PIEZORESISTIVE CANTILEVERS FOR MOLECULAR FORCE DETECTION

G. Villanueva, G. Rius, J. Montserrat, F. Pérez-Murano and J. Bausells
Centro Nacional de Microelectrónica (IMB-CSIC),
Campus UAB, 08193 Bellaterra (Barcelona), Spain
Guillermo.Villanueva@cnm.es

Silicon microcantilevers, originally developed for atomic force microscopy, are being increasingly used for biochemical sensing [1,2]. A high sensitivity can be obtained by detecting molecular binding forces between a functionalized cantilever tip and a functionalized surface [3]. We are interested in using this method for detecting proteins using a portable instrument, which leads us to detect the deflection electrically by using an integrated piezoresistor.

The forces to be measured for biomolecular detection are in the range of tens to hundreds of pN [4]. For piezoresistive cantilevers, this requires [5] small dimensions, around 100 μm in length, 1μm in width and <1μm in thickness. We have fabricated two types of cantilever chips with a common structure, the first type using a dedicated technology [5] and the second type using a commercial CMOS process with post-processing and integrating the cantilevers with on-chip amplifiers, with a high sensitivity and resolution.

The cantilevers have been fabricated in polycrystalline silicon, for compatibility with their fabrication in a CMOS process. Two polysilicon layers (400 and 200 nm thick) are stacked, separated by a thin silicon dioxide. The upper layer is used as a piezoresistor. We have used a U-shaped structure [6] to minimize the cantilever width. We calculated in [5] the theoretical sensitivity, noise and resolution as a function of the cantilever properties and dimensions. We have fabricated cantilevers in silicon chips with structure and dimensions compatible with standard AFM instruments. The process uses standard optical lithography, which limits the leg width to about 2 μm. The cantilever spring constants range between 1 and 0.006 N/m. Fig. 1 shows one of such cantilevers. The current version includes a silicon nitride structure on the tip to allow specific functionalisation, and also a silicon nitride layer near the cantilever support for stress compensation purposes. In order to increase the cantilever response, we have also used electron beam lithography to decrease the cantilever width. In this way cantilevers with a 500 nm leg width have been obtained (Fig. 2), with a k ~ 1-10 mN/m depending on the length.

Using a commercial CMOS process (0.8-μm process of Austriamicrosystems) the cantilevers have been fabricated using the two CMOS polysilicon layers. Four pairs of identical cantilevers (Fig. 3) have been integrated in each chip connected as voltage dividers [7]. The output of each voltage divider is fed through a multiplexer into a circuit consisting on a variable-gain low-noise chopper amplifier, a low-pass filter and a second variable-gain amplifier [7]. The maximum gain is 320.

The electromechanical behaviour of the cantilevers has been measured by applying a known displacement (i.e. a bending force) with the tip of an AFM [5]. With a voltage divider configuration with a reference cantilever, the deflection sensitivity obtained for a non-CMOS cantilever with L=200 μm and w=2μm has been about 0.5 μV/nm (at 10 V bias). The corresponding gauge factor is 12. The cantilever chips have also been measured on a specifically modified STM instrument (Nanotec Electrónica S.L.).

A typical result for the measurements on a CMOS cantilever (L=200 μm) is shown in Fig. 4. The mean deflection sensitivity for a 10 V bias from measurements on various cantilevers has been about 180 μV/nm. For these cantilevers (k = 9 mN/m) the corresponding force sensitivity is about 19 μV/pN. A root-mean-square noise amplitude of about 0.4 mV has been measured, which would result in a force resolution of about 22 pN.

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References:

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Figures:

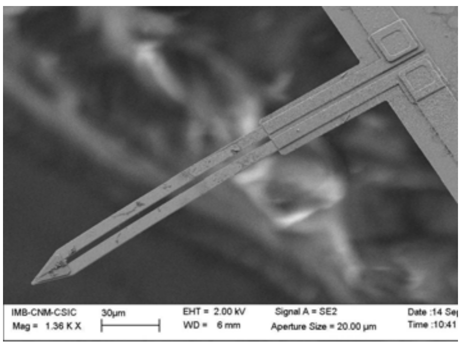

Fig. 1. Cantilever fabricated with a dedicated process, including silicon nitride in the tip and the supporting area.

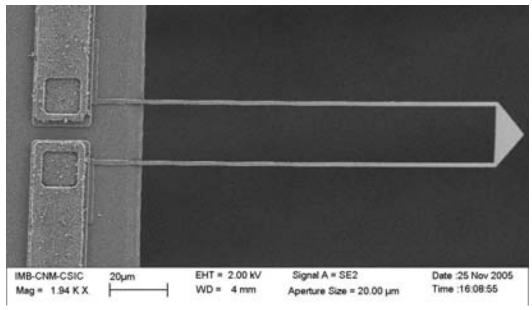

Fig. 2. Narrow (500 nm) cantilever fabricated with a dedicated process using electron beam lithography.

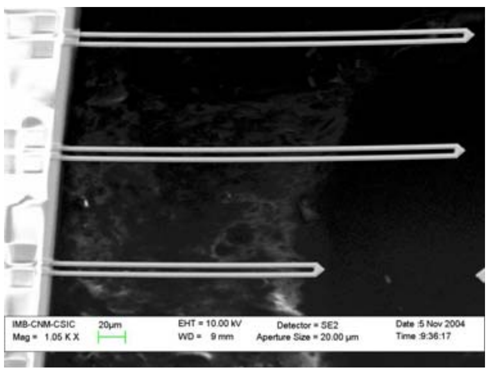

Fig. 3. SEM micrograph of the CMOS cantilevers.

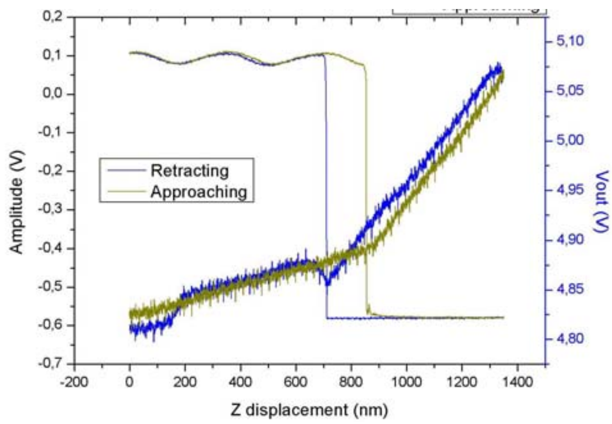

Fig. 4. Oscillation amplitude of the AFM used to deflect the cantilever and the corresponding output of the integrated system.