Silicon microcantilevers with MOSFET detection

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Silicon microcantilevers, originally developed for atomic force microscopy, are increasingly used in biochemical sensing [1]. Commonly, the detection of the cantilever deflection involves optical transduction which presents a very low noise but has some associated problems, e.g. integration, parallel detection and use in opaque fluids. One alternative is piezoresistive transduction that can be achieved either by embedding a resistor [2] or a MOSFET [3] as transducing element. Historically, resistors have been more used than MOSFET mainly because their simpler fabrication, but MOSFET-based stress detectors offer improved performances, compared to the piezoresistance-based ones, due to their sensitivity to local stress at the channel surface and their better noise properties.

MOSFET-based cantilevers have long been used in MEMS, and only very recently for biomolecular sensing [4] to detect surface stress caused by molecular binding to the cantilever surface. We choose a different approach for the biomolecule detection, based on the detection of intermolecular binding forces between a functionalized cantilever tip and a functionalized surface [5], and therefore propose a novel device design. In our case the cantilevers are supported by two legs to reduce the stiffness, and are oriented in the non standard <100> direction to optimize the piezoresistive properties improving these ways the force sensitivity.

The devices have been fabricated on (100) SOI wafers with the active layer thickness of 340 nm. The procedure uses common micromachining techniques, DRIE to free the cantilever and counts 6 photolithographic steps (Fig. 1). Two MOSFETs in series are fabricated using As implantation for source and drain with the channel and the cantilever aligned on <100> direction, i.e. rotated 45° respect to the wafer flat. The <100> longitudinal piezoresistive coefficient for N-type conduction is higher than the normally used <110> orientation for P-type [6]. This also results in a lower spring constant due to the lower Young modulus of silicon in this direction. Every chip consists of a couple of identical cantilevers (Fig. 2), with a width of 24 μm and a leg width of 10 μm (channel length L_{CH}=10 or 20 μm and width W_{CH}=4 μm, cantilever length L= 200 or 400 μm and theoretical spring constant of around 4 and 0.4 mN/m respectively).

We report the electrical characteristics, I_D/V_D, of the transistors (L_{CH}= 10 μm) for different gate voltages V_G (Fig. 3). For this purpose a semiautomatic probe system Karl Suss PA200 and a semiconductor parameter analyzer HP4155 were used. The transistor characteristics present small deviations inside the chip and a standard deviation between 6% and 12% on wafer. The electromechanical characteristics of the cantilevers (L=200 μm) were obtained by using an AFM probe to deflect them, as described in [7]. The output voltage, V_0, (Fig. 4) was recorded continuously as a function of the cantilever deflection, Δz, for both movements downwards and upwards after amplification and one filter stage. The results (Fig. 5) are the average of 25 measurements. The measured displacement sensitivity is $\Delta V/\Delta z$ = 2.46 V/μm and the relative estimated force sensitivity for an applied force, F, at the end of the cantilever is $\Delta V/F$ = 25 μV/pN. The total noise of the circuit was calculated integrating the power spectral density measured, between 0.1 Hz and 10 kHz, by a dynamic signal analyzer (SR785) yielding a value of 1.4 mV. With these values the minimum detectable force is 56 pN (Fmin=Vnoise/($\Delta V/F$)). This result is very promising and suggests that it is possible to achieve a resolution of around 20 pN for the system for an optimized thickness (V_G=3V, V_D=5V, V_S=1V).

References:

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Figures:

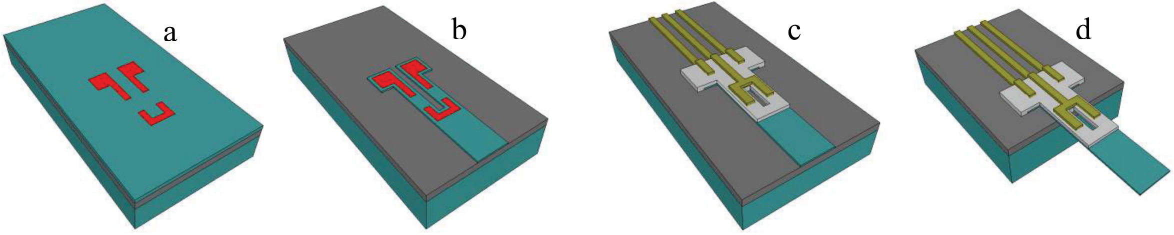

Figure1: Different steps of the technological process: a) implantation, b) definition of the cantilever, c) windows and gates definition, d) metallization, DRIE and cantilever release.

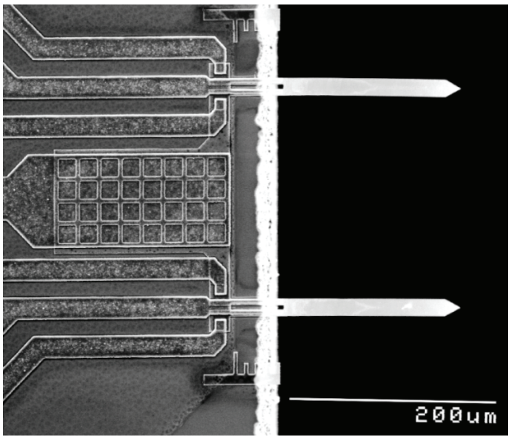

Figure2: SEM image of a part of the chip with a pair of identical MOSFET cantilevers

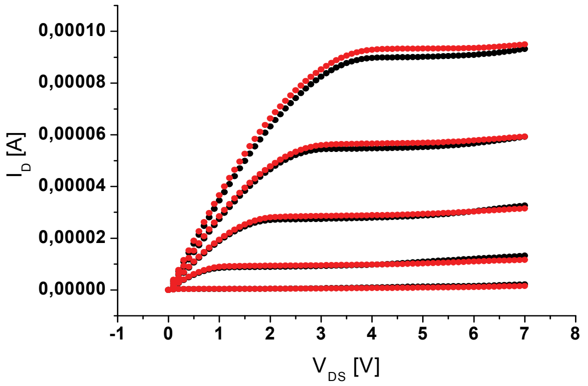

Figure 3: Electrical characteristics of the two MOSFETs on a chip(V_G= 0V÷4V)

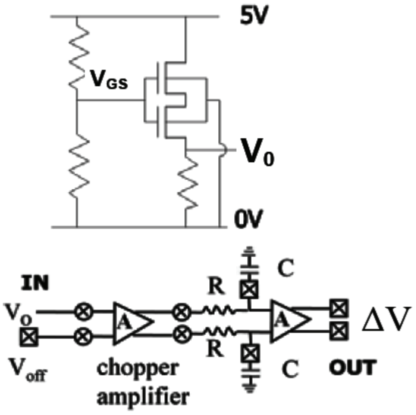

Figure 4: Electronic setup used for the measurement of the electromechanical behaviour of the cantilevers (ampl. = 630)

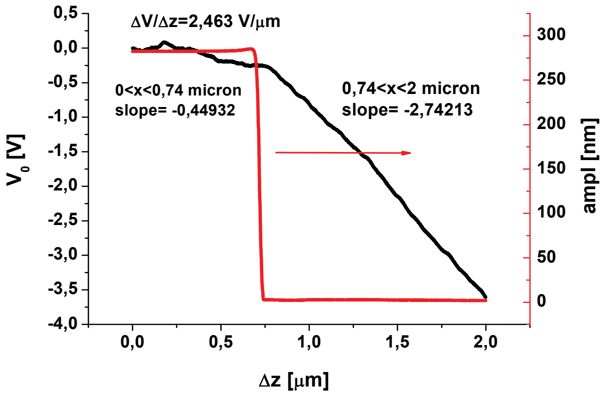

Figure 5: Electromechanical response (ΔV) of the cantilever against cantilever deflection (black) produced by a stiff AFM probe (20 N/m). In red the oscillation amplitude of the AFM probe used to determine the contact point.