# Fabrication of a Microelectromechanical Device for On-Chip Mechanical Testing of Nanoscale Thin Films in a Transmission Electron Microscope

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## Abstract:

**Typically, deformation and failure mechanisms in materials and interfaces are studied either quantitatively (measuring stress-strain behavior) or qualitatively (post-mortem or off-line imaging with a microscope). The transmission electron microscope (TEM) is unique in the sense that it visualizes specimen microstructures (dislocations, grain boundaries, precipitates, cracks) with very high resolution. Therefore, if experiments could be conducted *in situ* inside a TEM, we could avoid 'modeling' as the tool for bridging the mutual exclusiveness of the quantitative and qualitative streams of materials behavior research. Unfortunately, the TEM chamber is very small; it allows a volume of 3 mm diameter and 0.5 mm thickness in which the specimen and the force and displacement sensors must be accommodated.**

**The objective of this research is to shrink an entire tensile testing machine (on the order of meters) to 3 mm diameter size using nanofabrication techniques. Such drastic miniaturization involves photolithography, thin film deposition and bulk micromachining techniques on both sides of a silicon-on-insulator (SOI) wafer.**



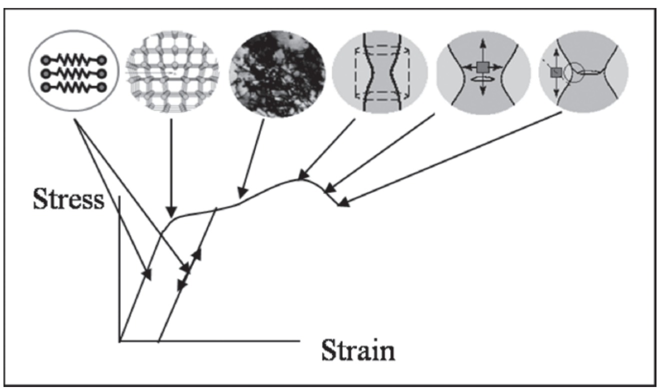


*Figure 1: How materials fail—qualitatively and quantitatively.*

## Introduction:

Figure 1 includes a typical graph of stress versus strain that shows quantitative material deformation. The linear portion of the curve is the elastic region, where material deformation is reversible and the material acts much like an elastic spring. The non-linear portion of the curve is the plastic region, where deformations are irreversible, and dislocations have occurred in the material. The pictures above the graph demonstrate qualitative analysis of material deformation. We would like to be able to match up this qualitative and quantitative data better than we have previously been able to using post-mortem techniques.

The devices that we design for this purpose have to be capable of straining a nanoscale thin film while in the TEM. The design utilizes a thermal actuator to place a tensile load on the specimen. The thermal actuator consists of pairs of micro-beams, as seen in the right hand side of Figure 2. To actuate, a voltage is applied across the ends of the inclined beams actuator. This causes the beams to heat and expand. The beams are inclined so that the net force on the specimen (once the beams expand) is to the right in Figure 2.

Another important feature of the device is that it has a hole etched through the backside. This is needed because the TEM passes electrons through a specimen in order to acquire an

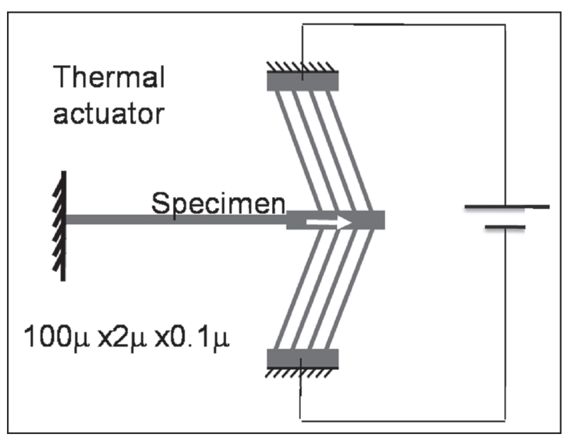


*Figure 2: Diagram of thermal actuator.*

image. The thick silicon layer is "opaque" to electrons, so it is important to have a nanoscale thin film that is free-standing above the backside hole.

## Experimental Procedure:

The procedure for fabricating the devices consists of multiple lithography and etching steps. The devices were made on a silicon-on-insulator (SOI) wafer. The wafer consists of a 35 $\mu$m silicon device layer, a 1-2 $\mu$m silicon dioxide layer, and a 350 $\mu$m silicon handle layer. Before lithography processes begin, a metal layer on the order of nanometers was deposited on top of the device layer.

First, a 100 nm metal layer was evaporated onto the front side of the wafer. Next, the front side of the device was patterned using the Karl Suss MA 6/BA 6 lithography tool. The metal was then etched, and the silicon device layer was etched using deep reactive ion etching (DRIE). After these steps, the device was essentially complete except for the backside hole that is required for imaging in the TEM.

To etch the backside hole, a circular-shaped hole was patterned on to a thick photoresist (SPR 220-7) using the backside alignment technique in the Karl Suss MA 6/BA 6. DRIE was used again for anisotropic backside etching. The oxide was then etched anisotropically using the Plasma Therm. DRIE was again used to etch the device layer just underneath the specimen so that it would be freestanding. Finally, HF vapor was used to release the beams for mobility.

## Results and Conclusions:

We were able to etch the frontside of several devices, but had more difficulty fabricating the backside hole. We were able to produce SEM compatible devices to nearly one hundred percent yield, but the backside hole required for TEM compatibility was more difficult to fabricate. The backside etching was a problem because the wafer broke easily during backside DRIE. The residual stress of the SOI wafer was a big factor contributing towards the breakage.

We were able to etch through the handle layer using a xenon difluoride ($XeF_2$) isotropic etch of silicon, and we completed the first backside etching of the device. Figure 4 shows the backside of a device that was successfully etched and we can see through the optically transparent silicon dioxide layer to the beams on the front side that attach the device to the SOI wafer.

## Future Work:

We plan to continue developing a better method to etch the backside hole of the device. We will continue to etch isotropically with xenon difluoride, and may try a different mask with a smaller backside hole so that an isotropic etch is anticipated. Once the devices are successfully made, we will then do simultaneous quantitative and qualitative testing in the TEM.


## Acknowledgements:

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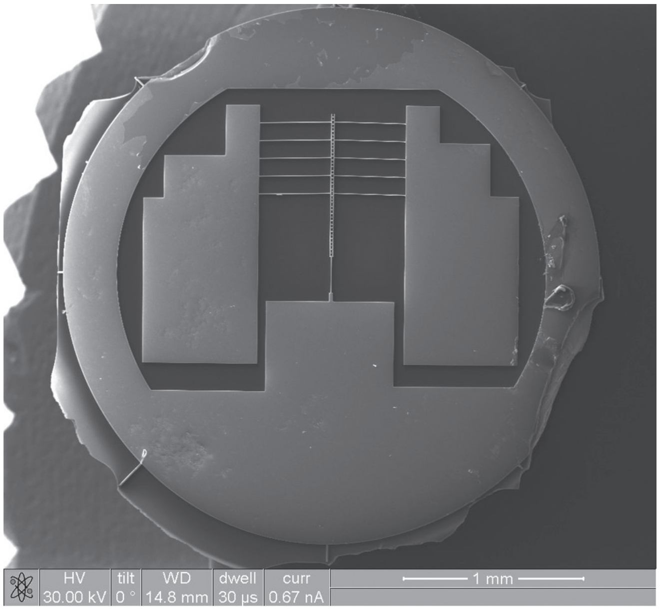


*Figure 3: SEM image of a device.*

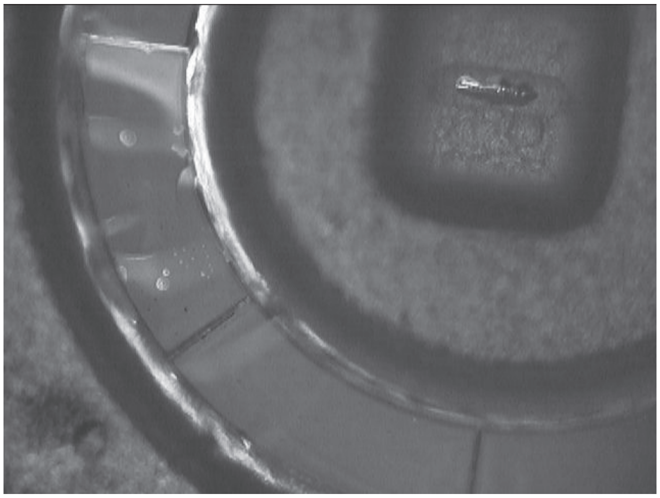

*Figure 4: Backside image of a device with isotropically etched handle layer.*