

# METAL-ORGANIC THIN-FILM ENCAPSULATION FOR GRAVIMETRIC GAS MICROSENSORS

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## ABSTRACT

Here we demonstrate a novel metal-organic thin-film encapsulation technique for resonant gas microsensors to efficiently filter out airborne particles which can negatively affect device performance. The gravimetric sensors are ZnO-on-silicon extensional mode resonators coated with a gas-sensitive material. Mass change caused by chemical reaction and/or physical adsorption can be detected through measured resonant frequency shifts. The gas sensors are encapsulated in microcavities made from multiple layers of Novolac-based positive-tone photoresist. Particle filtering is achieved by minimizing clearance in the lateral access holes and electrostatic attraction from the organic polymer gas channels.

**KEYWORDS:** MEMS packaging, gravimetric sensing, gas sensor, piezoelectric resonator

## INTRODUCTION

Although negative-tone photoresist has been used to form cavity structures for encapsulation [1, 2], its poor adhesion and swelling properties make it unsuitable to package micromechanical devices. Typical Novolac-based positive-tone photoresists have stronger adhesion but are restricted to single-layer patterning because solvent in subsequent coatings can remove pre-exposed resist. We break through this limitation and achieve multiple coatings/exposures followed by a single development step to build micro cavities for gravimetric resonant gas sensors. ZnO-on-silicon extensional mode resonators are encapsulated for a proof-of-concept demonstration. The gravimetric sensor has two annexed platforms to be coated with gas sensitive material (Figure 1). The encapsulation goal is to efficiently block airborne particles in the analyte gas flow.

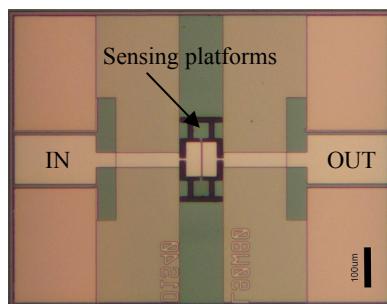


Figure 1. Optical micrograph of a ZnO-on-silicon extensional mode resonator in a two-port electrode configuration. The annexed platforms are used for sensing.

## EXPERIMENTAL

ZnO-on-silicon resonators are fabricated on a 4-inch SOI wafer using a 6-mask process, similar to the 5-mask process in [3]. The additional step involves recessing the device layer down to the buried oxide for the signal in/out pads. The metal-organic thin-film encapsulation is completed before the resonators are released by plasma removal of the buried oxide from the handle side.

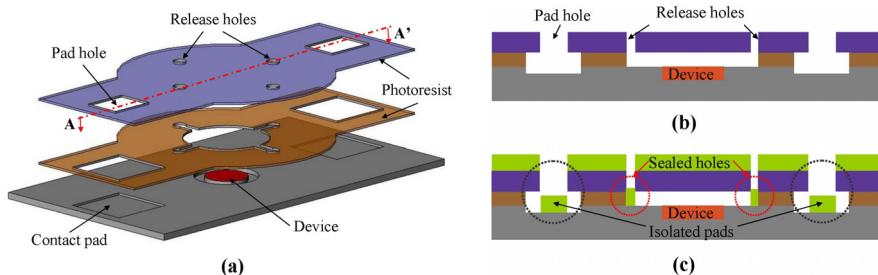


Figure 2. Schematic overview of the metal-organic thin-film encapsulation technique based on standard photolithography: (a) an exploded view of the encapsulation; (b) a cross-section view of AA'; (c) blanket metallization for sealing or partial sealing of release holes while leaving contact pads electrically isolated due to the predefined recesses and roofs.

The encapsulation scheme is shown in Figure 2. The first layer of positive photoresist (Shipley SPR220-7) is spun, softbaked and UV-exposed with a mask exposing contact pads, cavities, and release holes. Prior to the second coating, the first layer is passivated with fluorocarbon polymer thin film (formed by CHF<sub>3</sub> plasma treatment of the first layer for 2 minutes) to protect the UV-exposed resist from being dissolved in the second coating. Then the second layer is spun, softbaked and UV-exposed to pattern contact pads and release holes. A single development process removes the exposed resist in both layers within about 50 minutes.

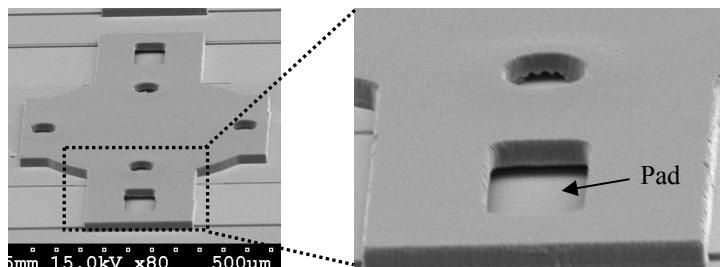
## RESULTS AND DISCUSSION

SEM images of the developed encapsulations are shown in Figure 3. The lateral release holes can be partially or fully sealed by blanket metallization without shorting the signal in/out pads due to the predefined recesses (Figure 4), and the remaining clearance in the lateral holes for gas access can be controlled by a quartz crystal microbalance during metallization within a resolution of several angstroms. The encapsulated resonators are characterized with an Agilent network analyzer. Figure 5 shows the length extensional mode's fundamental resonant peak at 30.73MHz with a quality factor of approximately 1300.

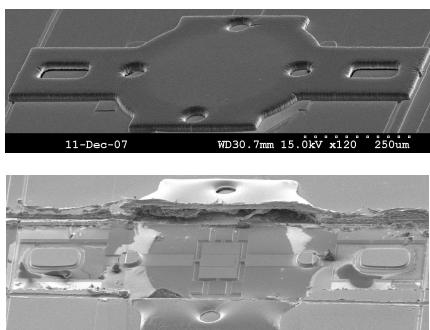
## CONCLUSIONS

We have demonstrated a metal-organic thin-film encapsulation technique for resonant gas microsensors to efficiently filter out airborne particles. The particle filtering is achieved by both minimized clearance in the lateral access holes and electrostatic attraction from the organic polymer channel. This is also the first report on

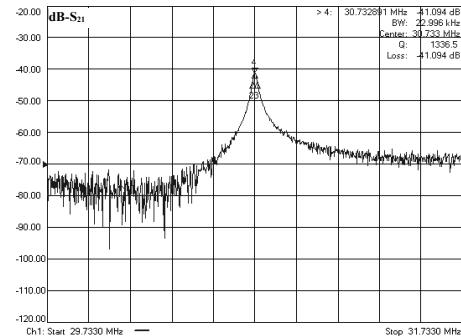
construction of three-dimensional microstructures with multiple layers of Novolac-based positive photoresist. In addition to encapsulation of resonant gas microsensors, this technique can be used to build micro fluidic systems for lab-on-chip applications.



*Figure 3. SEM images of the developed encapsulations prior to blanket metallization: greater clearance above the pad hole than the release hole is achieved by the predefined recess in the pad hole.*



*Figure 4. SEM images of an encapsulation after blanket metallization: (top) a complete encapsulation; (bottom) opened package showing device.*



*Figure 5. Fundamental resonant peak of an encapsulated ZnO-on-silicon extensional mode resonator.*

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