Large-scale integration of nano-electromechanical resonators and switches

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Micro- to nanosize scaling enables development of reconfigurable radio-frequency front ends, miniaturized and sensitive chemical and biological sensors, and low-power computers.

Nano-electromechanical systems (NEMS), devices with characteristic dimensions in the nanometer range, represent an emerging technology that harnesses these reduced sizes to provide sensing, actuation, computing, and signal-processing functionalities that are not attainable with currently available components. Despite significant progress in the development of NEMS components, a major remaining challenge is their ability to efficiently transduce mechanical devices (i.e., to effectively transfer the external electrical signal into mechanical motion and vice versa). Our efforts focus on the scaling of piezoelectric aluminum nitride (AlN) films from the micro- to the nanoscale realm for fabrication of efficient NEMS resonators and switches that can be interfaced directly with conventional electronics and, therefore, integrated on large scales.

We have demonstrated the performance of NEMS AlN resonators (250–500nm thick with lateral features as small as 300nm) that vibrate at record-high frequencies approaching 10GHz with quality factors (Q) in excess of 500 (see Figure 1).1 Q is an inverse measurement of the energy dissipation in the NEMS device: the higher the value, the lower the power consumption. For comparison, at 10GHz, on-chip resonators made with standard components (such as inductors and capacitors) have Q values that do not exceed 10. AlN piezoelectric nanomechanical resonators exhibit much higher Q values and occupy a fraction of the space taken by conventional capacitors and inductors.

Simultaneously, we functionalized the surfaces of these resonators with single-stranded DNA to yield unprecedented sensitivities and used them to measure analyte concentrations reaching part-per-trillion levels. Preliminary results2 in the context of gas sensing show that scaling to the nanoscale realm can be used to demonstrate large-dynamic-range, extreme-resolution, low-power, compact, and eventually disposable chemical and biological detector arrays.

Using 100nm-thick nanopiezoelectric films to develop NEMS actuators (see Figure 2) for switching applications, we also confirmed that bimorph nanopiezoelectric actuators have the same piezoelectric properties as their microscale counterparts.3 These actuators define a realistic pathway toward demonstrating nanomechanical computing elements that significantly reduce power consumption in both the dynamic and standby (leakage) states with respect to state-of-the-art CMOS devices. We are currently pursuing optimization of these NEMS resonators for insertion into microwave systems for synthesis of low-loss filters and high-precision time references.

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Figure 2. SEM and schematic diagram of a bimorph actuator formed by two 100nm-thick layers of AlN and three 50nm platinum (Pt) electrodes. Si: Silicon. +V: Power supply.

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References

