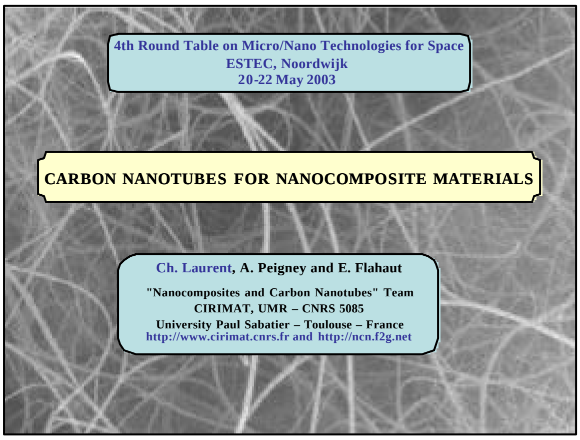
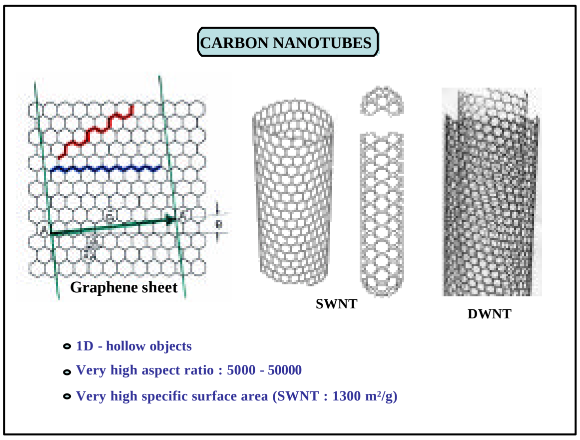
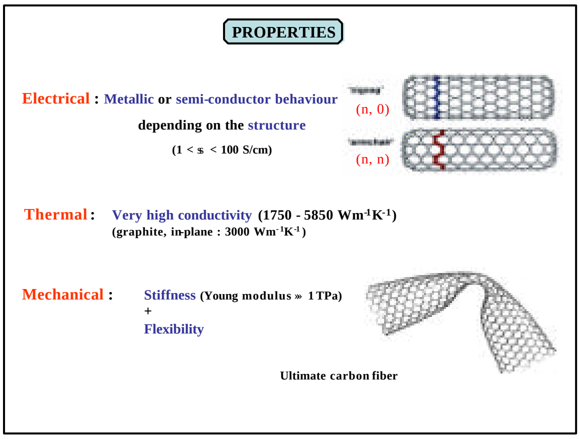
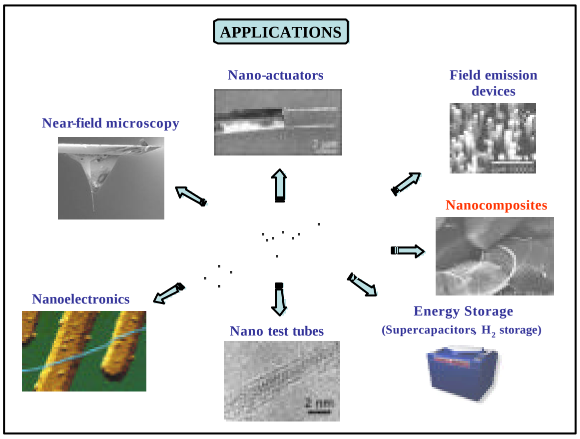

4th Round Table on Micro/Nano Technologies for Space
ESTEC, Noordwijk
20-22 May 2003
CARBON NANOTUBES FOR NANOCOMPOSITE MATERIALS
Ch. Laurent, A. Peigney and E. Flahaut
"Nanocomposites and Carbon Nanotubes" Team
CIRIMAT, UMR – CNRS 5085
University Paul Sabatier – Toulouse – France
http://www.cirimat.cnrs.fr and http://ncn.f2g.net


CARBON NANOTUBES
Graphene sheet
SWNT
DWNT
1D - hollow objects
Very high aspect ratio : 5000 - 50000
Very high specific surface area (SWNT : 1300 m²/g)


PROPERTIES
Electrical : Metallic or semi-conductor behaviour
depending on the structure
(1 < s < 100 S/cm)
(n, 0)
(n, n)
Thermal : Very high conductivity (1750 - 5850 Wm-1K-1)
(graphite, in-plane : 3000 Wm-1K-1)
Mechanical : Stiffness (Young modulus » 1 TPa)
+
Flexibility
Ultimate carbon fiber


APPLICATIONS
Nano-actuators
Field emission devices
Near-field microscopy
Nanocomposites
Nanoelectronics
Nano test tubes
Energy Storage
(Supercapacitors, H2 storage)

SYNTHESIS

Electric arc discharge	No catalyst => MWNTs With catalyst (Ni, Y) => SWNTs	length : a few µm
LASER ablation	With catalyst => SWNTs (big bundles)	length : ca. 100 µm
CVD or CCVD methods	Without or with catalyst SWNTs, DWNTS or MWNTs More flexibility - simple set-ups Possibility of localized or oriented growth	length : > 100 µm

Metal-matrix composites

Preparation by powder metallurgy techniques

Arc MWNTs-Al composites
T. Kuzumaki, K. Miyazawa, H. Ichinose and K. Ito, J. Mater. Res. 13, 2445 (1998)

Tensile strength and elongation only slightly affected by annealing at 873 K in contrast to those of pure Al

Ac MWNT-Ti composites
T. Kuzumaki, O. Ujiie, H. Ichinose and K. Ito, Adv. Eng. Mater. 2, 416 (2000)

Young's modulus is about 1.7 times that of pure Ti.
Vickers' hardness is about 5.5 times that of pure Ti

CCVD MWNT-Cu composites
S. R. Dong, J. P. Tu and X. B. Zhang, Mater. Sci. Eng. A, A313, 83 (2001)

Higher hardness and lower coefficient of friction and wear loss
The composites can reach a deformation of 50-60%

CCVD MWNT-Ni-P composite coatings (electroless deposition)
W. X. Chen, J. P. Tu, H. Y. Gan, Z. D. Xu, Q. G. Wang, J. Y. Lee, Z. L. Liu and X. B. Zhang, Surface and Coatings Technology 160, 68 (2002)

High wear resistance and a low friction coefficient compared to SiC-Ni-P and graphite-Ni-P coatings

Polymer-matrix composites

Epoxy, PMMA

PVA, PAN, polyurethane acrylate, polycarbonate, polyaniline, polystyrene, polyethylene

Conjugated polymers (polyphenylenevinylene (PPV) and derivatives)

Bulk materials, thick and thin films

Mechanical properties : load transfer

Electrical conductivity : percolation threshold

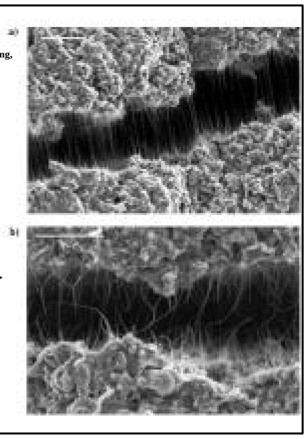
Photoluminescence studies for light-emitting diodes

1 wt % CNT-epoxy composites
X. Gong, J. Liu, S. Baskaran, R. D. Voise and J. S. Young, Chem. Mater. 12, 1049 (2000)

Importance of interfacial interaction

Prepared with surfactant
Tg increses from 63°C to 88°C
E increases by more than 30 %
in comparison with the matrix

Prepared without surfactant
Only moderated increses of Tg and E



5 wt.% SWNT-epoxy composites →
P. M. Ajayan, L. S. Schadler, C. Giannaris and A. Rubio, Adv. Mater. (Weinheim, Ger.) 12, 750 (2000)

Pull-out of SWNTs bundles
Possibility of crack-bridging

CCVD MWNTs (inner diameter 5 nm, outer diameter 10 nm, length a few micrometers)-epoxy composites (0.0225-0.15 wt % MWNTS)
J. Sandler, M. S. P. Shaffer, T. Prasse, W. Bauhofer, K. Schulte and A. H. Windle, Polymer 40, 5967 (1999)

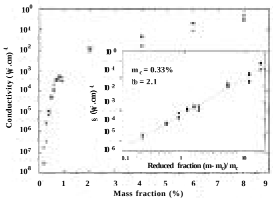
Percolation threshold between 0.0225 and 0.04 wt % MWNTs

Electrical conductivity of about 10^{-2} S/m, sufficient for anti-static applications, with 0.04 wt % MWNTs, i.e. using a loading about one-tenth of that needed using carbon black

Arc SWNT (diameter 1.3-1.5 nm)-PMMA composite films (10 µm thick)
J. M. Benoit, B. Corraze, S. Lefrant, W. J. Blau, P. Bernier and O. Chauvet, Synth. Met. 121, 1215 (2001)

Most SWNTs form bundles (7-12 nm)

The electrical conductivity increases by 9 orders of magnitude from 0.1 to 8 wt %



Ceramic-matrix composites

Al_2O_3, $MgAl_2O_4$, MgO, TiO_2, SiO_2

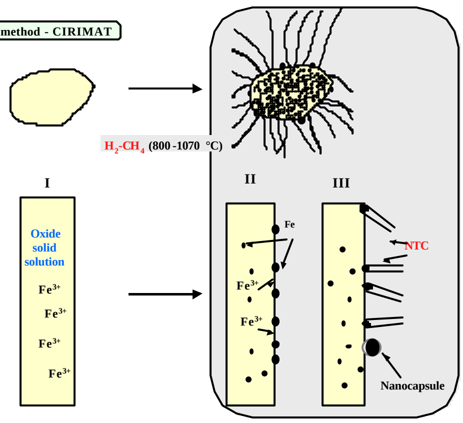
SiC, carbon

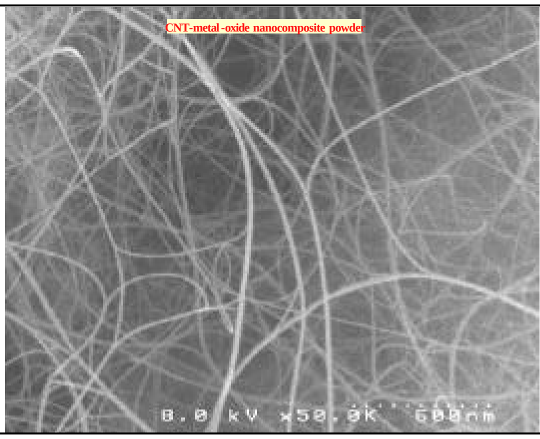
Mixing CNTs with matrix or matrix-precursor

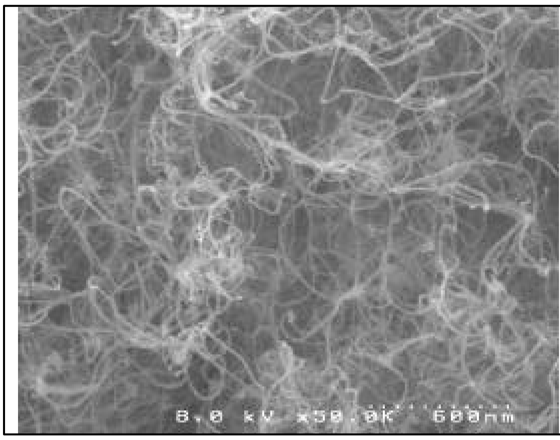
or

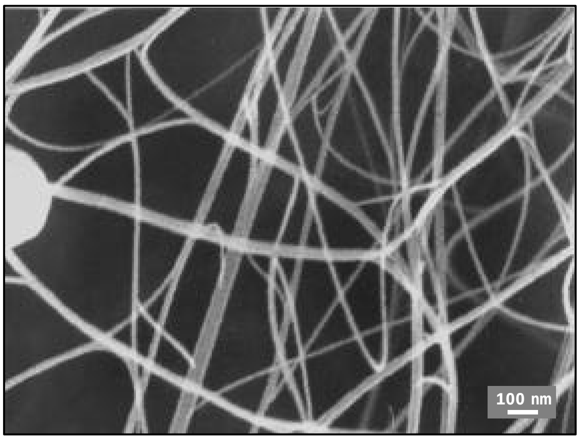
Direct synthesis of composite powders
A. Peigney, Ch. Laurent, F. Dobigeon and A. Rousset, J. Mater. Res. 12, 613 (1997)

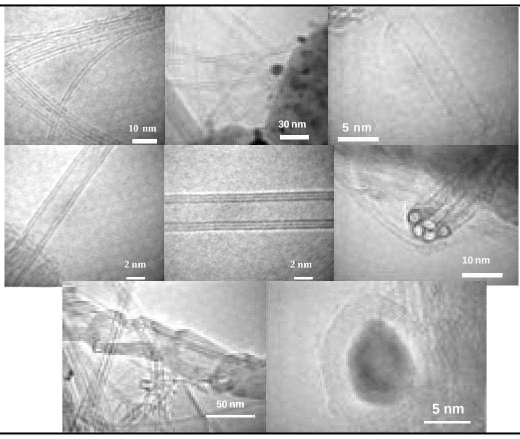
CCVD method - CIRIMAT



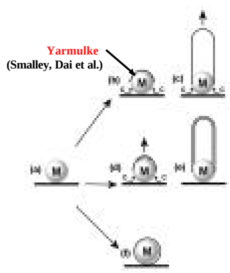


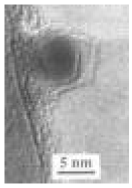






Metal particles nanometric at the CH4 decomposition temperature (800-1070°C)

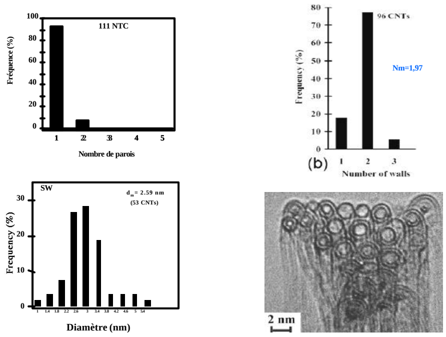




d £ 3-5 nm ® CNT
5 £ d£ 10 nm ® capsule
d ³ 10 nm ® nanofibre

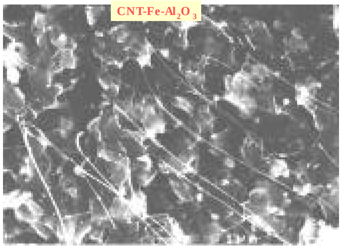
Adapt carbon feed to catalyst quantity

High selectivity on the number of walls



HOT-PRESSED COMPOSITES

Hot-pressing (1450-1500°C)



Mechanical properties only "correct"

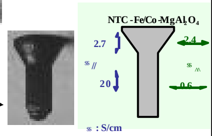
CNTs hamper densification

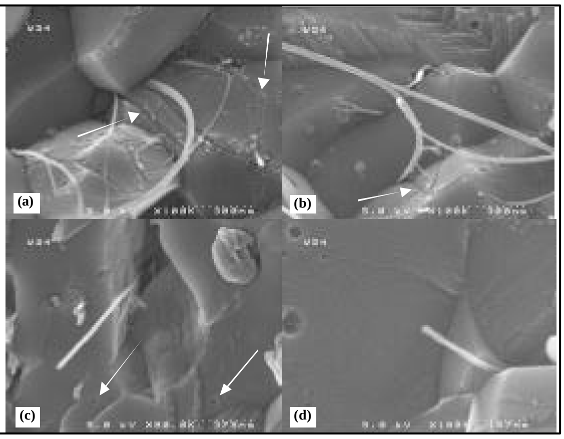
Electrical conductivity : 10^{-2} - 10 S/cm

Percolation thresholdat about 0.5 wt %

Anisotropy of conductivity in extruded composites

Possibility of fieldemission





EXTRACTION AND PURIFICATION

NTC - Co - MgO —HCl (1 mol.L^{-1})→ NTC + $(Co)_{capsules}$

S_w = 600 - 1200 m^2/g

↓

Dispersion in polymer

Bulk epoxy-matrix composite : percolation threshold at 0.3 wt.%

Thin film : percolation threshold at 0.1 wt.%

APPLICATIONS FOR SPACE

High-strength lightweight composites

Membranes

Heat-exchangers

Coatings : radiation shielding, antistatic applications

Supercapacitors

Sensors : force, pressure, chemical…

CONCLUSIONS

CNTs of various characteristics do exist

CNTs are available for testing and high-added-value applications

Key issues to overcome in CNT-composites include :

- achieving the homogeneous dispersion of the CNTs, especially at high loadings
- achieving a total (or very high) densification of the composite,
- achieving a certain degree of bonding between the CNTs and the matrix,
- understanding and/or controlling the reactivity between the CNTs and the surrounding materials, both during the processing and during in-service conditions.

To appear : *Ch. Laurent and A. Peigney*
Carbon Nanotubes in Composite Materials
Encyclopedia of Nanoscience and Nanotechnology
American Scientific Publishers