Design and Fabrication of AlN RF MEMS Switch For Near-Zero Power RF Wake-Up Receivers

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Abstract—We describe an AlN-based resonant switch (resoswitch) for use in a Near-Zero (NZero) RF Wake-up receiver. A folded beam structure compensates for the curvature caused by the stress gradient in sputtered AlN and ensures that the free end of center actuation beam is level with the side anchor beams. A 80.13 kHz resoswitch with Q over 4000 and an actuation gap of approximately 600 nm turns on when a -4 dBm, 800MHz signal square wave modulated at 80.13 kHz is applied to the actuator. This AlN electrostatic resoswitch enables integration of a high gain RF piezoelectric transformer with a high-Q electrostatic resoswitch for an ultra-low power RF receiver.

Keywords—AlN, Resoswitch, MEMS, Zero Power Receiver

I. Introduction

AlN-based piezoelectric RF transformers have recently been demonstrated and enable potential applications in zero-power RF wake-up receivers [1, 2]. For example, a MEMS high-Q AlN transformer can increase the voltage of an AM RF tone of interest, producing an output voltage signal to trigger the next stage of actuators, such as the MEMS resonant switch shown in Figure 1, or signal processing circuits. Therefore, AlN-compatible passive components, such as inductors, capacitors and switches, are essential to realizing high-performance, inexpensive, integrated AlN RF systems.

Conventional comb-drive electrostatic actuators can produce motion at the frequencies of interest but the impedance is not compatible with the AlN transformer [2]. Simple cantilever or fixed-fixed beam switches are restricted to ultra-low stress gradient and low-stress materials respectively. Other nanoscale sensitive switches demonstrated have very small actuation areas, leading to a very low driving capacitance [3, 4]. Piezoelectric AlN is typically deposited by reactive sputtering and both the insulating nature of AlN as a structural material and the built-in stress gradient from the deposition process cause challenges in fabrication of AlN-based MEMS resonant switches (resoswitches).

We seek to address the challenge of developing microelectromechanical AlN resoswitches with high Q, large on current and large electrical coupling for integration with AlN transformers.

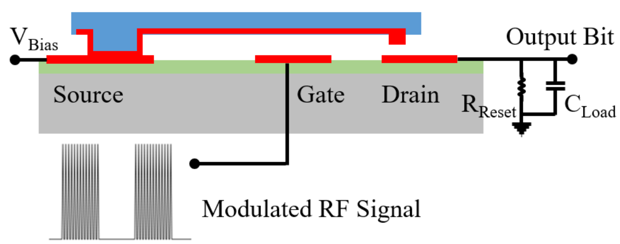

Figure 1 : Architecture of a near-zero power RF receiver

II. Sensor Design and Modeling

A novel folded micromechanical AlN-based resonant switch (resoswitch) has recently been demonstrated to detect modulated RF signals [5]. The structural design consists of three cantilevers in parallel and a slot from the back end of center beam. The anchors are located at the free ends of two side beams, while the other end is free to move. Figure 2a shows the simulated resonant mode shape and Eigenfrequency of a 168µm×30µm×2µm folded AlN resonant switch and figure 2b shows the SEM images of a fabricated resoswitch.

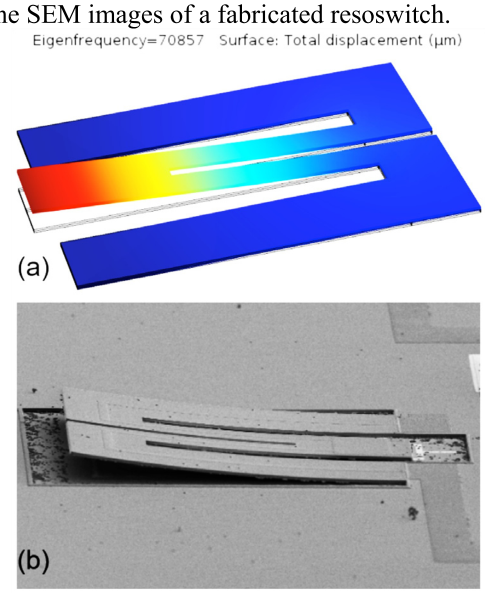

Figure 2: (a) simulation and (3D) SEM image of a 168µm×30µm×2µm folded AlN resonant switch

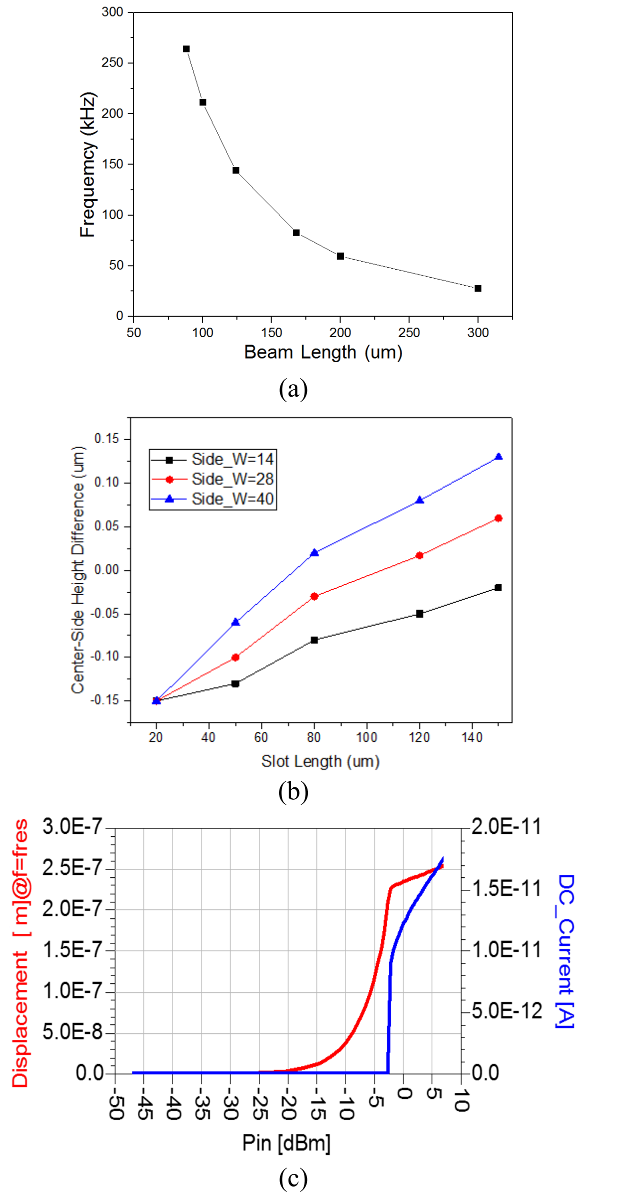

Figure 3 (a) *Simulated resonant frequency of folded beam and cantilever structures as a function of beam length, (b) Simulated center beam height to side beam height difference as a function of slot length; (c) Simulated resoswitch displacement as a function of modulated input RF power.*

Figure 3a plots the simulated resonant frequency of the folded beam structure as a function of beam length. A novel slot design has been implemented to tune the center beam contact end height with respect to the side beam height. Figure 3b indicates that the center to side beam height difference increases as the side beam width increases. Therefore either the side beam width or the slot length can be used to level the folded beam in the presence of stress gradients in the AlN. To predict the behavior of the switch, a numerical model was developed, with predicted results shown in Figure 3c. This model numerically solves nonlinear differential equations depicting the charge in the gate capacitor and the displacement of the beam during the resonant motion. As is evident, the simulation shows agreement with our experimental measurements.

III. Fabrication and Experimental Results

Previously reported resoswitches were fabricated on an LPCVD silicon nitride (SIN) insulating layer. However, the SIN film has a significant RF loss at frequencies above 300MHz and is not suitable for RF applications. Instead, approximately 500nm of AlN is deposited first as an insulating layer, providing good isolation and minimizing RF loss. As AlN material is not compatible with LOR and conventional TMAH/KOH based processing, we have developed an oxide/tungsten (ox/W) bilayer liftoff process to deposit Cr/Pt as the first contact and routing metal layer, as shown in figure 4. W is patterned with standard photolithography and SF6 based gases, followed by a timed BOE etch on oxide layer to form the desired undercut for liftoff. Approximately 600nm of amorphous silicon (a-Si) is used as sacrificial layer while 2µm AlN is deposited and patterned as resoswitch structural layer.

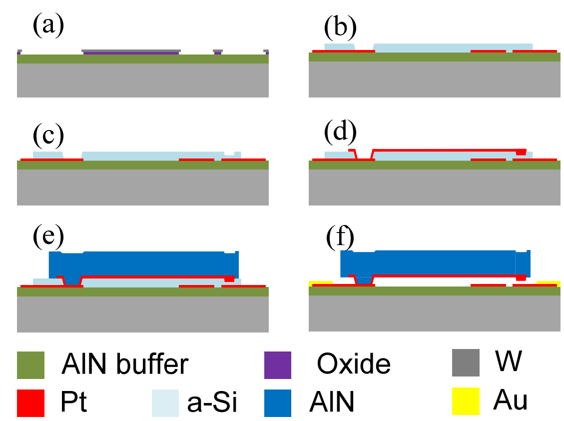

Figure 4 Fabrication process

Fabricated devices are loaded in a vacuum probe station for DC and RF testing. A Polytec vibrometer is used to measure the out of plane velocity of the center beam free end.

For RF characterization, modulated RF signals with a carrier frequency of 800 MHz and a modulation frequency at the resoswitch resonant frequency are generated to drive the resoswitches. Figure 5(a) shows the driving signal applied to the resoswitch. Figures 5b-e show the displacement as a function of input RF power and time. The maximum displacement is expected to increase with RF input power before contact. After contact occurs, the displacement saturates. This occurs at an RF power level of approximately -4 dBm. The vibrometer signals are captured in response to different RF powers in a short pulse burst mode to study the beam vibration dynamics. The beam velocity amplitude increases gradually at low RF power (no contact). As the beam amplitude becomes large enough to make contact, the velocity signal reaches a maximum value, which corresponds to the maximum displacement, i.e. the peak amplitude of vibration equal to the gap between the contacts on the beam and substrate.

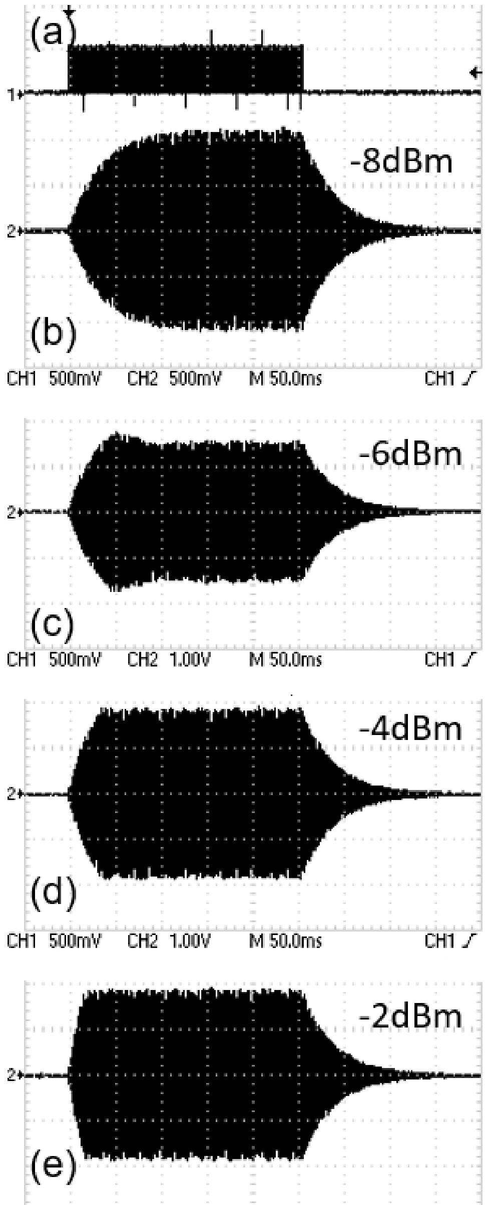

Figure 5 (a) Resoswitch input modulation signal; (b) through (e): Captured vibrometer velocity signal in response to different amplitude burst modulated signals at RF powers of (b) -8dbm, (c) -6dBm, (d) -4dBm, (e) -2dBm

At 0.1 V drain bias, the resonant frequency is found to be approximately 80.13 kHz and Q is over 4000 as shown in figure 6a. Figure 6b shows current flow from source to drain when the RF power is turned on and off. The RF input signal is an 800 MHz RF carrier signal square wave modulated at 80.13 kHz. When the modulated signal output power is set at -4 dBm, an average output current of more than 5 pico-ampere is measured at a bias of 0.1 V while the off state current is at the level of 3 pico-ampere. This low current level is attributed to the short contacting duty cycle at resonance as well as high contact resistance. The 3pA offset is due to limitations of the instrument. The current can be improved with a larger RF power voltage.

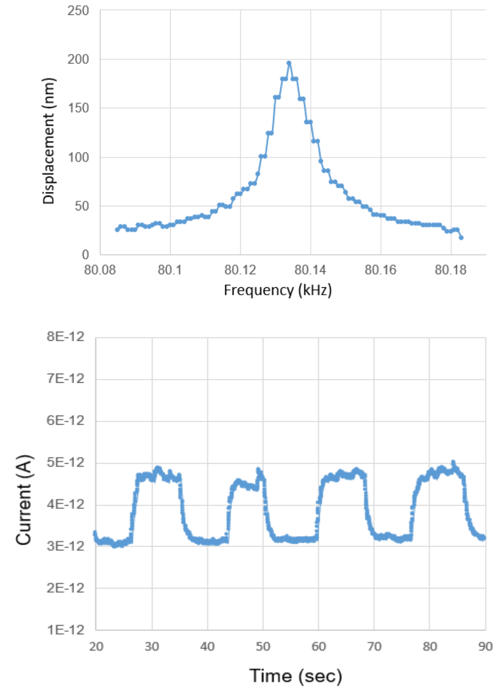

Figure 6 (a) Device resonant displacement as function of frequency; (b) resoswitch contact current at resonance when modulated RF is turned on and off at power level of -4 dBm.

IV. Conclusion

We have successfully demonstrated a micromechanical AlN resoswitch that can detect a -4 dBm 800 MHz carrier modulated at 80.13 kHz. As the actuation gap and the contact gap of the switch are scaled down, the RF sensitivity increases, making the system suitable for ultra-low power wake-up receiver applications.

V. ACKNOWLEDGEMENT

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