

APPLICATION NOTE

PUBLICATION

11/26_07

DATE

000306_APP

NUMBER

MULTIDIMENSIONAL CHARACTERIZATION OF A MEMS DEVICE

APPLICATION

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AUTHORS

INTRODUCTION

Electrical properties of micro-electro-mechanical systems (MEMS) have been tested for years, but the techniques for determining mechanical properties of these structures have been limited. This has resulted in knowledge deficits in the design process, leading to gaps in understanding the mechanical performance of the structures. A customer approached us with a need to mechanically characterize MEMS switches. Properties of interest were switch stiffness, corrosion/contamination of contacts, loads required to overcome corrosive/contaminant layers and failure mechanisms. All of these properties were characterized through high-cycle fatigue tests which terminated at contact failure. This application note describes the successful solution achieved using a NANO **Indenter**[®] system configured with the following options: Continuous Stiffness Measurement (**CSM**), **NiDAQ TestWorks**[®] Channel Manager, and **TestWorks**[®] Explorer.

THE MEMS SWITCH

The MEMS switch that was characterized in this test was a cantilevered switch with a length of 450 μm and a width of 40 μm. Each beam was manufactured with a 4 μm diameter contact on the end of the cantilever. The cantilever was suspended over a strike plate; both the plate and beam contacts were coated with gold. The contact plate was mounted to a piezo stack actuator to conduct high frequency cycling. To prevent capacitive charges from building up on the switch, a 480 Ω compliance resistor was placed in parallel with the supplied current source to allow voltage drain when the switch was out of contact with the strike plate. A schematic of the device is shown in **figure 1**.

INSTRUMENT CONFIGURATION

The MEMS switch of **figure 1** was characterized using a NANO **Indenter** system configured with the following options: Continuous Stiffness Measurement (**CSM**), **NiDAQ TestWorks Channel Manager**, and **TestWorks Explorer**. The **CSM** option allowed dynamic excitation and characterization of the switch. The **NiDAQ TestWorks Channel Manager** option allowed the integration

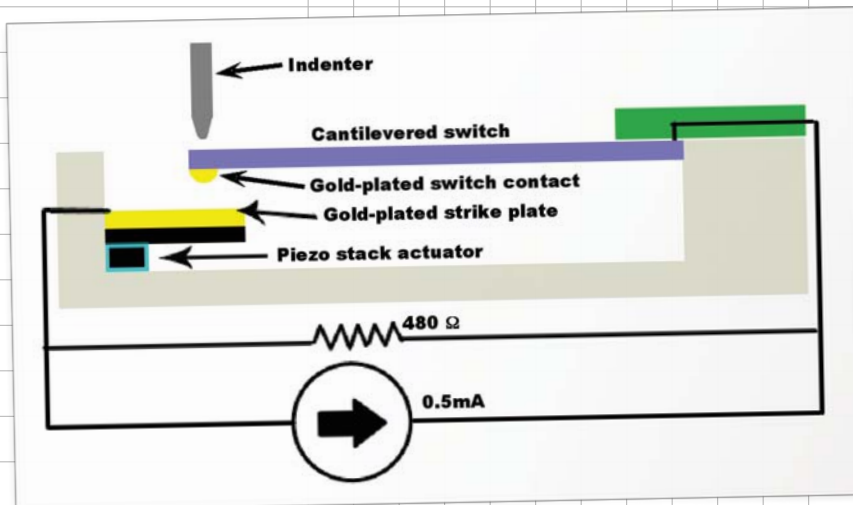


figure 1: Schematic of MEMS Switch

RELATED PRODUCTS:



and control of ohmmeters, voltmeters, current generators, high frequency generators, relay switches and piezo controllers in the **TestWorks** software. An

indispensable feature of the **NiDAQ TestWorks Channel Manager** option is the synchronization of the excitation and response data from external devices and sensors with the mechanical characterization data from the **NANO**

Indenter system, with the data acquisition and device stimulation controlled via the **Test-Works** software. Finally, **TestWorks Explorer** allowed the customization of the test protocol and data analysis.

TEST PROTOCOL

The contact fatigue test was conducted using the following test protocol:

- 1 Load the indenter until contact with the cantilever is detected.
- 2 Characterize the stiffness of the cantilever switch using the **CSM** technique.
- 3 Supply a user-defined current to the switch, default 0.5 mA.
- 4 Deflect the cantilever beam until mechanical contact is made with the strike plate.
- 5 Load the contact with 400 μ N of force while examining the electrical resistance response of the contact.
- 6 Hold the load constant for 5 seconds at 400 μ N.
- 7 Unload the contact while examining the electrical resistance response.
- 8 Move the indenter out of contact with the cantilever.
- 9 Activate a relay switch to conduct high frequency (100-4000Hz) contact fatigue cycling using the piezo stack actuator shown in **Figure 1** for a predetermined number of cycles.
- 10 Measure contact resistance to determine if failure has occurred.
- 11 If failure has not occurred, repeat steps 1-9 until failure by stiction or contact degradation is detected.

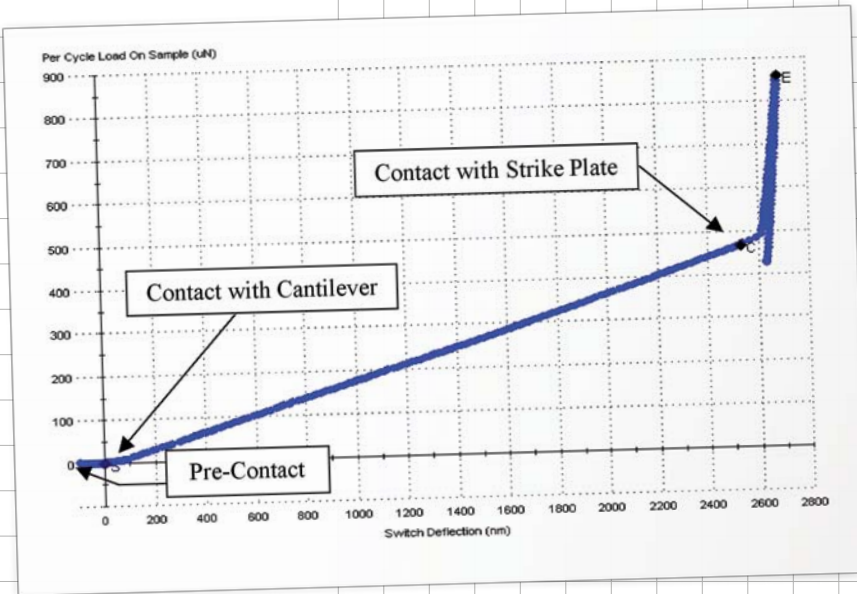


figure 2a:
Load on Sample versus Switch Deflection for one cycle

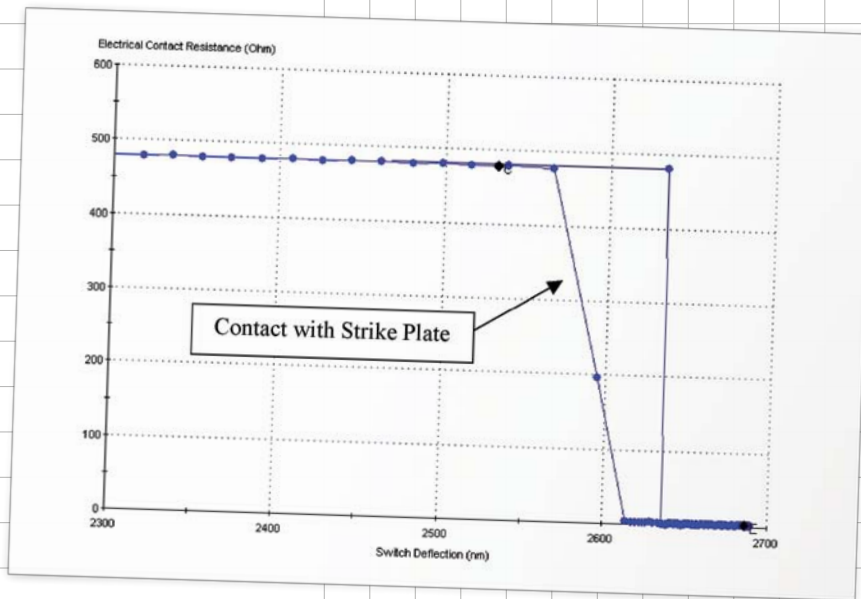


figure 2b:
Electrical Contact Resistance versus Switch Deflection for one cycle

RESULTS AND DISCUSSION

The results shown are directly from the TestWorks review page. **Figures 2a** and **2b** displays the synchronized load and electrical resistance versus displacement curves for

figure 3:
Electrical Contact Resistance versus Load on Contact for a new switch

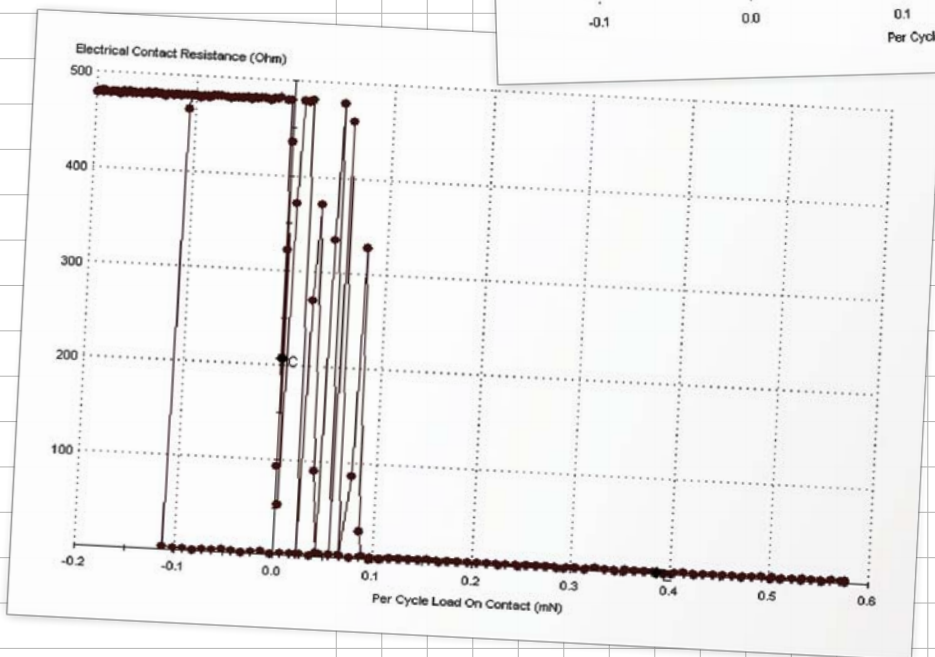
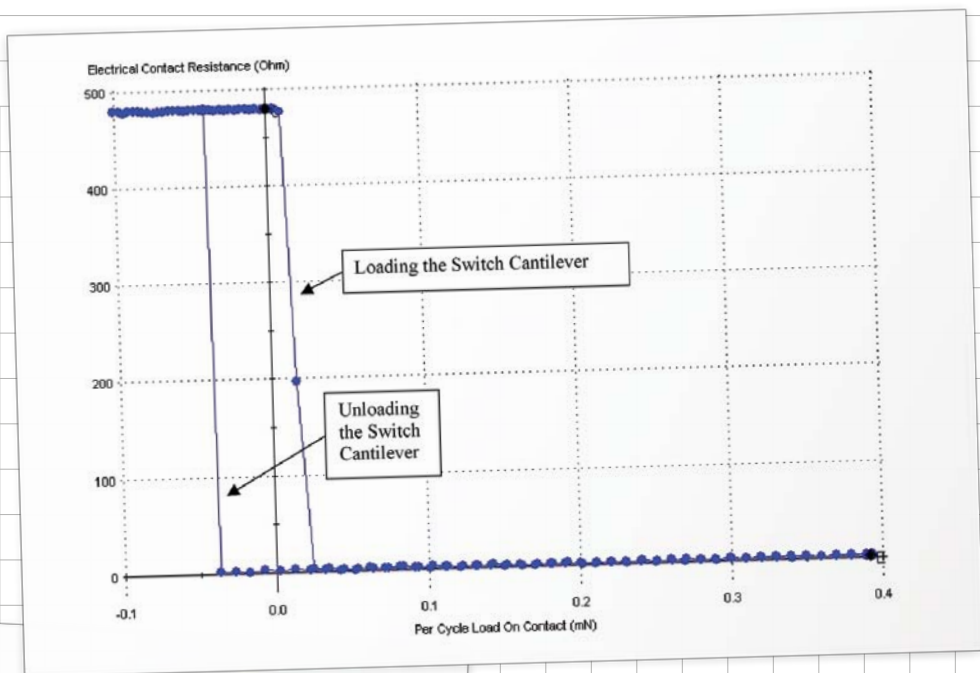


figure 4:
Electrical Contact Resistance versus Load on Contact just prior to failure

one cycle. The points of surface contact (S) with the cantilever, contact with the strike plate (C), and the end of loading (E) are labeled. Approximately 80 nm of displacement was required to achieve electrical contact after initial mechanical contact.

is the force applied to the switch after the switch cantilever made mechanical contact with the strike plate. Notice that a force of 24 μN was required to generate electrical contact (less than 3 Ω resistance). Interestingly, upon unload, a “pulling” force of 37 μN was required to separate the switch from the strike plate.

After 350,000 cycles the switch required 80 μN of force to generate electrical contact; this was over 3 times the force required to generate electrical contact at the start of testing. This switch went through 360,000 cycles before it failed

due to contact degradation; the final contact resistance at failure was 288.9 Ohms. There was evidence of arcing during the last mechanical deflection test which is displayed in Figure 4. Post-imaging analysis of the contact showed wear of the gold coating. Figure 5 shows the post analysis imaging of a contact which failed in a similar test to the results shown here.

Figure 3 displays the Electrical Contact Resistance versus the Load on Contact for the same test cycle shown in Figure 2a; Load on Contact

CONCLUSION

A NANO Indenter system, configured with the Continuous Stiffness Measurement (CSM), NIDAQ TestWorks Channel Manager, and TestWorks Explorer options was used to

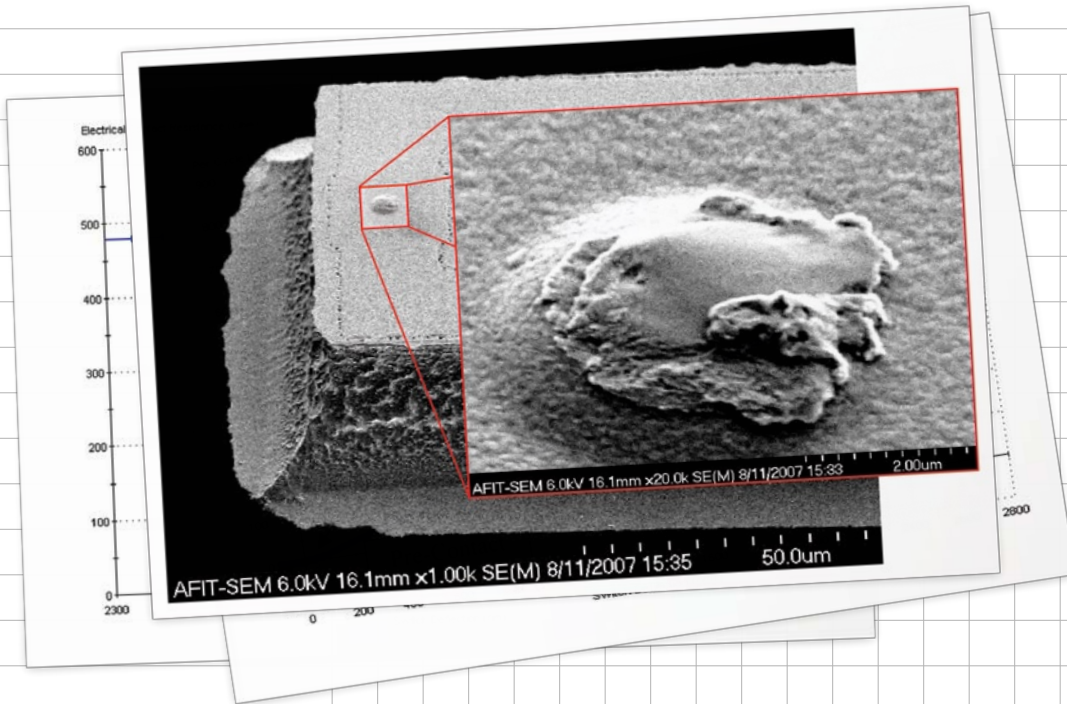


figure 5:
Post Imaging Analysis of MEMS
Cantilever Contact after Failure

characterize a MEMS switch in order to evaluate longevity and failure mechanism. The force required for electrical contact progressively increased with the number of switch cycles. When the switch was new, the force required for electrical contact was 24 μ N; immediately prior to failure, the required force was 80 μ N. The switch failed after 360,000 cycles due to degradation of the contacting surfaces. Just prior to failure, there was evidence of arcing

which was confirmed by post-mortem scanning-electron microscopy. No degradation in the structural integrity of the cantilever was detected.

The ability to incorporate external devices with the **NANO Indenter** system and control the devices using the **TestWorks** software allows multidimensional characterization. Without the **NIDAQ TestWorks Channel Manager**, the effects of contact corrosion/contamination, switch degradation, and stiction could not be observed and correlated with the mechanical excitation of the MEMS device. Understanding

the electrical and mechanical behavior of a MEMS device is vital to increasing reliability and reducing design-cycle time.

ACKNOWLEDGEMENTS

MTS Nano Instruments would like to thank Kevin Gilbert of the Air Force Institute of Technology for the samples and for his collaborative efforts in developing the test protocol.

OTHER DEVICES/SENSORS THAT CAN BE INCORPORATED USING THE NIDAQ TESTWORKS CHANNEL MANAGER:

Various MEMS Devices, Acoustic Sensors, Circuit Probes, Thermocouples, Strain Gauges, Integrated Circuit Probes, Piezo Devices



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Characterizing surfaces down to the level of a few nanometers has become increasingly important for a wide range of manufacturers and researchers. Properties at the nano scale can affect the performance of a variety of scientific and consumer products. **NANO Indenter** systems from **MTS NANO INSTRUMENTS** use the most advanced technology available to acquire fast, accurate mechanical data on a variety of surfaces at the submicron scale.