Nanosensors for structural monitoring in civil engineering: New insight on promising carbon nanotubes devices

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Nanosensors for structural monitoring in civil engineering: New insight on promising carbon nanotubes devices

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In recent years, requirements in terms of service-life of civil engineering structures have become more and more stringent, so that the focus of designers and owners is now set on structural durability. Foreseeing structural failures and repairing damaged structures at an early stage has become a major stake. This approach calls for an accurate knowledge of the state of the structure at any point in its lifetime. This is the incentive for the world-wide development of various *in-situ* monitoring techniques for structural materials. However, by measuring global structural quantities only, the existing monitoring techniques provide only indirect information on the structural health of the structure.

To this day, no existing sensor features the resolution required to investigate in-situ structural materials at the micro- and nanoscale. This is a major lack, as micro and nanoscale features play a significant role in the durability of cementitious materials. From this perspective, IFSTTAR working with CEA-LETI and LPICM has set itself the long-term goal to devise innovative **nanoscale structural health monitoring solutions based on nanosensors.** Two types of single-walled carbon nanotubes (SWNT) devices are currently being studied with highly promising results: **ultrasonic nanotransducers for microporosity assessment** [1] and **field-effect transistors for humidity monitoring** [2]**.**

The SWNT-based ultrasonic nanotransducer developed at the CEA-LETI consists in a metallic membrane of aligned nanotubes suspended above an actuation electrode (fig. 1). It vibrates by capacitive effect upon application of a varying voltage on the actuation electrode. Devices were fabricated by SWNT dielectrophoresis, e-beam patterning of anchoring electrodes and HF wet etching release (fig. 2) [3]. **Thanks to a breakthrough laser vibrometry experiment, we observed up-to-5 nm amplitude vibrations of the SWNT membrane in air at ultrasonic (3.7 MHz) frequencies** (fig. 3).

These high amplitudes of vibration is explained by the very low thickness of the membrane (fig. 4), obtained as a result of an extensive parametric study of SWNT dielectrophoresis. Our detailed numerical model shows that low membrane thickness is essential to the proposed sensing application. The model also indicates that the proposed devices embedded in a cementitious material could determine the volume and content of the microporosity in their vicinity [1]. Such microscale information would be invaluable in the evaluation of structural durability [4].

Structural durability specialists also know that not only size and content, but also humidity and chemical compositions are important for durability assessment [5]. With LPICM, we are focusing on relative humidity measurements based on field-effect transistors devices made with low density single-walled carbon-nanotubes networks (fig. 5). The CNTFET devices were fabricated on a silicon substrate with silicon oxide layer. A conventional photolithographic process was used to create the electrodes. Mostly semiconducting CNTs were sprayed to form the gate channel [6].

Although the sensitivity of such devices to water vapor has been very often considered a drawback [7], our electrical characterizations (fig. 6) suggest that it could be exploited as **a robust, high sensitivity means to probe high relative humidity environment (>60 %) such as concrete. The sensitivity of the devices to water vapor appears even stronger than that of other gases.** It might be due to the strong polar nature of water and its affinity to both the metallic and dielectric parts of the CNTFET. This interpretation could lead us to various original device optimizations to improve the sensing features of the CNTFET devices.

With their very promising outputs, these two studies open up the path toward *in*-situ morphology and composition monitoring of the microporosity of cementitious materials by nanosensors. This nanosensors-based microscale knowledge is the key to detect and prevent degradations of cement-based structures. As such, it will significantly contribute to an improved sustainability in civil engineering.

References

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Figures

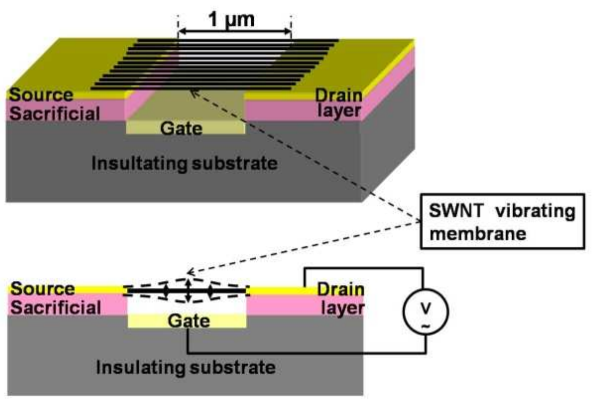

Fig. 1: Schematic view of SWNT-based capacitive ultrasonic nanotransducer

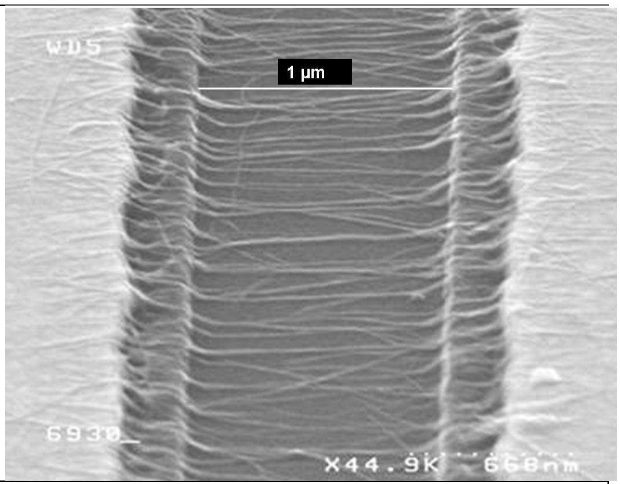

Fig. 2: SEM picture of a thin membrane of aligned SWNT obtained by AC dielectrohoresis

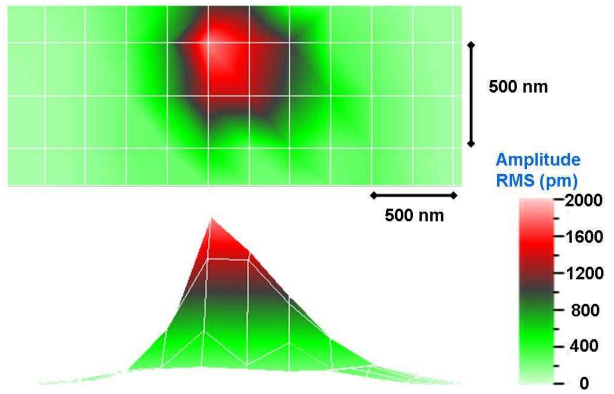

Fig. 3: Topview and sideview of the vibration amplitudes of a 2 µm-large SWNT membrane at 3.7 MHz, as measured by scanning laser vibrometry. Peak to peak amplitude of vibration is 5 nm.

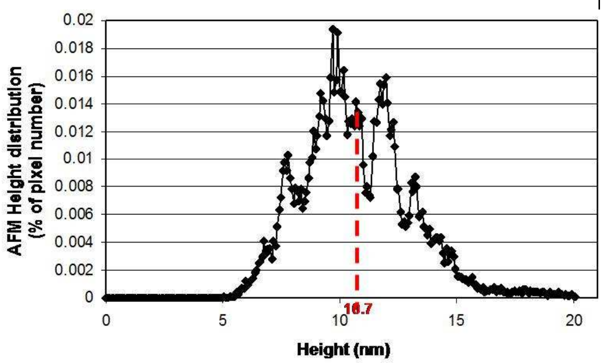

Figure 4: AFM measured height distribution of a SWNT based membrane before suspension. Membrane thickness is 10.7 nm.

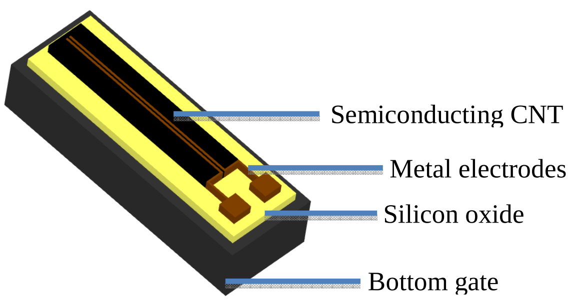

Fig. 5: Schematic view of a field-effect transistor using a low density SWNT network as channel material.

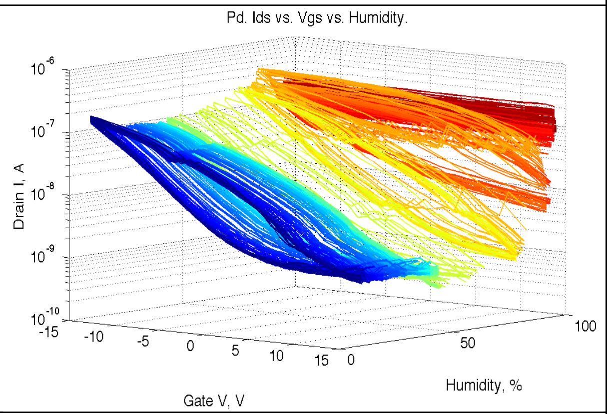

Fig 6: IV characteristics of a CNTFET device with Pt electrodes: Vds=3V; dual sweep of Vgs from -15 V to +15 V