NEMS Electrostatic Switch for Near Zero Power RF Wakeup

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Primary CNF Tools Used: ASML 300C DUV stepper, Heidelberg DWL2000, Gamma automatic coat-develop tool, Zeiss Ultra SEM, Zeiss Supra SEM, Oxford 81, 82, and 100 etchers, AJA ion mill, Hamatech hot piranha, Primaxx vapor HF etcher, Plasma-Therm deep Si etcher, Uniaxis 770 deep Si etcher, DISCO dicing saw, wire bonder, Aura 100, Zygo

Abstract:

A near zero-power laterally actuated nanoelectromechanical systems (NEMS) electrostatic radio frequency (RF) switch with multi-gate DC tunable threshold is presented as a portion of an overall wireless sensor node with less than 10 nW power consumption. Previously these switches were demonstrated as means of signal detection from a suite of zero power sensors. Various design updates and fabrication improvements have since been implemented to reach the desired -100 dBm RF sensitivity. The addition of folded trusses, compliant contacts and selections in contact material allow the device to be operated at resonance and reduce bending and variation, improving performance and reducing failure rate. Furthermore, processing with the Plasma-Therm Versaline deep reactive ion etch (DRIE) tool has resulted in 300 nm features within 5% of the drawn dimensions in CAD.

Introduction:

Sensor node reliability is limited by the longevity of the energy sources used to power them [1]. In order to maximize the sensor node operation time, power consumption by all components must be minimized. The power consumed by the sensors of the sensor node is especially critical because the sensors must operate all the time to generate a wakeup trigger for the digital and communication components. Previously, we demonstrated MEMS inertial, magnetic and acoustic sensors made of piezoelectric materials, which promise sensing without any power consumption [2]. These sensors, in conjunction with NEMS switches [3] showed successful classification of a portable electrical generator in different operation modes (on, off, eco) [4]. However, since these sensor nodes are wireless, detection of an RF wake-up signal is equally important and there must be an asleep-yet-aware detection method for RF signals. For this, we used the NEMS switch again with a reworked design and fabrication process in order to achieve the desired -100 dBm sensitivity.

Summary of Research:

A single photomask process is used to fabricate the NEMS switches on a silicon-on-insulator (SOI) substrate. Previously, alumina was used as a hard mask for a reactive ion etch (RIE) with subsequent alumina etch, metal deposition for conductivity, and release with wet hydrofluoric acid (HF) via critical point drying or vapor HF. This process resulted in over etched features, significant scalloping and large out of plane bending of released devices. By moving to a photoresist (PR)-only process with the Plasma-Therm VersaLine DRIE tool, the over-etching was minimized, scalloping reduced to < 20 nm, and out of plane bending minimized. Furthermore, additional design modifications were made to help push the sensitivity of the switch to -100 dBm. Folded springs and trusses help reduce bending and a compliant contact helps reduce contact lifetime and resistance. Additionally, smaller gaps were achievable with the new process, increasing the electrostatic force and helping sensitivity. Figure 1 shows a top down micrograph of a finished, unreleased device.

Figure 2 is a micrograph showing a 350 nm contact gap measurement. DRIE scallops can be seen on the left side of the image within the two release holes. The Figure 2 inset shows a Zygo white light interferometry image showing the out of plane bending of a released device. At the contact, there is a 30 nm out of plane displacement,

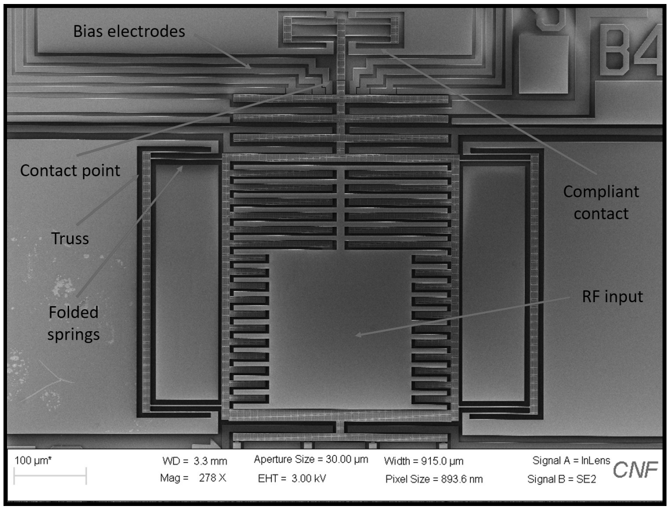

Figure 1: *SEM micrograph of NEMS switch from above showing important electrical contacts and features.*

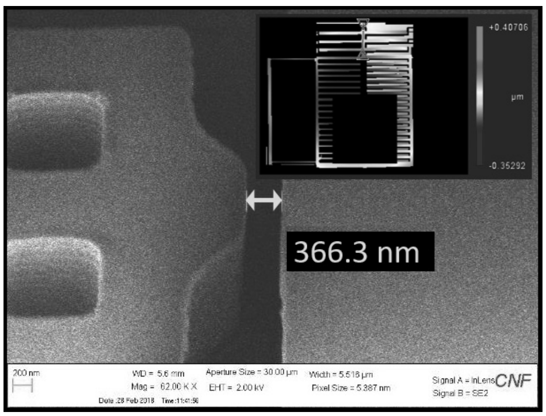

Figure 2: SEM micrograph with contact gap measurement. (Inset) Zygo optical profilometry measurement of out-of-plane bending of released device.

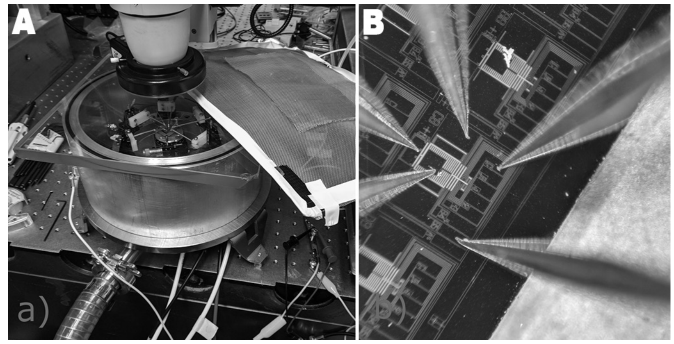

Figure 3: (a) Custom vacuum probe station. (b) Example image of device under test in probe station.

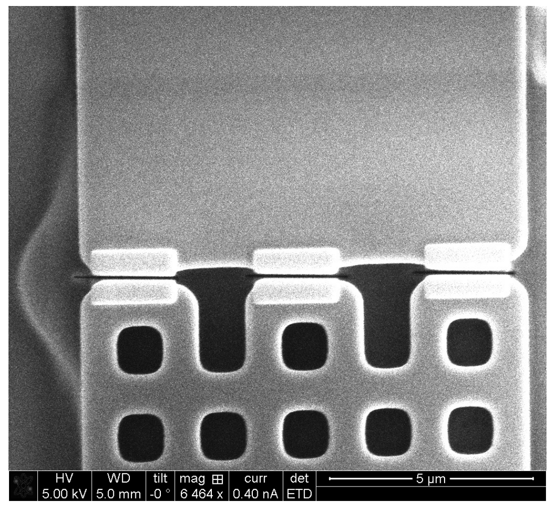

Figure 4: SEM micrograph after FIB Pt deposition and subsequent cutting with ion beam, resulting in near 100 nm gap.

which is small compared to the 2 μm device layer and 1 μm oxide layer.

Testing was done in a custom-built vacuum probe station (Figure 3a). An example image of a device under test can be seen in Figure 3b. Testing is currently underway for probability of detection (POF) and false alarm rate (FAR) using a high gain low noise Stanford Research Systems 570 TIA for detection, Keithley 2400s for biasing and a Rhode and Schwarz SMC100A RF signal generator.

Additional work still needs to be done to ensure reliable and repeatable contacting of the device. Efforts are underway to coat the contact interfaces with platinum (Pt) using a focused ion beam (FIB). Figure 4 shows an example device contact area (with three contact points) that has been completely covered with Pt and then re-cut with the ion beam to form approximately 100 nm contact gaps. There is also additional work being done to translate these devices to an out-of-plane design instead of in-plane. These devices are made via a flip-chip bonding process between a similar SOI chip and patterned lithium niobate ($LiNbO_3$ or LN) chip with graphene. These devices have the advantage of much larger electrostatic area (for better sensitivity) and RF filtering capabilities on the LN.

References:

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