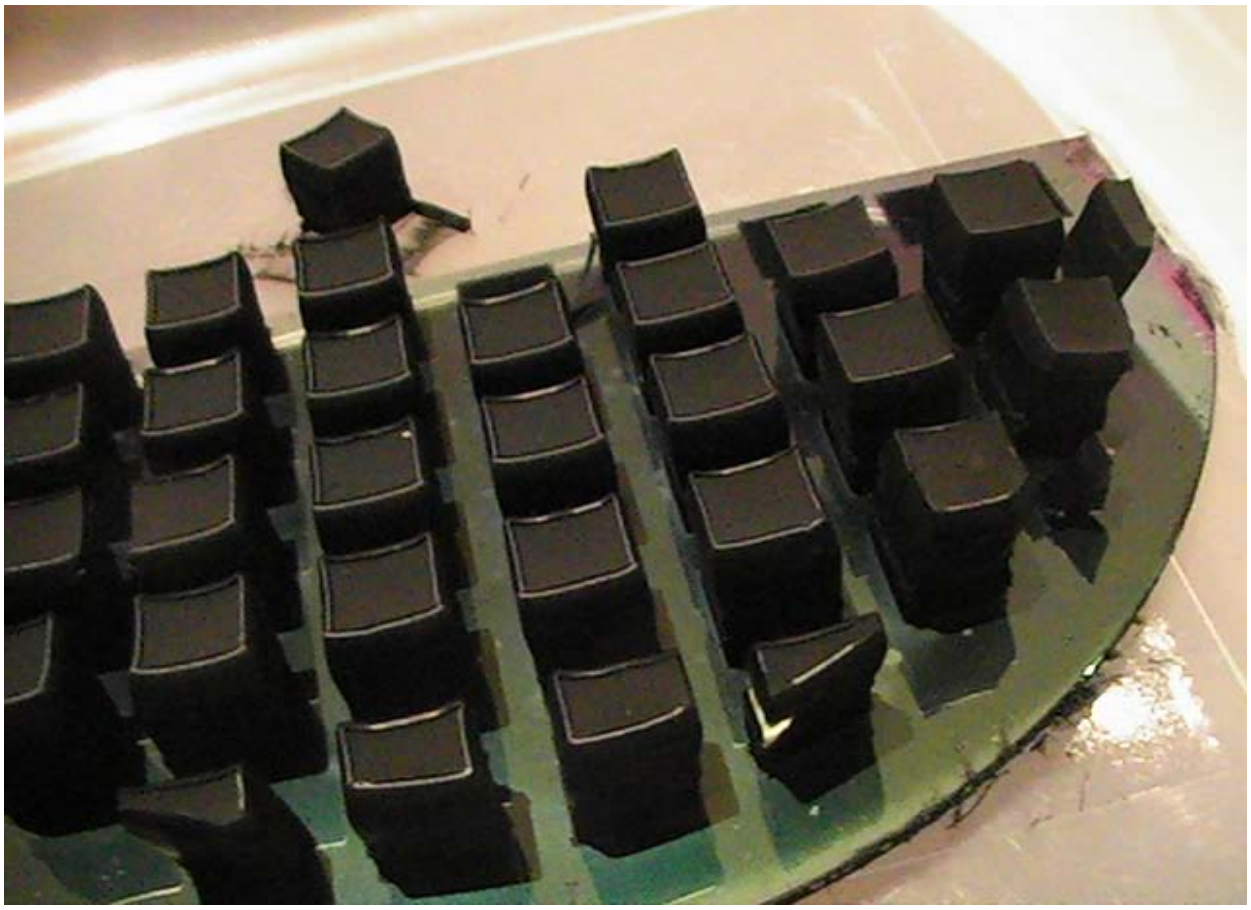
4th International Conference on Carbon Nanotechnology and Space Elevator Systems

BOOK OF ABSTRACTS – PART I

Saturday Dec 4, 2010



Carbon Nanotechnology

In cooperation with: Fonds National de la Recherche Luxembourg

Day 1: December 4, 2010

Conference Opening

Time	Topic	Speaker
09:00	Introduction	**Markus Klettner**, ESW, Luxembourg
09:30	Keynote: The Carbon Nanoworld – Advances in synthesis and application of carbon nanotube materials	**Prof. Dr. Vesselin Shanov**, Nanoworld, University of Cincinnati, USA
10:30	Coffee break	

Carbon nanotube growth – the challenge

Time	Topic	Speaker
11:00	Project CLAVIS: striving for ultra long CNTs	**Dr. Martin Lades**, ESW/ISEC, Germany
11:15	Keynote: From CNT strength to growth: Key overarching concepts	**Prof. Dr. Boris Yakobson**, Smalley Institute, Rice University, USA
12:00	Tailoring the self-organization of 3D CNTs microstructures	**Dr. Michael De Volder,** IMEC, Katholieke Universiteit Leuven, Belgium
12:45	Advanced Materials and Structures	**Dr. David Ruch**, CRP Henri Tudor AMS, Luxembourg
13:00	Lunch	

Design and production of macroscopic CNT fibers

Time	Topic	Speaker
14:00	Carbon nanotubes functionalized with metallic nanoclusters	**Dr. Jerome Guillot**, CRP Gabriel Lippmann, Luxembourg
14:30	Optimisation of wet spinning of CNT fibers: Millifluidic experiments for the development of novel fibers	**Prof. Dr. Philippe Poulin**, CRPP Bordeaux, France
15:00	Yarn-like high performance CNT fibers	**Matthew James**, University of Cambridge, UK
15:45	LASER micro-processing of carbon nanotubes	**Dr. Karl Fleury-Frenette**, Centre Spatial de Liège, University of Liège, Belgium
16:00	Coffee break	

Challenging strong CNT fibers: NASA's Strong Tether Challenge

Time	Topic	Speaker
16:30	NASA Strong Tether Challenge 2010	**Ben Shelef**, Spaceward Foundation, USA
17:15	Presentation of top entry of NASA Strong Tether Challenge 2010	**Dr. Bryan Laubscher**, Odysseus Technologies, USA **Dr. Martin Lades,** ISEC/ESW, Germany
18:00	End of 1st day	

9.15 – 9.30, Mr. Markus Klettner (ESW): ***Introduction – Carbon Nanotechnology and Space Elevator Systems: the win-win strategy***

Markus Klettner is Executive Director of EuroSpaceward. He received a MSc. degree in Space Management from the International Space University. In addition he owns a university degree in engineering and post-graduated in International Business Management. His MBA thesis in 1990 analysed the emerging commercial space market in Europe. During several years he edited the quarterly astronomical journal S.P.A.C.E at the House of Nature in Salzburg.

Abstract: Carbon nanotechnology is en route to change our world. Most innovations made are still incremental. However, the pursuit of a stairway to heaven may soon lead to quantum leap innovations. The realization of the concept of the space elevator is a highly challenging endeavor. It is inspiring extreme engineering on both ends, the mega-world and the nano-world.

Carbon nanotubes and its sister material graphene have the potential for all sorts of real world applications, assuming that scientists and engineers can find a way to actually manufacture it at sizes greater than the microscopic.

Since year 2007 EuroSpaceward is following a win-win strategy in order to stimulate the development of strong CNT fibers for the mega cable of a space elevator. Leading scientists and engineers of both streams, carbon nanotechnology and space elevator systems, are regularly brought together in this workshop in order to engender cross-fertilization of ideas and activities. So far the efforts have already started to pay-off: A proposal for an international research project on ultra-long CNT growth has been elaborated with a good chance of funding by European research funds.

We expect that EuroSpaceward's 4th conference will build up additional momentum and further align international research work to a concerted endeavor!

Notes /questions:

9.30 – 10.30, Prof. Dr. Vesselin Shanov (University of Cincinnati, USA): ***The Carbon Nanoworld – Advances in synthesis and application of carbon nanotube materials***

Prof. Dr. Vesselin Shanov is a leading authority on carbon nanotube growth. Together with Mark Schulz he established the Smart Materials Lab at the University of Cincinnati, where his team has grown record length carbon nanotube arrays. He has won several prestigious awards, including the Fulbright Award for Research and Teaching in USA.

Prof. Shanov presented world record long CNT arrays at EuroSpaceward's conference in 2007.

Abstract: Recent results in catalytic synthesis of 2 centimeter long CNT arrays by CVD will be presented. Current scale up efforts to develop methods that industry needs to "mass produce" aligned CNTs and to process them into fibrous products will be reported. Nanotechnology innovations under development in our Nanoworld laboratories include: big area synthesis of Black Cotton™ and processing this highly aligned and pure CNT material into light, strong and electrically conductive fibers.

Our team has developed techniques for spinning long CNTs directly from the array into thread, yarn and ribbons. This technique has produced CNT thread with strength above 1 GPa and electrical conductivity of 0.8×10^4 $(\text{ohm. cm})^{-1}$. Efforts for post processing the CNT based materials in order to improve their strength and conductivity will be reported. The talk will also illustrate novel applications of the CNT arrays, threads, ribbons and yarns for fabrication of electronic, aerospace, and biomedical devices.

Co-author of paper: Dr. Mark Schulz, Mechanical Engineering, University of Cincinnati, OH 45221-0072

Notes /questions:

11:00 – 11:15, Dr. Martin Lades (ESW/ISEC***): Project Clavis: striving for ultra-long carbon nanotubes***

Dr. Martin Lades, Technical Director of EuroSpaceward, is a senior research scientist. As such he is currently leading CNT fiber research projects at EuroSpaceward building cooperation with research facilities in Europe, the USA and Japan, with the aim to support the development of super strong CNT tethers for the space elevator and other aerospace or industrial applications. Previously Martin has been working on image processing, biotech, information security and strategic planning. Since 2005 he is involved with the NASA Beam Power Challenge where he designed the laser optics and climber tracking for the team Kansas City Space Pirates from 2007 on. He is also a founding member of the International Space Elevator Consortium (ISEC).

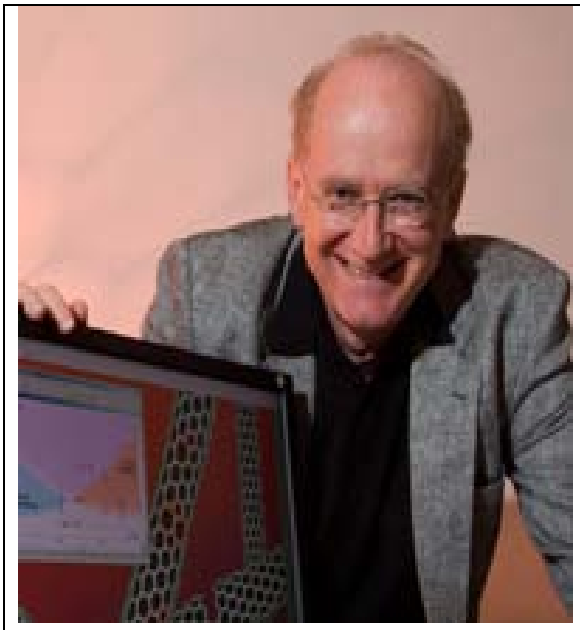
Abstract: CNT-based high strength industrial fibers and cables have ubiquitous potential applications, e.g., in construction, aerospace, automotive industry, and energy transmission. High strength needs filaments of long CNTs, mitigating the empirical law: the shorter the weaker. Arrays of CNTs, so-called forests, grow in laboratories to a length of a few centimeters, then suffering from an effect called self-termination. Despite recent efforts to understand and mitigate it, self-termination still remains substantially unexplained.

In cooperation with national and international partners EuroSpaceward has proposed research project CLAVIS with the purpose to find a sufficient explanation for the stopping of CNT growth to overcome the self-termination effect.

The presentation briefly reviews several aspects of the construction of light, strong fibers from CNTs and other polymer molecules interesting in the context of CLAVIS and the SE. Fiber strength specific to volume and weight depends on strength and packing density of aligned covalent bonds per volume. The application of fibers in a Space Elevator also requires robustness against influences such as temperature, strain, chemistry, electricity, and radiation.

Notes /questions:

11.15 – 12.00, Prof. Dr. Boris Yakobson (Smalley Institute, Rice University, Houston, USA): ***From CNT strength to growth, via the overarching concepts***



Prof. Dr. Boris Yakobson is professor for material science, mechanical engineering & chemistry. His research interests are in theory and modeling of structure, kinetics, and properties of materials, derived from both macroscopic and fundamental molecular interactions. Computational methods and simulation are used to visualize and enhance the understanding of underlying physics and to identify the efficient degrees of freedom in complex systems, especially in connecting different length scales of description. He is an editorial board member of the Journal of Nanoparticle Research and a member of the American Physical Society and the Electrochemical Society.

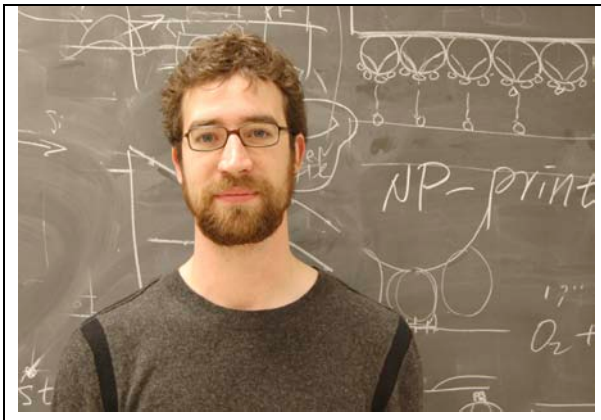
Together with the late Nobel Laureate Richard Smalley Prof. Yakobson published the first scientific article on CNT use for the space elevator cable.

Abstract: Early promise of nanotube strength has also posed a challenging question: What are the initial steps of carbon network relaxation, under the high tension, and what is the breaking strain limit [1], at least theoretically? Two mechanisms appear to be leading, at low temperature a brittle failure and at high temperature plastic relaxation [2]. In the course of these studies, several fascinating and conceptually important things emerged. One was the possibility of super-plasticity in nanotubes [3], and of their self-healing in evaporation [4], both due to particular pentagon-heptagon 5|7 defect, able to glide or climb across the nanotube as edge dislocation. Recognition of these dislocations led us further to appreciate the chirality as key factor in growth [5], thus bridging the seemingly disconnected fields, fracture and synthesis. Most recently, we discovered profound connection between the graphene-edge makeup [6] and the ways nature chooses which chiral tube to create. As this understanding deepens, it should offer a control knob for chirality in nanotube

	production, for strong cable designs and other far-reaching applications. [1] B.I. Yakobson and R.E. Smalley, *American Scientist* **85**, 324 (1997). [2] T. Dumitrica¸ et al., *Proc. Natl. Acad. Sci.* **103**, 6105 (2006) [3] F. Ding, et al., *Phys. Rev. Lett*., **98**, 075503 (2007). [4] F. Ding, et al., *Nano Letters* **7**, 681 (2007). [5] F. Ding, et al. *Proc. Natl. Acad. Sci.*, **106**, 2506 (2009). [6] Y. Liu, "Graphene edge from A to Z—and the origins of nanotube chirality", *Phys. Rev. Lett*. **105**, in press (2010).

Notes /questions:

12.15 - 13.00, Dr. Michaël de Volder (IMEC, KU Leuven): ***Tailoring the self-organization of 3D CNTs microstructures***



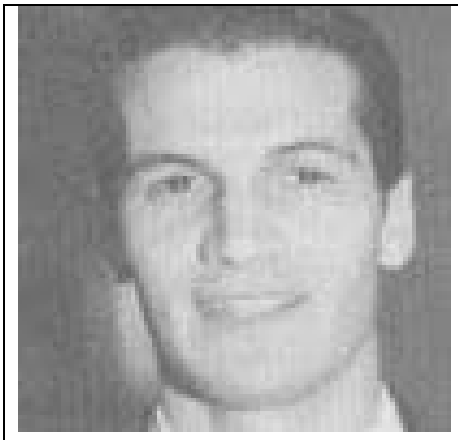
Dr. Michaël De Volder is a postdoctoral researcher, currently investigating nano/microsystems technology, and specifically the integration of nanotubes in MEMS devices. He stayed as a visiting fellow at the Tokyo Institute of Technology, the Massachusetts Institute of Technology and the University of Michigan. He obtained the Iwan Akerman, the BOF-POR, and the Robert M. Caddell Award.

Abstract: This talk presents a new method for high-throughput fabrication of robust three-dimensional (3D) carbon nanotube (CNT) microstructures. This method is based on our finding that condensation of liquid onto vertically aligned CNT microstructures, followed by evaporation, causes a deterministic transformation of individual microstructures to intricate 3D shapes. By tailoring this self-assembly process, delicate and heterogeneous geometries can be fabricated in close proximity and over large areas. We have defined a diverse library of forms having controllable bends, twists, and re-entrant curves, as well as patterns having complex arrangements of in-plane and out-of-plane features. Owing to their mechanical robustness and anisotropic electrical conductivity, we demonstrate applications of these novel CNT structures on the one hand as electrically integrated sensors and actuators, and on the other hand as master moulds for mass-production of 3D structures.

This research was performed in collaboration with S. Tawfick, S.J. Park, D. Copic and Prof. A.J. Hart of the mechanosynthesis group at the University of Michigan.

Notes /questions:

12.45 – 13.00, Dr. David Ruch (CRP Henri Tudor, AMS): ***Advanced Materials and Structures at Centre Recherche Public Henri Tudor***



Dr. David Ruch heads the department of Advanced Materials and Structures at CRP-HT, which is focussing on the elaboration of new materials, its characterisation and performance validation.

Abstract: The department of Advanced Materials and Structures (AMS) belongs to the Centre de Recherche Public Henri Tudor and is composed by two units: the materials unit (UMAT) and modeling and simulation unit (ModSi). It employs a staff of nearly sixty five persons.

The main competence of AMS lies in the materials characterization (chemical, physical and thermomechanical characterization and testing), processing, micromechanical modelling and development of physically-based constitutive laws, computational modelling and numerical simulations. AMS is also active in the development and improvement of materials performance, design and processing of new materials, surface treatment by atmospheric plasma pressure process, and characterization of materials properties and validation of materials performance.

R&D topics are the following: structural adhesives, nanocomposites, innovative coatings, biopolymers, smart materials, design and optimisation of advanced composite materials and structures. The necessary facilities for processing, characterisation and thermomechanical testing of materials and structures are present in the department (Microextruder, compression-molding press, XRD, SEM, XPS, DSC, DMA, MALDI-ToFMS, FTIR, mechanical tests machines…).

AMS has obtained the DIN EN ISO 17025 accreditation to carry out tests in areas of selected mechanical tests of materials, geotextiles and selected corrosion and thermal tests.

AMS is also fully equipped in numerical and computational facilities (Ansys multiphysics, abaqus CAE-standart-explicit, In house finite element code, matlab, simulink, etc…).

AMS is participating in some National and European scientific and technological projects.

Notes /questions:

14.00 – 14.30, Dr. Jerôme Guillot (CRP Gabriel Lippmann, SAM): ***Nanotubes Functionalized with Metallic Nanoclusters: Deposition via Atmospheric Pressure Plasma and Characterisation***

Dr. Jerôme Guillot is a Researcher on CNT functionalisation at the Department for Science and Material Analysis (SAM) at the Public Research Centre Gabriel Lippmann in Belvaux, Luxembourg. His research activity mainly focuses on the characterisation of materials, nano-materials and carbon nanotubes. He is also involved in research projects dealing with the functionalization of surfaces and particles with atmospheric pressure plasma treatments.

Abstract: Functionalization of Carbon Nanotubes (CNTs) by inorganic particles or by chemical groups is intensively studied because of numerous possible applications in the fields of catalysis, nanoelectronic, sensor, energy…

This work focuses on the development of a gas sensor based on nanotechnology: CNTs have been randomly decorated with metallic nanoclusters using plasma processes in order to detect toxic gases with a high selectivity and sensitivity.

The characterization of the hybrids materials were carried out using main High Resolution Transmission Electron Microcopy and X-ray Photoelectron Spectroscopy in order to study the influence of the treatment parameters on the samples morphology, the composition, the clusters distribution etc... Sensors were then designed and prepared from the functionalized CNTs and their sensitivity was tested towards different gases.

This work was funded by the EU Commission (Nano2hybrids, EC-STREP-033311).

Co-authors: A. Mansour[1], H.-N.

	Migeon[1], F. Demoisson[2], F. Reniers[2], A. Felten[3], J.-J. Pireaux[3], R. Leghrib[4], E. Llobet[4] [1] SAM, CRP-GL, 41 rue du Brill, L-4422 Belvaux, Luxembourg [2] CHANI, ULB, CP255, 2 Boulevard du Triomphe, B-1050 Bruxelles, Belgium [3] LISE, FUNDP, 61 Rue de Bruxelles, 5000 Namur, Belgium [4] MINOS, DIE, URV, 26 Avda. Països Catalans, 43007 Tarragona, Spain

Notes /questions:

14:30 – 15:00, Prof. Dr. Philippe Poulin (Centre de Recherche Paul Pascal CRPP, CNRS Bordeaux, France): ***Optimisation of wet spinning of CNT fibers: Millifluidic experiments for the development of novel fibers***

Prof. Dr. Phillipe Poulin is a leading expert on CNT fiber production at Centre de Recherche Paul Pascal, where he serves as director of research. He has invented the first continuous CNT polymer fiber spinning process in Y2000 yielding tough CNT composite fibers. Currently he is working on the physical chemistry of nanotube dispersions and their self assemblies with polymers. Dr. Poulin is also in charge of an industry laboratory to develop nanotube applications in partnership with the Arkema group.

Abstract: The development of new and strong fibers requires always more advanced processing with the use of novel polymer molecules or the inclusion of reinforcing fillers such as carbon nanotubes in composite fibers. Wet spinning is particularly suitable for such developments as it allows the processing of materials which cannot be melted and the mixing of various particles and polymers. Nevertheless fiber wet spinning becomes delicate when complex formulations are used. In particular the kinetics of fiber solidification is critical to achieve fibers that can be produced at a reasonable rate via robust and scalable processes. We show in this presentation how millifluidic devices can be used to characterize the kinetics of fiber solidification and optimize thereby the wet spinning of fibers loaded with carbon nanotubes. We also show how millifluidic technologies can be used to characterize the mechanical properties of electrospun nanofibers. The basic principle lies on the controlled induced scission of fibers in the extensional flows generated by constrictions in millifluidic channels. The present approach could be extended to other types of fibers and be potentially useful to advance the development of new synthetic fibers or our understanding of the formation of remarkable natural fibers such as spider silk.

Notes /questions:

15.00 – 15.45, Mr. Matthew James (Cambridge University, UK): ***Advancements on CNT fibre strength***

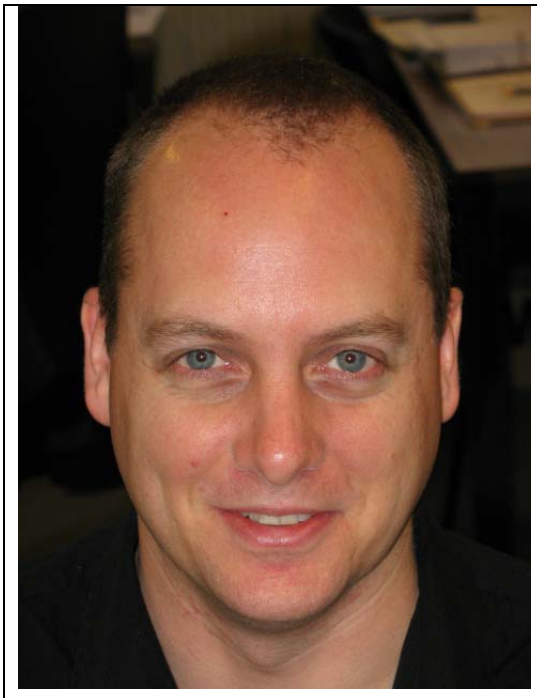
Mr. Matthew James is working in the team of Prof. Windle at the Department of Materials Science at the University of Cambridge, which is leading the global quest for super strong CNT fibers. His PhD research focuses on photon induced effects in carbon nanotube fibres, paying particular attention to the electronic and structural changes.

Abstract: Space elevators have been investigated widely as a means to provide easy access to space. However, the design of and construction of such a device presents significant unsolved challenges. One solution is to use carbon nanotubes as the space elevator cable as they have the theoretical strength required to support such a structure. Fibres of carbon nanotubes have already been synthesised on the macro scale but the problem of transferring the properties of individual carbon nanotubes to the macro scale remains.

In this presentation the recent advances in fibre production using the Cambridge "direct spinning from the CVD reaction zone" process will be discussed. Finally, possible sources of energy for transporting payloads into orbit using the space elevator cable will be discussed.

Notes / questions:

15:45 – 16:00, Dr. Karl Fleury-Frenette (University of Liège, Belgium): ***Laser micro-processing of carbon nanotubes***



Dr. Karl Fleury-Frenette graduated from McGill University in physics, obtained a master's degree from Laval University in Québec, and a PhD after working on magneto-optical thin films at Liège University. He has been leading the Surface Micro & Nano Engineering Division (formerly Advanced Surfaces) at the Centre Spatial de Liège since 2000. His main research interests include sputtering processes, optical characterization of surfaces, and the generation of nano-objects and nanostructures for optical applications.

Abstract: The development status of the laser station for surface and material processing at the Centre Spatial de Liège will be presented. This multi-process station integrates four different lasers for the purpose of local ablation, physical deposition, chemical growth and metrology. We will discuss the use of this station for carbon nanotubes growth and processing. More specifically, laser chemical vapor deposition of CNTs and direct laser writing of growth micro-templates will be addressed. Preliminary results on the deposition of catalysts by laser-induced forward transfer and thermo-reflectance-based thermal diffusivity measurements will also be presented.

Notes /questions:

16.30 – 17.15, Mr. Ben Shelef (The Spaceward Foundation): ***NASA/Spaceward Strong Tether Challenge 2010***

Ben Shelef is founder of the Spaceward Foundation that manages the NASA sponsored Space Elevator games. An aerospace engineer by day, Ben dons the mask and cape of a space crusader by night, and engages in daring escapades such as Space Elevator games and robotic challenges. Ben holds a B.Sc. in electrical and computer engineering from the Technion university in Haifa, Israel. He previously worked on ground and space based astronomical instrument design.

Abstract: The Space Elevator Strong Tether Challenge is a $2M technology competition organized by the Spaceward Foundation, in partnership with NASA's Centennial Challenges office which provides the prize purse. The challenge requires competing teams to fabricate a tether sample that must have a specific strength higher than 5 N/Tex (5 MYuri). While Carbon Nanotubes continue to be measured at near 40 MYuri, current tether samples have fallen far short of the challenge goal. The talk covers the competition rules, past team performance, and future prospects

Notes / questions:

17:15 – 18:00, Dr. Bryan Laubscher, Dr. Martin Lades (ESW/ISEC***): Presentation of top entry of NASA Strong Tether Challenge 2010***

Dr. Bryan Laubscher is Astrophysicist. He was a project leader at Los Alamos National Laboratory until 2008. Over the last 20 years he has carried out research and development in astrophysics, electromagnetic detection physics, space instrumentation, spacecraft, non-linear optics, laser technology, lidar and spectrometer development. He is now with Odysseus Technologies focussing on the development of strong CNT threads.

Dr. Martin Lades, Technical Director of EuroSpaceward, is a senior research scientist. As such he is currently leading CNT fiber research projects at EuroSpaceward building cooperation with research facilities in Europe, the USA and Japan, with the aim to support the development of super strong CNT tethers for the space elevator and other aerospace or industrial applications. Previously Martin has been working on image processing, biotech, information security and strategic planning. Since 2005 he is involved with the NASA Beam Power Challenge where he designed the laser optics and climber tracking for the team Kansas City Space Pirates from 2007 on. He is also a founding member of the International Space Elevator Consortium (ISEC).

Abstract: The NASA/Spaceward strong tether competition targets breakthroughs that exceed tethers made from commercially available materials such as Zylon by 50% in tensile strength. Rule changes this year permitted the production of a competition tether by Odysseus with substantially less than the several grams of expensive CNT material required in previous years. Odysseus successfully composed a tether of several centimeter length from 0.04 g of CNTs in a proprietary spinning process. We present about the participation in the NASA strong tether challenge from Odysseus' point of view. Odysseus Technologies took the top spot in the 2010 tether competition.

Notes /questions: