Noncontact Measurement of Charge Induced Voltage Shift in Capacitive MEM-Switches

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***Abstract*—The use of a modulated microwave signal to directly measure the voltage shift induced by charge in the dielectric layer of a capacitive microelectromechanical (MEM) switch is presented. This method does not require the metal bridge to contact the dielectric layer and is thus much less intrusive than previously reported measurements. The technique is a useful tool for understanding charge build up and dissipation in capacitive MEM switches.**

***Index Terms*—Capacitor, dielectric charging, MEMS, micromachining, microwave, millimeterwave, reliability, switches.**

I. Introduction

THE accumulation of charge in the dielectric layer of capacitive microelectromechanical (MEM) switches has been identified as a primary source of switch failure [1], [2]. It has been shown that a static charge in the dielectric causes the capacitance-voltage (C–V) curve of the switch to shift by an amount directly proportional to the magnitude and polarity of the charge [3], [4]. While measurements confirmed this shift [3], [4], it has proven difficult to monitor charge build up and release because the act of taking the measurement can skew the results. This is largely due to the fact that previous measurements have relied on contact between the suspended beam and the dielectric layer [3]–[5]. During the time the metal bridge is in contact with the dielectric, the dielectric is subject to high mechanical and electrical stresses. Indeed, the switch typically sees a field strength on the order of 10^8 V/m resulting in rapid charge injection. Reid and Webster have proposed that a significant amount of charging can occur in less than 10 ms [5]. In addition to charge injection during the measurement, contact measurements can also be skewed by environmental factors such as contaminants, humidity, and temperature. Contaminants and humidity change the adhesion force between the bridge and the dielectric thereby affecting the voltage at which the switch separates, or releases, from the dielectric. Temperature affects the stress in the metal beam, changing both the pull-in and release voltages of the switch.

By avoiding contact during the measurements, the new method described here measures the voltage shift caused by charge in the dielectric without introducing additional charge. Contact is avoided by driving the switch with a bias that always remains below the pull-in voltage. This low voltage results in only a small deflection of the bridge. The bridge deflection is dependent upon the applied bias and the charge in the dielectric. Although this deflection is small, it is sufficient to modulate a microwave signal. Therefore, by monitoring the modulated signal, the voltage shift can be directly observed.

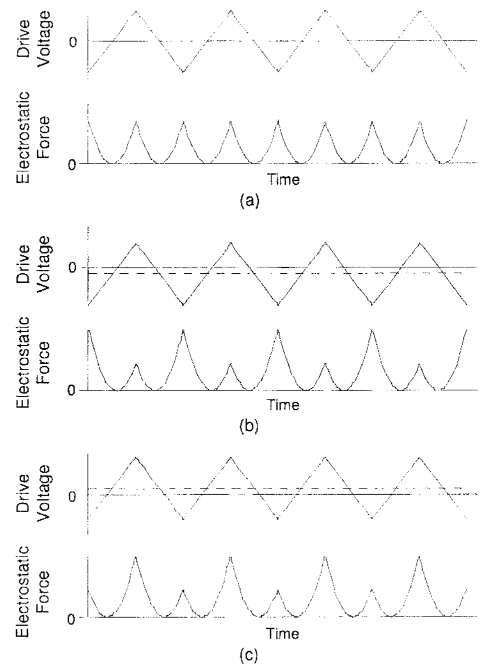

Fig. 1. Ramp waveform with no offset and the corresponding electrostatic force applied to the beam are shown in (a). When a negative (b) or positive (c) offset is added to the drive waveform, the shape of the resulting force waveform changes with alternating peaks having different magnitudes.

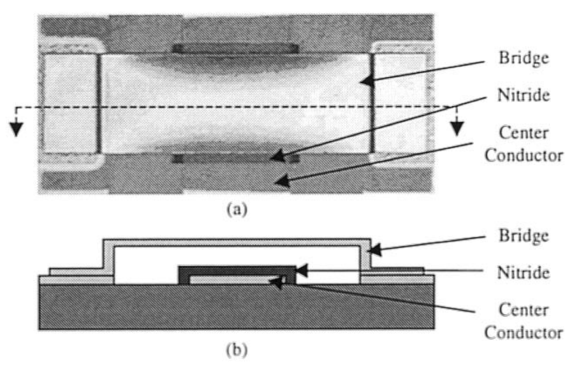

Fig. 2. Typical capacitive MEM switch consists of a bridge suspended over the centerline of a coplanar waveguide. The switch used for these measurements was 270 μm long, 60 μm wide, and suspended 3.0 μm above the dielectric layer.

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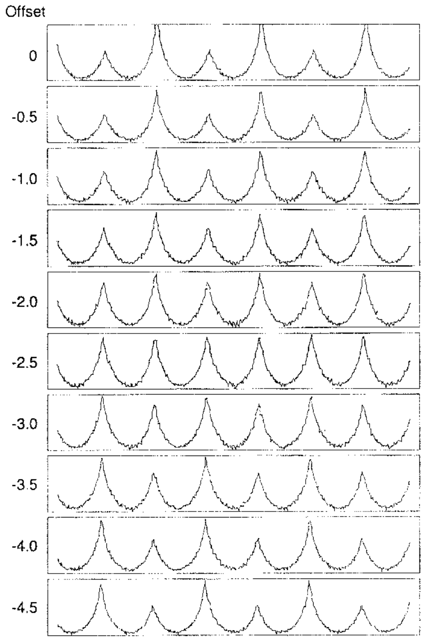

Fig. 3. Output from measuring a switch driven with a 17 Hz ramp function and 26 V amplitude. The asymmetry is clearly visible in the zero offset plot. When the offset is adjusted to -2.5 V, the asymmetry has reversed. The net charge induced shift is thus -2.4 V $+/-0.1$.

II. Theory

In a capacitive MEM switch, the bridge deflects due to an electrostatic force that can be calculated as

$$F_{ES} = \frac{\epsilon_0 A V^2}{2(g-d)^2} \quad (1)$$

where ϵ_0 is the permittivity of free space, A is the area of overlap between the bridge and the control electrode, V is the applied bias, g is the initial separation between the bridge and the dielectric, and d is the effective gap between the bridge and the control electrode. Using (1), the force resulting from an applied bias waveform can be calculated. Fig. 1(a), shows a ramp waveform with no offset and the shape of the resulting force waveform. This force waveform is symmetric with an equal magnitude peak occurring each time the magnitude of the drive signal reaches a maximum. When an offset is applied to the drive waveform, the shape of the deflection waveform changes as shown in Fig. 1(b) and (c) for negative and positive offsets respectively. The changed waveform is no longer symmetric.

Previous work has shown that charge in the dielectric layer results in a shift in the C–V curve of the switch [3], [4]. This shift occurs because the metal bridge sees an electric field that is the combined field of both the applied bias, and the charge trapped in the dielectric [4]. From the bridge's point of view, the additional field from the trapped charge appears as a voltage offset. If the charge is fixed, this offset results in a shift in the C–V curve along the voltage axis. Applying a ramp waveform with a low frequency (< 100 Hz), no offset, and an amplitude below the pull-in voltage results in a force function that will follow either that found in Fig. 1(b) or (c), depending upon the polarity of the charge in the dielectric. Adding an offset to the applied ramp waveform will either increase or decrease the asymmetry. The offset can be easily adjusted so that the force function becomes symmetric. At this point, the applied offset voltage is equal to the charge-induced shift.

III. Measurements

A continuous microwave signal of 10 mW is applied to the input of a -10 dB coupler. The direct output of the coupler (9 mW) is sent into the local oscillator (LO) port of a mixer while the 1 mW coupled output is sent into a bias-T and combined with a drive signal generated by a HP 3245a universal source. The drive signal is a 17 Hz ramp function with a 2.6 V amplitude that is amplified by an internal $10\times$ amplifier. The resulting 26 V amplitude is well below the 31 V pull-in voltage of the switch being measured. The combined microwave and drive signal is then sent through the MEM switch, a dc block, an isolator, and then into the mixer RF port. The IF output of the mixer is sent to an oscilloscope triggered by the original 2.6 V amplitude ramp function. After triggering, the oscilloscope averages 128 traces to reduce noise. The frequency of the microwave signal is adjusted to set the phase shift between the RF and LO paths to maximize the IF signal change between the up and down positions of the switch. The frequency is selected one time, at the start of the measurement sequence and then used for all testing. For the testing done here, the frequency was set to 15.383 GHz. This measurement can also be made using a diode detector instead of a microwave mixer.

An optical microphotograph and cross section of the switch are shown in Fig. 2. The switch consists of a metal beam suspended over the centerline of a coplanar waveguide. The tested switch was nominally 270 μm long, 60 μm wide, and suspended 3.0 μm above the signal line. Cascade microtech ground-signal-ground probes were used to take the measurements. Measurements were taken by applying the drive signal with no offset, and then decreasing the offset in steps of 0.5 V until a -4.5 V offset was applied. Fig. 3 shows the measured output for each offset. For the 0-V offset condition, the asymmetry in the detected signal is very clear. At an offset of -2.5 V, the asymmetry is barely visible. Based on this data, the switch is found to have a $2.4+/-0.1$ V charge-induced voltage shift. Making the simplifying assumption that the charge is a uniform sheet charge on the dielectric surface, this shift corresponds to a trapped sheet charge density of $1.87 \cdot 10^{-4}$ C/m^2, or an electron sheet density of $1.17 \cdot 10^{11}$ e$^-$/cm^2.

IV. Conclusions

A new technique for measuring the voltage offset caused by charge in the dielectric layer of capacitive MEM switches is presented. This technique does not require that the bridge come into contact with the dielectric. By avoiding contact between the bridge and the dielectric, this technique eliminates the major sources of measurement error found in previous techniques. The technique is capable of measuring the charge induced-voltage shift with better than 0.2 V resolution.

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