Powering MEMS Devices Using the S100 Nanomanipulator System

By Kimberly Tuck and Matt Ellis, Zyvex Corporation

Introduction

The ability to power MEMS devices inside a scanning electron microscope (SEM) is a featured application of the Zyvex S100 Nanomanipulator System. This functionality enables greater characterization of MEMS devices than existing alternative methods. While many researchers have examined the performance of MEMS devices in ambient conditions, very little has been done in vacuum. Because MEMS devices often operate in hermetically sealed packages, characterizing their properties in vacuum presents a more accurate representation of the device properties in the field.

Probe station characterizations in ambient environments are limited both by the resolution of the optics, as well as the relatively uncontrolled conditions which introduce unknown variables (such as dust and temperature fluctuations) into the tests. In contrast, a scanning electron microscope environment not only eliminates the particle variable, but also offers very high resolution photographic capability.

The S100 system is equipped with four quick-change positioners so that probes and other end effectors can be used for testing a large variety of devices. Complex MEMS structures require at least two probes, while most active electronic components such as transistors require at least three probes for *in situ* testing. The S100 system was designed for 4 point probing, a capability which extends the use of the system from device characterizations to materials evaluations.

This application note will discuss techniques used for actuating and evaluating MEMS devices using the S100 system.

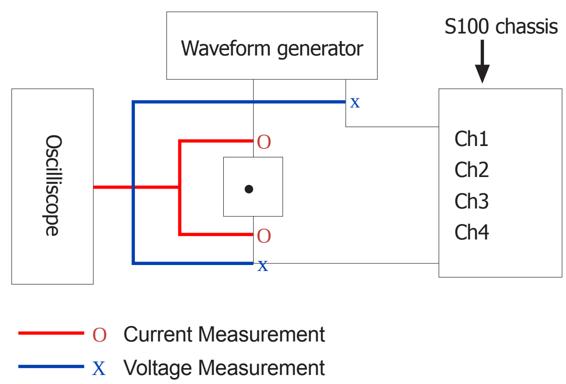

Figure 1 Power data collection set-up

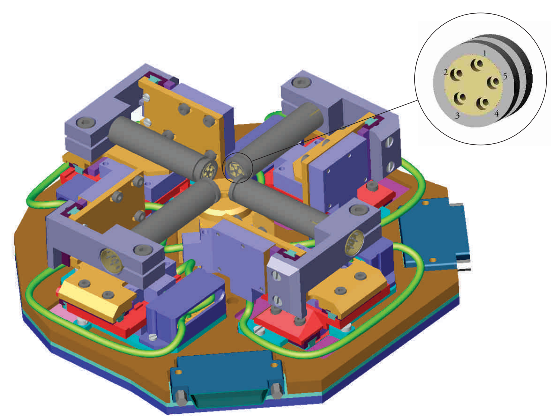

Figure 2 S100 electrical head

www.zyvex.com

Characterization using the S100

Characterization of Powered MEMS in the S100

This document will discuss the following:

1. Measuring Current and Voltage
2. Experimental Set-up
3. Powering Devices
4. Observing Backlash and Creep
5. Measuring Plastic Deformation
6. Measuring Device Lifetime
7. Dynamic Behavior of a Device
8. Powering an Electrostatic Actuator
9. Powering an Electrothermal Actuator

Various MEMS devices have been powered and tested in the S100. From the data obtained comparisons can be made between testing done in air verses in vacuum.

Measuring Voltage and Current

During the experiment the voltage and current were monitored using a 2-channel oscilloscope as shown in **Figure 1**. The current is measured across a resistor of known value. The voltage is measured on another channel of the oscilloscope. It is shown that quadrant "positioners" 4 and 1 are used in the experiment to drive the actuator. This will vary depending on which quadrant is in use to power the device.

Experimental Set-up for Powering MEMS using the S100

An electrothermal actuator can be powered in the SEM using the S100 system. The user must be careful to track which positioner is being powered, and which pin associated with that positioner is connected to the probe. **Figure 2** shows the electrical head. **Figure 3** shows a close view of the 5 electrical connections on the head where the probe can be placed.

It is good practice to make note of the probe positions for all quadrants before placing the S100 system in the SEM. But sometimes it is not obvious which quadrant will be best for powering the device until the S100 is in the SEM and the image is in view. In such cases, the powered probe can be identified by applying a square wave with a voltage greater than 1V. This will cause the contrast to change and the probe will change contrast with the signal.

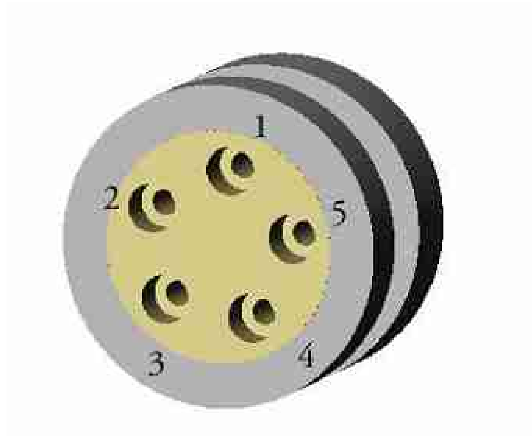

Figure 3 Head connector close-up view 5 pins

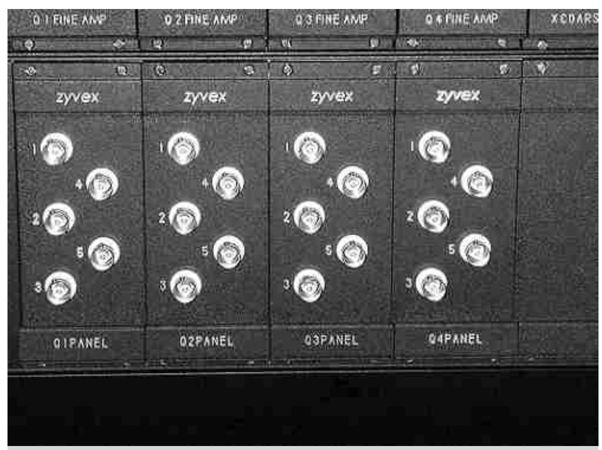

Figure 4 S100 patch panel interface

The Power Data Collection set-up shown in **Figure 1** is connected to the S100 patch panel. The S100 Patch panel interface is shown in **Figure 4**. There are separate panels for each positioner and each BNC connection corresponds to one of the 5 pin connections on the electrical head shown in **Figure 3**.

Powering a Device

The power on and off positions can be captured in the SEM, giving a double exposure effect which makes it useful for taking measurements. The SEM was put into an averaging mode to create this effect. Videos of the device were also taken. Various useful measurements can be taken using the SEM tools. **Figure 5** shows the electrothermal actuator designed with the *on* and *off* states superimposed in one image. This actuator was powered with a 15 V peak to peak square wave to minimize the time between the *on* and *off* states of the device. It was noticed that one state (on or off) was brighter than the other. By modifying the duty cycle of the input signal the contrast can be adjusted so that both states have the same brightness. The driving frequency was varied between 5Hz and 30Hz and adjusted manually until one could clearly see the *on* and *off* position of the actuator on the screen.

Observing Backlash/Creep

Backlash has been observed while the device is in the powered (forward moving) state. This is shown with the zoom view of the edge of the device **(Figure 5)**. The device overshoots slightly at first and the backlash is observed as the device moves backwards. Creep can be observed if the device moves slowly while being powered by a DC signal. The amount of creep can be measured using the measure tool in the SEM.

Measuring Plastic Deformation

The MUMPS bimorph shown in **Figure 6** has been purposely overdriven and the resulting plastic deformation is shown in **Figure 7**. The two pictures in **Figure 7** show the plastically deformed overdriven condition. The pictures on the right show the normal rest position of the bimorph. It is observed that the final rest position of the bimorph is now several microns backwards based on the vernier scale. The SEM measure tool can also be used to quantify the displacement. This is demonstrated by comparing the bottom two images in **Figure 7**. This plastic deformation of the bimorph does not reduce the total range of motion of the bimorph.

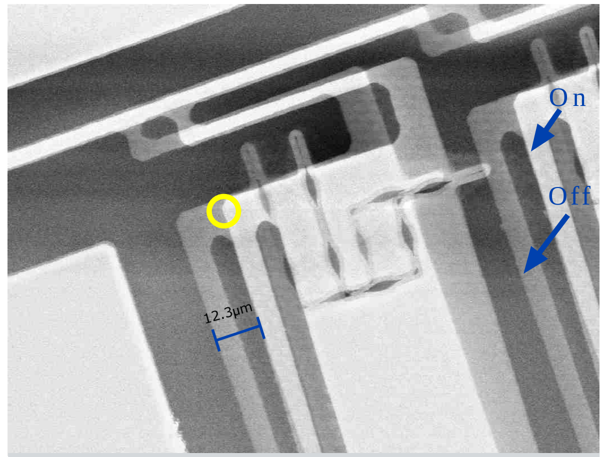

Figure 5 Electrothermal ganged bimorph actuator

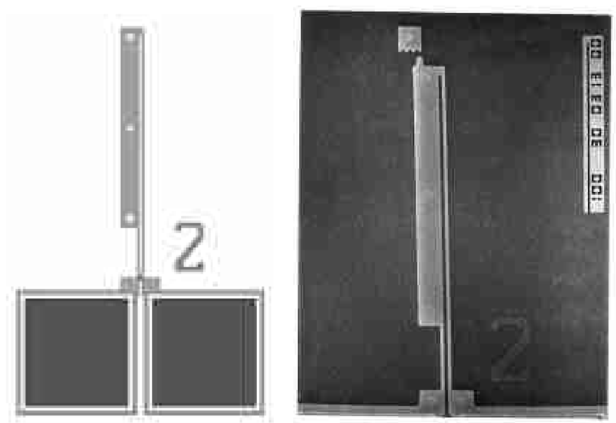

Figure 6 SEM image MUMPS bimorph

Square waves of sufficient amplitude drive the thermal bimorph about its equilibrium position. **Figure 8** shows a 2 micron bimorph driven by a 358 Hz square wave with a 2 Volt amplitude. The driving frequency was chosen so that the image could easily record the two extreme positions of the thermal bimorph's motion. The leftmost position of the thermal bimorph corresponds to the voltage off position. In **Figure 8**, the off position is different from the fabricated position, probably due to the higher thermal mass of the cold arm. When driving the bimorph with a square wave, both the hot arm and the cold arm reach a steady state temperature distribution if the length of the square wave pulse exceeds the thermal time constant of the actuator. When the voltage returns to zero, the hot arm cools down faster than the cold arm since it has less thermal mass. The cold arm also takes longer than the hot arm during the power off part of the square wave cycle. This produces motion about the power off equilibrium position.

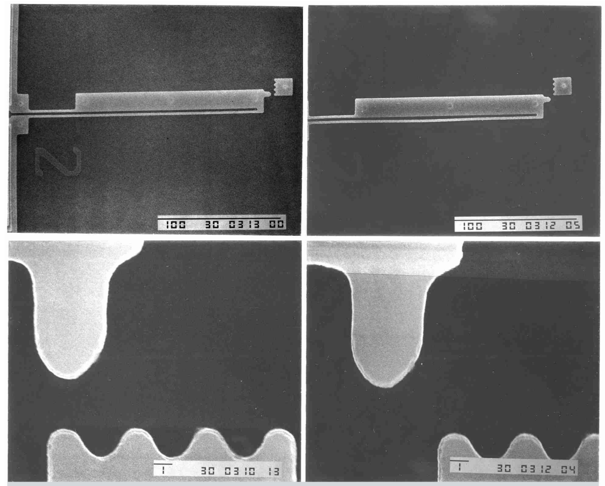

Figure 7 Before and after overdriving the actuator

Lifetime Measurements/Analysis

Extended testing of the thermal bimorphs showed that they could be operated for long periods of time under the appropriate conditions. **Figure 9** shows two images of a 2 micron thermal bimorph in the power off position. The image on the left was taken prior to operation. The image on the right was taken after the thermal bimorph had completed about 30 million cycles. The driving frequency during the test was approximately 357 Hz and the amplitude of the square wave was about 1.5 volts. No difference can be seen in the equilibrium position.

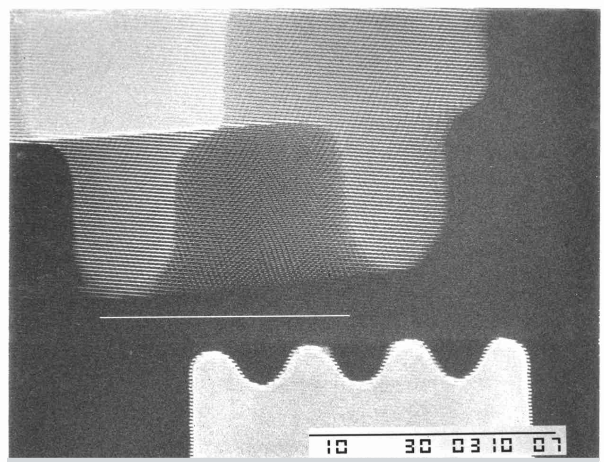

Figure 8 Thermal bimorph 358 Hz

Qualitative data regarding the performance of MUMPS thermal bimorphs has been obtained by testing several thermal bimorphs from three different dies. The current versus displacement is easily measured. This is done by measuring the voltage across the resistor as shown in **Figure 1**. The voltage is divided by the resistance value of the resistor used. The displacement is measured using the SEM measure tool. Current, voltage and resistance versus displacement can be taken with the set-up shown in **Figure 1**.

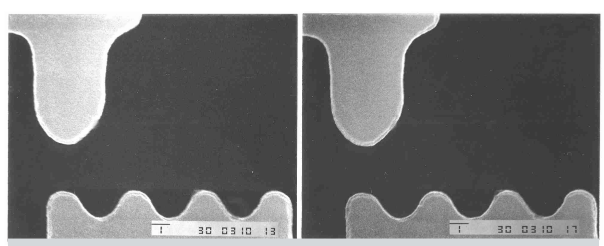

Figure 9 Before and after lifetime testing

Dynamic Behavior Measurements

Dynamic behavior was measured by sweeping the frequency of 1 volt peak to peak sine wave from zero to 120kHz. The dynamic behavior of thermal bimorph actuators operating in vacuum is of interest for determining the maximum operating frequency of the actuator. The thermal time constant of the device determines the maximum operating frequency independent of the resonant frequency. This time constant is a measure of the time required for the actuator to cool down after actuation. For ambient operation, heat transfer out of the device can be convective through the surrounding air, and conductive through the anchors connecting the actuator to the substrate. In vacuum the heat transfer only occurs via conduction and radiation; thus the thermal time constant in vacuum should be longer and the maximum operational frequency should be lower. This was confirmed from the data obtained.

Powering an Electrostatic Actuator in SEM

The electrostatic device tested is shown in **Figure 10**. This electrostatic device requires higher voltage than electrothermal devices (between 40V and 150V). Therefore some external amplifiers are required to boost the signal. The power was monitored in a similar fashion as shown above in **Figure 1**. Again the contrast of the image was modified (on an off states) by adjusting the duty cycle on the square wave signal from the signal generator.

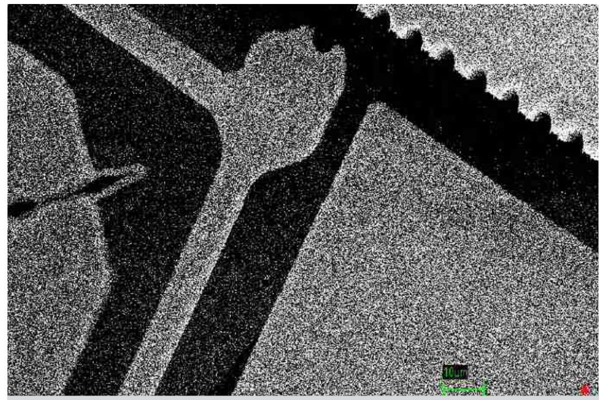

Figure 10 SEM image of an electrostatic actuator

Powering an Electrothermal Hula Actuator in SEM

The electrothermal "hula" actuator has been tested in the SEM because this device actually changes form after it has been powered. The pictures show distinct before and after orientation in **Figure 11** (before) and in **Figure 12** (after). The device plastically deforms and retains its shape after it has been powered. This device has been specifically designed utilizing the mismatch in thermal expansion coefficient of metal and polysilicon to bend the structure out of plane like an accordion. The "before and after" actuation pictures of the device can be taken at one time in the SEM due to the ability to power MEMS devices in the SEM using the S100.

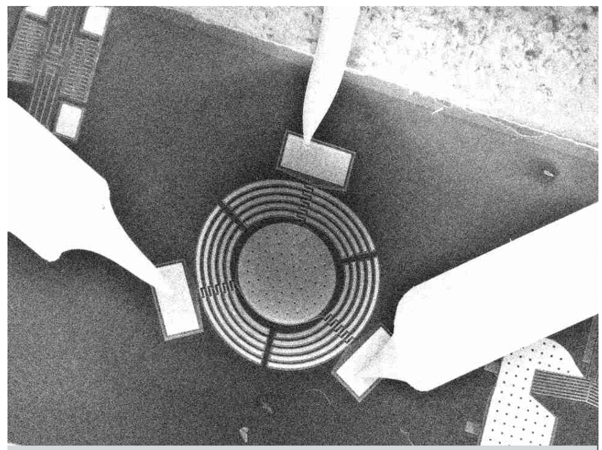

Figure 11 Hula Actuator before power is applied

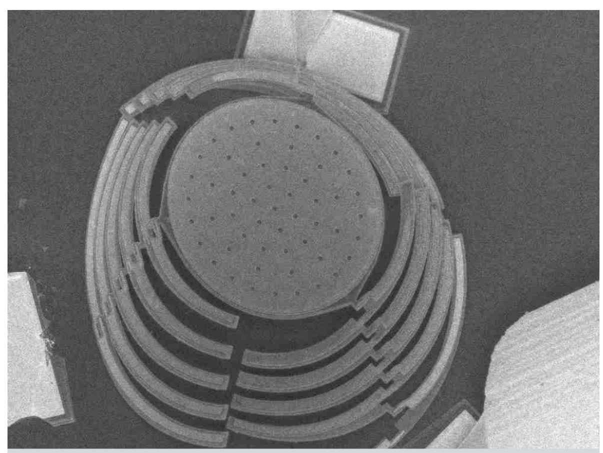

Figure 12 Hula actuator after power is applied

Conclusions

Various MEMS devices can be easily characterized and analyzed in the SEM using the S100. The method of testing is very similar to that possible with an optical microscope at a probe station, yet with the versatility and capability of an SEM.

 Document #S1PM-ZZAN-001e