ANALYSIS OF CYCLE LIFETIMES AND FAILURE MODES FOR RF MEMS SWITCHES

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ABSTRACT
RF MEMS switch lifetimes are limited by stiction of the moving components and degradation of the metal to metal contact points during cycling. Currently, maximum switch lifetimes are around 10 to 25 billion cycles. Past experimentation has shown that some stiction problems can be overcome by carefully controlling the operating parameters, but problems at the contact points remain [1]. It is believed that by developing a set of tribological design rules which limit the factors leading to catastrophic failure, switches can operate in excess of 100 billion cycles.

Recent research has quantified the reliability and durability of gold contact points on RF MEMS switches as a function of current [2]. Most experimentation on RF MEMS switches has focused on controlling the operating parameters such as current, voltage, electrode materials, contact area, switching mode and force; however, limited work has been performed on a single device type in multiple environmentally controlled testing conditions such as vacuum, cryogenic temperatures, etc. This presentation will discuss performance of the wiSpry RF MEMS switch focusing on quantification of device reliability and failure mechanisms under various atmospheric and temperature conditions. Environmental testing conditions include switching in open air, vacuum and inert gasses, in temperatures ranging from 294 K to 4 K.

Keywords: RF MEMS, gold, contact surface, reliability, cryogenic, failure mode.

INTRODUCTION
MicroElectroMechanical Systems (MEMS) devices have the potential to dominate future developments in switching and relay technology due to their ability to operate over a large temperature range and higher off-state resistance than their solid-state counterparts. In particular, RF MEMS have the potential to enhance many applications through their capability to operate with low loss at wide bandwidth ranges and low manufacturing cost. They are currently used in military and commercial applications such as electronically steerable array antennas and tunable filters.

In order to maximize switch performance and lifetime the tribological issues limiting development and commercialization of moving MEMS devices must be understood.

Failure in MEMS switches can be classified in two types: stiction failures and resistive failures. Common forms of stiction failure are:
- Adhesion. Soft contacting materials flatten over time resulting in Van der Waals forces stronger than the spring force used to return the switch to the open state.
- Melting / nanowire formation.
- Welding

The most prevalent failure modes are a result of increasing resistance during cycling. Common causes are:
- Current. Switches are supplied a constant input voltage. Resistive changes due to current are governed by Ohms Law.
- Thermochemical Gradient. Contacts exposed to open air conditions will form a film layer which creates nonohmic contact behavior and increased resistance.
- Electromigration. Electrons conducted through contact points collide with lattice atoms out of place due to high temperatures.
- Contact Area. Real contact area changes over time due to deformation of asperities. The resistance is dominated by either the Sharvin Mechanism or diffuse scattering depending on the radius of contact [3].

The focus of this experiment is to evaluate RF MEMS switch performance in varying environmental conditions and cryogenic temperatures. The relative importance of each individual failure mode to the overall degradation of switch performance can be determined by controlling operational environment and temperature.

TESTING AND MEASUREMENTS
RF MEMS devices provided by wiSpry were used to investigate the performance of contact areas under variable environmental conditions with a focus on cryogenic temperatures. The switch can operate at both low and high frequency and has a demonstrated capability of 10 billion
cycles. The wiSpry MEMS relay uses metal-to-metal contact to transfer a signal via ohmic contact behavior with the electrodes. The switch is designed around a cantilever beam which contains both an actuation plate and contact dimples. The cantilever arm’s equilibrium position is in the switch open state. To actuate the switch, a voltage of approximately 20V is applied to the lower actuation electrode producing an electrostatic force which pulls the cantilever arm downward forcing the contact dimples into contact with the lower electrodes carrying the input signal. The contact dimples bridge a gap in the input/output signal, thus completing the circuit.

To maintain environmental control and low temperatures switches will be tested in a cryostat. The cryostat allows for known failure modes such as electromigration and thermochemical gradient to either be isolated or removed during the testing process. The setup can be pumped down to vacuum or operated in ambient open air conditions. In addition the device chamber can be filled with inert gases such as Argon or Nitrogen after being pumped down, thus allowing testing in non-ambient atmospheric conditions. The design also allows for testing across a broad range of temperatures down to 4 Kelvin.

The MEMS device is attached to a ceramic sidebraze package with gold leads which is mounted on a zero insertion force socket housed in a thin steel cylindrical chamber. 1mil gold wire is used to connect the MEMS switch to the leads on the ceramic package. Wires attached to the socket exit the canister via a feedthrough which allows the drive electronics to supply the actuation voltage and input signal to the switch without compromising the vacuum sealed environment.

Measurements are made using the Electrical Contact Resistance (ECR) method. The ECR is an in situ diagnostic tool for contact interface characterization [4]. Fluctuations in the ECR can be directly linked to ohmic and nonohmic behaviors, especially those associated with the rupture of thin film oxides on the gold contact surfaces. In addition the ECR can change depending on the statistical distribution of asperities and the means by which they deform creating a dynamic real contact area during cycling.

**RESULTS**

In ambient conditions the wiSpry switch shows a decrease in ECR during early cycling, a period of stable resistance and greater variability toward the end of the switch’s lifetime (Figure 1). The initial decrease in ECR can be attributed to the removal of the thin film creating ohmic contact between the gold electrodes and the creation of additional contact area due to flattening of asperities. The variability toward the end of switch lifetimes can be explained by adhesion between the gold contact surfaces.

Environmentally controlled testing and cryogenic temperatures will have variable affects on the ECR. Cryogenic temperatures should limit adhesion by lowering the impact of melting / softening and maintaining the surface roughness.

Adhesive properties will be driven mostly by the adhesion energy of gold at low temperatures. Thermochemical resistance properties will decrease when tested in the cryostat. Removing humidity via vacuum environments will limit stiction failures and the formation of oxide layers on the gold surfaces.

Cryogenic temperatures will intermediate to significantly impact resistance due to softening and electrochemical effects. The lower temperatures, especially near 4 Kelvin, will decrease lattice vibrations and electron scattering, resulting in lower internal resistivity of the gold contacts. In addition, applications of the Wiedemann-Franz Law shows that the input voltage needed to melt the gold contacts will double when lowered the temperature is lowered to 4 Kelvin from [5].

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**REFERENCES**