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Micro- and nanomechanical resonators for sensing applications

Due to the combination of mechanical structures with electrically active elements for actuation and sensing, the technology of micro- and nanoelectromechanical systems (MEMS/NEMS) bears a huge potential for sensing applications. Common resonant mass sensors like quartz oscillators operate by providing a frequency shift which is directly proportional to the increase of mass when any kind of material accumulates at its surface. Small active masses enhance the sensitivity for very small mass loadings which leads to a trend of miniaturization into the submicron domain [1]. Reported resonant frequencies up to 1 GHz and quality factors of 10 000 can be achieved only at low temperatures and ultra-high vacuum. For sensing applications, especially biological ones, it is necessary to work under ambient conditions or even in liquids. In this work we demonstrate MEMS and NEMS resonators which operate with a magnetomotive actuation on ambient conditions.

This approach paves the way to other sensing applications like examining the viscosity of picoliter-droplets or the detection of single molecules or viruses within a liquid in case of functionalized surfaces [2]. However, the quality factor Q of typical nanomechanical structures is significantly lower than that for the above mentioned macroscopic system (several 100 compared to 100.000) which makes the performance on ambient conditions difficult to achieve.

The active layers of MEMS and NEMS were realized using silicon carbide (SiC) deposited by high-vacuum chemical vapor deposition and polycrystalline aluminum nitride (AlN) grown by reactive sputtering on silicon substrates. The top electrode necessary for magnetomotive actuation consists of an evaporated titanium/gold layer system. The resonator design is based on free-standing single- and double-clamped resonators with beam lengths of 10 to 500 µm (fig. 2) and widths of 0.9 to 8 µm [3].

In case of the magnetomotive actuation, the oscillation of the beams is caused by an applied alternating voltage in a permanent magnetic field induced by the Lorenz force. Because of the inherently low read-out voltage a measurement setup was established which separates the excitation signal and the response signal from each other. This method allows to observe the free decay of the oscillations, from which the resonant frequency and quality factor can be derived.

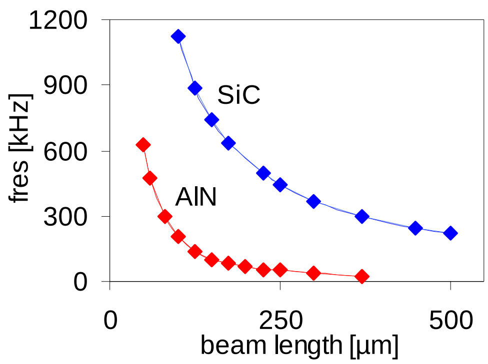

Figure 1: Resonance frequency of AlN and SiC double-clamped beams of different length.

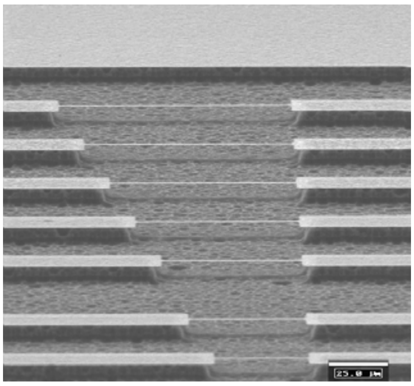

Figure 2: SEM pictures of AlN-based double-clambed beams of different length.

The resonators have been characterized on ambient conditions. The resonant frequencies of the AlN and SiC-beams were in the range of 5 to 750 kHz and 0.32 to 2 MHz (fig. 1), respectively. The values of the resonant frequencies were affected by film thickness, beam length and internal homogeneous strain. The quality factors in air reached values up to 350. In order to test the sensitivity of the resonators, an additional mass loading of 50 to 250 pg was applied to AlN-beams of 105 nm thickness by sputtering thin layers of metal. This resulted in a clearly detectable shift of the resonant frequency of about 5%. Similar experiments with SiC-beams and a mass loading of a very thin metal layer indicated a resonant frequency shift of 1.8%, which agrees with calculations based on theoretical models. First observations of oscillations in liquids like propanol showed promising results. Though the amplitude was lowered by damping effects, it remained visible. Thus with an optimized geometry it should be possible to determine the viscosity of surrounding liquids. In addition measurements of resonators with functionalized surfaces will allow to detect molecules or even viruses in liquids. With a controlled growth of nanowires on the basic beam geometries it should also be possible to enable further applications like flow sensors.

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