Epitaxial Silicon Microshell Vacuum-Encapsulated CMOS-Compatible 200 MHz Bulk-Mode Resonator

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Abstract:

We report on the first successful combination of dielectrically-transduced 200 MHz resonators with the epi-silicon encapsulation process, and demonstrate a set of important capabilities needed for construction of CMOS-compatible RF MEMS components. The result shows the resonant frequency of 207 MHz and quality factor of 6,400. The high $f\cdot Q$ ($1.2 \times 10^{12}$ Hz) makes this encapsulated resonator an excellent candidate for applications in local oscillator and RF spectrum analyzer.

Figure 1: Epi-silicon microshell encapsulation process for dielectrically transduced resonators.

Summary:

Microelectromechanical system (MEMS) resonators have potential for replacing conventional resonators used in portable wireless applications. They have the merits of small size, high frequency, high quality factor ($Q$), and low power consumption [1]. However, packaging for MEMS resonators remains a critical challenge. Because of their extreme sensitivity to the environment, MEMS resonators need vacuum encapsulation to achieve high quality factors and enable post-MEMS complementary metal oxide semiconductor (CMOS) integration. This work demonstrates a manufacturable solution to these challenges. The main resonator beam consists of three layers — a 100 nm polysilicon electrode layer, a 100 nm silicon nitride transducer layer, and a 3 µm single-crystal silicon resonator layer. The fabrication process is the fusion of two technologies developed at Cornell and Stanford [2,3]. The main challenge is to create vertical low-loss interconnects connecting to two different conductive layers of the resonator (the poly electrodes and silicon device layer).

As shown in Figure 1, the fabrication starts with a silicon-on-insulator (SOI) wafer with a device layer of 3 µm. A 100 nm silicon nitride (SiN) and 100 nm polysilicon stack was deposited using low pressure chemical vapor deposition (LPCVD). The polysilicon layer was patterned to create electrodes. Part of the SiN layer was etched to create electrical ground contact to device layer. The resonator was then patterned and deep reactive ion etched (DRIE) through the nitride/silicon stack. Low temperature oxide (LTO) was deposited as the sacrificial layer to create a cavity on top of the resonator. Highly phosphorus doped epi-silicon was then grown on the top of the wafer to encapsulate the resonators. Vent holes were patterned to open access to the sacrificial LTO. After releasing the resonators by an HF vapor etcher, vent holes were again sealed by LTO in a low pressure CVD vacuum-encapsulating the resonators. Finally, an aluminum layer was used for
electrical interconnect and bond pads. Figure 2 shows the SEM of fabricated resonator.

To overcome the capacitive feed-thru, the resonator was characterized using a differential measurement technique, inspired by [4,5]. An RF signal from the network analyzer first goes into a splitter to create in-phase \((+RF_{in})\) and out-of-phase signals \((-RF_{in})\). In order to induce resonance of resonator, a VDC was added into the in-phase signal. Two identical resonators were driven by \(+RF_{in}\) and \(-RF_{in}\). While \(+RF_{in}\) was driving the resonator, the pure AC \(-RF_{in}\) was driving the dummy resonator, which serves as the parasitic capacitance. The outputs from both structures were combined, where the out-of-phase current from the parasitic capacitance cancels out the parasitic component in the signal from resonator (Figure 3). The result is plotted in Figure 4, showing the resonant frequency of 207 MHz and quality factor of 6,400.

This is the highest reported frequency for a MEMS resonator packaged in a microshell, making it an excellent candidate for insertion in local oscillator and RF spectrum analyzer applications.

References: