New paradigms and New Devices based on Nanomechanics for Ultrasensitive Biological detection

Javier Tamayo, Johann Mertens, Priscila M. Kosaka, Eduardo Gil, Montserrat Calleja
Bionanomechanics Lab-Instituto de Microelectrónica de Madrid- CSIC, Isaac Newton 8 (PTM), Tres Cantos 28760, Madrid, Spain
jtamayo@imm.cnm.csic.es

The goal of discovering new devices and new transduction concepts for biological detection remains of paramount importance. Nanotechnology based approaches are promising candidates for providing portable and low cost nanosensor devices, capable of analyzing tiny amounts of sample, and specifically disease markers from patients. We present here recent advancements in the development of novel MEMS/NEMS devices and new sensing paradigms to achieve the ultimate limits in biological detection based on nanomechanics. The presented results are divided in the following battle fronts,

- Multifunctional nanomechanical systems for highly selective and sensitive biological detection

We propose the combination of multiple nanomechanical structures in arrays in order to detect multiple signatures of adsorbed biomolecules such as the mass, the mechanical properties and the surface stress[1]. A prototype device is shown in Fig. 1. The nanomechanical arrays provide a double flavour of the adsorbed molecules: the added mass reported by the cantilevers with the Au area at the tip and the nanoscale elasticity reported by the cantilevers with the Au area at the clamp. The devices in Fig. 1 were applied for DNA detection based on Watson-Crick pairing rules. The proposed design for nanomechanical resonators provides higher specificity for DNA sensing in comparison with conventional single cantilevers.

- Ultrasensitive mass detection based on single silicon nanowire resonators

Silicon nanowires together carbon nanotubes represent the ultimate limit in the minituarization of nanomechanical resonators. Silicon nanowires present resonance frequencies of 10-1000 MHz, quality factors 10^3-10^5 and active masses of 10 femtograms. It is expected that these devices can be applied for ultrasensitive mass sensing at the sub-zeptogram level and for mass spectroscopy of single biomolecules. However, the achievement of the optimal performance of these devices requires a detailed understanding of the nanomechanical response and a major development of the optical instrumentation for the detection of the picometer scale vibrations. We have developed advanced optical instrumentation and in depth models of the nanomechanical response of the silicon nanowire vibrations.

- Arrays of coupled nanomechanical resonators for ultrasensitive mass sensing

The elastic coupling of identical nanomechanical resonators via overhangs offers a new paradigm for biosensing. Firstly, the vibrational energy of the system is found delocalized in both, nanomechanical resonators and vibration eigenmodes. However, the landing of a minute mass on one of the resonant structures produces a large perturbation in the vibration localization that can be exploited for ultrasensitive mass sensing. The intrinsic common mode rejection of these devices allows quantification of the differential mass between coupled resonators. We have modelled the response of coupled nanomechanical resonators and we have experimentally characterized the response of coupled resonators to

controlled adsorbed masses[2]. A picture of two coupled cantilevers used in this work is shown in Fig. 2.

References:

[1] D. Ramos, M. Arroyo-Hernandez, E. Gil Santos, H. Duy Tong, C. van Rijn, M. Calleja, J.Tamayo, Analytical Chemistry 81 (2009) 2274

[2] E. Gil Santos, D. Ramos, A. Jana, M. Calleja, A. Raman, J. Tamayo, Nano Letters 9 (2009) 4122

Figures:

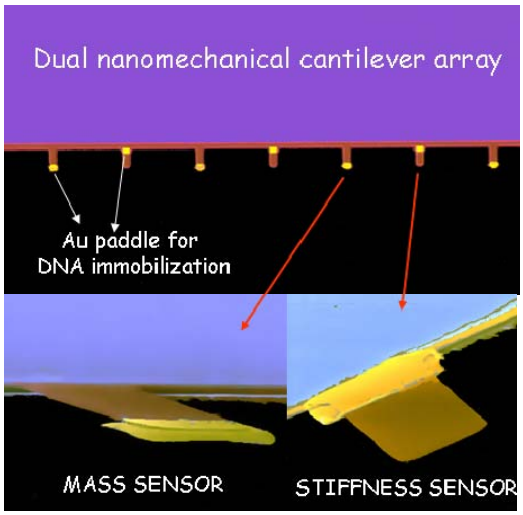

Figure 1. Optical (top) and scanning electron microscopy (bottom) images of a nanomechanical system consisting of cantilevers with a gold area at the tip and cantilever with a gold area at the base. The gold area confines the immobilization of bioreceptors tethered with a thiol linker. The cantilever length, width and thickness are 15 μm, 6 μm and 100 nm, respectively. The operation principle of this device is that the resonance frequency of the cantilevers with the Au area on the tip is sensitive to the adsorbed mass whereas the resonance frequency of the cantilevers with the Au area at the clamp are sensitive to the mechanical properties of the adsorbate.

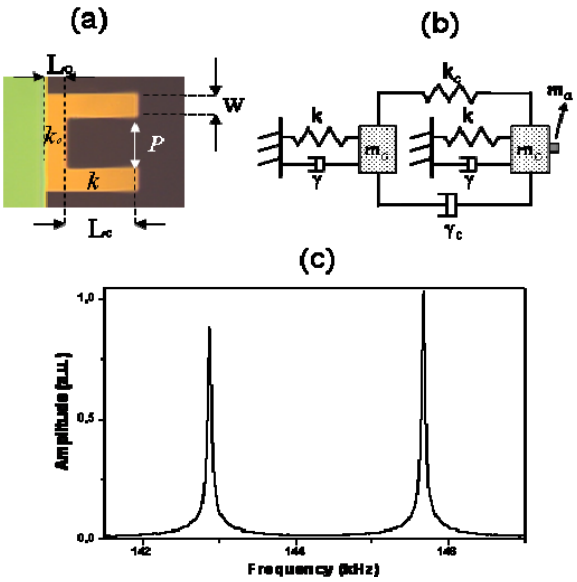

Figure 2. Optical micrograph of an array of two identical silicon nitride microcantilevers coupled via an overhang. Each cantilever has a length L_c = 25 μm, width b = 10 μm and thickness h =0.1 μm. The gap between the cantilevers is P=20 μm and the overhang length is L_o = 7 μm. **(b)** Simple model based on the harmonic oscillator theory. **(c).** Thermomechanical spectra of one of the cantilevers that shows two vibration modes. The first resonant peak is related to the two cantilevers vibrating in phase, whereas the second peak is related to the cantilevers vibrating in antiphase.