CAMBRIDGE NANOMATERIALS TECHNOLOGY LTD

Carbon Nanomaterials: Synthesis and Nanocomposite Applications

Dr. Bojan O. Boskovic

Cambridge Nanomaterials Technology Ltd

Bojan.Boskovic@CNT-Ltd.co.uk

www.CNT-Ltd.co.uk

Formerly at: Nanocyl S.A., Sambreville, Belgium
Meggitt Aircraft Braking Systems, Coventry, UK
University of Cambridge, Cambridge, UK
Morgan Crucible PLC, Worcester, UK
University of Surrey, Guildford, UK

Nanomaterials 2010, 8th – 10th June 2010, London

CAMBRIDGE
NANOMATERIALS
TECHNOLOGY LTD

Outlook

- Carbon nanomaterials (nanotubes and nanofibres):
  - Introduction
  - Properties
  - Applications
- Aerospace and automotive application
- Low temperature growth of carbon nanofibres
- Carbon nanotube – carbon fibre composites
- In situ growth of carbon nanotubes and nanofibres within carbon fibre cloth
- Composites with in situ grown carbon nanotubes and nanofibres within carbon fibre cloth
- Conclusions
- Acknowledgements
- Contact & Information

Cambridge Nanomaterials Technology Ltd

• The Cambridge Nanomaterials Technology (CNT) Ltd is a nanomaterials innovation, management and technology consulting company based in Cambridge, England.

• The CNT Ltd helps companies, academic and government institutions to develop nanomaterials related R&D and IPR strategy, partnership, products, technologies and market.

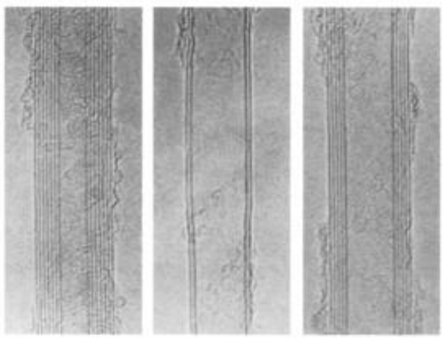
•The CNT Ltd is specialised in carbon nanomaterials R&D consulting and collaborative R&D project management, such as EC FP7 project consortium building, proposal preparation and exploitation management.

Cambridge Nanomaterials Technology Ltd

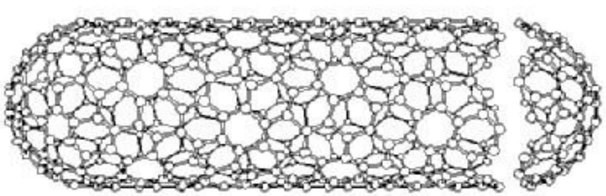
Carbon Nanomaterials - Introduction

Carbon nanomaterials are a family of carbon-based materials with at least one dimension in the nanomater range. One of the most widely studied and used carbon nanomaterials are carbon nanotubes and nanofibres. A carbon nanotube (CNT) is a tubular carbon structure with cylindrical graphene walls parallel to the longitudinal axis, capped by fullerenic hemispheres with nanometer-sized diameters and multi-sized lengths.

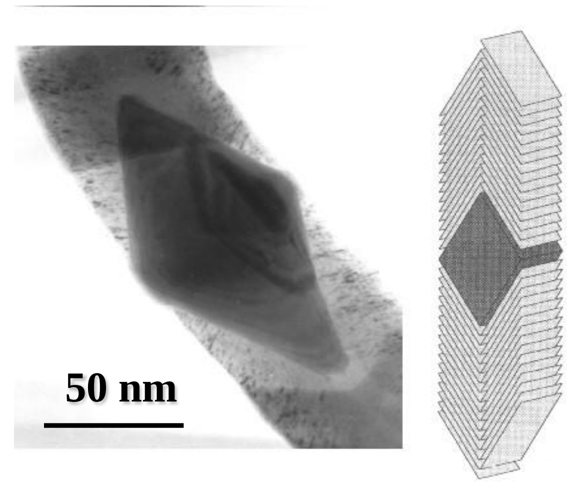
(a)



(b)



(c)



(a) MWCNT (Iijima, Nature, **354,** 1991, 56)

(b) SWCNT (Dresselhaus, Nature, **358,** 1992, 195)

(c) CNF

- Single-wall CNT (SWCNT): one carbon sheet rolled to form a tube and capped with half fullerenes
- Multi-wall CNT (MWCNT): many SWCNT nested inside each other like Russian Dolls.
- Carbon Nanofibre (CNF): larger in diameter and a less perfect structure than CNT with graphitic layers often in a fishbone arrangement.

Properties of Carbon Nanotubes

- Diameter: SWCNT, 0.6-1.8 nm; MWCNT and CNF, 5-100 nm.
- Electrical: Metalic/semiconducting.
- Density: 1.33-1.40 g/cm^3 (Al: 2.7 g/cm^3).
- Tensile Strength: 45GPa (High strength steel alloys:~2GPa).
- Current Carrying Capacity: 10^9 A/cm^2 (copper: 10^6 A/cm^2).
- Heat Transmission: 6000W/mK (Diamond: 3320 W/mK).
- Required field for field emission: 1-3V/mm (Mo tips: 20-100 V/mm).

(Source: P.G. Collins and P. Avouris, Scientific American, Dec 2000, 38-45)

CAMBRIDGE NANOMATERIALS TECHNOLOGY LTD

Applications of carbon nanotubes and carbon nanofibres

- Sport equipment
- Aerospace
- Automotive
- Fuel cells and batteries
- Filtration
- Electromagnetic shielding
- Sensors and actuators
- Flat panel displays
- Biomedical implants
- Packaging
- Nanoelectronic devices

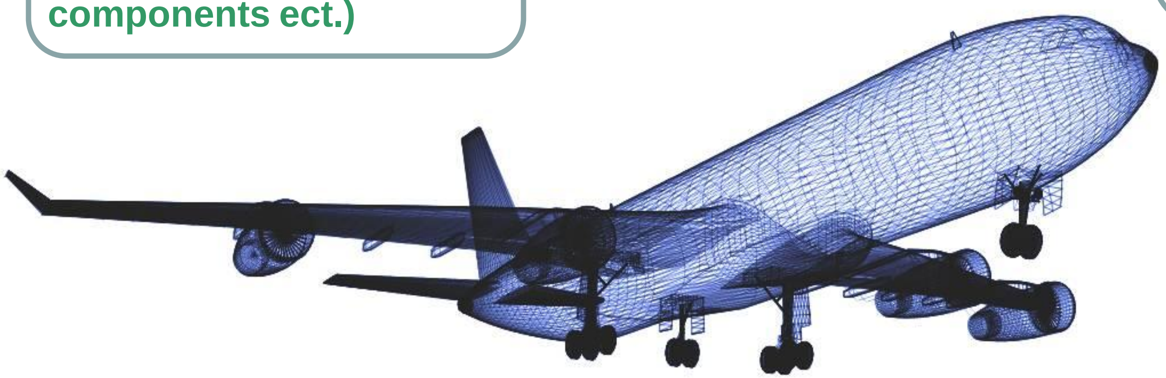
Dr Bojan Boskovic, CEO of the Cambridge Nanomaterials Technology Ltd at The Royal Society’s Summer Science Exhibition 2005 in London, holding a tennis racquet as one of the first products that contains carbon nanotubes.

CAMBRIDGE NANOMATERIALS TECHNOLOGY LTD

Possible Use of Carbon Nanotubes in Aerospace Applications

Engine Control Systems with carbon nanotubes (sensors and electronic components ect.)

Aero-Structures with carbon nanotubes (wings with enhanced lighting protection, de-icing, health monitoring, ect.)



Engine Components with carbon nanotubes (MMC and carbon composites)

Avionics Systems with carbon nanotubes (displays, sensors and actuators, fuel cells and batteries, wiring ect.)

C-C composite brake discs with carbon nanotubes, sensors

Possible Use of Carbon Nanotubes in Automotive Applications

CAMBRIDGE NANOMATERIALS TECHNOLOGY LTD

Carbon nanotube composite materials could be used for the windows, windscreen etc. This will add good electrical conductivity properties and allow the windscreen and windows to be connected to a heater and the car to de-ice easily and quickly.

The smart carbon fibre – carbon nanotube body will decreased the car's weigh and will also improve performance. The body could also be infused with carbon nanotube epoxy and this will give the body stronger structural and sensing properties.

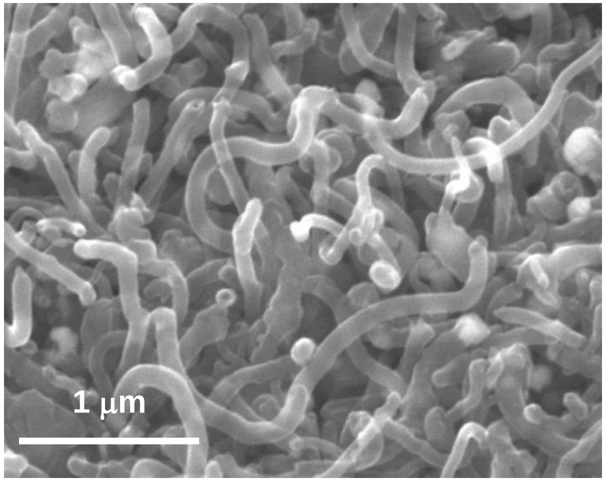
Carbon nanotubes used in MMC could make the engine weigh less and will also improve structural properties. Carbon nanomaterials could be also used in fuel cells and butteries in hybrid and cars powered by alternative energy.

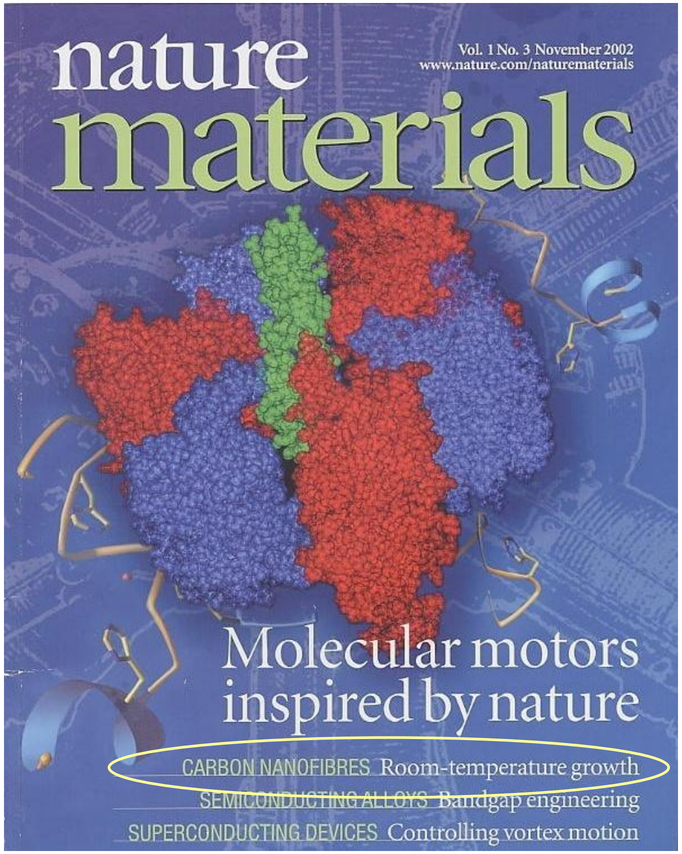
Image courtesy of Jim Dowle from JJAD

Carbon nanotube carbon-carbon composites have already been developed for braking applications in aerospace industry. This brakes will add further weigh loss and improved performance.

A nanotube pressure gauge could be installed to measure air pressure in the tyres. The gauge could be very accurate and precise due to the unique electrical and mechanical properties of nanomaterials.

CARBON NANOFIBRES - Room temperature growth



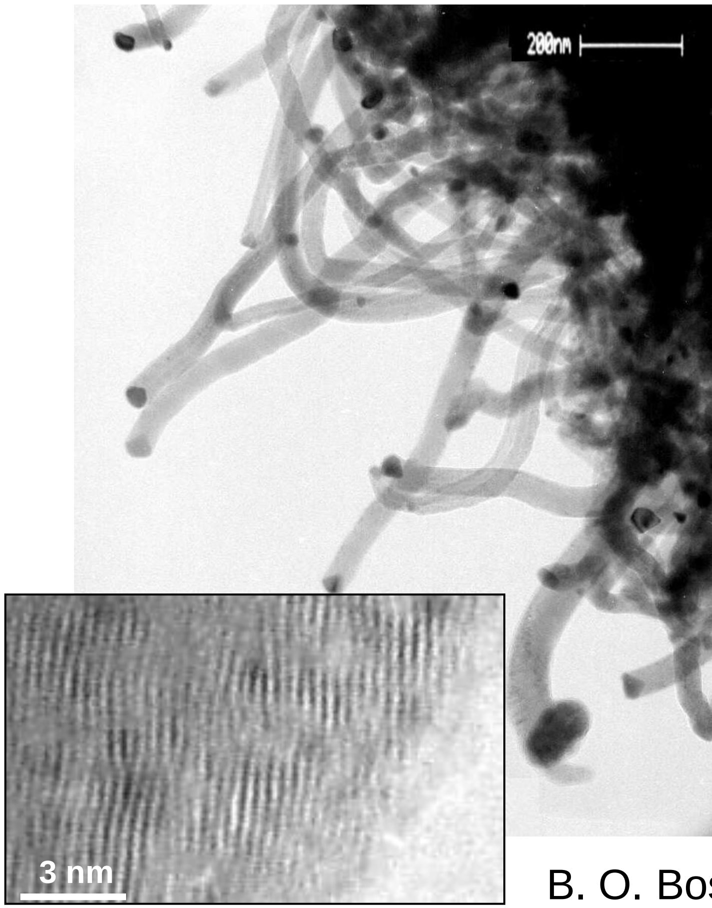


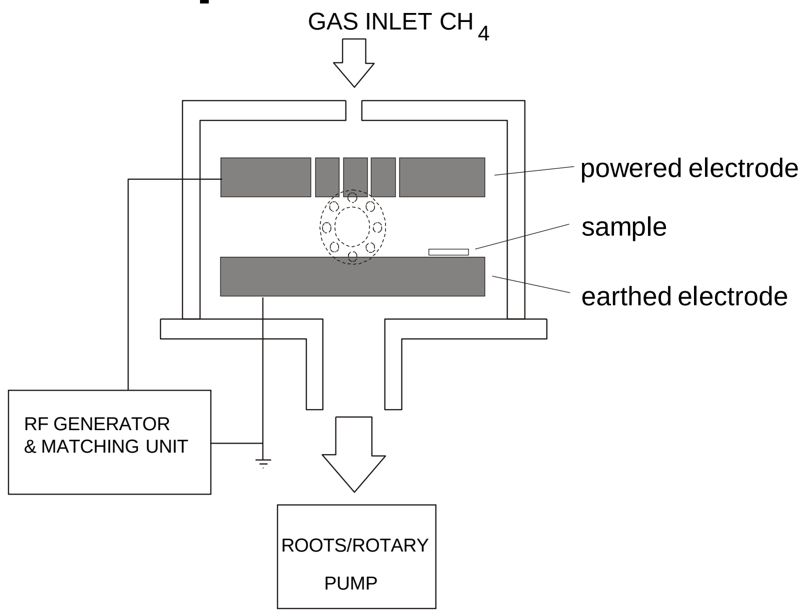
Dr Boskovic and co-workers at the University of Surrey and BAE Systems invented a carbon nanofibre synthesis method that allows growth of carbon nanofibres at room temperature. This work has been published in Nature Materials and granted a patent.

B. O. Boskovic et al., *Nature Materials*, **1** (2002) 165-168.

Patent US 20040253167, 16th Dec 2004.

Carbon nanofibres grown using r.f. PECVD at room temperature





Dr Boskovic and co-workers at the University of Surrey and BAE Systems invented a carbon nanofibre synthesis method that allows growth of carbon nanofibres at room temperature. This work has been published Nature Materials and granted a patent.

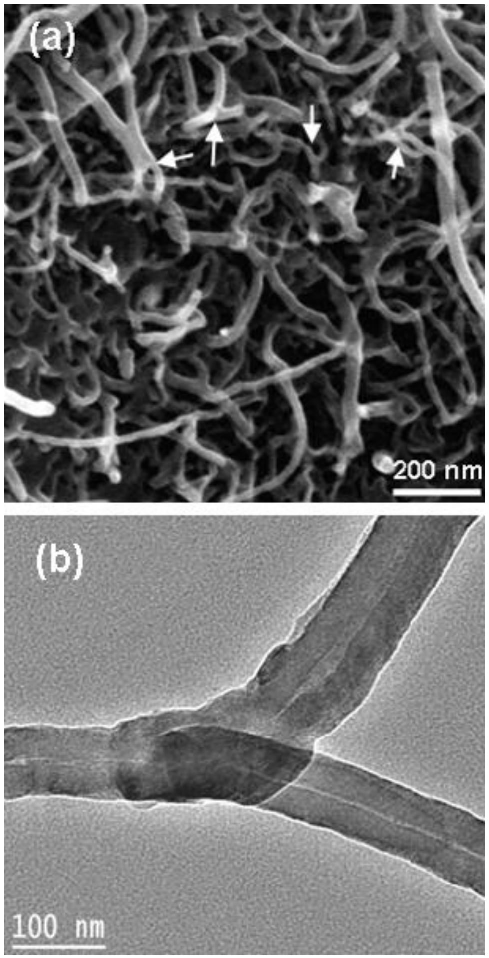
B. O. Boskovic et al., *Nature Materials*, **1** (2002) 165-168.

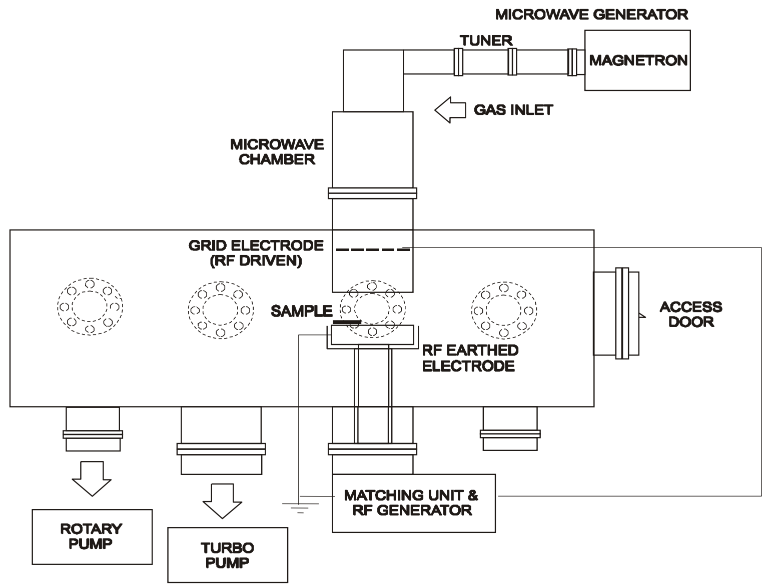
Patent US 2004253167, 16th Dec 2004.

UniS
University of Surrey

CAMBRIDGE NANOMATERIALS TECHNOLOGY LTD

Branched carbon nanofibres grown using r.f. combined MW PECVD at room temperature





Dr Boskovic and co-workers at the University of Surrey and BAE Systems invented a carbon nanofibre synthesis method that allows growth of carbon nanofibres at room temperature. Part of this work has been also published in Journal of Applied Physics.

B. O. Boskovic et al, *J. Appl. Phys*. **96** (2004) 3443

BAE SYSTEMS

UniS University of Surrey

Cambridge Nanomaterials Technology Ltd

Room temperature growth commercialisation – Surrey Nano Systems Ltd

Dr Boskovic and co-workers at the University of Surrey and BAE Systems invented a carbon nanofibre synthesis method that allows growth of carbon nanofibres at room temperature. This work has been published Nature Materials and granted a patent. It has been utilised by a carbon nanotube synthesis equipment manufacturer Surrey Nano Systems Ltd.

B. O. Boskovic et al., *Nature Materials*, **1** (2002) 165-168.

Patent US 2004253167, 16th Dec 2004.

BAE SYSTEMS

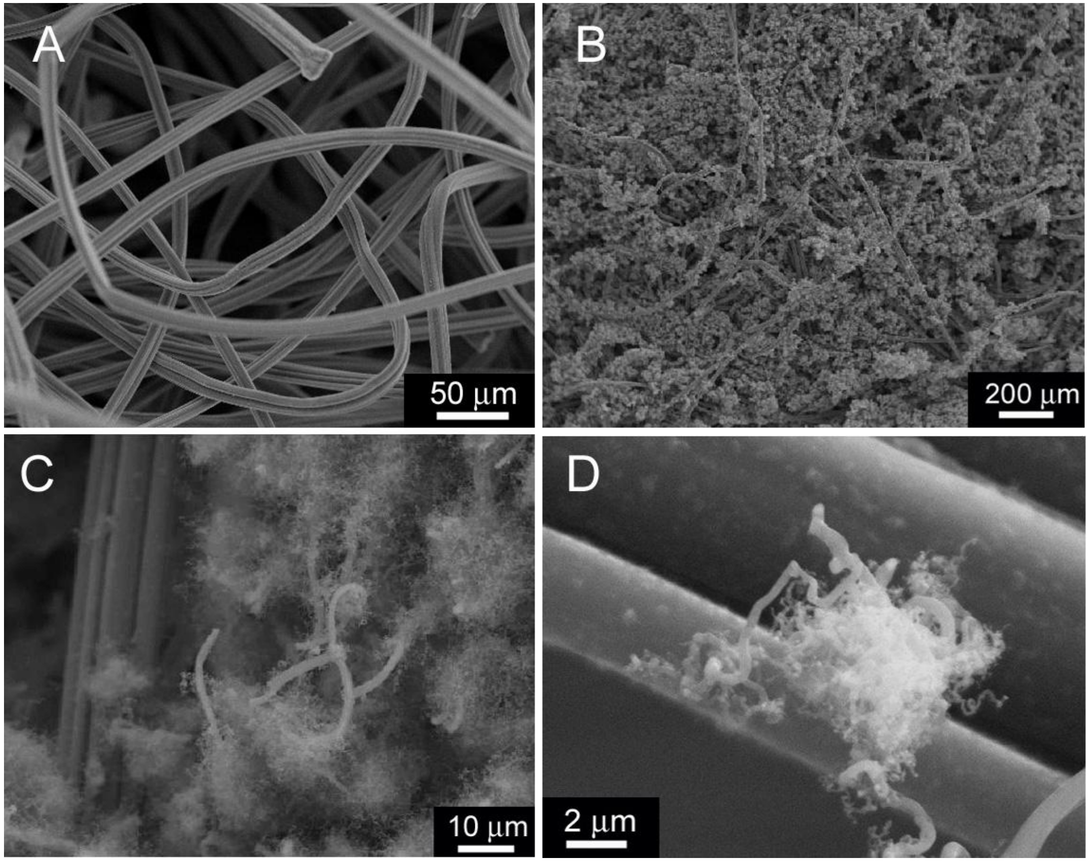
Carbon nanotube – carbon fibre composites

Motivation

- Three-dimensional structures that can transfer exceptional properties of carbon nanotubes to meso- and micro-scale engineering materials are essential for development of many applications.
- Carbon nanotubes and nanofibres synthesised using chemical vapour deposition (CVD) are usually in the form of a powder, carpets, thin films, fibres, yarns.
- Three-dimensional carbon nanotube and nanofibre macroscopic structures are still challenging from the synthesis perspective.

Cambridge Nanomaterials Technology Ltd

Carbon nanofibre synthesys within carbon fibre cloth



Dr Boskovic, while working for Morgan Crucible Plc, has invented a method for *in situ* synthesis of carbon nanofibres and nanotubes within carbon fibre cloth using iron powder or nickel powder as a catalyst and ethylene and hydrogen gas mixture at temperature 550 ^{o}C to 850 ^{o}C.

(A) Non-woven carbon fibre cloth VCL N from Morgan Crucible Plc, (B) carbon fibre cloth impregnated with carbon nanofibres, (C), (D) Carbon nanofibre aglomerates filling the space between carbon fibres in the cloth.

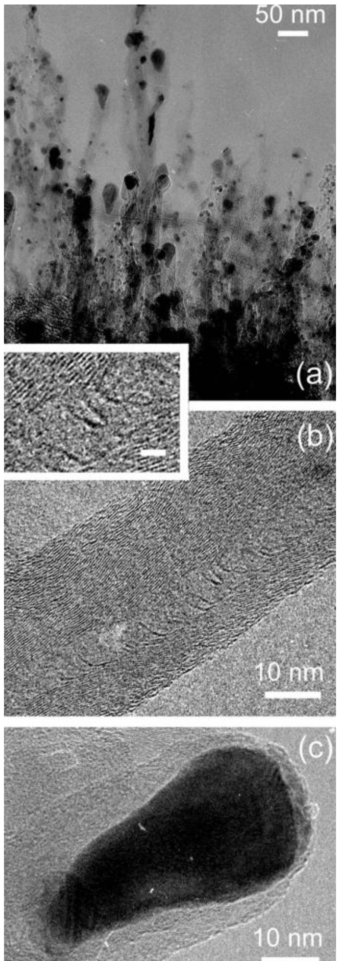
B . O. Boskovic, Morgan Crucible Plc, Patent WO 2004/078649

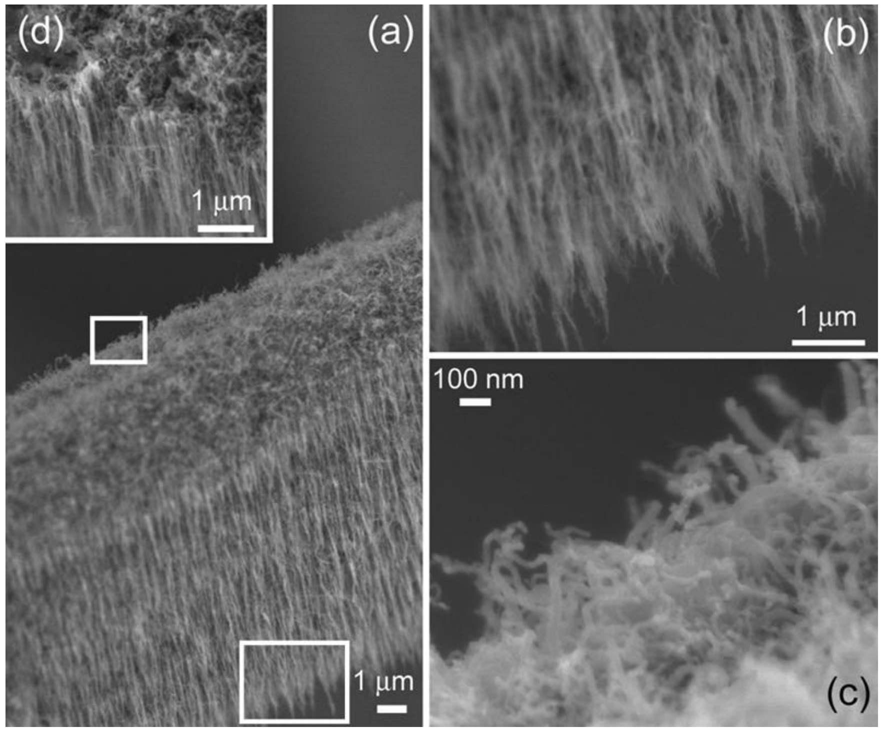
MORGAN GROUP TECHNOLOGY

UNIVERSITY OF CAMBRIDGE

CAMBRIDGE NANOMATERIALS TECHNOLOGY LTD

Low temperature growth of carbon nanofibres on carbon fibre cloth



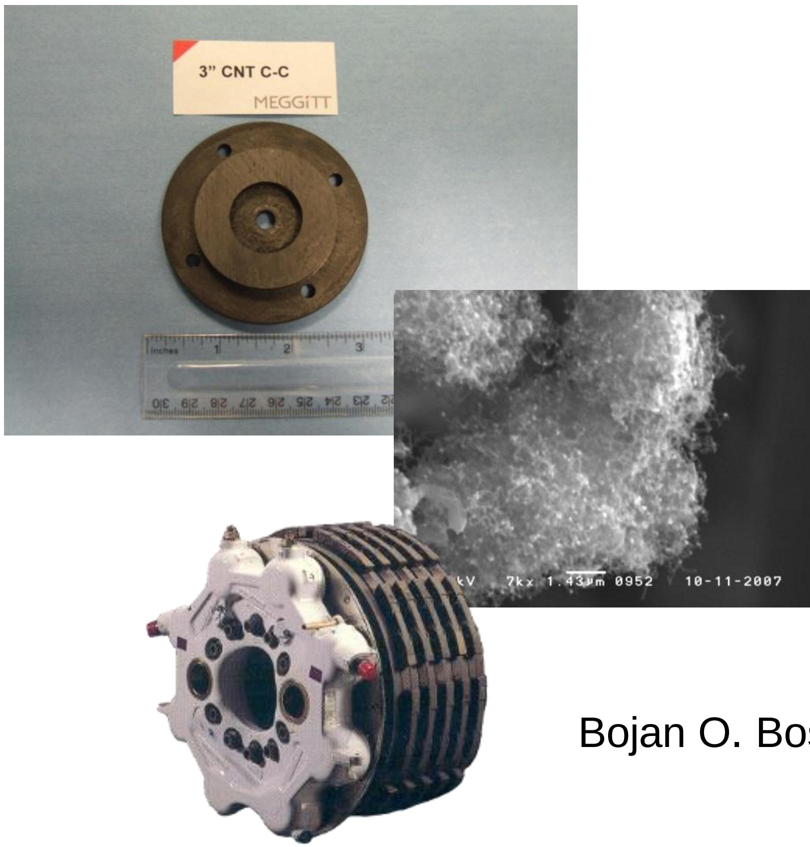


Dr Boskovic and co-workers at the University of Cambridge developed a method for low temperature synthesis of carbon nanofibres and nanotubes on the carbon fibre surface using DC PECVD.

B. O. Boskovic *et al*, *Carbon* **14** (2005) 2643-2648

Science Direct TOP25 Hottest Articles, Mat. Sci., Carbon, Jun – Dec 2005

Carbon-carbon disc with “in situ” grown carbon nanotubes and nanofibres

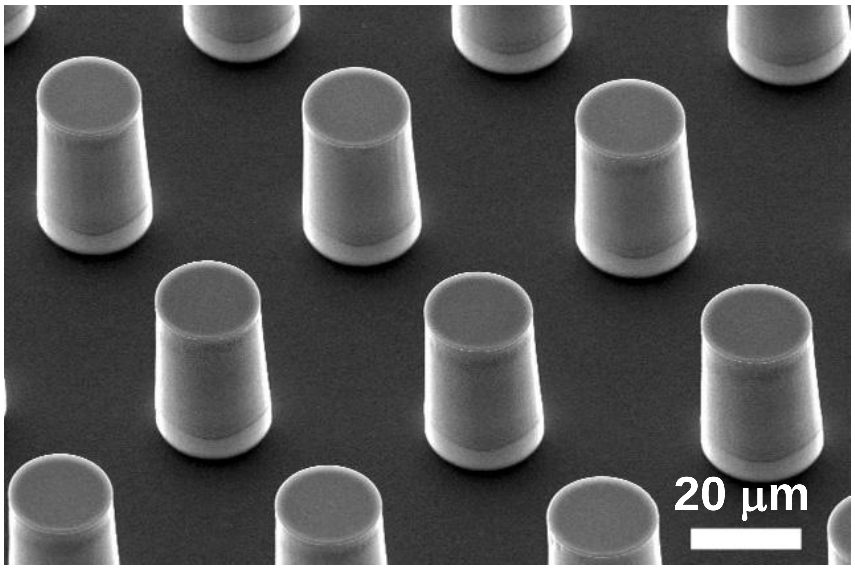


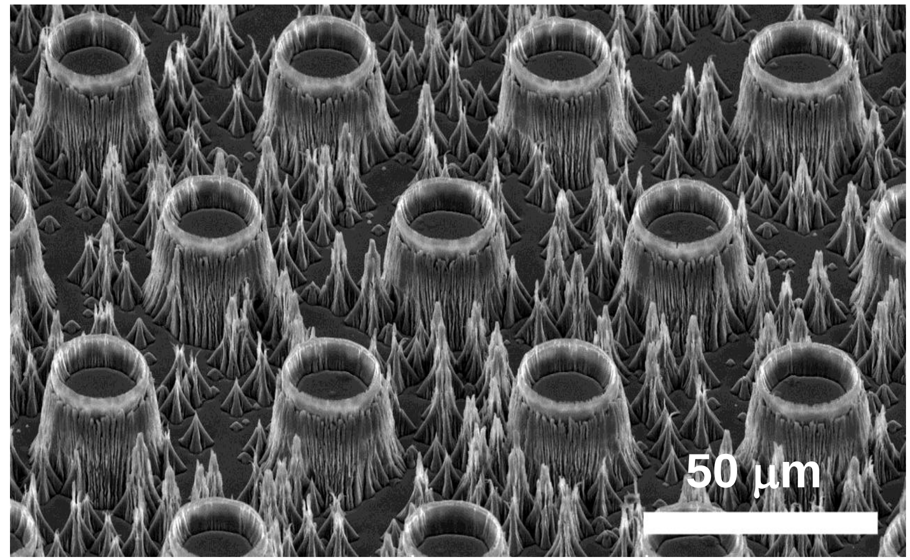
Dr Boskovic, while working for Meggitt Aircraft Braking Systems in Coventry invented a method for *in situ* synthesis of carbon nanofibres and nanotubes within carbon fibre cloth that is compatible with a standard CVI process used for production of carbon-carbon composite materials for aircraft and automotive brake discs.

Bojan O. Boskovic, Patent Appl. No.. WO 2009/004346 A1

CAMBRIDGE NANOMATERIALS TECHNOLOGY LTD

3D micro-machined Si substrates used for demonstration of CNT and CNF thermal and plasma CVD growth on arbitrary 3D objects





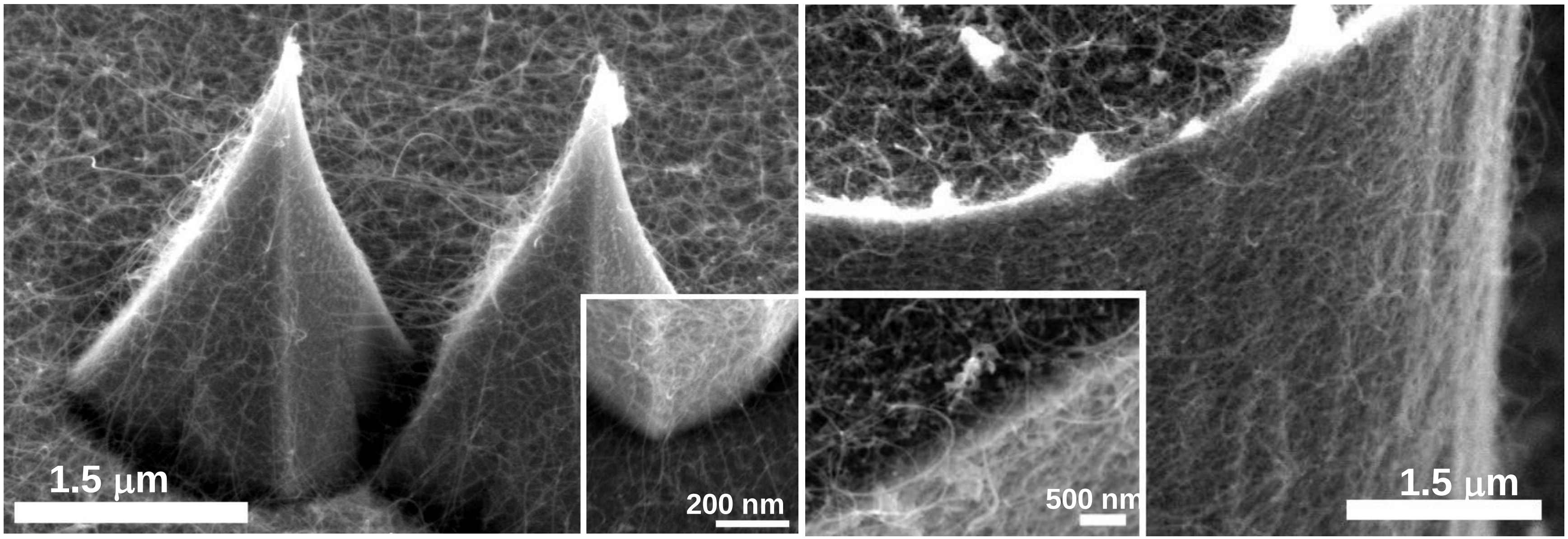
Dr Hart at the MIT and Dr Boskovic and co-workers at the University of Cambridge demonstrated that is possible to grown carbon nanotubes and nanofibres on the surface of any 3D micro object. Arbitrary micro-machined Si substrates were used for this demonstration. This joint work between MIT and University of Cambridge has been published in Nanotechnology in 2006.

A. J. Hart, B. O. Boskovic *et al*, *Nanotechnology* **17** (2006) 1397-1403

UNIVERSITY OF CAMBRIDGE

Demonstration of CNT growth on 3D micro-machined Si substrates using thermal and plasma CVD

Cambridge Nanomaterials Technology Ltd



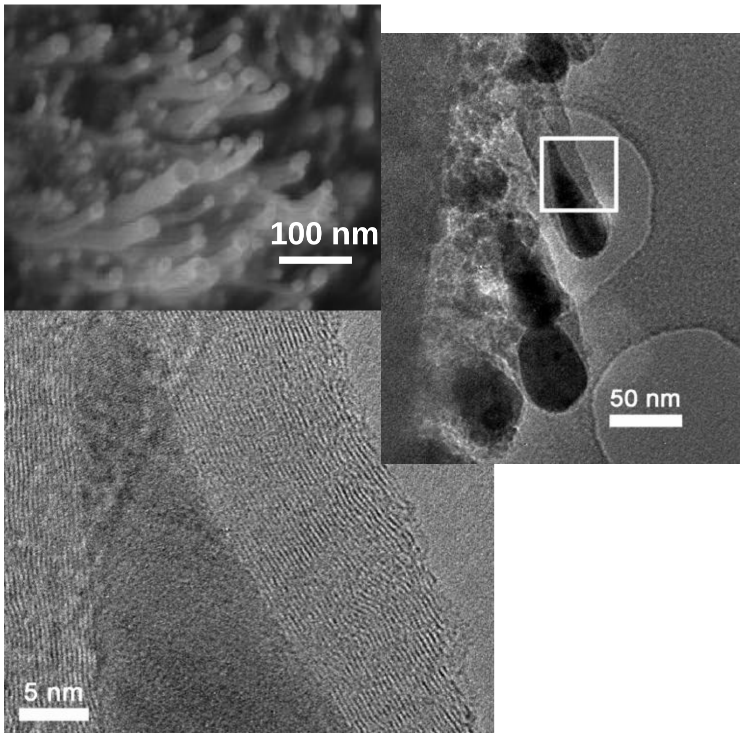
Dr Hart at the MIT and Dr Boskovic and co-workers at the University of Cambridge demonstrated that is possible to grown carbon nanotubes and nanofibres on the surface of any 3D micro object. Arbitrary micro-machined Si substrates were used for this demonstration. This joint work between MIT and University of Cambridge has been published in Nanotechnology in 2006.

A. J. Hart, B. O. Boskovic et al, *Nanotechnology* **17** (2006) 1397-1403

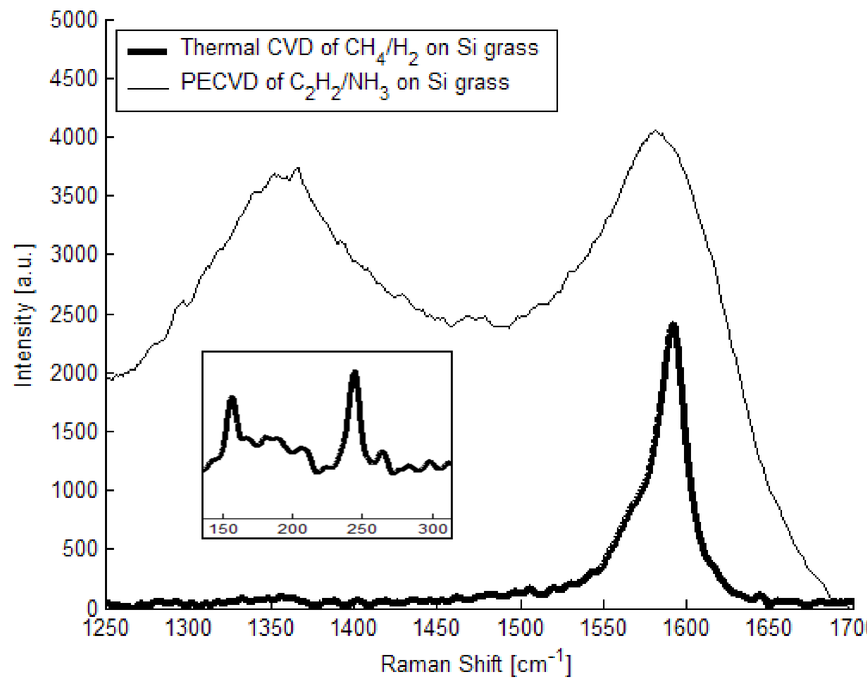
University of Cambridge

CAMBRIDGE NANOMATERIALS TECHNOLOGY LTD

Single wall carbon nanotubes grown using thermal CVD and carbon nanofibres growth using plasma CVD on 3D micro-machined Si substrates



Carbon nanofibres on Si Grass substrate. DC PECVD, Co colloidal catalyst, V=600V, p=1.5 mbar, T=500 ^{o}C, C_2H_2:NH_3 (1:4), t=20 min



Raman spectra of SWCNTs and CNFs

A. J. Hart, B. O. Boskovic *et al*, *Nanotechnology* **17** (2006) 1397-1403

UNIVERSITY OF CAMBRIDGE

Conclusions

- Carbon nanomaterials are seen as one of the most promission nanotechnology materials with applications in many industries.
- Three-dimensional carbon nanotube and nanofibre macroscopic structures could be synthesised using carbon fibres and other traditional engineering materials as a scaffold.
- Addition of carbon nanotubes and nanofibres could significantly improved mechanical, electrical and thermal properties of the composite materials.

Acknowledgements

Krzysztof Koziol, Ian Kinloch, Keith Paton, Cate Ducati and Alan Windle, Department of Materials Science and Metallurgy, University of Cambridge
Alfred Chuang, Brita Kleinsorge, Mirco Cantoro, Stefan Hofmann and John Robertson, Department of Engineering, University of Cambridge
Vlad Golovko and **Brian Johnson**, Department of Chemistry, University of Cambridge
Stuart Boden, Department of Materials, University of Oxford
Danny Csete de Gyoryfalva, Wilson Wall, Nashim Imam, Morgan Crucible PLC
Neil Fletcher, Toby Hutton, Meggitt Aircraft Braking Systems

Contact and Information

Dr Bojan O. Boskovic
Managing Director
Cambridge Nanomaterials Technology Ltd
14 Orchard Way
Lower Cambourne
Cambridge
CB23 5BN
UK

Tel. +44(0)1954 710865
Mob. +44(0)7780874335
E-mail: Bojan.Boskovic@CNT-Ltd.co.uk
Web: www.CNT-Ltd.co.uk