

ABSTRACT

KEYWORDS: MEMS ; Actuators; Resonators; Electrostatic; Internal Dielectric Transducer.

MEMS actuators and resonators have many promising applications, from RF switches, micro-mirrors, nano-positioners, and ultrasonic transducers to integrated timing references, sensors, and RF filtering. Typically, these devices utilize piezoelectric or electrostatic transduction. The piezoelectric actuators have a full range of motion and bidirectional deflection, whereas resonators have high electromechanical coupling and low motional impedance but have a lower quality factor. The drift of thin-film properties and piezo thickness-dependent resonant frequency makes it difficult to tune. Electrostatic resonators have high-Q, but motional impedance is very high, and electromechanical coupling is low. The external electrostatic transducers are also highly nonlinear.

The heart of almost all microelectromechanical devices are actuators and/or resonators working in symbiosis to implement the desired outcome. In modern MEMS applications, the most desired characteristics for actuators include accurate directional control, analog deflection adjustment, and efficient low-voltage digital switching. Because of their uncomplicated functionality and rapid switching, MEMS actuators are frequently preferred for applications such as RF switches, relays, micro-mirrors, nano-positioners, ultrasonic transducers, and closed-loop sensor systems. These actuators are known for their low power consumption and straightforward manufacturing processes.

This thesis work provides an alternative to piezoelectric transduction for large deflection pull-in free actuators or flexural mode resonators by employing an ultrathin (≈ 10 -nm) dielectric-filled (UDL) structure as an ultrathin internal dielectric for transduction (UDT). UDT has been used for bulk mode resonators with a few nm amplitudes but has not been considered for large deflection actuators. Conventional airgap devices have low coupling coefficients, while alternative piezoelectric devices require complex fabrication. UDL using atomic layer deposition (ALD), on the other hand, is a standard process in all foundries and shows good uniformity over large wafers. The proposed device achieves a coupling coefficient comparable to piezoelectric devices with a more straightforward, CMOS-compatible process.

The study extends to designing and fabricating a hybrid actuation system that combines UDT and airgap actuation in the same device. The hybrid actuation utilized in two ways, the air gap and UDT, can be used synergistically to reduce the pull-in voltage (“hybrid

downward actuator”). This is especially useful in RF switches where a large gap is desirable to increase the figure of merit. In the upward actuation version of the device, the direction of actuation of the UDT is opposite to that of the airgap transducer, so the two can be utilized to provide bidirectional actuation. This can be useful in deactuation of MEMS switches or in the closed-loop operation of actuators. The air gap combined with an upward actuator is called as “hybrid upward actuator”.

In addition to that, UDL used in these devices can undergo breakdown (BD) primarily due to Poole-Frenkel conduction similar to MOSFET’s and RF switches. Understanding the causes and progression of BD events is essential for improving device performance and reliability. Therefore, the characterization of devices focuses on investigating the BD and reliability characteristics of a UDL ring resonator, previously reported as a pull-in free actuator, thereby serving as a benchmark for evaluating the device’s performance. It also introduces a spiral resonator with internal electrostatic transduction, specifically designed to achieve signal amplification at a higher mode resonance frequency for an asymmetrical area drive and sense electrode configuration.

Furthermore, it explores the design, fabrication, and characterization of depletion layer transducers, which capitalize on internal forces affecting the stationary charges within the space-charge region and combine the advantages of solid dielectric and airgap actuators for transduction. This study also employs the parametric effect for signal amplification by stiffness modulation of a micromechanical resonator with a depletion layer transducer manufactured using a process compatible with CMOS technology.