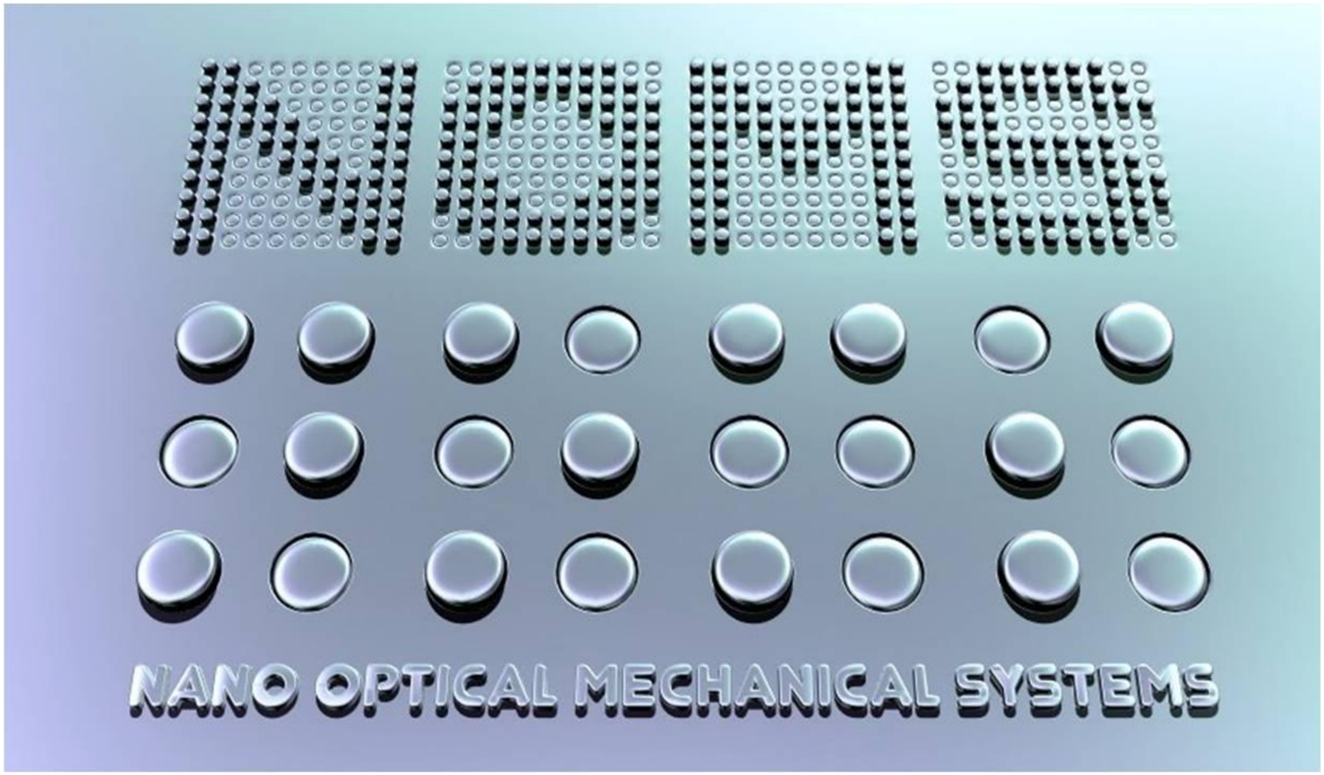
Nano-Optical Mechanical Systems (NOMS)



Theory and modelling of optical actuation in nanocomposites through in situ electron microscopy studies

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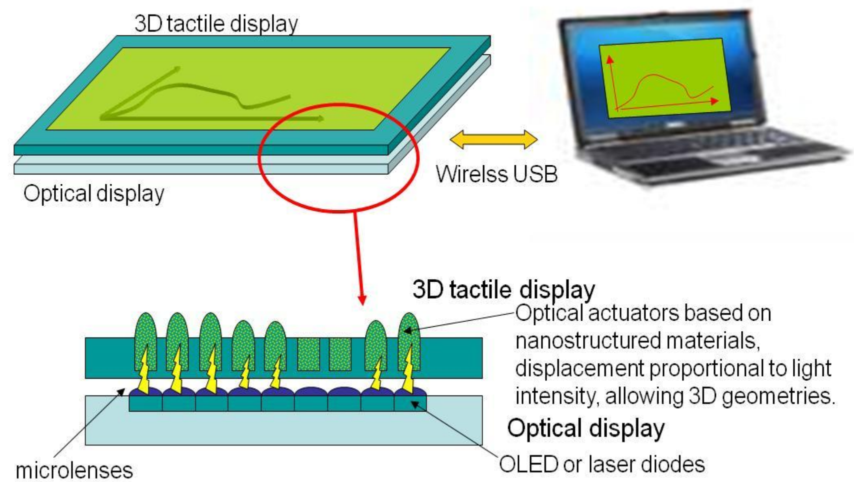
NANO-OPTICAL MECHANICAL SYSTEMS
NOMS: OBJECTIVES

- The original video signal from a computer screen can be transformed into pulses that trigger the appropriate emitters in the tablet.LED/LD-like platform will be focused on a <u>polymer nanocmposite film whose actuation can be tailored to enable graphic representation.</u>
- The proposed device will comprise an invaluable added advantage over current assistive technology:
  - Direct interface with computer displays
  - truly portable, wireless, and fast to browse the internet in real time.
  - Enable graphics representation
- Harnessing photoactuation to instantly propel further development in multiple adjacent fields such as medicine or robotics through artificial muscle technology



Braille Ecoplus-ONCE under a conventional QWERTY keyboard.

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Framing NOMS in TNT 2010

- **Unique insight into the landscape of nanotechnology activities worldwide; where efforts in catalysis, plasmonics and other pressing nanotechnologies have been thoroughly described. And we will see more CNT work later this morning.**
- **More relevant to NOMS; work has been presented in modelling order and conductivity of CNTs embedded in polymers (Simoes) along with problems involved in synthesizing these composites (Roussel) and also evidence of thermal actuation (Poulin).**
- **Very relevant: graphene session and touch screen technologies.**
- **NOMS deviates somewhat from the well-established topics; the focus is to develop an understanding of a novel functionality: photoactuation at the nanoscale. This is an emerging field, and we are far from understanding the phenomenon or even the whole impact roadmap.**
- **Overview of our incipient activities in trying to understand photoactuation at the nanoscale.**

Polymer nanocomposites: the possibilities

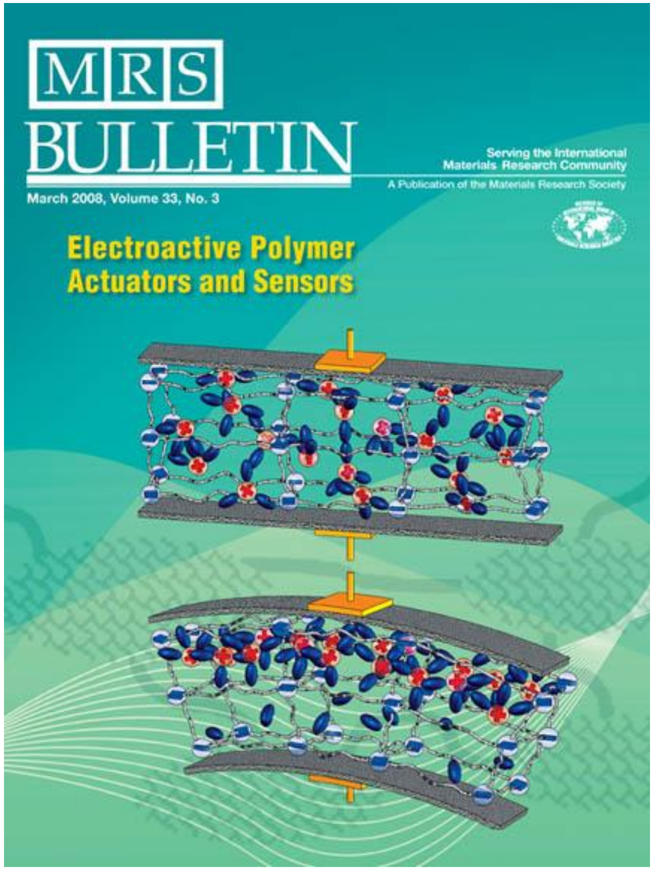
Good processability of polymers combined with functional properties of the CNTs are expected to yield:

- High-strength composites
- Energy storage and energy conversion devices
- Sensors
- Field emission displays and radiation sources
- Nanometer sized semiconductor devices
- Probes
- Interconnects

Also, innovative functionalities such as:

- Electrical actuation
- Optical actuation

Will originate innovative applications beyond structural composites



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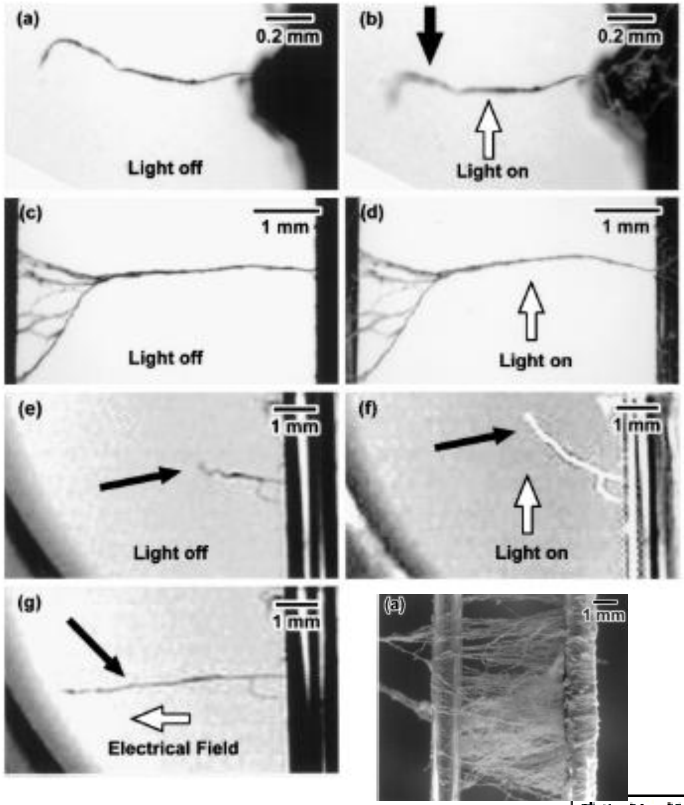
Baughman et al. Science, 297, 787 (2002)

MRS Bulletin March 2008

PHOTOACTUATION: MOTIVATION AND HISTORY

- Photomechanical actuation is preferred to electromechanical transduction due to:
  - Wireless actuation
  - Electrical-mechanical decoupling
  - Low noise
  - Easy scaling up/down
- However, few materials exhibit this property; SUCH AS CNT'S
- Zhang and Ijima studied the elastic response of Carbon Nanotube bundles to visible light. This is one of the earliest reports on photomechanical actuation on CNT.
- The free end displacement in (e) is as much as 1.3 mm, in a 5 mm long filament that is about 20% strain. In this case, the filament was 50-100 um thick.
- Displacement has been attributed to the action of electrostatic forces, but the mechanisms is not well understood.



Zhang and Iijima, Phys. Rev. Lett. 82 (17) 1999

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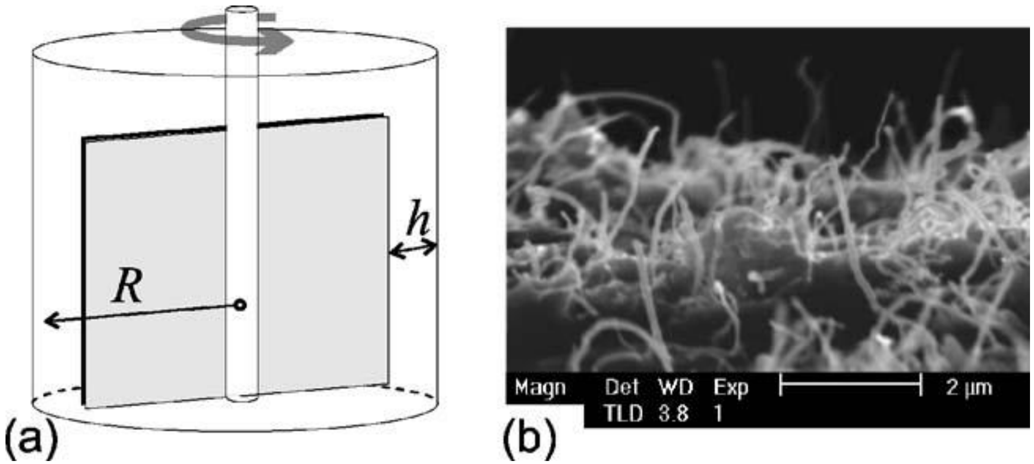
NANOCOMPOSITE MANUFACTURING

Polymer matrix - polydimethylsiloxane (PDMS) Sylgard 184TM, Dow Corning was mixed with various amounts of multiwalled carbon nanotubes (Nanostructured & Amorphous Materials, Inc. are used with purity verified as 95%, length *5–15 µm and outer diameter 60–100 nm)* .



Scheme of Ika Labortech. centrifuge(a) and SEM image of freeze-fractured surface of a well-dispersed 7 wt.% CNT composite, time of mix=61 h (b).

Rotation speed 1000 rpm and the mixing temperatures 30±0.5 °C.

Crosslinker was added to the mixture after 24 hours, ratio to PDMS is 1:10.

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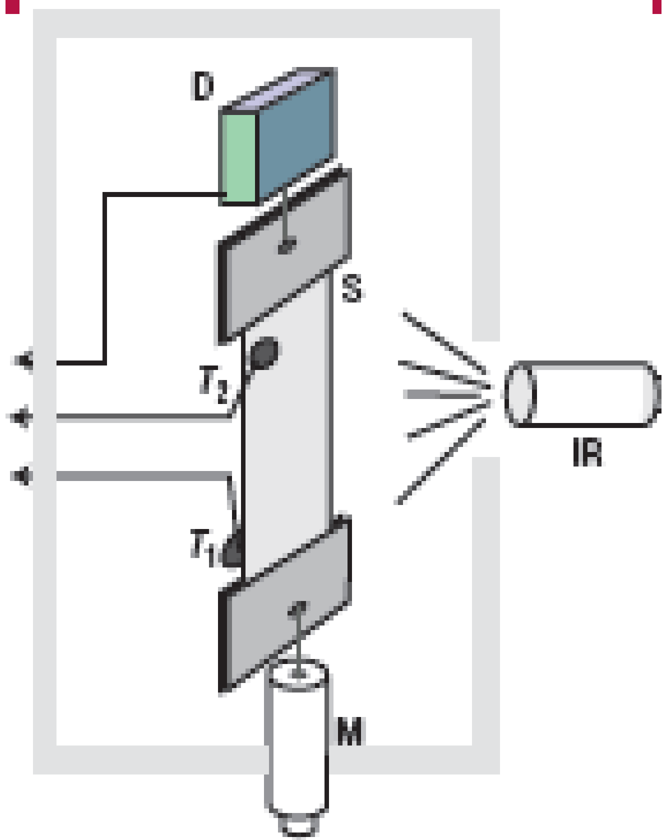
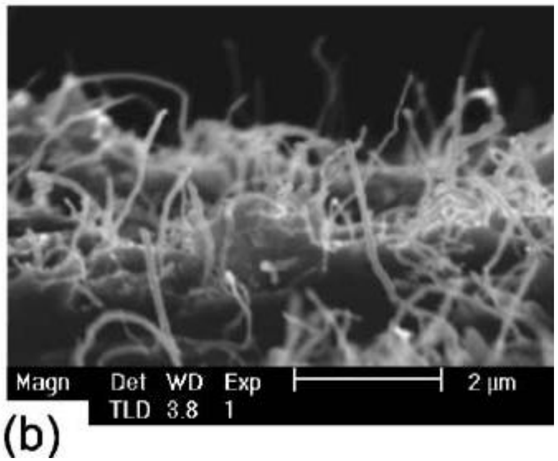
Y. Y. Huang, S. V. Ahir, E. M. Terentjev, Physical Review B, 73, 125422, 2006.
S. V.. Ahir, E. M. Terentjev, Nature Mat., 4, 491, 2005.

BACKGROUND
Smart Material Development
State of the Art



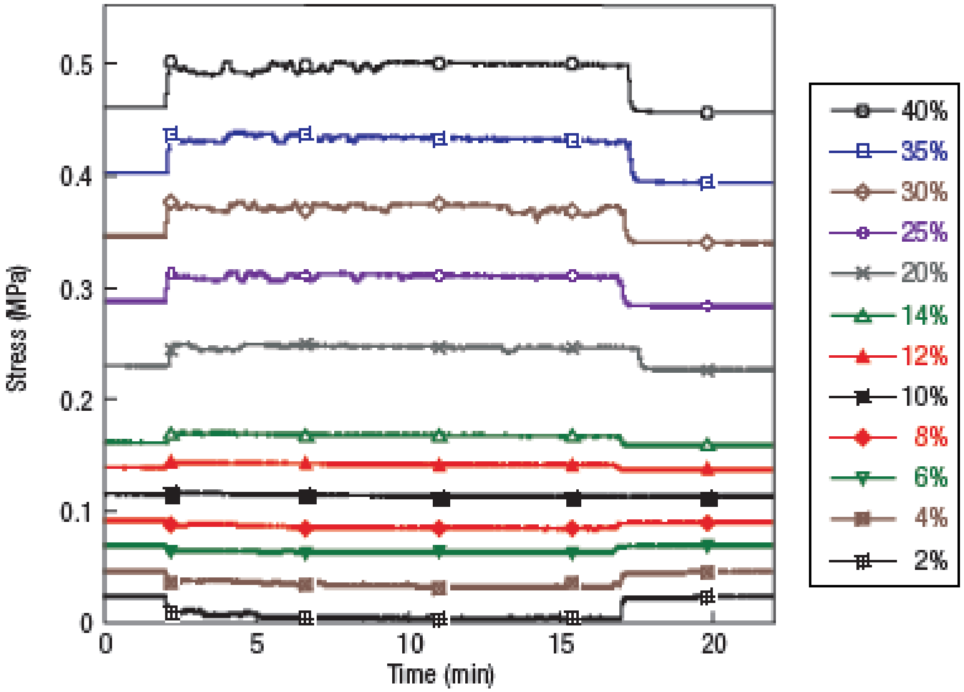


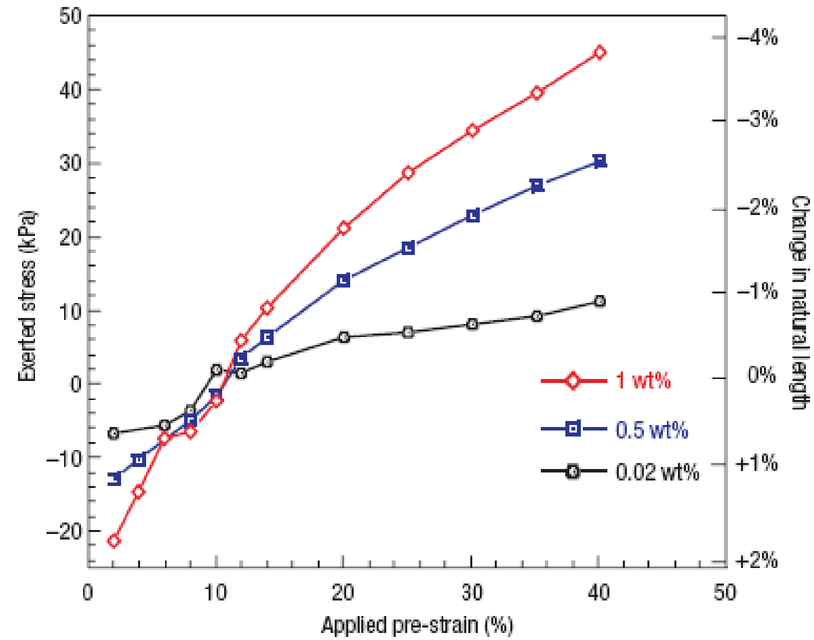
(b)

- **Applied strain and reported actuation under infrared radiation of a whole nanowire assembly embedded in PDMS.**
- **Synthesis of composites involve dispersion and alignment of the MWCNTs for effective photoactuation.**

Ahir and Terentjev, Nature Materials, Vol. 4, 2005

TIME-BASED RESPONSE AT DIFFERENT APPLIED PRE-STRAINS





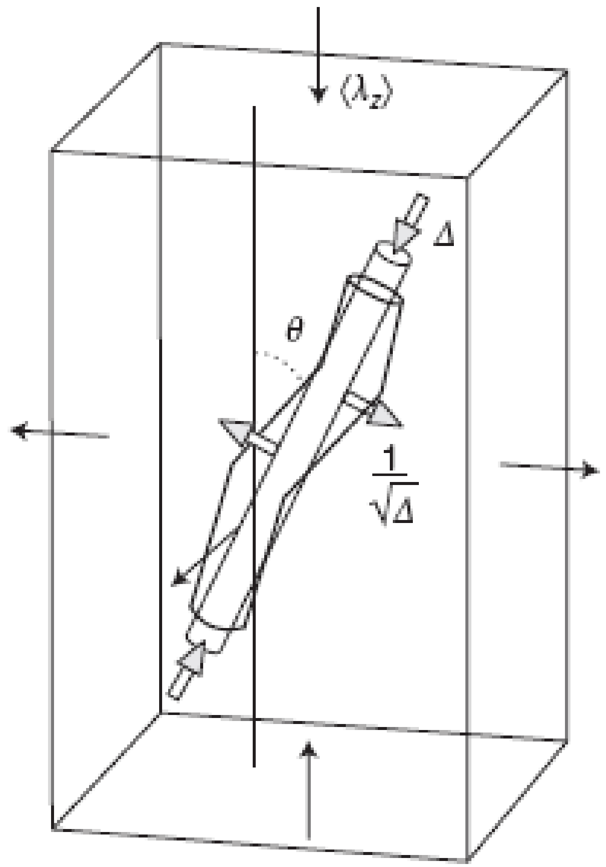
Light source: Schott KL1500 LCD, maximum intensity at ~675 nm, 702 μW cm2 at 1 m distance) was positioned 20 mm — from the sample surface. The total power of light delivered to the sample was of the order of 8 mW.

Ahir and Terentjev, Nature Materials, Vol. 4, 2005

PROPOSED ACTUATION MODEL AND EXPERIMENTAL VERIFICATION

SEVENTH FRAMEWORK PROGRAMME

- **Thermal effects ruled out.**
- **Process is reversible.**
- **The change in sign of the exerted stress is believed to be associated with nanotube alignment.**
- **Attributes actuation to torsional-orientation effects of the MWCNT within the matrix, although this has not been observed experimentally and the physical mechanism is not well understood**



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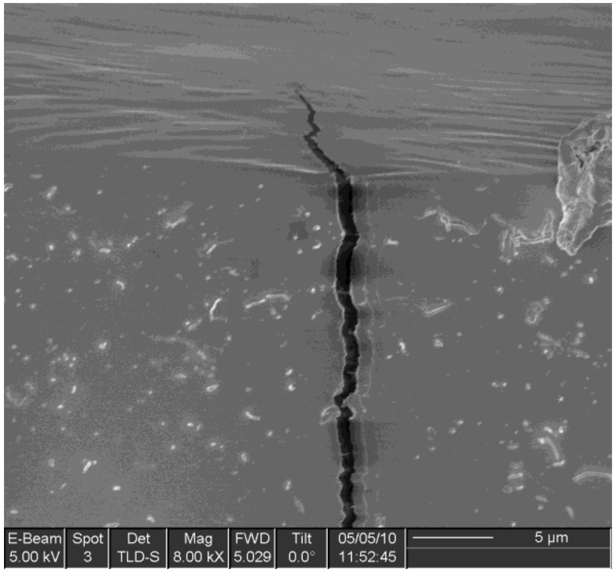
Ahir and Terentjev, Nature Materials, Vol. 4, 2005

TECHNOLOGY DRAW BACKS IN NANOCOMPOSITES

Orientation and distribution of CNTs on the matrix is paramount for augmented or novel properties in composites:

- **Nano-fillers have a stronger tendency to agglomerate than micro-fillers; ultrasound and high-speed sheering are commonly used to promote dispersion**
- **They bundle together and entangle producing defects in the composite and limiting target performance efficiency and therefore hindering technological implementation in operating devices**



(Wagner, Appl. Phys. Lett. 72 (1998) 188)
(Quian, Appl. Phys. Lett. 76 (2000) 2868)

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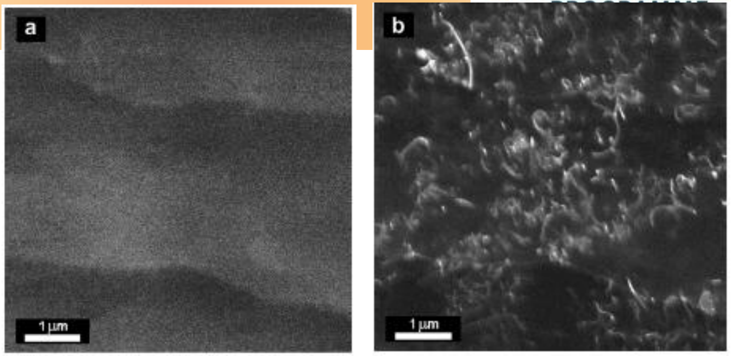
IMPORTANCE OF ELECTRON MICROSCOPY IN POLYMER COMPOSITES

- **Dispersion and orientation analysis of nanoparticles in polymer matrix is a subject of much interest in the nanocomposite community. However optical observation of CNTs is not possible, therefore SEM/TEM is needed**
- **Electron beam damage (thermal and electric) is a concern in polymer composites. Low atomic number of the species and the chemical similarity between filler and matrix does not help create contrast mechanisms.**
- **Kovacs (Carbon 45 (2007) 1279–1288) conducted SEM imaging analysis to study:**
  - **Influence of detector**
  - **Spin-coating thickness**
  - **Voltage contrast**
  - **Dwell times**



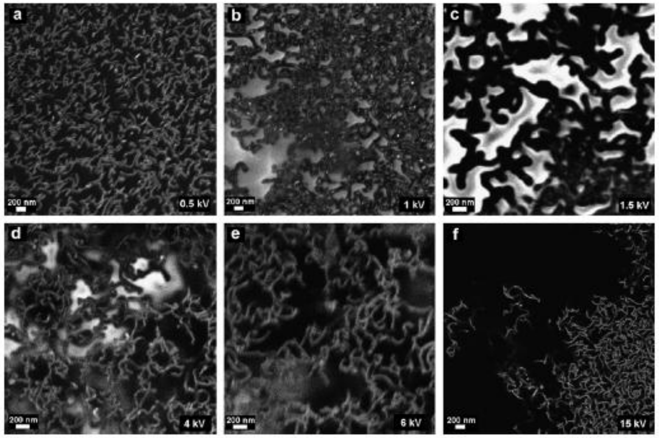
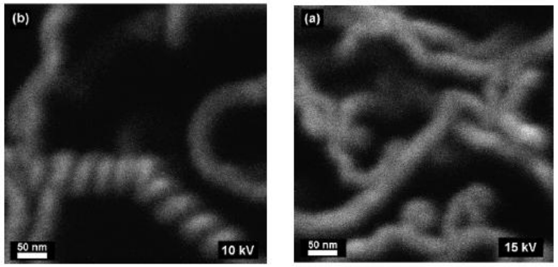


Fig. 5. The same sample as in Fig. 2 recorded at 25,000× magnification and different acceleration voltages: (a) 0.5 kV, (b) 1 kV, (c) 1.5 kV, (d) 4 kV, (e) 6 kV, and (f) 15 kV.



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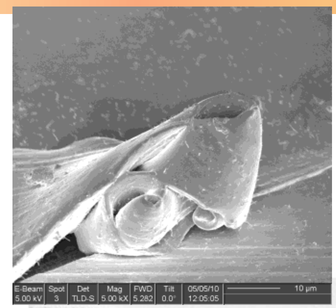
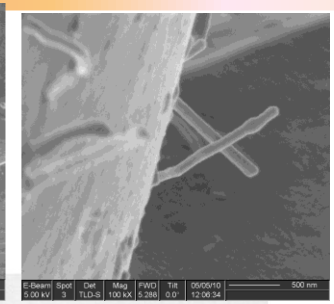
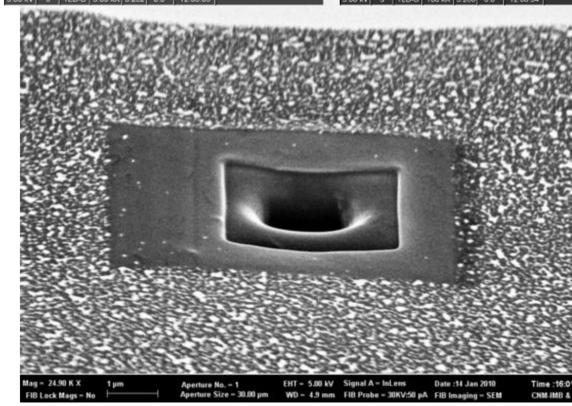
Campo et al. Scanning Microscopy SPIE Proceedings 2010

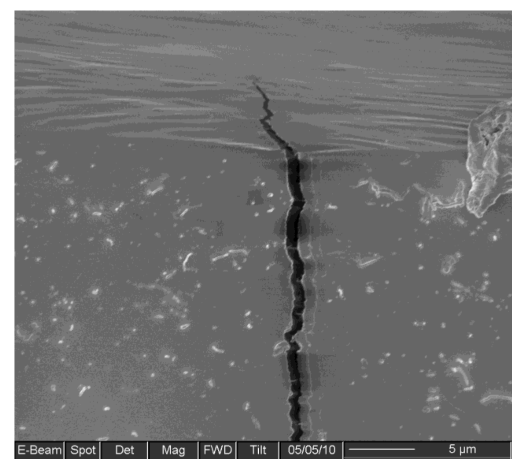
IMPORTANCE OF ELECTRON MICROSCOPY IN POLYMER COMPOSITES

- In situ TEM analysis of optoactuation could help determine the fundamentals behind actuation: how do we obtain a electron-transparent slab that photoactuates?
- FIB irradiation of polymer-nanoparticle composites is a promising technique that has been attempted before with limited results due to lack of control of Ion and electron beam damage. This is still in development stage
- We propose a methodic approach to minimize sample preparation damage and optimum inspection.









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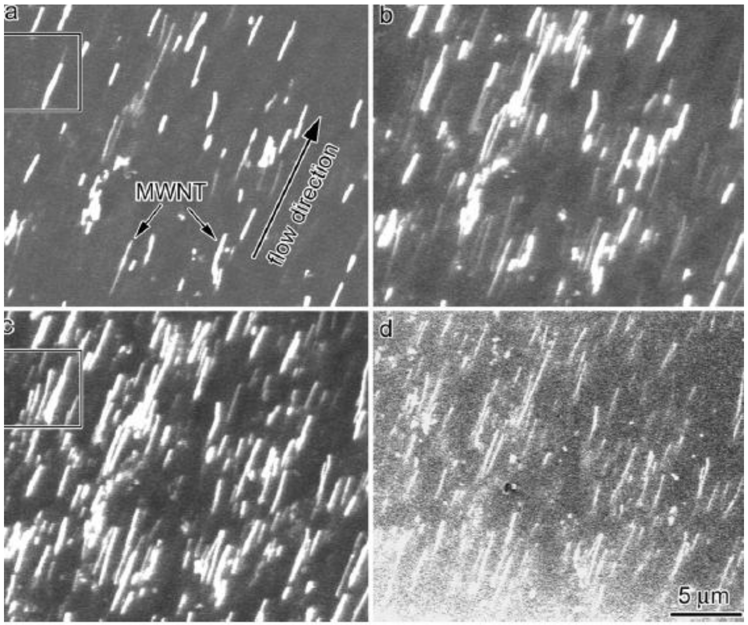
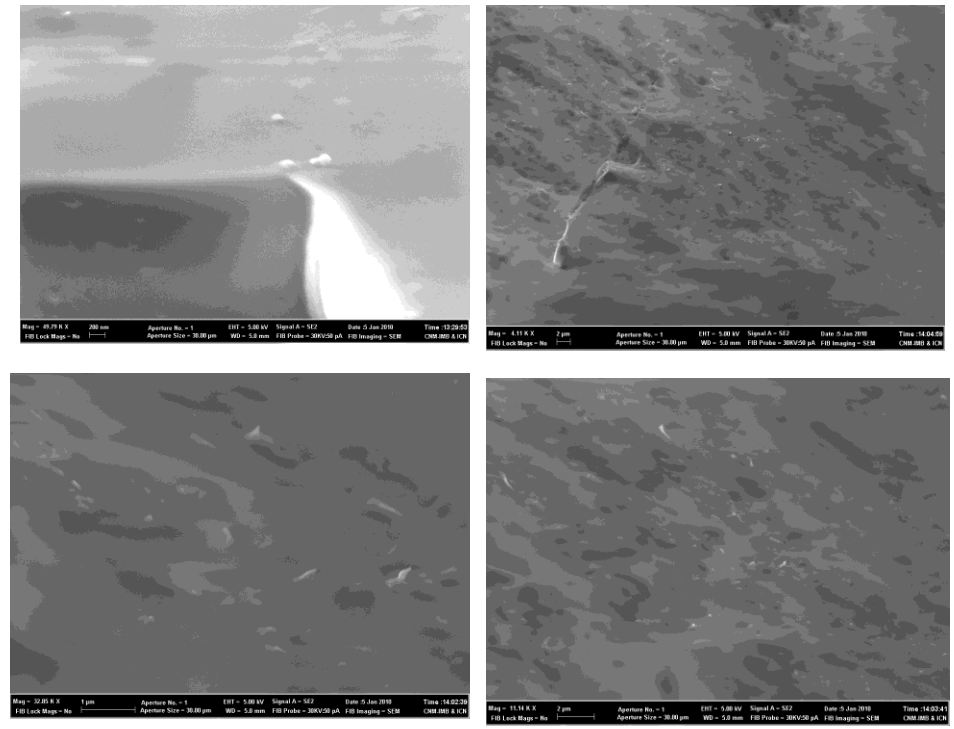
Ion beam irradiation to identify CNT in polymer



Characterization of alignment and orientation of CNTs on polymer matrices has been cumbersome up to now, Deng et al recently reported successful characterization of CNT orientation by FIB.

Deng et al. Materials Letters 61 (2007) 5095-5097



Progressive FIB irradiation of 2wt% MWCNT at 50 pA shows bright filament contrast that we will attribute to the embedded MWCNTs. The MWCNT are 50 to 80 nm in diamenter and 10-15 µm long.

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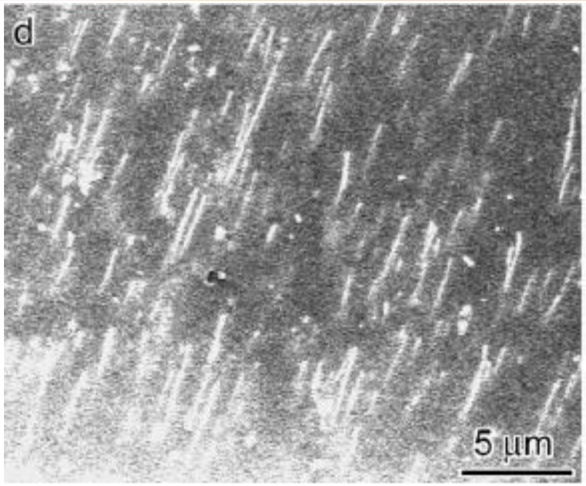
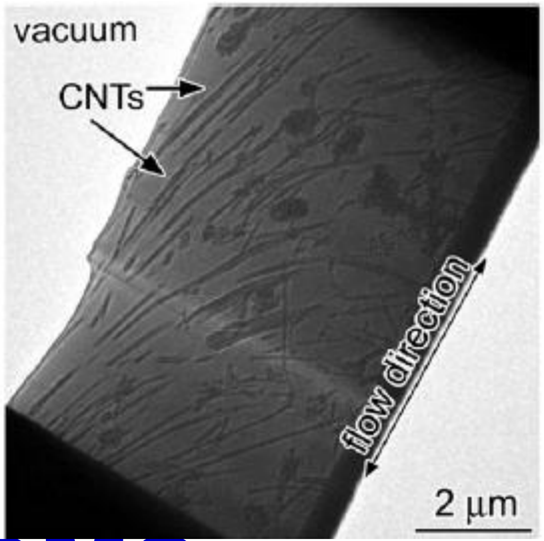
HANDICAPS ON TEM SAMPLE PREP OF POLYMER-CNT COMPOSITES





How can we achieve both electron transparency and photactuation?

- Microtomy could alter the orientation of CNTs relative to the polymer matrix (Deng) and even initial manual slicing at room temperature would easily modify this spatial relation and the orientation of CNTs in the matrix which could hinder actuation.
- Deng first report on FIB use in Polymer-CNT composites-showing high contrast of CNTs both in FIB and TEM modes.

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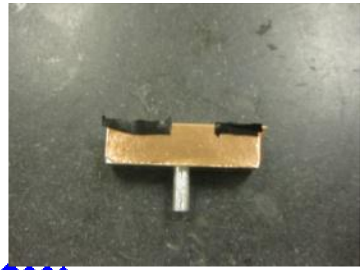
STRATEGY FOR ELECTRON MICROSCOPY ANALYSIS

- **Initial cut:**
  - **Freeze-fracture-effects on motility of the CNTs for in situ inspection are unclear**
- **Microtome**
- **FIB**
  - **Room Temperature**
  - **Cold-stage milling**
  - **He-FIB: in cooperation with NIST**
  - **"Slice and view" for tomographic analysis.**
- **In-situ TEM**
  - **Photoactuation**
  - **Thermal actuation**



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NANO OPTICAL MECHANICAL SYSTEMS

FIB milling for TEM sample preparation

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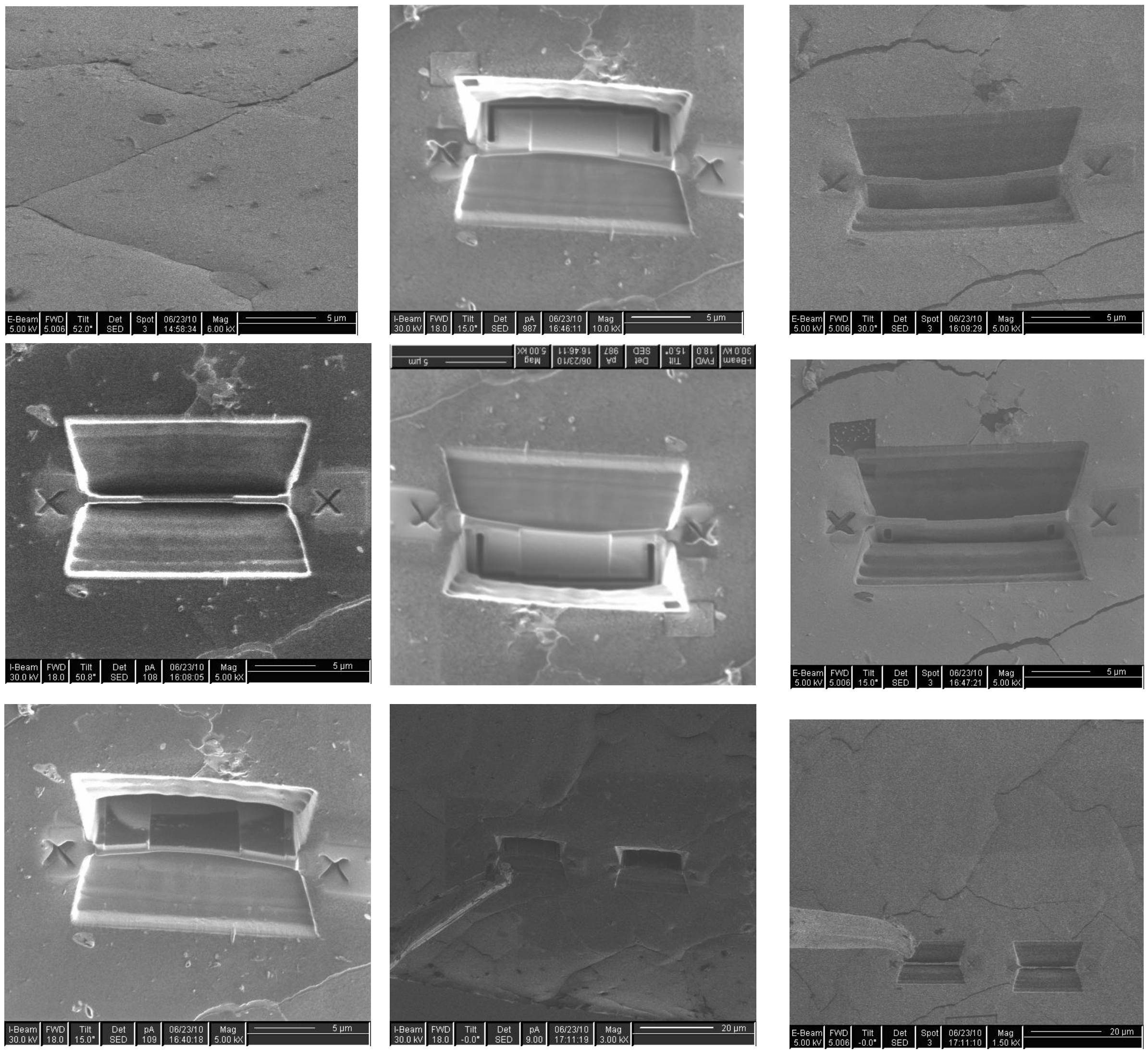

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In situ Studies

"…Mechanical testing methods have evolved over time to test materials at the micro- and nanoscale while observing the changes in the specimen. Recent advances in micro- and nanotechnology offer a new generation of sensitive sensors and actuators that allow *in situ* studies of both living and nonliving materials in analytical instruments…."

IN SITU TEM OPTO-MECHANICAL ACTUATION
On-going PENN collaborative

TEM holder retrofitting for in situ photoactuaction: thread an optical fiber through the length of the holder mantaining vacuum conditions.

Outlook

- Expectation of in situ observation
  - MWCNTs, SWCNTs, graphene nanoribbons?
- Photoactuation: a physical model
  - Parallelism with thermal and electron transport and defect generation (e-beam)
- Photoactuation of nanocomposites will be soon launched to main stream research and project NOMS will partially lead this effort. Atomistic understanding of photoactuation along with appropriate integration in Micro/nanosystem technologies will position photoactuation in the device arena.
- A fundamental understanding of photoactuation will be conducive to incorporate NOMS in multiple environments such as intracellular motors, artificial muscles, and tactile displays for the general public.

CALLS FOR PAPERS

Scanning Microscopies 2011:

Advanced Microscopy Technologies for Defense, Homeland Security, Forensic, Life, Environmental and Industrial Sciences

- Nanotechnology imaging and characterization
- Nanofabrication and nanolithography with scanned probes
- Particle beam/specimen interaction (WORKSHOP)

SPIE Defense Security and Sensing DSS-- http://spie.org/defense-security-sensing.xml -- 25 - 29 April 2011, Orlando World Center Marriott Resort & Convention Center, Orlando, Florida

Abstract Due Date: 11 October 2010

NOMS SPIE-NOMS 2011:

Synthesis mechanisms; dispersion and alignment of nanoparticles and moieties
First principle and mechanistic modeling
Microsystem Integration
Material and Device Characterization. Statitc and Dynamic testing.
- Thermal Analyisis
- Atomic Probe
- In-situ actuation

Applications:
- Human-machine interfaces: Tactile displays
- Artificial muscles
- Biomimetics
- Power storage

Dissemination and Education

21-25 August 2011: SPIE's Optics + Photonics in San Diego, CA

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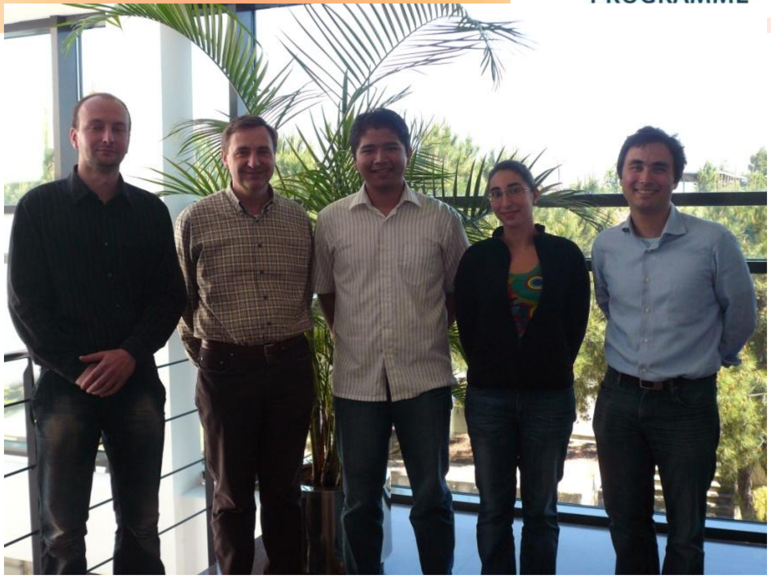

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Acknowledgements

SEVENTH FRAMEWORK PROGRAMME

- The NOMS project is partly funded by the European Commission (Grant Agreement No. 228916)
- NOMS Web Page: www.noms-project.eu

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Centre Nacional de Microelectrònica IMB

UAB Universitat Autònoma de Barcelona

UNIVERSITY OF CAMBRIDGE Department of Physics

Microsharp Corporation Limited

Universität Hamburg

iXscient

PHILIPS

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NOMS
Nano-Optical Mechanical Systems

- **Project Coordinator in execution phase: Dr Jaume Esteve**
- **Project Coordinator assistant: Dr. Eva M. Campo**

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  Tel: + 34 93 594 7700 E-mail: info@noms-project.eu

- **Timetable: September 2009 to August 2012**

  Total cost: €3.39 million EC funding: €2.55 million

  Instrument: Small or Medium Scale Focused Research Project

  Project Reference: 228916

- **Website: www.noms-project.eu**

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