Aqueous Transduction of Poly-SiGe Disk Resonators

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Abstract

This paper demonstrates an electrostatic transducer for lateral contour-mode resonators in which the transduction gaps are filled with a liquid dielectric (water) having much higher permittivity than air ($\varepsilon_{water} = 80.1$). Aqueous transduction is more efficient than air-gap transduction (lower motional impedance) and has a larger frequency tuning range than solid-dielectric transduction. We demonstrated a 42 megahertz (MHz) poly-SiGe disk resonator with deionized (DI) water confined to the electrode gaps. The resonator has a measured quality factor ($Q$) of 3,800, motional impedance of 3.9 kΩ, and 3% series frequency tuning range.

Summary

Sounart and others have demonstrated that by using an local oscillator (LO) signal that is faster than the response time of a polar fluid, it is possible to prevent electrode polarization and double-layer formation, enabling electrostatic transduction in liquid media [1, 2]. To determine whether the same approach enhances the performance of contour-mode radio frequency microelectromechanical systems (RF MEMS) resonators, we used a air-gap poly-SiGe disk resonator ($f_0 = 49.2$ MHz, $Q_{air} = 5,300, R_s = 510$ kΩ @ $V_P = 5$V) (Figure 1) [3] and submerged it in a water droplet. However, immersing the resonator in water caused excessive mass-loading and $Q$ losses resulting from viscous drag. To eliminate mass-loading and viscosity effects of the water droplet on the resonator, we coated the resonators with a hydrophobic self-assembled monolayer (SAM). The SAM is non-conformal, coating the top surface of the poly-SiGe disk resonator while leaving the 60 nm transducer gaps hydrophilic.

We placed a drop of DI water on the resonator and then slowly tipped the chip to one side to let the water droplet roll off the structure. The DI water ‘wicked’ the electrostatic transducer gaps (Figure 2a-b) and resonator performance improved to $Q$ of 430 at 36 MHz due to reduced viscous damping (Figure 2c). This low $Q$ resulted from water remaining underneath the
resonator after the droplet rolled off. Even though the gap under the disk was < 2 µm, water underneath would cause viscous damping and degrade the quality factor. To reduce this effect, we placed the water droplet a few microns away from the resonator and tipped the chip, letting the water droplet roll over the disk resonator (Figure 3a). The short time that the water droplet overlapped the resonator was enough to wick the transduction gaps but greatly reduced the chance of water seeping under the resonator. We were able to repeat the measurement multiple times with similar results. All measurements gave $Q > 3,500$ and $R_x < 4.2 \ \text{k}\Omega$ near 42 MHz (Figure 3b). The 100× improvement in motional impedance from air-gap-to-water is comparable to previous solid-dielectric transduced resonators [4, 5]. The experimental $R_x$ improvement is smaller than the theoretical enhancement (~ 3000×) due to the loss tangent of water, which adds to the total series impedance of the resonator.

References


Figure 3: (a) Schematic of water droplet rolled across the resonator, wicking the transducer gap, but minimizing the water left underneath the resonator (b) transmission response: $Q$ of 3,800 at 42 MHz with $R_x = 3.9 \ \text{k}\Omega$. 

\[ R_x = 3.9\text{k}\Omega \] 
\[ Q = 3800 \] 
\[ V_p = 5\text{V} \] 

\[ 41.9 \quad 41.9 \quad 42.0 \quad 42.1 \quad 42.2 \quad 42.3 \] 
\[ -50 \quad -45 \quad -40 \quad -35 \quad -30 \] 
\[ \text{Frequency (MHz)} \] 
\[ \text{Transmission (dB)} \]