An Active MEMS Device for Microtensile Testing of Thin Films

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Abstract:

The goal of this program was to fabricate an active micromachined structure for mechanical testing of nano-scale thin films. The intended benefits of the active version of the microelectromechanical systems (MEMS) device included: integrated load measurement with a piezoresistive, very sensitive stress measurement at high strain rates, table-top testing compatibility, in situ electron microscope testing compatibility, intrinsic specimen alignment, and protection of the specimen during handling. During the project period we succeeded in fabricating and testing a prototype active test die. This device functions but displays several serious shortcomings that we hope to address in a future project.

Summary of Research:

Few techniques exist to easily study strain rate effects, fatigue failure, and wear behavior of freestanding thin metal films. Phenomena like these are poorly understood because of the difficulty associated with performing reliable mechanical measurements at small length scales. The device fabricated at the CNF was intended to address the need for convenient testing of a wide variety of materials at high strain rates. Other microtensile techniques are either too slow to study the phenomena of interest to us, are difficult to carry out, or are very limited in the types of materials from which they can be made [1-6]. An active MEMS device with built-in electrical load measurement capability is therefore highly desirable, as long as the process flow for sample fabrication is compatible with a wide variety of test materials and is suitable for exchange between laboratories.

The following activities were a part of this effort:

A mask set was designed for fabrication of piezoresistive active elements based on SOI wafers. This approach makes it relatively easy to fabricate. Once the process is fully developed, the repeatability of the device should, in principle, be excellent as the doping and thickness of the Si device layer used to make the piezoresistors should be very consistent across a given wafer, and reasonably uniform among batches of wafers. Also, the compatibility with elevated temperature testing should be good as there are no concerns about diffusion of implanted species.

A photolithography mask set was created with several different passive die design alternatives for evaluation of the processing and mechanical features. The parameters of the relevant deep silicon etch, e-beam metal deposition and photo processing capabilities available at the CNF were characterized, and process conditions were developed that allowed fabrication of a working test die.

Prototype “silicon only” passive testing chips (i.e., the test beam is made of Si rather than metal) were fabricated at the CNF. Several wafers were produced, some with working passive devices and some with prototype active devices.

The prototype device design was used to create an unconventional process flow that would allow deposition of a metal test beam at the end of the fabrication sequence rather than at the beginning (the current state of the art). This is a promising new approach that may avoid fabrication artifacts that could limit test material selection and influence behavior.

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The feasibility of fabricating a working MEMS test die based on piezoresistivity has been demonstrated. The ability to mount, electrically probe, and mechanically strain the device has also been demonstrated.

page 210
Customized electrical test probes were fabricated and used to evaluate the electrical performance of the built-in piezoresistive load cell structures. I-V curves were measured, as well as long-term output voltage stability. A balanced piezoresistive Wheatstone bridge was achieved via the use of an external resistor.

The SOI-based piezoresistors have a number of undesirable electrical characteristics that have so far prevented use of the device for useful mechanical testing. Instead, the device is being used to characterize the piezoresistor performance as feedback to a future iteration of the device design.

References:


Figure 1: The layout of the active test die, using SOI wafers. The piezoresistive load-sensing element is a pair of freestanding device-layer Si cantilevers. Three additional elements form a Wheatstone bridge to enhance performance. The other elements are based on those designed by Haque and Saif, and are purely mechanical in nature.

Figure 2: SEM of the active region of the test die, rotated 180° compared to Figure 1. The test specimen is the thin horizontal member suspended between two large blocks and surrounded by a temporary support frame. The piezoresistive load-sensing elements extend from the block on the right side of the test specimen. Two of the three additional resistive elements that make up the Wheatstone bridge are visible to the right. The bright areas are the gold contacts bridging the resistive elements.

Figure 3: A photograph of the MEMS device mounted for mechanical testing in a table-top test apparatus. A small chamber surrounds the device for control of the local atmosphere. The first inset shows a magnified image of the four custom-built electrical probes making contact to the pads on the top end of the MEMS device. The second inset is a higher magnification image of the probe tips themselves.