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Development of a conductive MEMS-SPM for nanoelectrical characterisation of nanostructured materials

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Summary:

A conductive MEMS based scanning probe microscope (MEMS-SPM) has been developed to measure the mechanical and electrical properties of nanostructured materials including nanopillars and nanowires for energy harvesting devices. The MEMS-SPM features an integrated AFM cantilever gripper, with which various conductive AFM probes can be used as tactile stylus for nano-dimensional, nanomechanical and -electrical measurements. First measurement results will be presented.

Keywords: Microelectromechanical systems, scanning probe microscopy, conductive SPM, nanoelectrical measurement, nanowires energy harvesting devices

Motivation

Energy harvesting from renewable sources like solar, waste heat, and mechanical movement has become a prominent solution to create small amounts of electrical energy in areas of difficult access, and correspondingly energy harvesting devices can help to address the world energy problems. Nanowire (NW) based energy harvesting systems, including photovoltaic solar cells, thermoelectrical, and electromechanical energy nanogenerators have achieved encouraging progress. Meanwhile, the nanometer (nm) dimensions of the wires incorporated in large size of the devices (m^2) raise considerable challenges for testing and characterization. It is worth noting that averaged properties of energy harvesting devices can now be measured, but a quantitative link and correlation between the performance of single NWs and that of the overall device is lacking.
Within the frame of the EMPIR project 19ENG05 NanoWires, a microelectromechanical system (MEMS) based scanning probe microscope (MEMS-SPM) head [1] has been developed, with the aim to characterize the electrical properties of single nanowires with diameters <100 nm.

Principle of the conductive MEMS-SPM

As illustrated in Fig. 1, this innovative conductive MEMS-SPM utilizes integrated electrostatic comb-drives for force and displacement sensing with a force resolution down to nN (10^{-9} Newton) and a depth resolution < 1 nm. A passive AFM cantilever gripper has been integrated, allowing the conductive MEMS-SPM to utilize various commercially available conductive AFM probes for surface topography measurement and local electrical measurements of nanostructured materials.

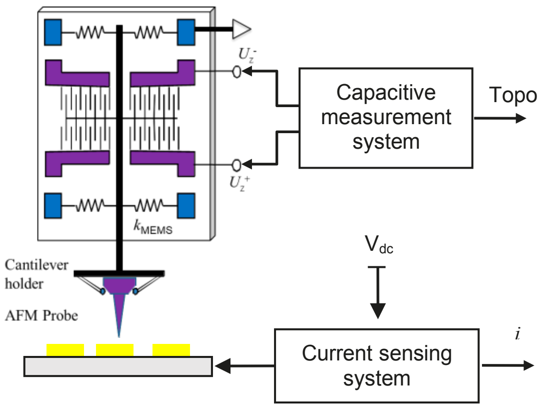


Fig. 1. Schematic of the conductive MEMS-SPM together with the data acquisition systems for nanoelectromechanical measurements.

A home-developed current sensing system with a resolution < 100 pA has been realized to measure the through-tip current with a bandwidth up to 300 Hz.

Results

The conductive MEMS-SPM has been prototyped by means of deep reactive ion etching combined with a silicon-silicon bonding step (B-DRIE) [2]. Silicon micro-structures with an aspect ratio of 25 have been fabricated. Fig. 2 shows the passive cantilever gripper in the MEMS-SPM together with a clamped AFM probe for topography and electrical measurements.

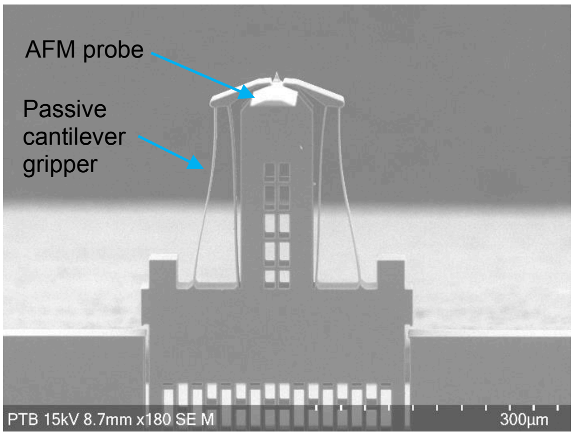
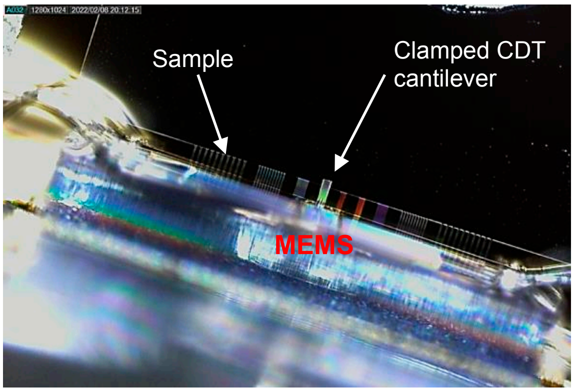
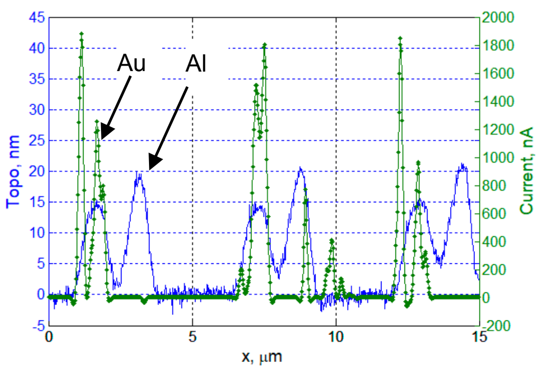


Fig. 2. Detailed view of the cantilever gripper integrated in the MEMS-SPM, in which a CDT-NCHR AFM probe is held as stylus for nanoelectromechanical measurements.



(a) Test sample under measurement



(b) Typical line profile of the test structures

Fig. 3. Topography and electrical measurements of Al and Au line arrays using the conductive MEMS-SPM prototype.

To demonstrate the capability of the MEMS-SPM prototype, a test sample with Al and Au line arrays for KPFM and EFM [3] has been measured, and the current through the Au lines has been acquired. Fig. 3 illustrates one of the typical line profiles of the test structures. It can be seen from Fig. 3 that the topography of the Au and Al lines can be well revealed, and the through-tip current on the Au line can be clearly detected.

Summary and outlook

A conductive MEMS-SPM for nanoelectromechanical characterization of nanostructured materials has been developed. First measurements of test samples indicate that the prototype of this MEMS-SPM is able to simultaneously measure the topography and electrical properties of nanostructures with a lateral resolution better than 50 nm.

The modelling and characterization of the conductive AFM probes for nano-electrical measurements belongs to one of the foci of our future work. The resolution and bandwidth of the through-tip current measurement system will be further improved to enable high-throughput surface measurements. The conductive MEMS-SPM head is also planned to be integrated into a commercial AFM for high-speed areal characterization of nanostructured materials including vertical aligned nanowires used in energy harvesting devices.

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