PARYLENE-BASED HOLLOW NANOMECHANICAL RESONATORS FOR BIO-APPLICATIONS

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We present the fabrication of parylene-based hollow nanomechanical resonators, following a simple two step fabrication process with a thermal budget of less than 120°C. This process is ideal for fast prototyping and compatible with most materials used in micro- and nano-fabrication. In particular, the example we present here shows a hybrid structure with silicon nitride and parylene, but we have also demonstrated compatibility with metallic electrodes and aluminum nitride piezoelectric layers.

Nanomechanical resonators have demonstrated great capabilities for sensing. However, when tackling biosensing applications, like protein or DNA detection, the immersion into fluids leads to low performance due to increased damping given by the surrounding fluid [1]. To avoid this and retain sensing performances achievable in vacuum, resonators with embedded micro-fluidic channels can be used [2]. The fluid to be analyzed flows inside the resonator and thus viscous damping is almost completely suppressed. One of the major limitations of resonators with embedded fluidics (SMCs) is the costly and rather challenging fabrication process, with many steps and the use of aggressive chemicals [2].

We demonstrate a simple two lithographic step fabrication process (see Figure 1) with a low thermal budget to obtain resonators with embedded micro-channels. Photoresist is used as sacrificial layer for the channel definition, and parylene as the structural material for the channel walls. In the particular implementation we show here, the channels are fabricated on a thin layer of silicon nitride. However, the bottom material can be changed as the process is compatible with most materials used in micro- and nano-fabrication. No aggressive chemical or thermal processing is needed. In addition to the results presented here, we have also successfully realized hollow silicon nitride-parylene resonators with integrated metallic electrodes and aluminum nitride piezoelectric layers.

We investigate two different geometries: clamped-free (see Figure 2) and clamped-clamped beam resonators. Figure 3 shows a SEM image of a released device where the parylene walls are deposited on a 100 nm thick low stress silicon nitride. Figure 4 shows the result of the measured resonance frequency via optical detection on an empty doubly clamped beam, which exhibits a resonance frequency of 394 kHz and a quality factor of 103. On the other hand, measured free-clamped beams exhibit a resonance frequency of 8.6 kHz and a quality factor of 14.

Compared to conventional silicon/silicon nitride cantilevers, parylene-SMCs show low mass, stiffness and thermal conductance. This makes these devices ideal for detection of mass, density changes and stiffness of add-on species, assuming the same minimum Allan Deviation for all the resonators. The high temperature responsivity of these devices makes them suitable for temperature monitoring, photothermal spectroscopy and calorimetry for bio-applications [3].

[1] Tamayo J et al., Biosensors based on nanomechanical systems. Chem Soc Rev. 2013;42:1287-311.
[2] Burg TP, Manalis SR. Suspended microchannel resonators for biomolecular detection. Appl Phys Lett. 2003;83:2698-700.
[3] Lee W et al., High-sensitivity microfluidic calorimeters for biological and chemical applications. Proc Natl Acad Sci U S A. 2009;106:15225-30.

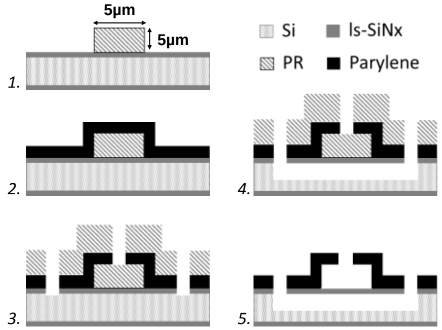

Figure 1. Fabrication process of silicon nitride-parylene resonators with embedded micro-channels. 1. Channel geometry definition by photolithography. 2. Parylene deposition (2µm). 3. Resonator and access holes definition by photolithography and dry etching. 4. Resonator releasing through a combination of isotropic and anisotropic dry etchings. 5. Channel emptying and PR strip in MicroChem Remover 1165.

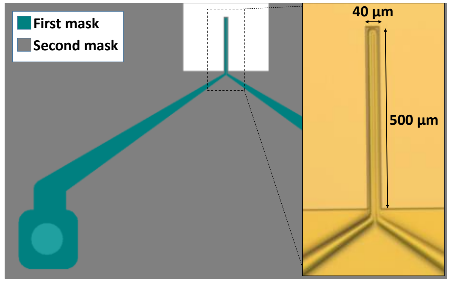

Figure 2. Two mask design for the clamped-free beam resonators. The inset shows an optical microscope image, with relative dimensions, of the device after the two lithographic steps. Both free-clamped beams and clamped-clamped beam designs are investigated in this work.

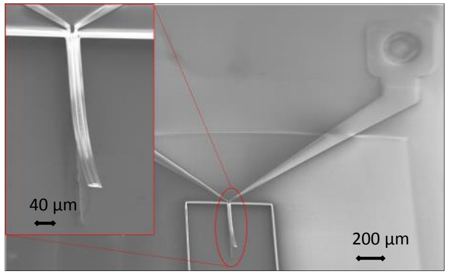

Figure 3. SEM image of released silicon nitride-parylene resonator. 300µm diameter microfluidic inlet is visible in the top right of the picture. The inset shows the u-shaped parylene micro-channel on top of the clamped-free beam resonator.

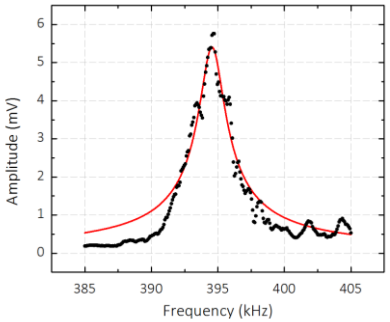

Figure 4. Measure of resonance frequency by means of optical detection of a clamped-clamped beam resonator. The device exhibits a resonance frequency of 394 kHz and a quality factor of 103.