2nd EU/FET Cluster meeting – Las Palmas de Gran Canaria (Spain)

November 14, 2007

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Carbon nAnotube Technology for High-speed nExt-geneRation nano-InterconNEcts

Prof. M.S. Sarto

Scientific Coordinator

Research Center on Nanotechnology applied to Engineering – Sapienza University of Rome

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HIGH-SPEED INTERCONNECTS

Outline

- Consortium
- Objectives & Innovation
- Workplan

Consortium

1	**Consorzio Sapienza Innovazione.** Dr. S. Trueman (Project Manager)
2	**Sapienza Univ. of Rome - CNIS.** Prof. M.S. Sarto (Scientific Coordinator)
3	**Technical University of Delft.** Dr. K. Zhang
4	**Universite Paul Sabatier Toulouse III - UPS**. Dr. L. Ararault
5	**Università degli Studi di Salerno.** Prof. P. Ciambelli
6	**Latvijas Universitates Cietvielu Fizikas Instituts.** Dr. Y. Zhukovskii
7	**IMT Bucuresti.** Dr. A. Dinescu
8	**Swedish Defence Research Agency.** Dr. M. Hoijer
9	**Istituto Nazionale di Fisica Nucleare.** Dr. S. Bellucci
10	**Philips Electronics Nederland B.V.** Dr. O. van der Sluis
11	**Smoltek AB.** Dr. S. Kabir

Consortium

	University	Res. Org.	Industry	SME
Italy	✗ ✗	✗		✗
The Netherlands	✗		✗	
Sweden		✗		✗
France	✗			
Romania		✗		
Latvia		✗		

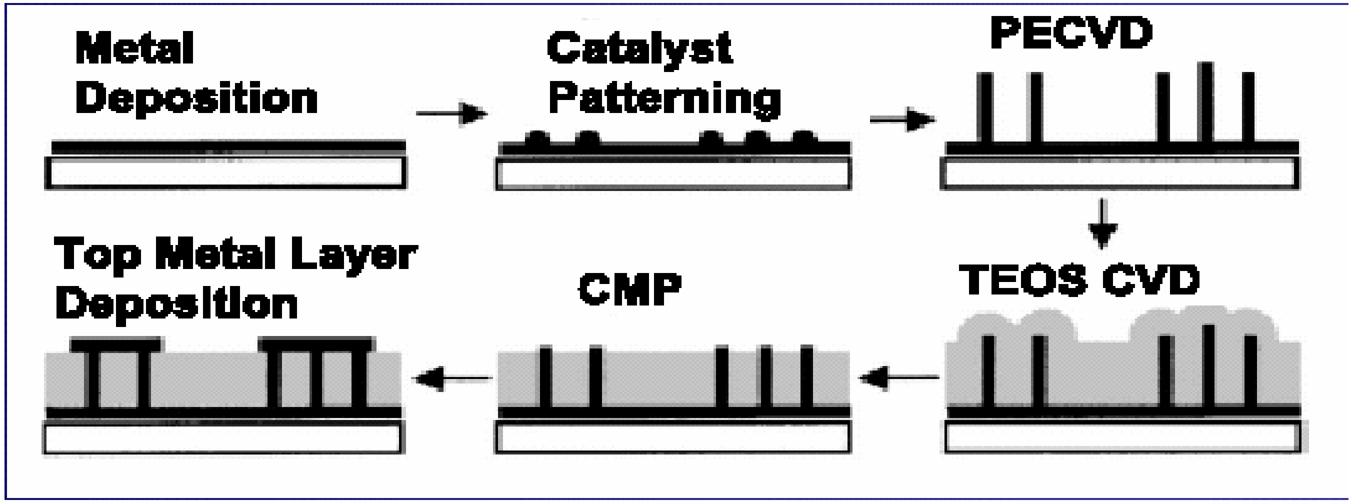
Project objectives & Innovations

- **To develop** an **innovative cost-effective** and **reliable** technological solution for high-performance **next-generation nano-interconnects beyond the limit of current technology** with**:**
  - **high-transmission speed**
  - **high current density,**
  - **exceptional mechanical and thermal properties**
  - **optimum signal and power integrity**
- The new approach exploits the **carbon nanotube technology**

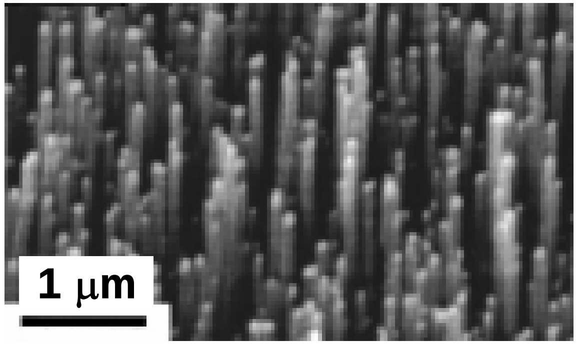
CNT interconnect technology: state-of-art

Fabrication process:

J. Lin, Q. Ye, A. Cassell, H.T. Ng, R. Stevens, J. Han, M. Meyyappan, *Applied Physics Letters*, Vol.82, No.15, 14 April 2003



SEM



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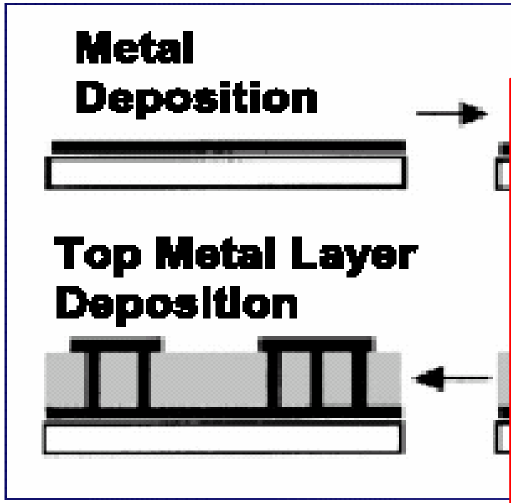

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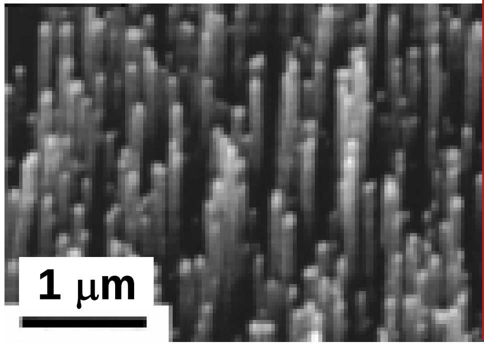

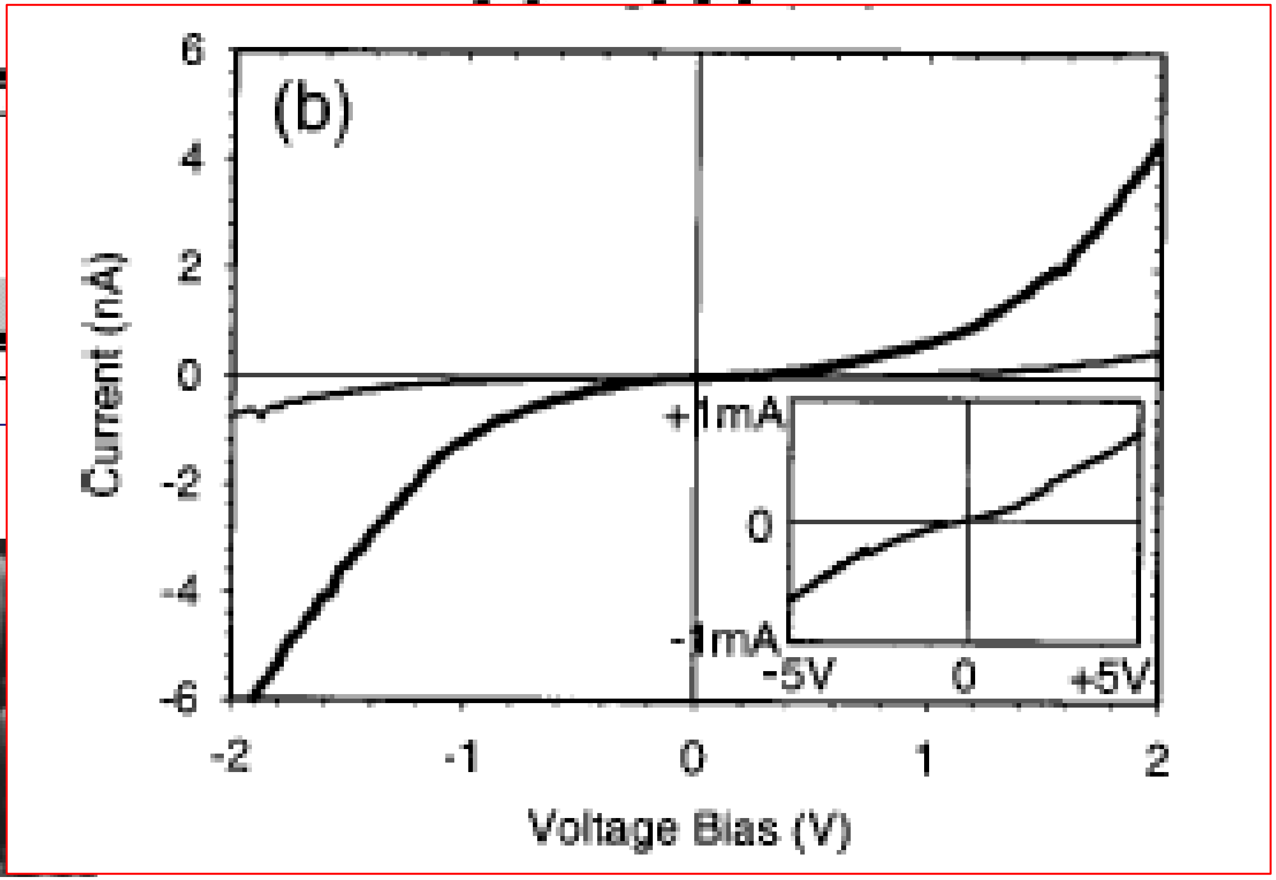

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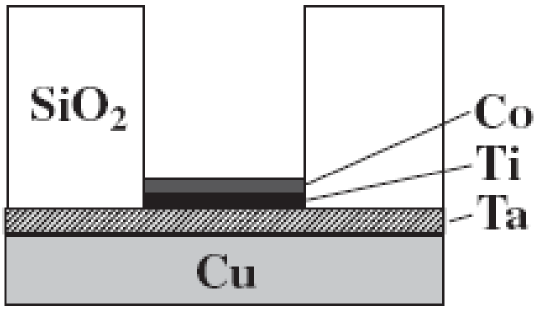

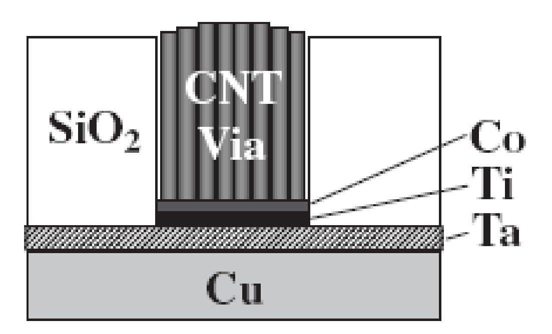

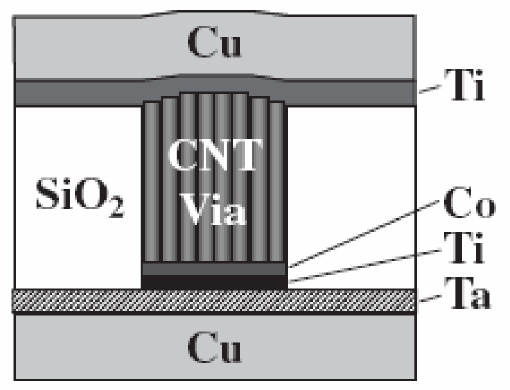

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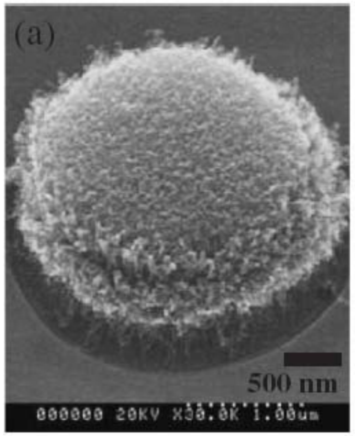
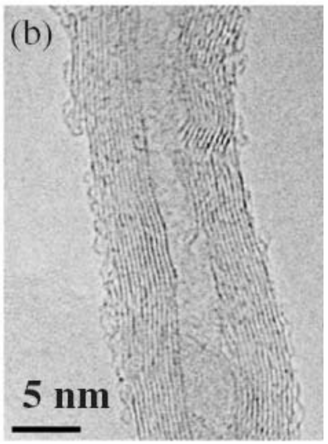


TEM



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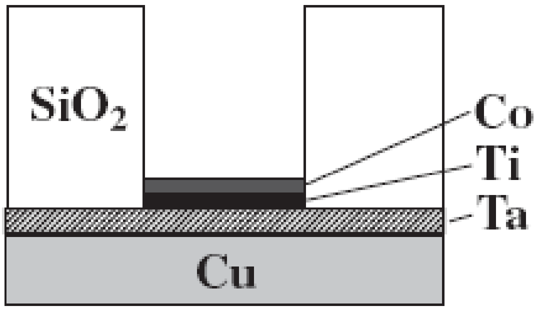

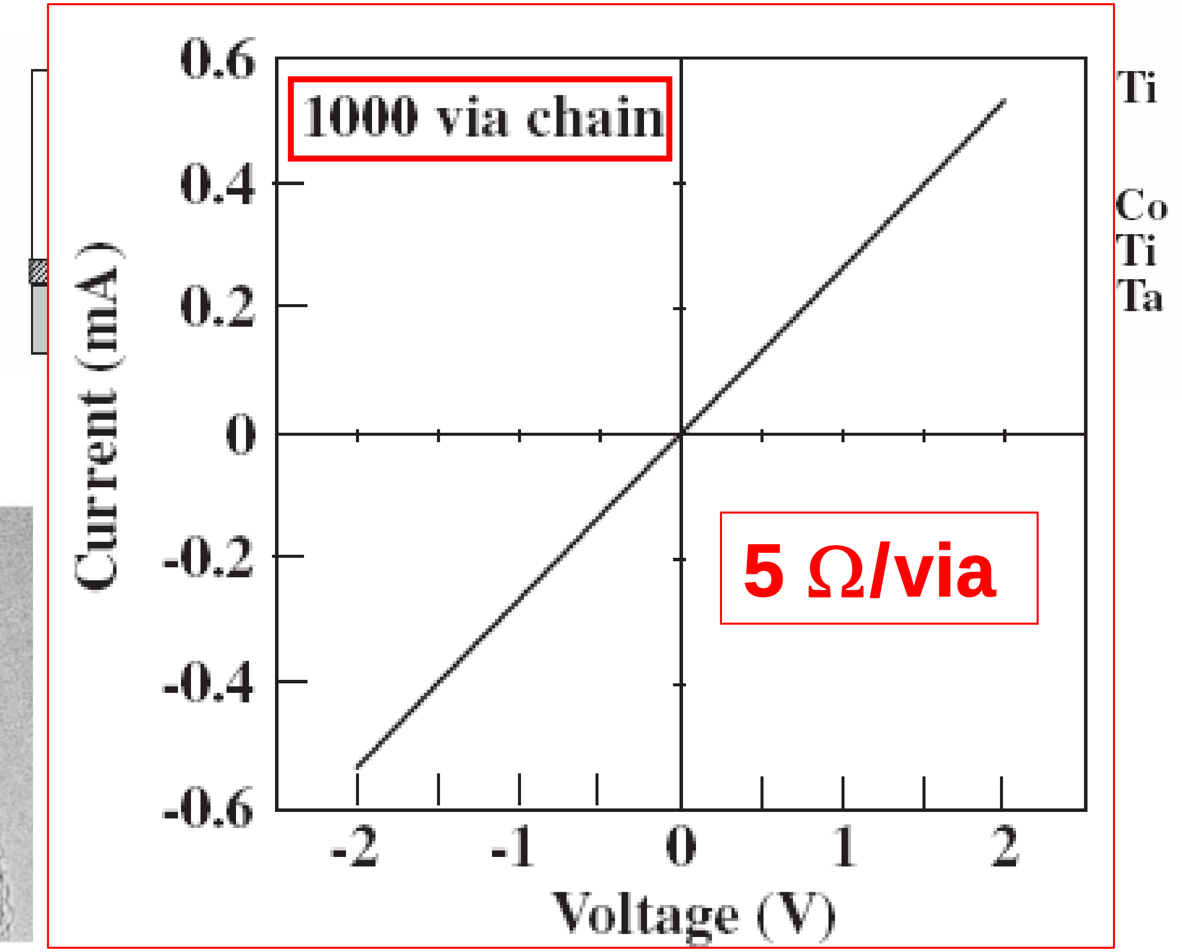

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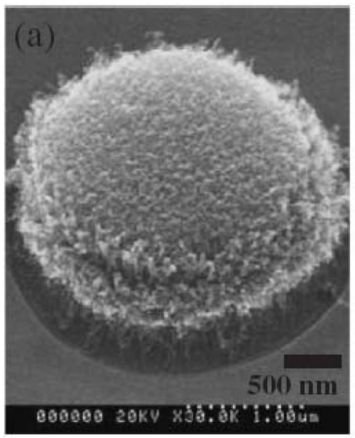

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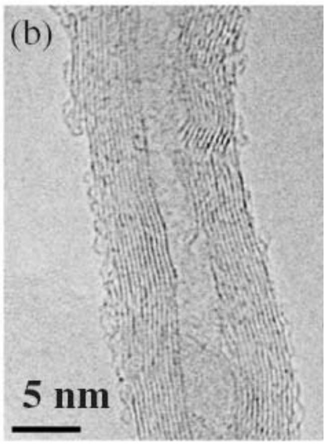

Controlled growth of CNT interconnects inside Al_2O_3 porous membrane

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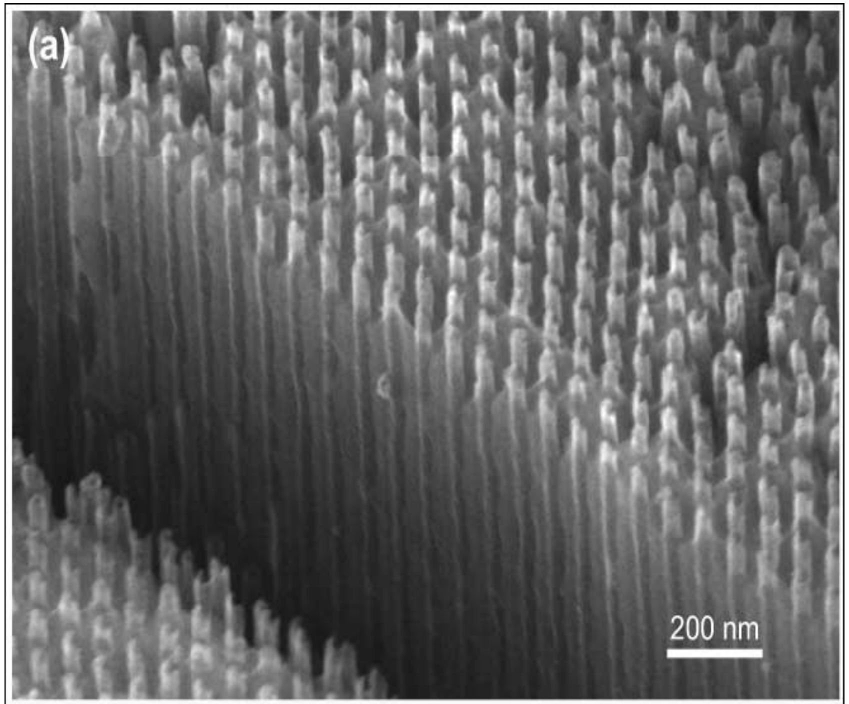
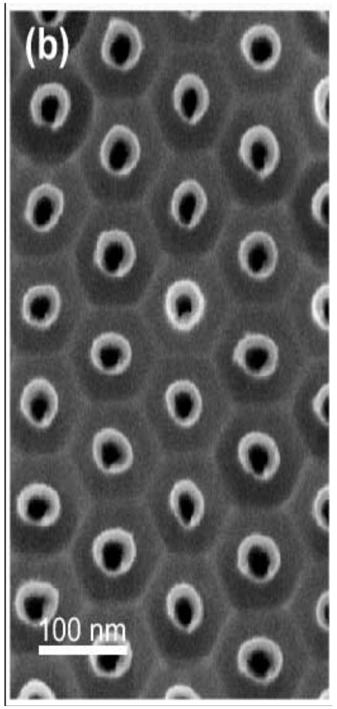
Side view **Top view**

SEM





Advantages:

Controlled growth of MWCNTs by means of the control of the membrane geometrical characteristics

Closed design-fabrication-properties assessment chain

2 MAIN GOALS

G1 : *To develop innovative technological solution* *for high-performance next-generation nanointerconnects.*

G2 : *To develop proof-of-concept* *nanointerconnects to assess and verify the new proposed solution*

2 PRODUCT DELIVERABLES

P1: Integrated data-base for nanointerconnect design

P2: Proof-of-concept nanointerconnect

4 MAIN EXPECTED RESULTS

R1 : Definition of all causal relations within the design-chain "microstructure characteristics – fabrication process – functional properties"

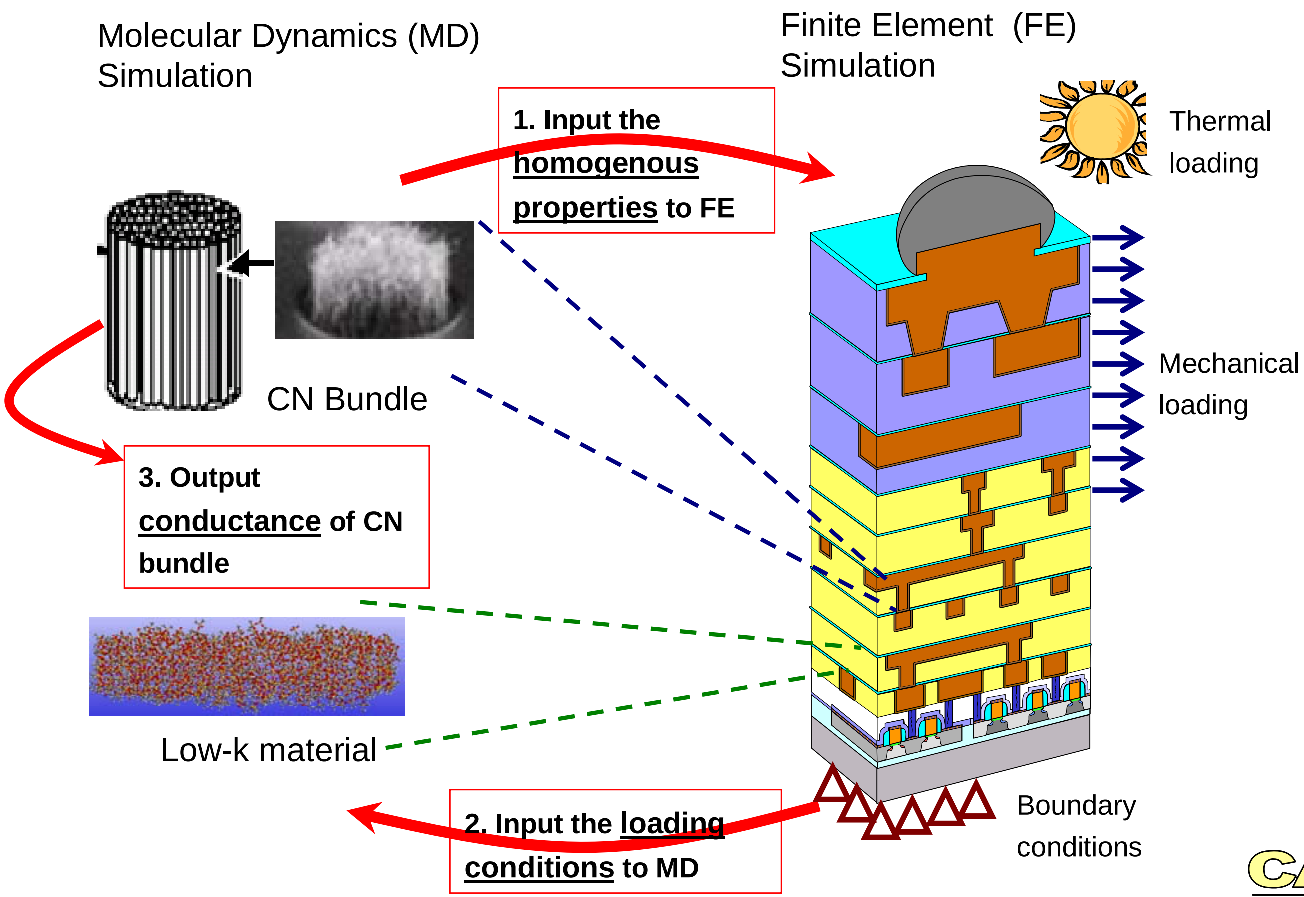
R2 : Development of multiscale multiphysics simulation models for the prediction of the multifunctional performance of the interconnect and for the EMC analysis;

R3 : Development of electromagnetic and multifunctional test procedures and experimental characterization methods

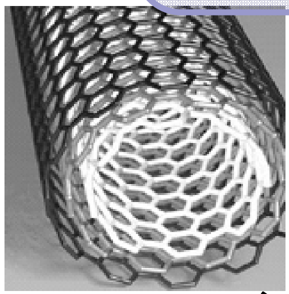
R4 : Manufacturing and testing of proof-of-concept samples of nanointerconnects at laboratory level.

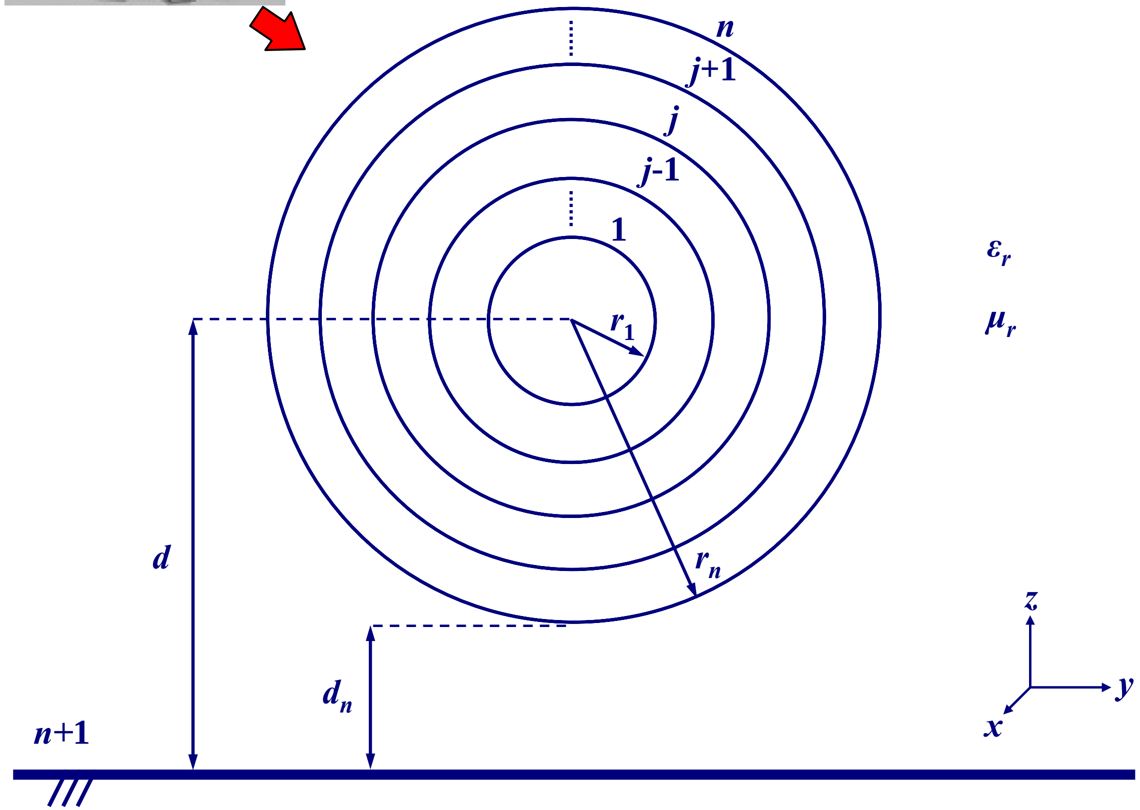
Model data-base for MWCNT-nano-interconnect design

Multiscale simulation of CNT-interconnected IC backend structure



EM modelling of MWCNT-interconnect



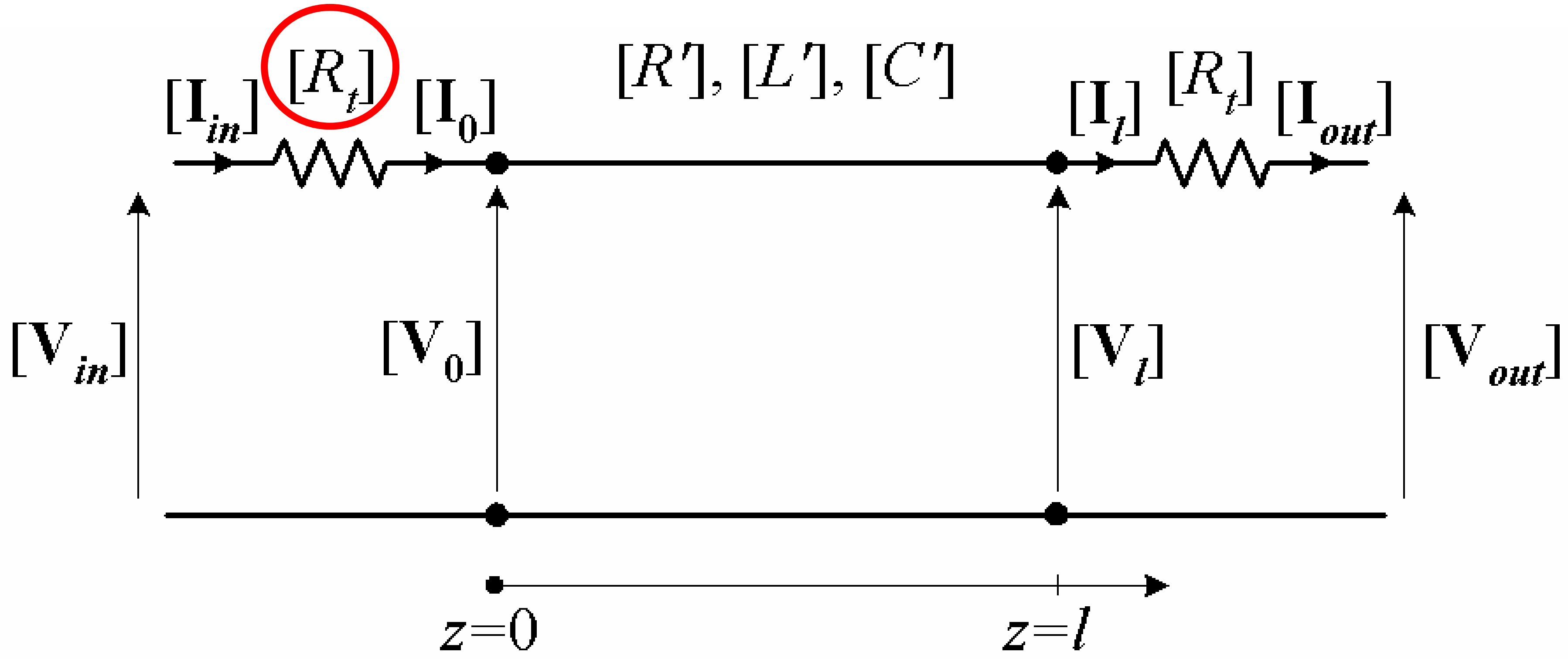


The inter-shell distance δ is constant and equal to inter-graphene distance of 0.34 nm.

The number of shells *n* is related to the inner and outer radius of the MWCNT:

$$n = \frac{r_n - r_1}{\delta} + 1$$

Equivalent transmission line circuit



	Max current density (MA/cm^2)											
	65 nm technology			45 nm technology			30 nm technology			22 nm technology		
ITRS-2006	3			8			13			17		
Cu	8			5			4.3			4		
MWCNT	Diameter [nm]	Total resistance [kΩ]	Max current density [MA/cm^2]	Diameter [nm]	Total resistance [kΩ]	Max current density [MA/cm^2]	Diameter [nm]	Total resistance [kΩ]	Max current density [MA/cm^2]	Diameter [nm]	Total resistance [kΩ]	Max current density [MA/cm2]
L=5 mm	65	0.4	7.2	45	0.61	10.4	30	0.92	15.3	22	1.28	20.5
L=0.5 mm	65	0.07	43.8	45	0.10	62.6	30	0.15	92.6	22	0.21	124.1

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Time delay at 50%

65 nm- and 45-nm node technology

	Length [mm]	Diameter [nm]	Shell	Time delay [ps]
Cu	10	65		0.034
	5	65		0.017
	0.5	65		0.00174
MWCNT	10	65	95	0.093
	5	65	95	0.0278
	0.5	65	95	0.00173
Cu	10	45		0.041
	5	45		0.0169
	0.5	45		0.00177
MWCNT	10	45	65	0.113
	5	45	65	0.033
	0.5	45	65	0.00176

30 nm- and 22-nm node technology

	Length [mm]	Diameter [nm]	Shell	Time delay [ps]
Cu	10	30		0.0908
	5	30		0.0241
	0.5	30		0.00179
MWCNT	10	30	43	0.144
	5	30	43	0.0424
	0.5	30	43	0.00185
Cu	10	22		0.197
	5	22		0.05
	0.5	22		0.00177
MWCNT	10	22	31	0.178
	5	22	31	0.0526
	0.5	22	31	0.002

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HIGH-SPEED INTERCONNECTS

WP1 Management
- 1.1 Executive Management
- 1.2 Financial Management
- 1.3 Scientific Coordination Support

WP2 Requirements and definition
- 2.1 Functional requirements
- 2.2 Technological requirements
- 2.3 Definition of data-base format

WP3 Modelling and simulation
- 3.1 Nano- & meso-scale modelling of growth mechanism
- 3.2 Electronic/electrical properties modelling
- 3.3 EM modelling at radio-frequency and EMC analysis
- 3.4 Mechanical & thermal modelling
- 3.5 Integrated data-base for interconnect design

WP4 Fabrication
- 4.1 Membrane
- 4.2 Nanoimprint lithography
- 4.3 Carbon nanotubes & nanofibers
- 4.4 Contacts and nanointerconnects

WP5 Experimental characterization
- 5.1 Definition of test procedures
- 5.2 Microscopy investigations and microstructure characterization
- 5.3 Electrical and electromagnetic tests
- 5.4 Mechanical and thermal tests

WP6 Optimizations of proof-of-concept nanointerconnect
- 6.1 Requirements of proof-of-concept specimen
- 6.2 Design by simulation
- 6.3 Fabrication
- 6.4 Testing and demonstration

WP7 Exploitation and dissemination
- 7.1 Patenting
- 7.2 Dissemination/user groups
- 7.3 Licensing
- 7.4 Workshops/ Conferences
- 7.5 Web-site
- 7.6 Publications
- 7.7 Joint collaboration with FET Projects