Nanosensors for structural monitoring in civil engineering

New insight on promising carbon nanotubes devices

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Nanotechnologies in the construction sector : why ?

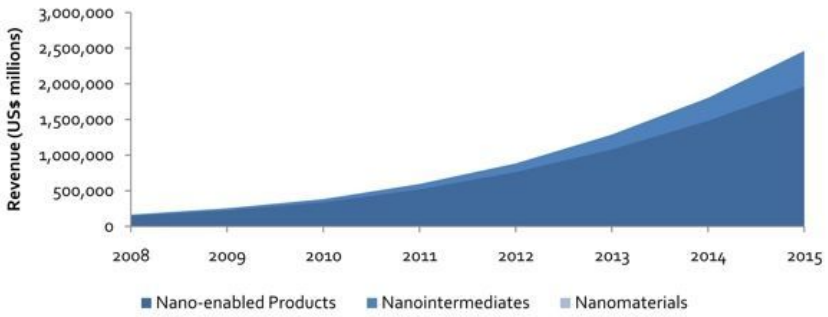
- Nanotechnologies :
  - Already plenty of (niche) products
  - Global market : 2500 G€ in 2015

  ⇒ Goal : finding large market opportunities

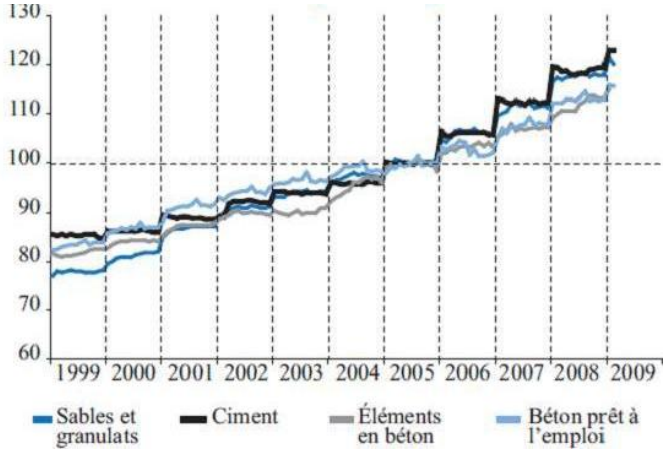
- Construction sector :
  - More than 10 % of European GDP
  - Toward sustainability...and cost reduction

  ⇒ A new priority : improving structural service expectancy

Market of nanotechnologies [1]



Increasing costs [2]



1. Lux Research Inc., 2010 ; 2. Letournel, INSEE, 2009

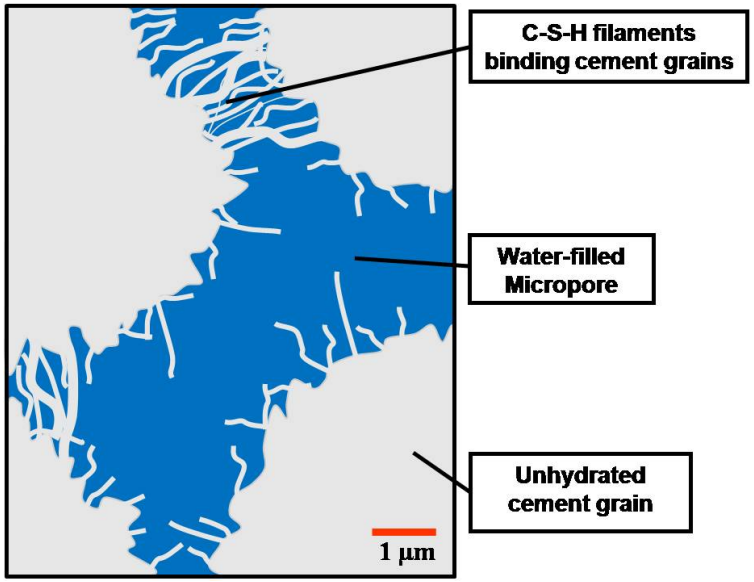
Concrete materials : degradations and durability

- Various degradation processes
  - Corrosions, cracks, swelling...
  - Origin : particules and gas transport within microporosity

$\Rightarrow$ To control durability, one needs to MONITOR MICROPOROSITY

Degradations caused by internal swelling [1]

Concrete microporosity



1. Baroghel-Bouny, Tech. Ingénieur, 2005

Monitoring microporosity with nanosensors

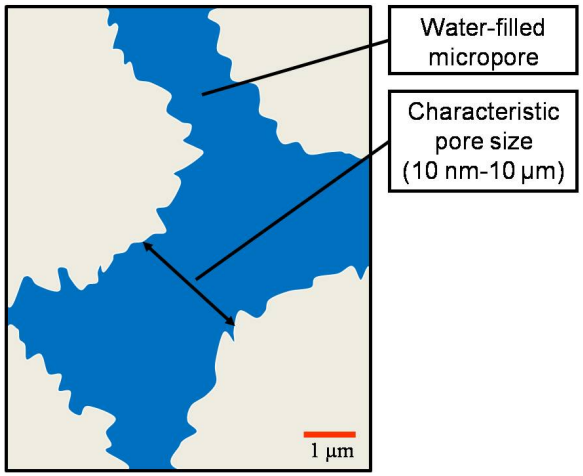
- Current monitoring solutions : large sensors with mm resolution averaging the microporosity

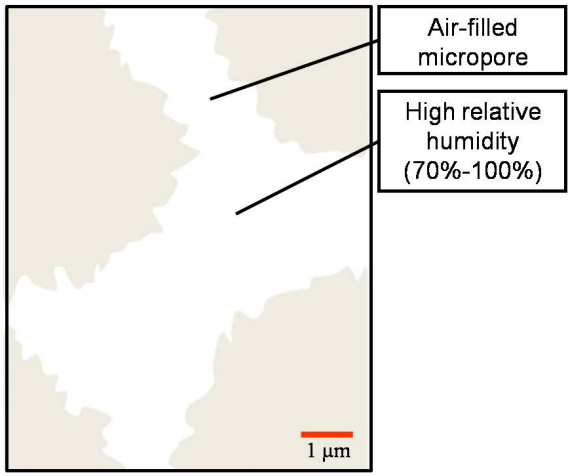
$\Rightarrow$ Challenge : to obtain **pore by pore** (μm) resolution

$\Rightarrow$ Solution : Monitoring with 1 μm size **nanosensors**

- We consider two parameters varying during service life
  - **Pore size** : 10 nm to 10 μm
  - **Humidity** : 70 % to 100 % relative humidity (RH)

$\Rightarrow$ determine gaseous/ionic transport parameters $\Rightarrow$ **Durability**

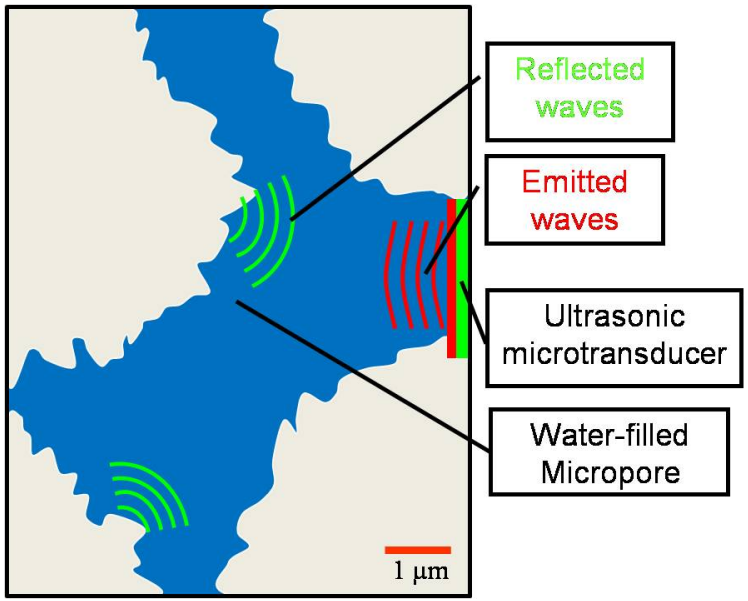


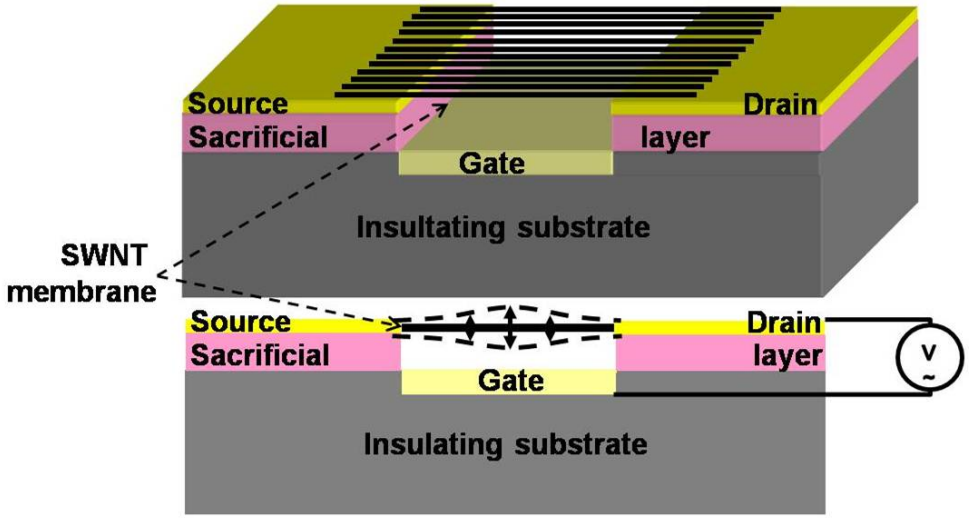


Carbon nanotubes based ultrasonic transducer

- Device concept [1] :
  - Suspended membrane of aligned SWNT actuated capacitively
  - 1 µm characteristic size

  ⇒ More than 1 range of magnitude smaller than existing US transducers

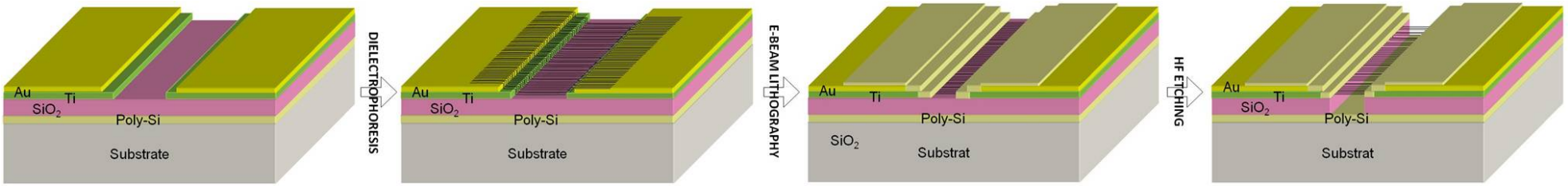


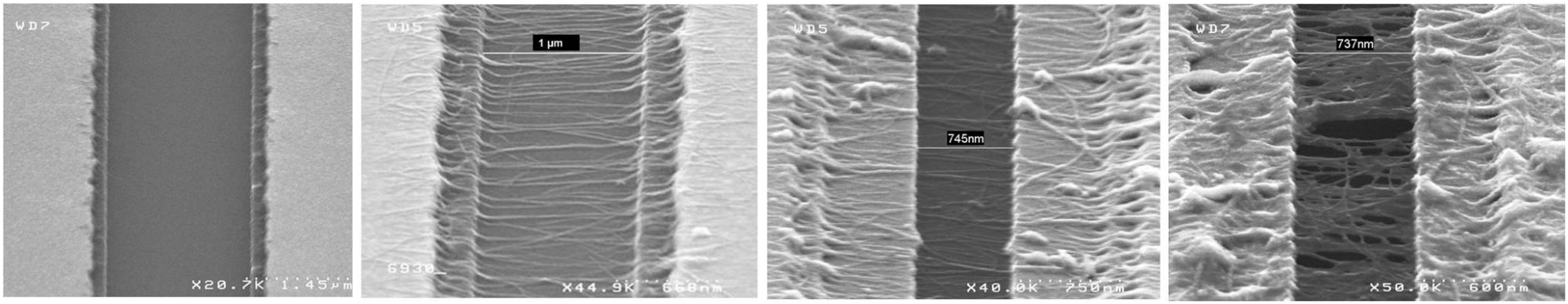


1. B. Lebental et al., 2008, Patents EN 08 57927 and EN 08 57928

Device fabrication process

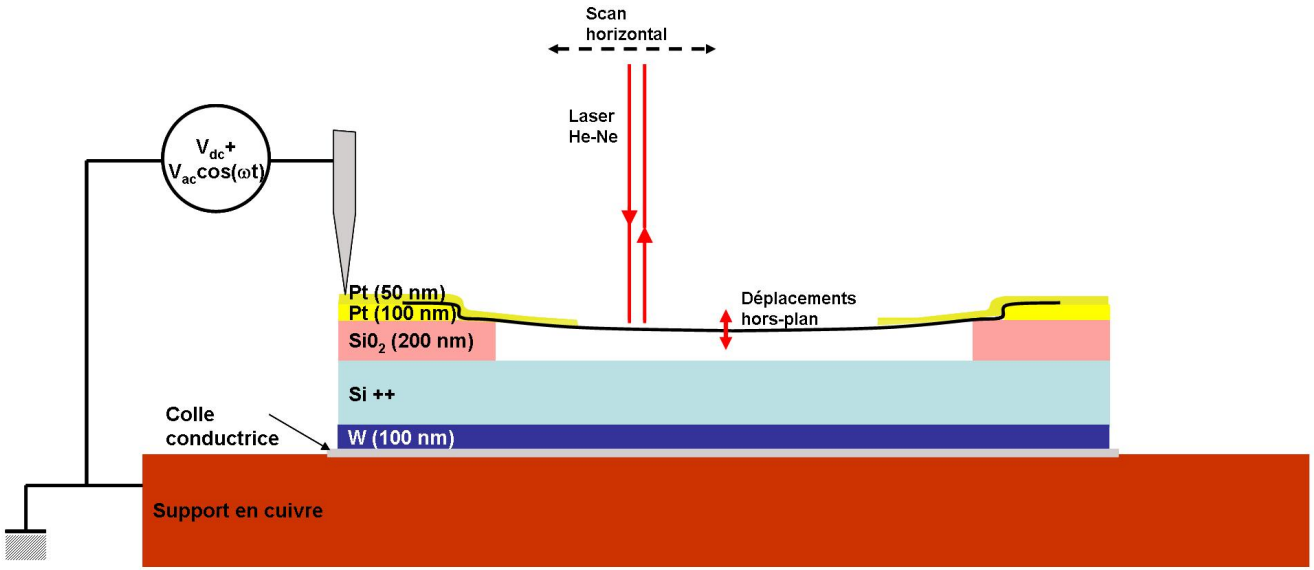
- Aligned deposition of SWNT
- SWNT anchoring
- Membrane release





Large amplitudes of vibrations and low thickness

- Demonstration of membrane vibrations by laser vibrometry [1]
  - under AC voltage+DC bias
  - from 100 kHz to 5 MHz



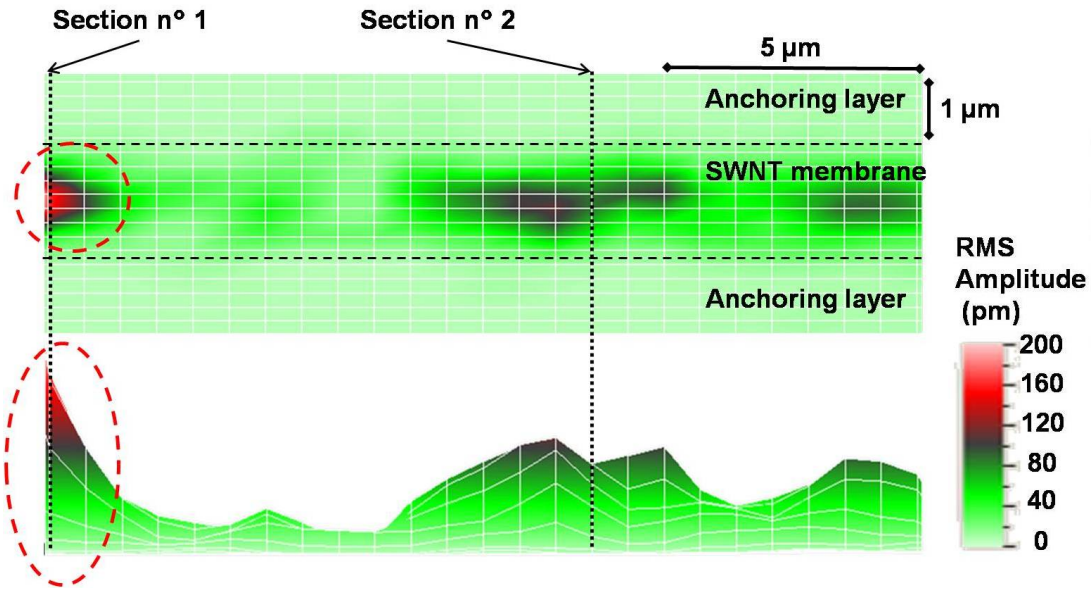
1. B. Lebental et al., submitted to Nanotechnology 2011

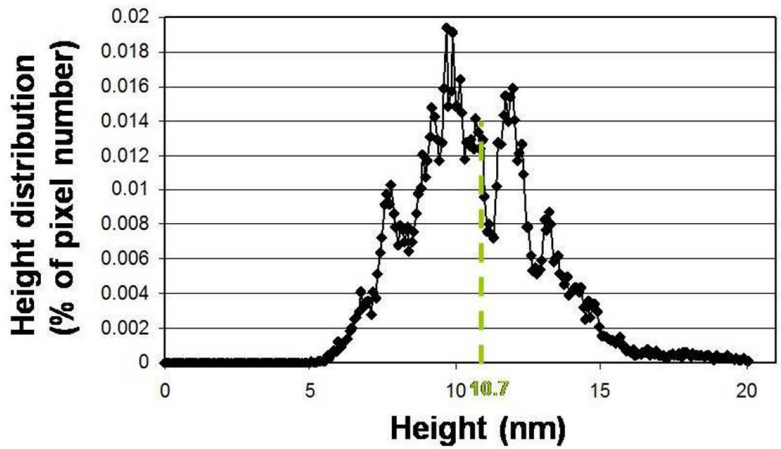
Large amplitudes of vibrations and low thickness

- Demonstration of membrane vibrations by laser vibrometry
  - under AC voltage+DC bias
  - from 100 kHz to 5 MHz

$\Rightarrow$ Amplitudes up to 5 nm peak to peak

$\Rightarrow$ explained by low thickness : 10,7 nm typically ; down to 1.5 nm



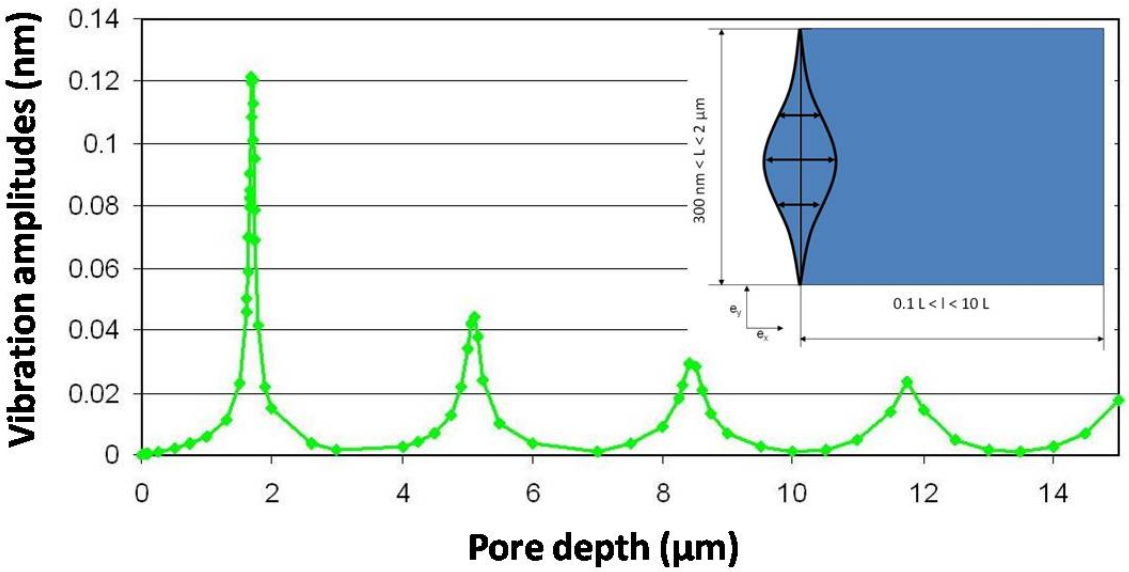


Applicative relevance

- The larger the vibrations, the easier they are to detect !
- The thinner the membrane, the more sensitive it is to pore features

$\Rightarrow$ Good candidate for in-situ monitoring of pore size

$\Rightarrow$ Validation by modeling [1]



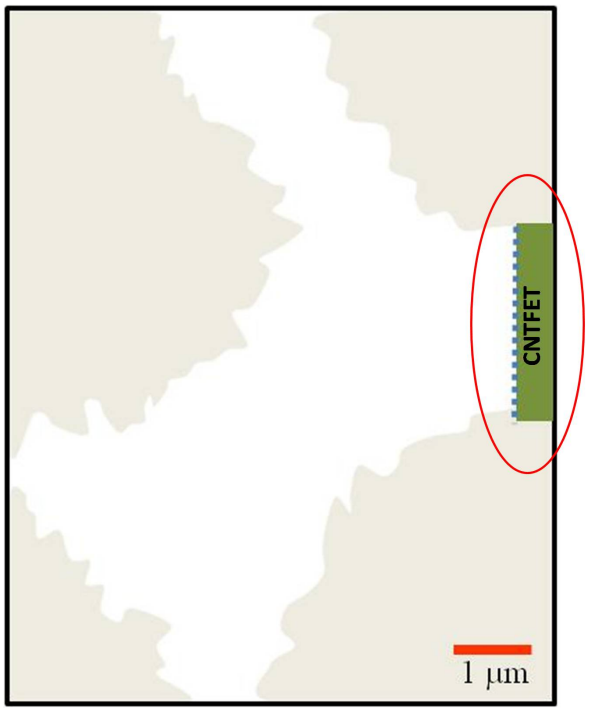
1. B. Lebental et al. EJECE 2011, 15, 649

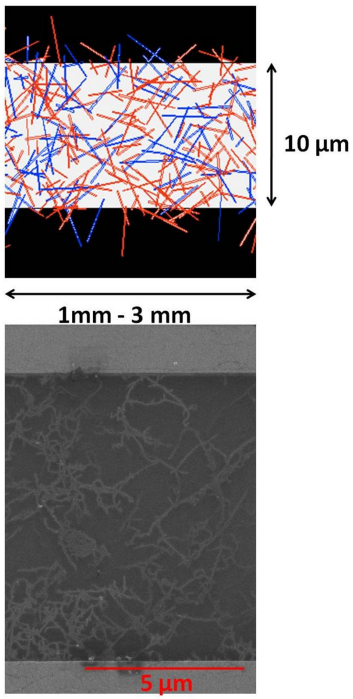
Carbon nanotubes FET

- Measuring moisture content in an air-filled pore
  - CNTFET known to be highly sensitive to humidity

  $\Rightarrow$ CNTFET based humidity sensor

  $\Rightarrow$ Fabrication by low-density spray-coating of SWNT atop 100 nm thermal SiO_2

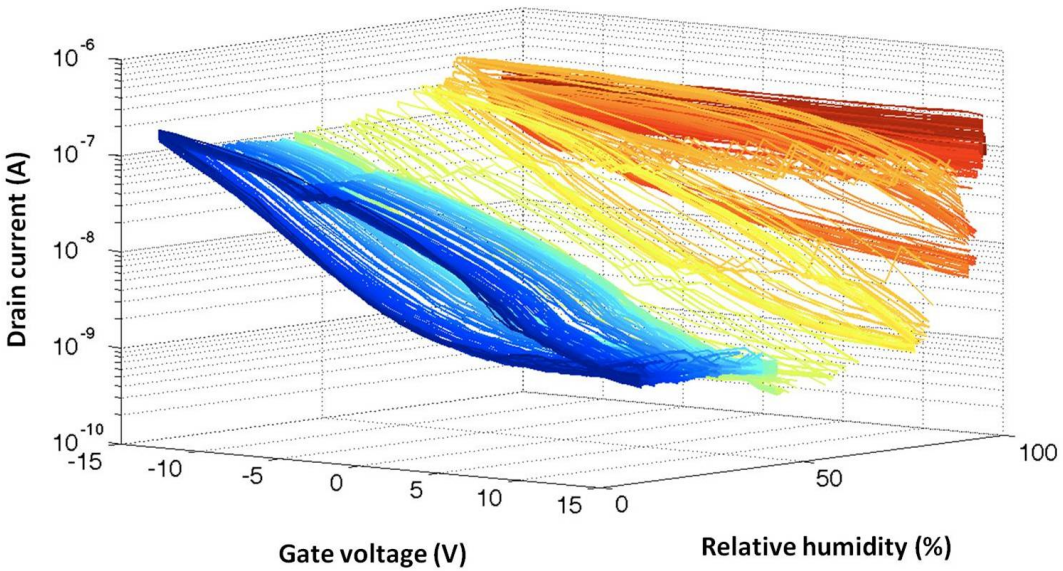


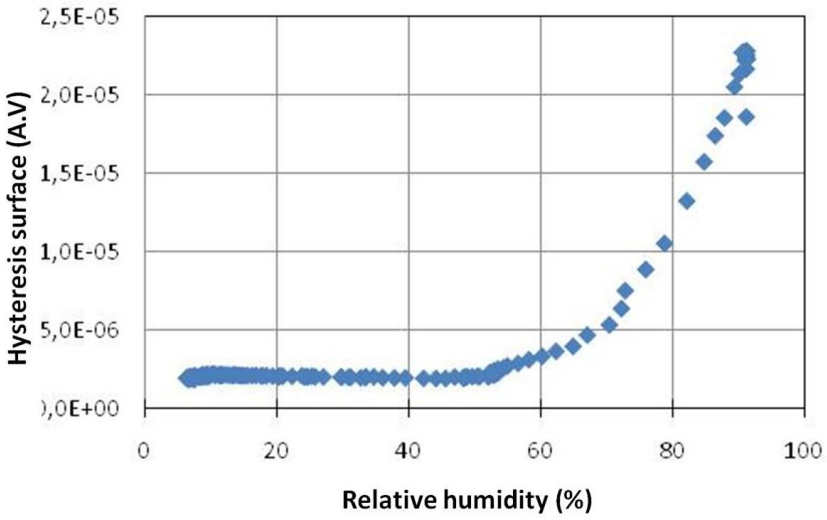


Hysteresis sensitivity to humidity

- Electrical features reproducibly sensitive to humidity
  - I_{on}, I_{off}, Hysteresis,...
  - Attributed to adsorption on silicon and on metal
  - Especially at high humidity

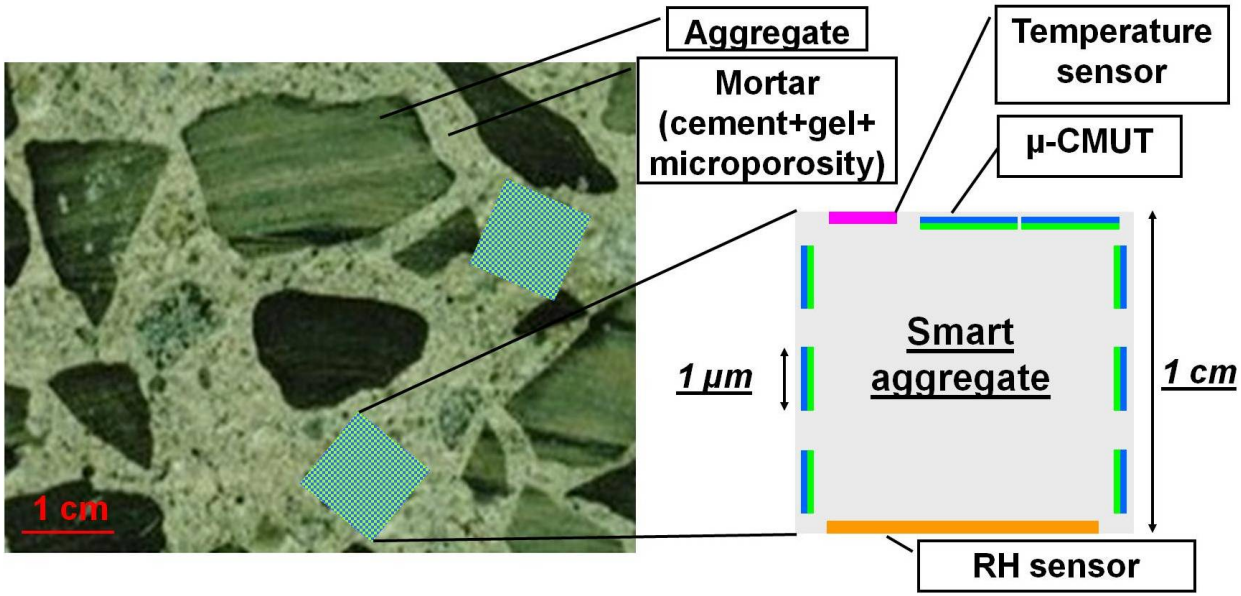
$\Rightarrow$ Well suited for high RH environment such as concrete





Conclusions

- Fabrication and evaluation of two promising sensing elements
  - Vibrating CNT membranes for ultrasonic micropore monitoring
  - CNTFET for humidity measurements in micropores
- Prospects :
  - Integration into embeddable sensing units : smart aggregates
  - Validation in the target environment
- A whole range of novel sensing opportunities ! ! !



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