

Micropillars patterned surface on in-plane MEMS resonator for enhanced airborne fine particles detection

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Summary:

In this paper, the impact of micropillars surface patterning on an in-plane MEMS resonator is described. Although lamé mode resonance frequency of patterned surface is found at a lower value than the plain one, the quality factor remains on the same order, confirming that particle detection is still feasible. Experiments involving inertial impaction of Polystyrene Latex (PSL) beads on these sensors, tend to show that ratio between pillars spacing and particle diameter is key to control local collection efficiency.

Keywords: MEMS, microbalance, resonator, airborne, collection efficiency, surface patterning

Background, Motivation and Objective

Numerous adverse effects on human health can be attributed to air pollution. The World Health Organization (WHO) global air quality guidelines set thresholds of mass concentration exposure for harmful pollutants, amongst which, one can find particulate matter with diameter lower than $10\mu\text{m}$ and $2.5\mu\text{m}$ (PM_{10} , $\text{PM}_{2.5}$) [1]. Gravimetric and optical sensors commonly used to obtain PM mass concentrations tend to be replaced by smaller and more sensitive ones like Quartz Crystal Microbalance (QCM). Micro Electro-mechanical Systems (MEMS) resonators are other serious candidates for this purpose with a high sensitivity allowing detection of mass at nanogram and even picogram order [2]. For airborne PM collection, inertial impaction is commonly used. Nevertheless, using smooth solid surfaces, bouncing effects occurs inducing a reduction in local collection efficiency (LCE). In order to increase collection, several surface modifications have been tried on QCM. Using printed 3D IP-DIP resin pillars on a QCM surface, Hajizadehmotlagh and Paprotny showed an increased airborne $4.8\mu\text{m}$ PSL beads collection with inertial impaction [3]. In this work, a new fabrication process leading to similar equally spaced pillars but etched within the active area of MEMS resonators is proposed. Electrical characterizations are performed to assess the impact on deposited mass detection. Finally, particles counting allows to control LCE for combinations of different pillars patterned surface densities and monodispersed particle sizes.

Fabrication and characterization methods

The MEMS resonator is fabricated from a doped silicon on insulator (SOI) wafer in several steps involving thermal oxidation, successive front and back deep reactive ion etching (DRIE), aluminum layers deposition, and anisotropic vapor hydrofluoric acid (VHF) etching. The detailed process is synthesized in Fig. 1.

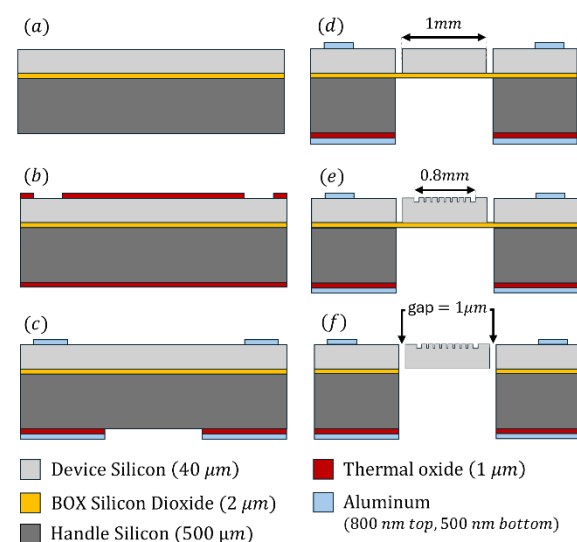


Fig. 1. Overview of the pillars patterned surface MEMS membrane fabrication process. (a) Initial SOI wafer. (b) Thermal oxidation creating an oxidation layer etched to form MEMS geometry. (c) Aluminum layers deposited on both sides then patterned to create electrode pads on top and the handle silicon cavity freeing the membrane. (d) & (e) Successive top and bottom DRIE employed to create the structure functionalization and $5\mu\text{m}$ diameter, $10\mu\text{m}$ height pillars patterned surface. (f) VHF release to eliminate the BOX layer remaining inside handle silicon cavity.

The final device, which can be seen on Fig. 2, is a 6mmx6mm chip incorporating a free membrane consisting of a 1mmx1mm square and 40µm thickness silicon device linked to the chip thanks to T-shaped tethers on each corner. Equally spaced micropillars are patterned during DRIE steps. In this work pillars dimensions are 5µm diameter and 10µm height and are spaced 40µm lateral surface to surface either by 5µm (E5) or 10µm (E10). Four actuation electrodes are located on membrane's flanks, separated from it by a 1µm gap. A body terminal from one tether allows to sense the motional current created on the membrane while vibrating.

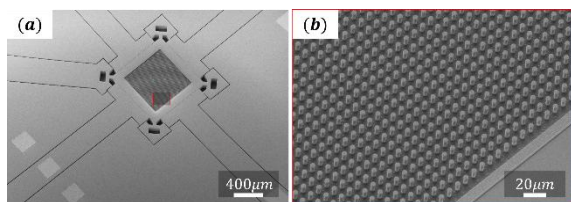


Fig. 2. MEMS resonator structure. SEM images of (a) E5 patterned membrane chip, (b) membrane zoom.

For lamé mode detection, electrical characterization is performed by injecting on two facing electrodes the same sum of two tensions $V_{AC}=10V_{pp}$ (sine form) and $V_{DC}=60V$. The V_{AC} frequency is swept around resonance frequency. The body terminal is linked to a lock-in amplifier (LIA), allowing synchronous detection of induced motional current with exciting frequency as reference. In these experiments, resonance frequency and quality factor are determined by detecting signal peak while sweeping actuation frequency before and after inertial impaction of monodispersed 2.5µm and 7µm commercial PSL beads from Thermofisher's Duke Stand.™ 4000 series. Finally, during the impaction, particle generation counts and size is controlled with an APS (3321 APS-TSI) and deposited particles number is assessed by automatic counting using MATLAB language program from Zeiss Axio lab optical microscope image acquisitions of the MEMS resonator's membrane after impaction. LCE is calculated using ratio between these particles counts for each experiment.

Results and discussion

Fig. 3 resumes lamé mode resonance frequencies, quality factors and LCE for E5 and E10 pillars patterned surfaces before and after impaction of 2.5µm diameter PSL. All experiments were run in the same conditions (PSL generation, impaction time, air flows). These results are compared with those of a plain surface giving resonance frequencies and quality factor of $f_0 = 4.109374$ MHz, $Q_0 = 10170$ before and $f_p = 4.109020$ MHz, $Q_p = 8137$ after impaction and CE of 3.3%.mm².

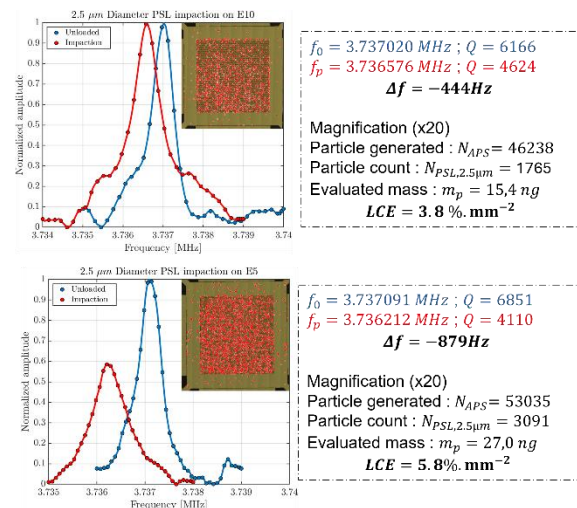


Fig. 3. Results of E10 and E5 2.5µm PSL impaction

Giving these results one can see a quality factor remaining high enough for detection. LCE is not significantly better for E10 structure (+0.5%) but almost doubled with E5. To go further, same experiment was done with a E5 surface but for 7µm PSL diameter to see the effect of diameter greater than pillar spacing, resulting in a CE of 33,9% with particles located on pillars surface.

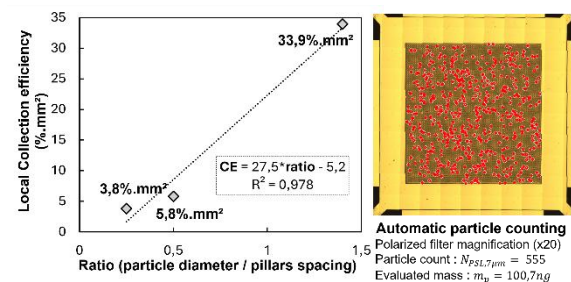


Fig. 4. Left : graph representing LCE vs ratio between particle diameter and pillars spacing. Right : particles counting after 7µm PSL impaction on E5.

These preliminary results are very encouraging, showing that surface patterning is feasible on MEMS resonator with small impact on detection and can increase LCE tuning pillars spacing according to particle diameter.

References

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