Mechanical Testing of Tiny Devices

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Very few analytical instruments are available for measuring the mechanical properties of micron-sized systems. Furthermore, MEMS devices and new materials have demonstrated the need for two types of mechanical testers.

The first is most suitable for engineering materials such as ceramics, composites, metals, and polymers. A sample with length dimensions in tens of millimeters is clamped into a palm sized tester, where it is pulled, pushed, or bent. This type of tester is capable of generating up to 5 kN of force and 50 mm displacement. It also records force-deflection data to determine the mechanical properties of the material while a microscope records the changes in microstructure.

The second type of instrument records the force-deflection characteristics of tiny MEMS structures (Fig. 1) or measures the mechanical properties of very small specimens. This instrument is equipped with a needle-type probe and is capable of indenting, scratching, pushing, pulling, and bending in very specific locations. It also has the sensitivity to measure forces no greater than 10 mN and displacements less than a millimeter requiring nanometer resolution. In this type of application, a microscope is used to verify positioning of the needle probe.

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This article describes the operation of these instruments and shows how they may be applied to test specific materials.

Palm- sized tester

Nanocomposites are typically polymer-based materials in which the microstructure and mechanical behavior are tailored via the incorporation of additives or nanometer-sized particles. They have significantly enhanced mechanical performance, as well as other properties such as elec-

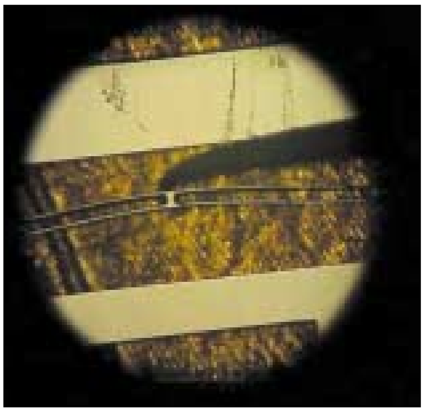

Fig. 1— Center portion of a double beam bistable microstructure as seen through a microscope. The double beam arrangement has two stable positions. If an actuation force is applied at the apex of this structure, the double beam will "snap through" to the opposite side and stay there without application of force. From Jin Qiu et al, "A Centrally-Clamped Parallel-Beam Bistable MEMS Mechanism," Proc. of the IEEE MEMS-01 Conference 353-357, January, 2001, Interlaken, Switzerland.

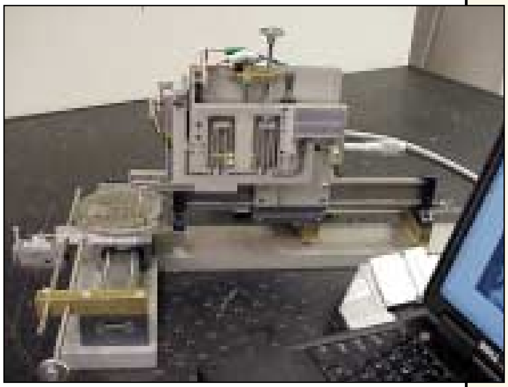

Fig. 6 — Picture of the Flextester developed by the Precision Engineering Group at the Massachusetts Institute of Technology to measure the stiffness of MEMS mechanisms. The Flextester features three axes of movement with 10 nm and 100 mN resolution for displacement and force, respectively. The author is currently working with several members of the Precision Engineering Group to commercialize the Flextester. J. Qiu, J. Sihler, J. Li, V. Sturgeon, M. Smith, A. Slocum: "An Instrument to Measure the Stiffness of MEMS Mechanisms", Proc. 10th International Conference on Precision Engineering, Yokohama, Japan, July 2001.

Evaluating MEMS structures

Figure 5 depicts a mechanically bistable mechanism that was developed by Jin Qiu, Jeffrey H. Lang and Alexander H. Slocum at the Massachusetts Institute of Technology. The mechanism has two stable positions and consists of two adjacent beams that are clamped at both ends and rigidly connected at the center. If an actuation force is applied at the apex of this structure, the double beam will "snap through" to the opposite side and stay there without application of force. The mechanism may serve as a relay, valve, switch, or memory cell in a MEMS device. The chief advantage of such a mechanism is that zero force is required to maintain contact during their "on" or "off" states.

Figure 1 shows the bistable mechanism as seen through a microscope. Each beam is approximately 3 mm long and on the order of 10 microns thick. An instrument (Fig. 6) developed by the Precision Engineering Research Group at MIT was designed to record the force-displacement curve for the bistable beam. The instrument, called the Flextester, is capable of 10 nm and 100 mN resolution for displacement and force, respectively. Figure 7 compares the theoretical force-displacement curve of the bistable mechanism with the actual curve as recorded by the Flextester.

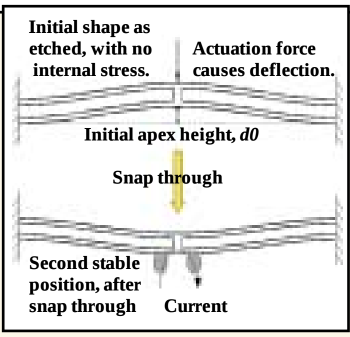

Fig. 5 — Diagram of a mechanically bistable MEMS mechanism. (From Jin Qiu et al, "A Centrally-Clamped Parallel-Beam Bistable MEMS Mechanism," Proc. of the IEEE MEMS-01 Conference 353-357 2001 January, Interlaken, Switzerland.)

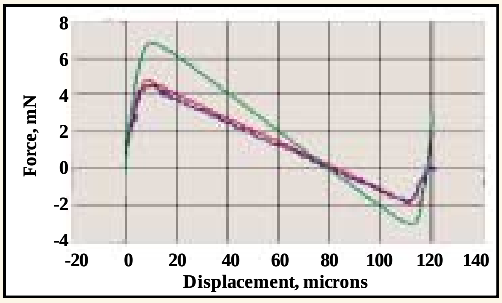

Fig. 7 — Theoretical and measured force-displacement curve for the mechanically bistable MEMS mechanism. Green line: Theoretical data for a 6.7 micron thick double beam. Red line: Theoretical data for a 6.0 micron thick double beam. Blue line: force-displacement data taken with the Flextester.

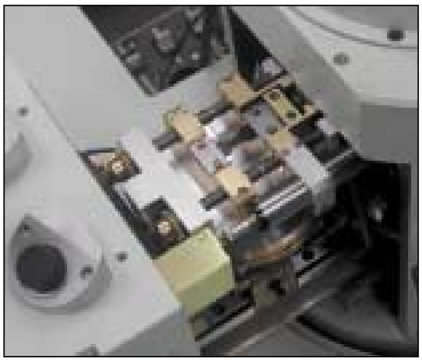

Fig. 2 — A 5 kN-capacity palm-sized tensile stage mounted inside a Scanning Electron Microscope (SEM). Picture shows a dog bone-shaped polymer specimen clamped in the stage. Tensile stage manufactured by Ernest F. Fullam Inc., Latham, New York.

trical conductivity, thermal conductivity, and resistance to permeability and abrasion. The additives and blending act to produce multi-phase structures in which the length scales of the different phases may range from nanometers to tens of hundreds of microns. The microscopic geometry and properties of the constituent phases govern the resulting macroscopic behavior.

The connections between microstructure and mechanical behavior

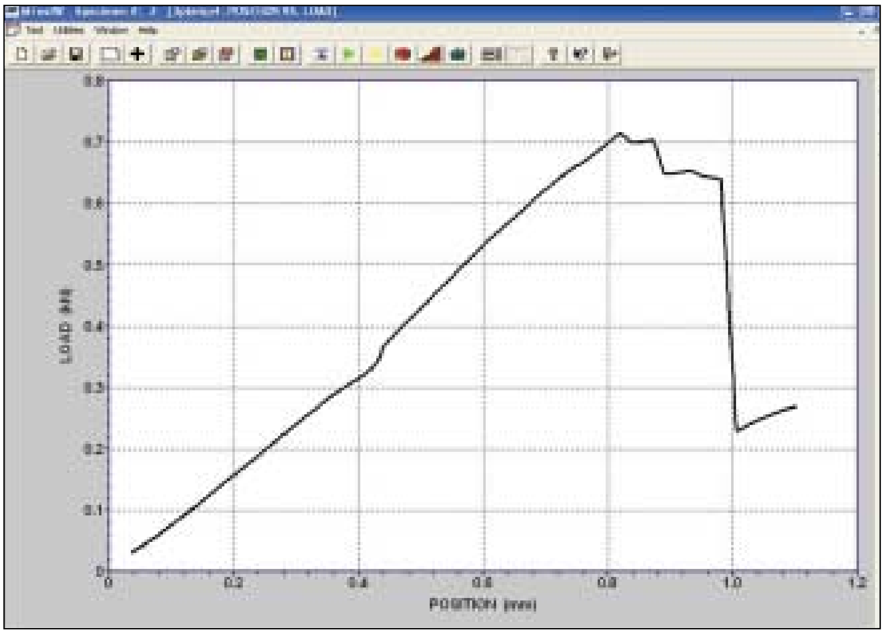

Fig. 3— Force-deflection curve from a three point bend test recorded by Admet's MTESTWindows on an Ernest F. Fullam Inc. flexural stage. Beam specimen was graphite epoxy of size 32.5 mm long x 6.46 mm wide x 2.04 mm deep.

must be understood to design and tailor nanocomposites

To help make that connection, palm-sized tension, compression, and flexural testers have been designed to fit inside the vacuum chamber of a scanning electron microscope (Fig. 2). The testers exert forces as small as a few grams or as much as 5 kN. They are suitable for testing tiny specimens of virtually anything, from a human hair or a single carbon fiber to recording tape, and miniature products made of metals, ceramics, wood, or polymers.

Fracture testing of silicon micro cantilevers

The Flextester was also used to measure the fracture strength of microfabricated cantilevers. Figure 8 is a micro cantilever as seen from a scanning electron microscope (SEM). Each cantilever has a length of 3 mm, a thickness of 150 microns, and a height of 480 microns (where 480 microns is equivalent to the wafer thickness). A bank of cantilevers was etched into silicon to generate a statistical measure of fracture strength. The end of each beam features a small lip that ensures the Flextester needle probe contacts each beam at its end. A microscope was used to verify the contact point.

Figure 9 is a close-up of the Flextester needle probe in contact with a micro cantilever. The cantilevers were manufactured in linear arrays so the coarse positioning axes of the Flextester could quickly move to the next cantilever for efficient testing of multiple samples. The figure shows a silicon wafer that contains a number of double beam structures clamped on the wafer holder of the Flextester.

Figure 10 is a force-displacement curve of two different sized micro-cantilevers loaded to fracture as recorded by the Flextester. Together with beam bending theory, the fracture stress and fracture strain were calculated.

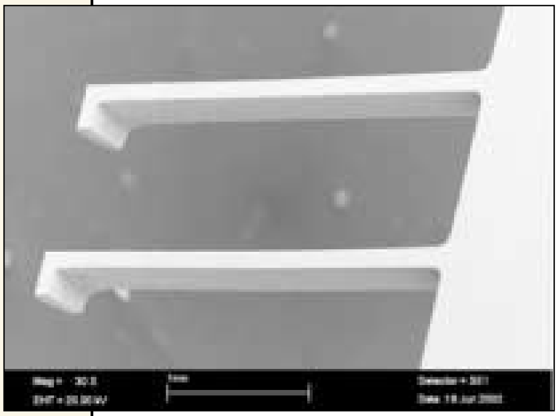

Fig. 8 — Two micron-sized cantilever beam specimens as seen from a scanning electron microscope.

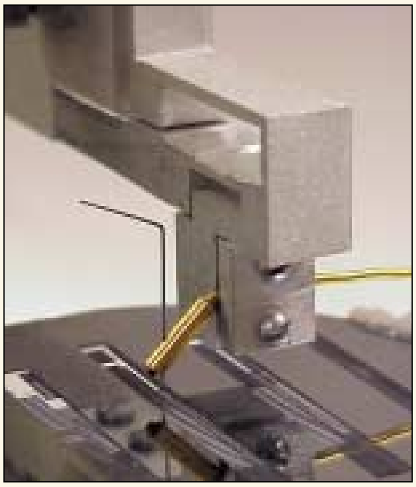

Fig. 9 — Picture of the Flextester needle probe. A bank of microcantilevers is clamped to the stage of the Flextester. Black line: 3 mm long cantilever beam. Blue line: 2 mm long cantilever beam

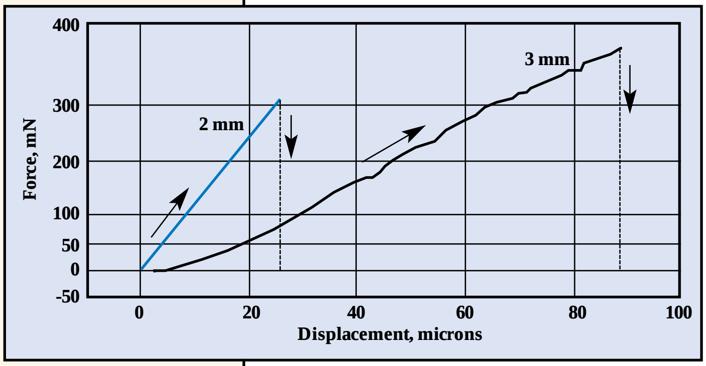

Fig. 10 — Force-displacement curve of two microcantilevers loaded to fracture, as recorded by the Flextester.

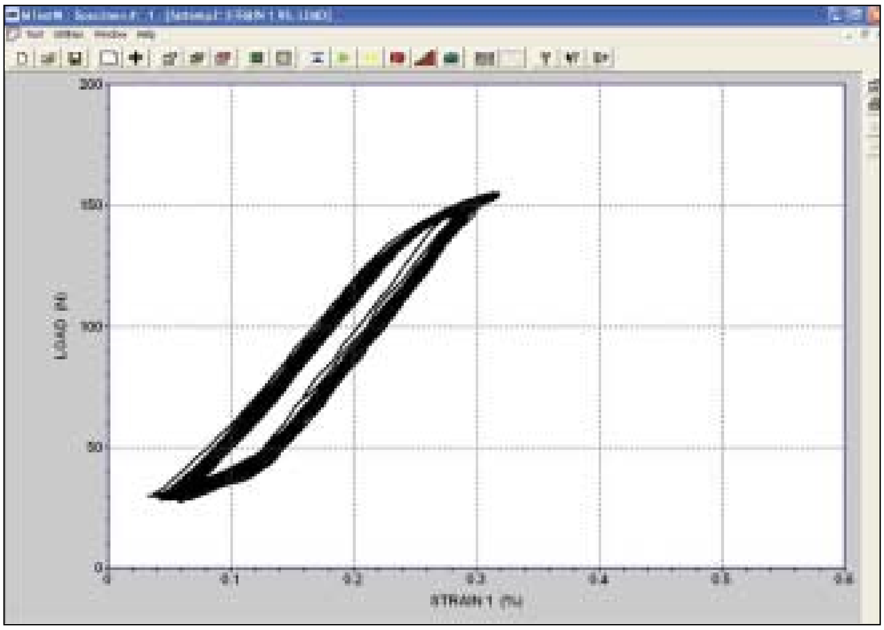

Fig. 4— Force-deflection hysteresis curve for a graphite epoxy beam specimen cyclically loaded in three point bending. Recorded by Admet's MTESTWindows on an Ernest F. Fullam Inc. flexural stage.

Optional heating and cooling units enable testing at different temperatures.

To measure macroscopic mechanical properties, the frames are outfitted with a Windows-based materials testing system, while the changes in microstructure are recorded with the scanning electron microscope. Figures 3 and 4 are force-deflection curves for a polymer loaded by a flexure stage under three point bending. The two curves illustrate the data acquisition and control capabilities for measuring macroscopic mechanical properties. ■

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Glossary

Lab-on-a-chip: A small chip (often the size of a credit card or smaller) containing microfluidic channels narrower than a human hair. They take advantage of the properties of liquids and gases to separate and better allow microsensors to analyze their constituent elements.

MEMS: Microelectromechanical systems. A term primarily used in the United States, it refers to machines with moving parts having typical dimensions of 10 to 100µm, which contain both electrical and mechanical components on silicon. Also referred to as microsystems, microstructures, microsystem technology (referred to as MST in Europe) and mechatronics.

Nanotechnology: The creation and use of objects at the nanoscale, up to 100 nanometers in size.

Nanocomposites: Composite materials prepared to have inhomogeneity in smaller scale than submicron (10^{-7} m) are called nanocomposites.

Polymers: Grouped into three general categories: thermoplastics, thermosets and elastomers. Thermoplastics can be softened and re-softened indefinitely by the application of heat, as long as the temperature is not so high as to cause decomposition. Thermosets are rigid materials that are not softened by the application of heat. Heat causes their bonds to break, which is not reversible on cooling. Elastomers, as a result of their molecular structure, allow considerable extension without permanent set.

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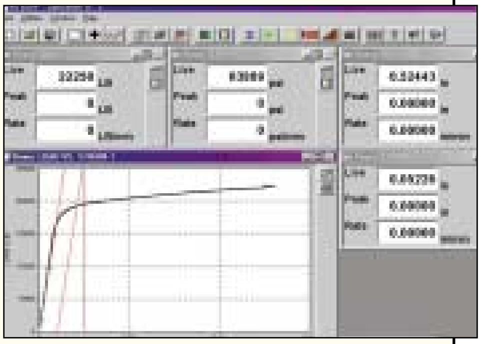

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