Role and characterization of the built-in stress in double clamped beam silicon nanowires

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Double clamped silicon beams are convenient building blocks for the realization of nanomechanical resonators. The practical application of nanomechanical resonators requires an efficient method for detecting their oscillation, which becomes increasingly difficult as the dimensions of the structures shrink. Electrical read-out of the oscillation is one of the most straightforward ways of obtaining compact systems, enabling the possibility of simultaneous detection of a large number of resonating elements. Electrical transduction can be implemented by piezoresistive read-out. Recently, we have shown that geometrical asymmetries present in DCBs cause an enhancement of the piezoresistive transduction, allowing to obtain large read-out electrical signals from silicon nanowire resonators obtained by top-down and bottom-up fabrication methods.[1,2]

Double clamped beam nanomechanical resonators are fabricated by a fast, accurate and flexible prototyping method based on the combination of focused ion beam (FIB) exposure and wet silicon etching.[3] Figure 1 shows an example of a device fabricated by this method.

We show that the amplitude of the piezoresistive transduced signal generated by the mechanical oscillation of double clamped beams is highly influenced by the presence of stress and asymmetries. By properly tuning the geometry of the beam, the electrical signal corresponding to specific resonant modes can be enhanced or diminished.

We employ atomic force microscopy operated under the peak force mode to evaluate the stress generated after fabrication. After the release of the silicon nanowires, the beams present a curved shape that lets to a bi-stable buckling behavior. This is confirmed by actuating the beams with the tip of the AFM and recording in real time its displacement. The force at which the beam is switched from up-bending to down-bending allows us to quantify built-in stress in the device.

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[1] M. Sansa, M. Fernández-Regúlez, J. Llobet, A. San Paulo, and F. Pérez-Murano, Nat. Commun., vol. 5, p. 4313, 2014.

[2] J. Llobet, M. Sansa, M. Lorenzoni, X. Borrisé, A. San Paulo, and F. Pérez-Murano, Appl. Phys. Lett., vol. 107, no. 7, p. 073104, 2015.

[3] J. Llobet, M. Sansa, M. Gerbolés, N. Mestres, J. Arbiol, X. Borrisé, and F. Pérez-Murano, Nanotechnology, vol. 25, no. 13, p. 135302, 2014.

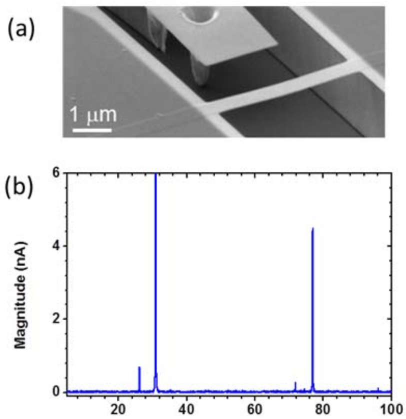

Figure 1. (a) SEM image of a suspended silicon nano-beam with the following dimensions: Length= 4.16 µm, width=540 nm; thickness = 35 nm. (b-c) Frequency response obtained by down-mixing methods using back-gate actuation and piezoresistive transduction.

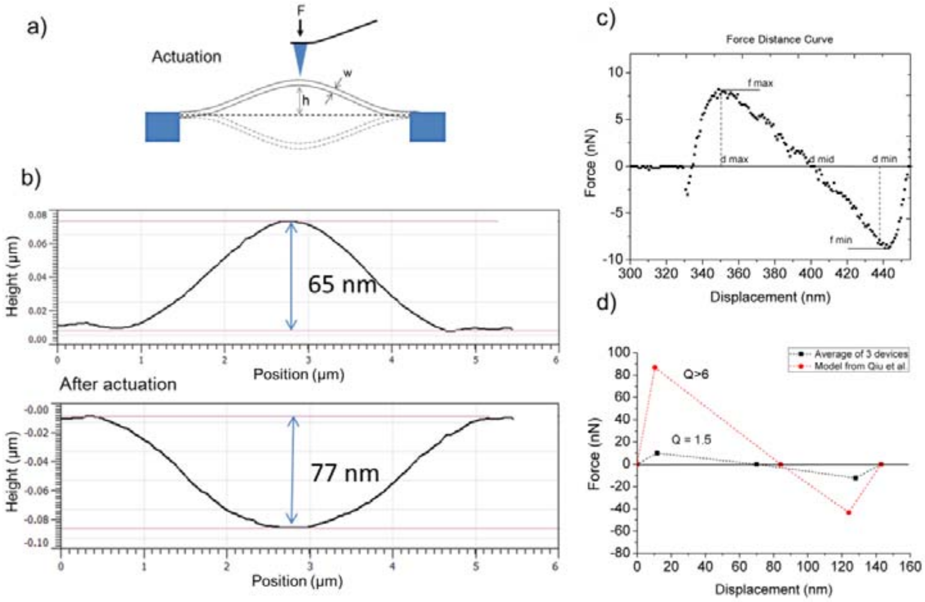

Figure 2:.(a) Actuation of an up-bended double clamped beam with the AFM tip, acquiring simultaneously the force and the beam deflection (F-d curve). (b) Once actuated the cantilever keeps the down-bend configuration.(c) The acquired F-d curves present the typical “z” shape with the beam passing through a so called “bifurcation point” at d_{max} and getting to the bi-stable configuration at d_{min} to finally reach the opposite configuration. (c) Comparison between the devices built and the modeled devices from the work of Qiu et al. “A Curved-Beam Bistable Mechanism” Journal of Microelectromechanical Systems 2004