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Sensitive detection of nonlinear nanomechanical motion using capacitive signal down-mixing for resonant M&NEMS inertial sensors

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A method of measuring resonance properties of high frequency nanoelectromechanical resonators based on capacitive down-mixing has been developed for inertial sensor applications.

Introduction:

Nanoelectromechanical systems (NEMS) are emerging as strong candidates for a host of important applications in semiconductor-based technology and fundamental science [1]. At this level of miniaturization, the electric characterization of capacitive NEMS is a challenge. In fact, the high-frequency signals are normally cut off due to the limited bandwidth of the readout circuitry dominated by stray capacitance between the large amplifier and the high impedance tunneling junction [2]. In order to overcome such limitations, some methods have been suggested: using several amplifier stages [3], inserting an LC resonator [4], or more recently the scanning tunneling microscopy down-mixing readout technique [5]. Here, a new characterization technique for resonant NEMS based on capacitive down-mixing has been developed and applied to M&NEMS accelerometers.

Manufacturing:

The M&NEMS process flow starts with the lithography and etching of the NEMS resonator and of the bulk contact. Then a $0.3\ \mu\text{m}$ thick oxide deposition followed by a lithography and etching of the nanoresonator protection are proceeded. In the same step, an over etching of the oxide is led to open the silicon bulk contact. A few microns thick silicon epitaxial growth is done to realize the MEMS part. Contacts are defined by a $0.5\ \mu\text{m}$ metal deposition followed by a lithography and etching of pads. A last lithography step and a DRIE of silicon thick layer is proceeded to make the MEMS structure, to isolate the bulk contact, and to open the SiO₂ protective layer of the NEMS. The release of the sensor then is achieved by HF-vapor etching.

Experimental characterisation:

A new technique for the electrical characterization of capacitive NEMS resonators is performed in order to overcome the problems of parasitic impedances at high frequency and extend the usability of low-frequency, high-input impedance measurement equipments. The measurements are performed on a M&NEMS resonant accelerometer shown in Fig. 1, which has been designed and fabricated in order to validate our characterization technique schemed in Fig. 2. It utilizes two AC signals and the intrinsic properties of the resonator to perform heterodyne down-mixing of the signal to a much lower frequency, which can then be detected by standard circuitry without significant signal loss. It also greatly reduces the unwanted background from the cross-talk between the detector and actuator circuits. As proof of principle, this down-mixing scheme has been applied to the detection of NEMS resonator with fundamental mode frequency of $13.5\ \text{MHz}$ (see Fig. 3). As shown in Fig. 4, this technique permits tuning the signal to nonlinearity ratio and sensing the nonlinear nanomechanical motion in high-frequency resonators.

Conclusions and perspectives:

In a future work, the nonlinear dynamics of the considered accelerometer will be modeled while taking into account the down-mixing characterization scheme. Experimental and model results will be compared, which will complete the experimental interpretations and finally improve the presented set-up.

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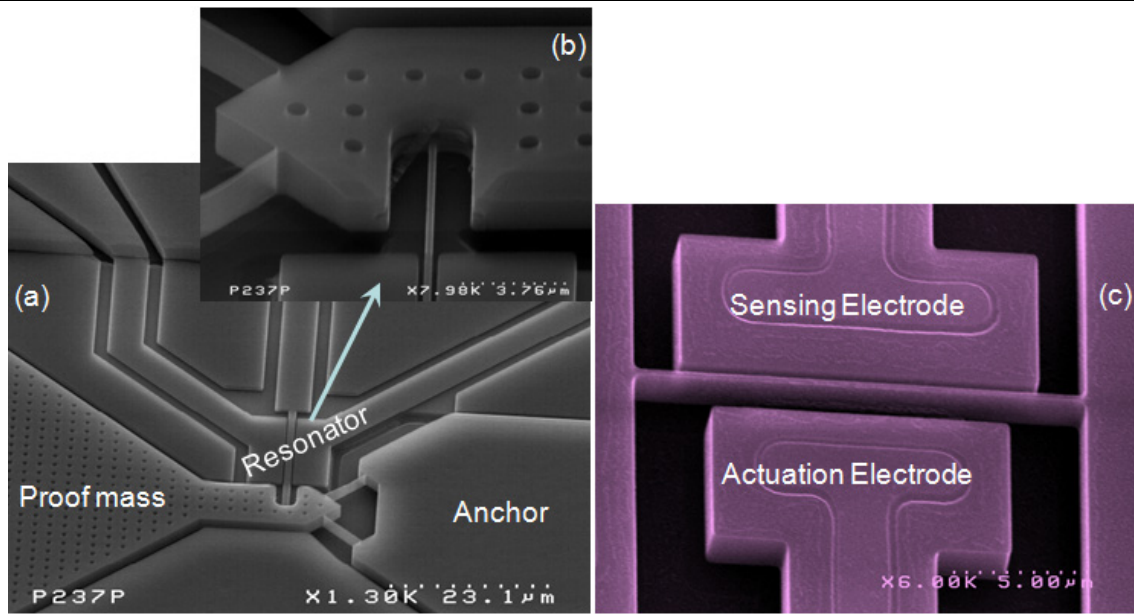


Fig.1: (a): SEM view of an in-plane M&NEMS accelerometer. (b): A focus on the gauge lets clearly appear the MEMS inertial mass of $2\ \mu\text{m}$ thick, and the sub- μm resonator that has a section of $0.25 \times 0.5\ \mu\text{m}^2$. (c): A SEM image of a designed nanoresonator.

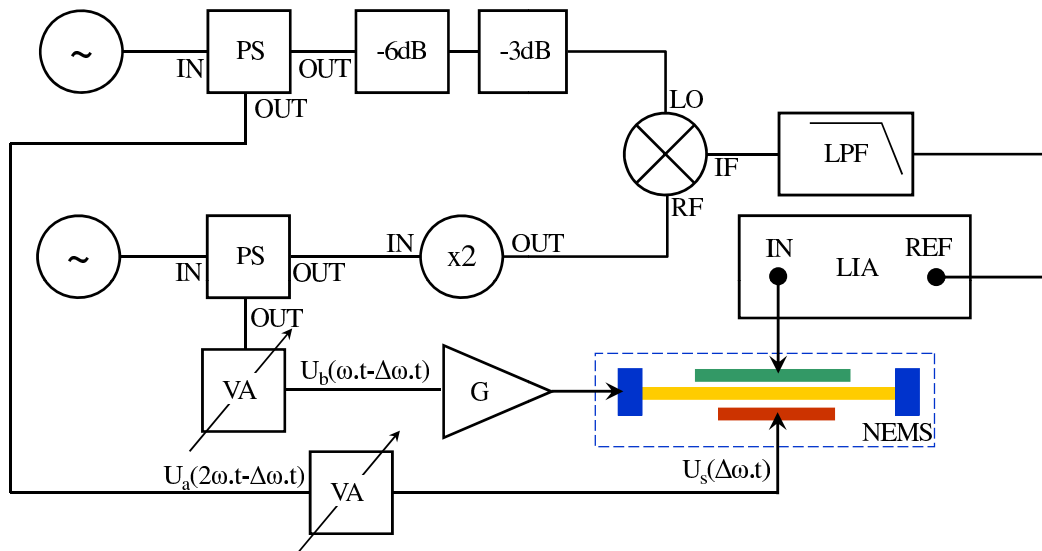


Fig.2: Schematic of the capacitive down-mixing setup using 2 AC voltages U_a and U_b .

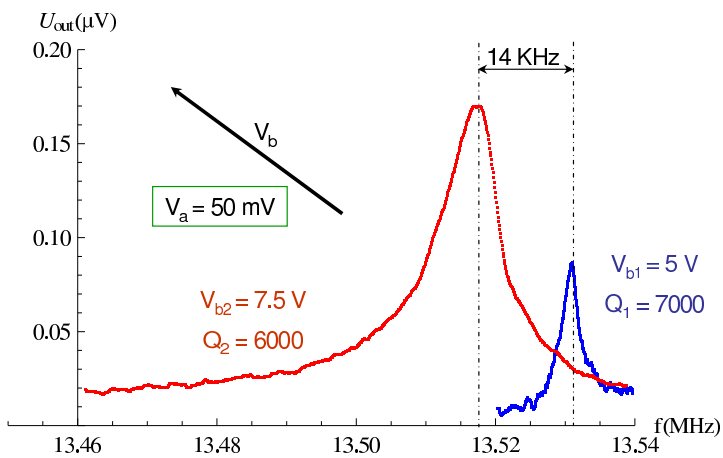


Fig.3 Linear resonance peaks measured using the developed capacitive down-mixing technique.

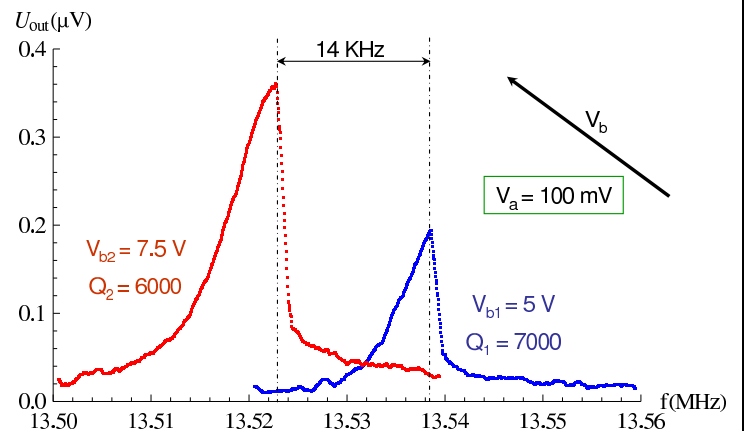


Fig.4 Nonlinear resonance peaks measured using the developed capacitive down-mixing technique.