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From MEMS to NEMS: Modelling and characterization of the non linear dynamics of resonators, a way to enhance the dynamic range

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In order to compensate the loss of performances when scaling sensors down to NEMS, a process, characterization methods and above all an original analytical model including main sources of nonlinearities are presented.

Introduction:

The permanent quest for cost cuts has led to the use of potential "In-IC" compatible thin SOI-based technologies, which imposes drastic size reduction of the sensors. Combined with the need of in-plane actuation for fabrication and design simplicity, this implies a large reduction in detectability. Moreover nonlinearities [1] occur proportionally sooner for small structures which reduce their dynamic range predicted using linear models. The idea is to find physical conditions in order to maximise the signal variations and to push the limits of the linear behavior.

Model:

Many studies have presented models on the dynamic behavior of MEMS resonators. Some of them are purely analytical [2, 3] but they include coarse assumptions concerning nonlinearities. Other models [4, 5] are more complicated and use numerical simulations which make them less interesting for MEMS designers.

In the present paper, a compact and analytical model including the main sources of nonlinearities is presented and validated thanks to the fabrication of a resonant accelerometer and the characterization of its sensing element, an electrostatically driven clamped-clamped beam.

A perturbation technique [6] was used in order to obtain two first order non linear ordinary-differential equations which describe the amplitude and phase modulation of the response and permits the computation of its stability. This analytical approach is a powerful and quick tool for the sensor design by enabling the description of the competition between the hardening and the softening behaviors (Fig.3), and thus may be used to enhance the dynamic range of the resonator, i.e. its detectability.

Manufacturing:

On the way from MEMS to NEMS, a "small" MEMS resonant accelerometer [7] shown in Fig.1 has been fabricated. The sensor structure has been designed in order to validate process, characterization and model choices. The fabrication starts with 200mm SOI wafers. The use of DUV lithography combined with deep RIE process has permitted 500nm wide gaps and lines. Some low stiffness beams have been designed, so FH-vapor technique had to be improved to enable the release and protection against in-plane sticking.

Experimental characterisation:

For a start, only the resonant beams were released. The fabricated resonators are electrostatically actuated in-plane. Considering the low capacitance variations and the high motional resistance, tracking the resonance peak purely electrically is rather awkward. An original SEM set-up was developed, coupled with a real-time in-situ electrical measurement, using an external low noise lock-in amplifier (Fig.4). This set-up allows the simultaneous visualization of the resonance by SEM imaging (Fig.2) and the motional current frequency response. Fig.5 shows one of the first current peaks obtained, slightly non-linear. First comparisons are in good agreement with model results.

Conclusions and perspectives:

In a future work, the whole sensor will be released and characterized under ac acceleration, so its overall dynamic behavior will be studied. Experimental and model results will be compared, which will complete the model validation.

REFERENCES

[1] T. Roessig, “IntegratedMEMStuning fork oscillators for sensor applications,” Ph.D. dissertation, Department of Mechanical Engineering, University of California, Berkeley, 1998.

[2] H.A.C. Tilmans R. Legtenberg, “Electrostatically driven vacuum-encapsulated polysilicon resonators Part II. Theory and performance”, Sensors and Actuators A 45, pp. 67-84, 1994

[3] Gui, C., Legrenberg, R., Tilmans, H.A., Fluitman, J.H.J., Elwenspoek, M.: “Nonlinearity and hysteresis of resonant strain gauges”, J. Microelectromech. Syst. 7, 122–127 (1998)

[4] F Najar,S Choura, E M Abdel Rahman, S El-Borgi and A Nayfeh, “Dynamics analysis of variable-geometry electrostatic microactuators”,J. Micromech. Microeng 16 (2006) 2449-2457.

[5] Nayfeh, Ali, Younis Mohammad, Abdel-Rahman Eihab, “Dynamic pull-in phenomenon in MEMS resonators”, J. Nonlinear Dynamics 48: 153-163, 2007.

[6] Nayfeh, A.H.: Introduction to Perturbation Techniques. Wiley, New York (1981).

[7] A. A. Seshia, M. Palaniapan, T. A. Roessig, R. T. Howe, R. W. Gooch, T. R. Schimert, and S. Montague, "A vacuum packaged surface micromachined resonant accelerometer," J. Microelectromech. Syst. 11(6), 784–793 (2002).

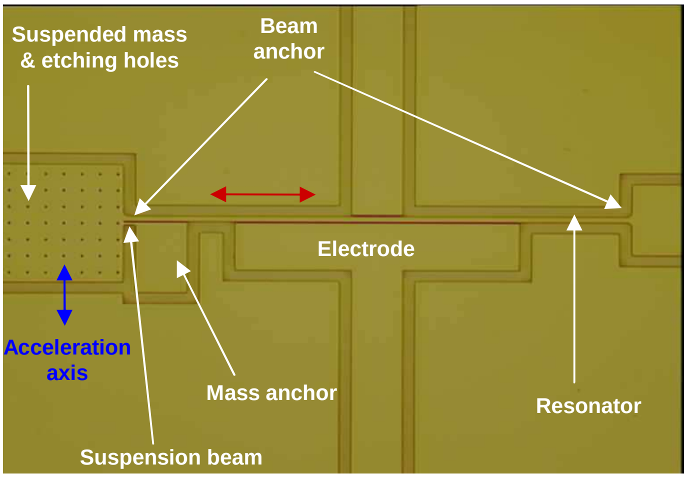


Fig.1: Optical microscope image of the resonant accelerometer.

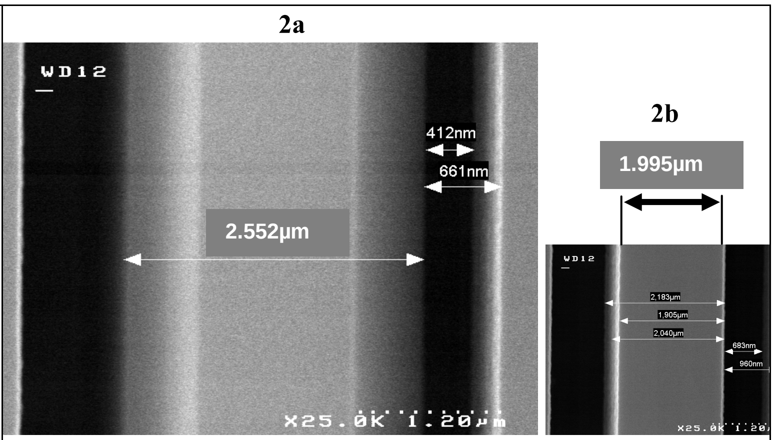
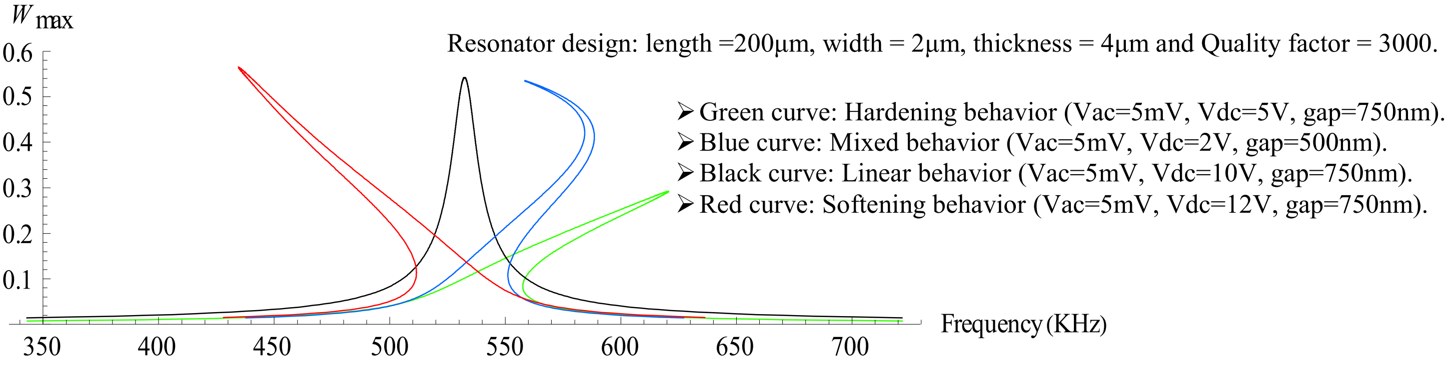


Fig.2 (2a): SEM image of the resonator resonance.
(2b): SEM image of the resonator at rest.
Dimensions: 200µmx2µmx4µm. The gap: around 750 nm.



Resonator design: length =200µm, width = 2µm, thickness = 4µm and Quality factor = 3000.

- Green curve: Hardening behavior (Vac=5mV, Vdc=5V, gap=750nm).
- Blue curve: Mixed behavior (Vac=5mV, Vdc=2V, gap=500nm).
- Black curve: Linear behavior (Vac=5mV, Vdc=10V, gap=750nm).
- Red curve: Softening behavior (Vac=5mV, Vdc=12V, gap=750nm).

Fig.3: Predicted forced frequency responses including fabrication defects and stress stiffening.
Wmax is the normalized displacement with respect to the gap. Specific parameters combination permits the compensation of the nonlinearities in order to obtain a linear behavior (black curve). Mixed behavior (blue curve) is also possible for a 500 nm gap.

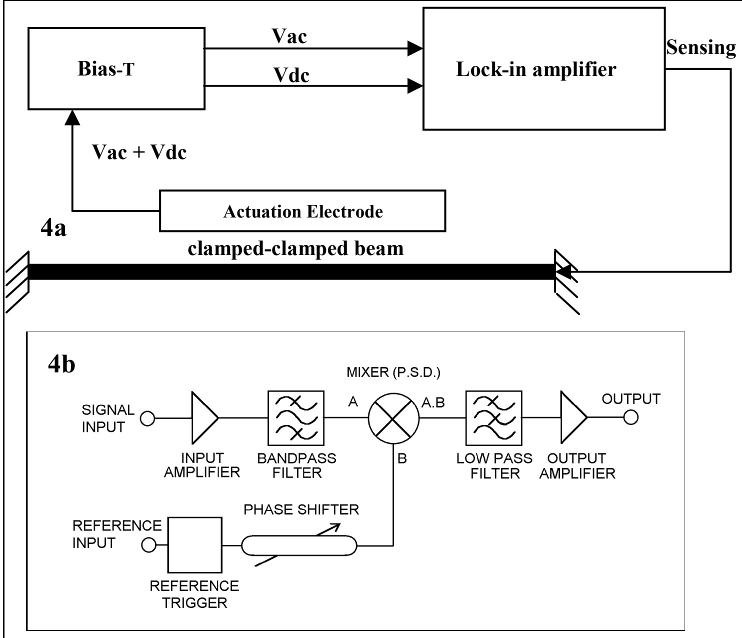


Fig.4 (4a): Connection layout for the electrical characterization.
(4b): Block diagram of a typical lock-in amplifier.

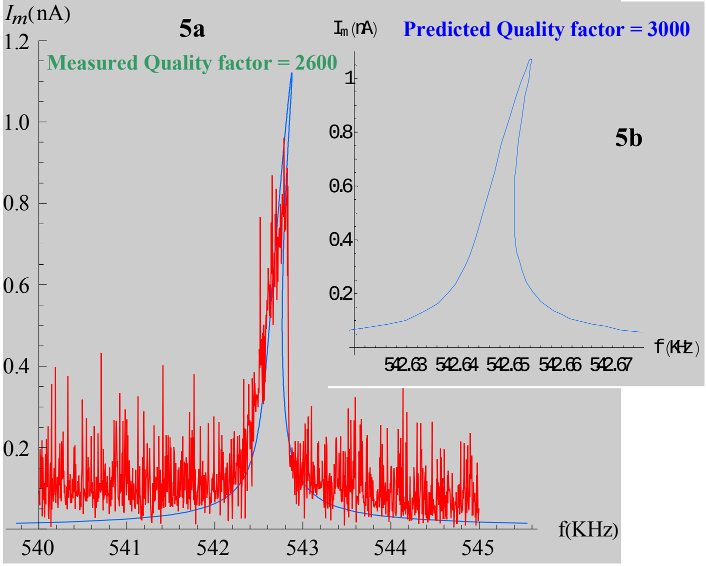


Fig.5 (5a): Measured (red) and predicted (blue) motional current frequency responses for an electrostatically driven resonator (Vac=10mV, Vdc=5V). Dimensions: 200µmx2µmx4µm.
(5b): Predicted motional current frequency response slightly non-linear.