Membrane Resonators Consisting of Cross-Linked Gold Nanoparticles: Influence of Geometry on Vapor Sensing Characteristics

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With progressive downsizing of mechanical devices, nanomaterials gain significant importance, especially regarding sensing elements[1]. Nanometer-thin composite membranes may constitute a promising active component for future microelectromechanical sensing elements.

Thin films of interconnected gold nanoparticles (GNPs) feature intrinsic environment-dependent properties, making them applicable as sensing element, for example as chemiresistors[2]. By transferring spin-coated GNP thin films onto three-dimensionally structured silicon substrates, a novel type of microelectromechanical resonator has been fabricated, as reported recently[3]. Examining the vibrations of dithiol cross-linked GNP membranes at reduced pressures (~20 mbar) enables the detection of volatile organic compounds (VOCs) due to a sizable, reversible frequency shift of the membrane's fundamental resonance mode. This effect is caused by a decrease of the membrane's pre-stress as well as a total mass increase by molecule sorption[3].

Due to strong damping at higher or ambient pressure, however, the detection of resonance modes becomes increasingly challenging. Here, we address this problem by modifying the resonator geometry. The vibrational behavior of the resonators can be manipulated by a number of customizations. Adding micrometer-wide channels to otherwise confined cavities enable a much easier gas flow into and out of the resonator's cavity (Figure 1). Appropriate modifications render measurements of resonance frequencies and, thus, the usage of such resonators as highly responsive microelectromechanical chemical sensors at ambient pressure feasible. This was shown for toluene vapor with concentrations as low as 0.5 ppm for which Frequency shifts as low as 1 kHz could clearly be resolved (Figure 2).

Additional experiments revealed a dependency of the fundamental frequency-shift transient upon exposure to VOCs on the accessibility of the resonators' cavity volume. Doubly-clamped membranes over elongated trenches featured quasi-instantaneous responses, while confined resonators exhibited much slower transients. Square resonators featuring diagonally arranged air channels displayed an intermediate behavior. Consequently, multiple sensors displaying distinct response characteristics are manufacturable from the same raw materials and can be used in combination for highly selective analyte detection.

References

[1] M. A. Cullinan, M. L. Culpepper, *Phys. Rev. B* **2010**, *82*, 115428.

[2] N. Olichwer et al., *ACS Appl. Mater. Interfaces* **2012**, *4*, 6151.

[3] H. Schlicke et al., *ACS Sensors* **2017**, *2*, 540.

Figures

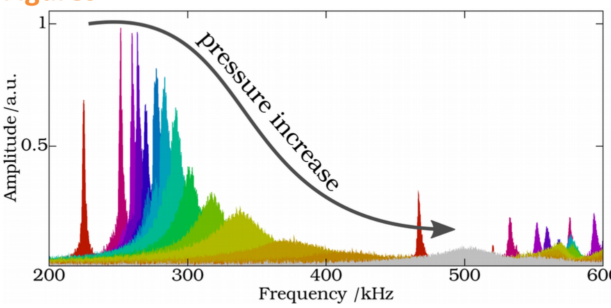

Figure 1. Damping of the device depicted below, measured in the range between 1.5 mbar to 1007 mbar.

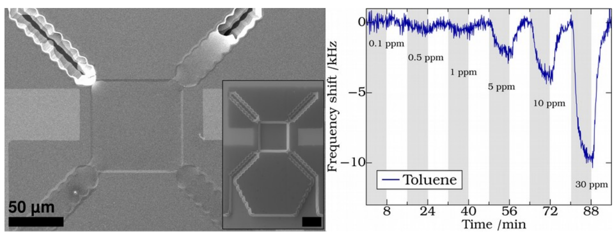

Figure 2. SEM image of microelectromechanical resonator (left); Substrate before membrane transfer (inset); Frequency-response transient for small comcentrations of toluene vapor at 1007 mbar (right).