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MEMS Stage and Piezoelectric Motor-controlled TEM Holder for Quantitative in-situ Testing of Thin Film Specimens

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When monitoring the behavior of materials at the micro or nano scale, it is desirable that the characterization technique be capable of providing both quantitative and qualitative information simultaneously. This may be accomplished, for example, by in-situ testing of electron-transparent specimens during TEM observation. The usual method for achieving electron transparency—successive dimpling in the gauge section of the specimen—is time-consuming and gives little or no control over cross-section at the gauge section, making reliable stress or strain measurement difficult or impossible. In addition, such specimens are generally loaded by thermal [1], piezoelectric, or mechanical motor driven [2] strain stages that are not capable of measuring or controlling stresses within the specimen. Here we report a means of overcoming these and other limitations through the combined use of 1) a MEMS stage that incorporates thin films for testing with an innovative mechanism for generating very small forces, as well as accurately measuring force and displacement, and 2) a new piezoelectric motor-controlled TEM strain holder designed, in part, to accommodate the MEMS stage.

Haque and Saif [3] recently developed a methodology that integrates MEMS force and displacement sensors with the specimen on a single chip using microelectronic fabrication procedures. The unique features of this methodology include 1) the small size of the device, enabling it to fit into the SEM or TEM for in-situ experiments; 2) its ability to measure tensile pre-stress in the specimen; 3) lithographically precise alignment between the specimen and applied loading axes; 4) its lack of a requirement for an extra gripping mechanism; and 5) the ability to measure creep strain in the material. The technique permits the testing of any single or multiple layers of materials that can be deposited/grown on a silicon substrate. This apparatus, in the TEM strain holder, allows one to image the specimen while performing static and dynamic testing, fatigue testing, fracture testing, and creep testing.

The MEMS stages, 0.1 x 3 x 10 mm, are secured so that the freestanding metal film is centered within the viewing range of the microscope, held at eucentric height within the beryllium–copper TEM holder by means of 1.2-mm-diameter mounting holes at each end that fit over 1-mm-diameter studs at the tip of the holder. The distal stud is secured to the holder, and the proximal stud rides on a sled that can be moved back and forth by means of a rod attached to an “inchworm”-style piezoelectric motor (Nanomotor©, Klocke Nanotechnik, Aachen, Germany) that is built into the shaft of the holder. The holder fits the Philips/FEI (Hillsboro OR, USA) CM series electron microscopes, may also be utilized for “bulk” specimens, and provides two additional electrical feedthroughs for other types of sample monitoring.[4]

[1] R. Behr et al., Intermetallics, 7 (1999) 423–436.
[2] I.M. Robertson et al., Ultramicroscopy, 40 (1992) 330–338.
[3] M.A. Haque, M.T.A. Saif, Sensors and Actuators A, (2002) In Press.
[4] Aman Haque acknowledges grant no. ECS-9734368 from NSF.

FIG. 1. Scanning electron micrograph of the central portion of the MEMS stage, with inset.

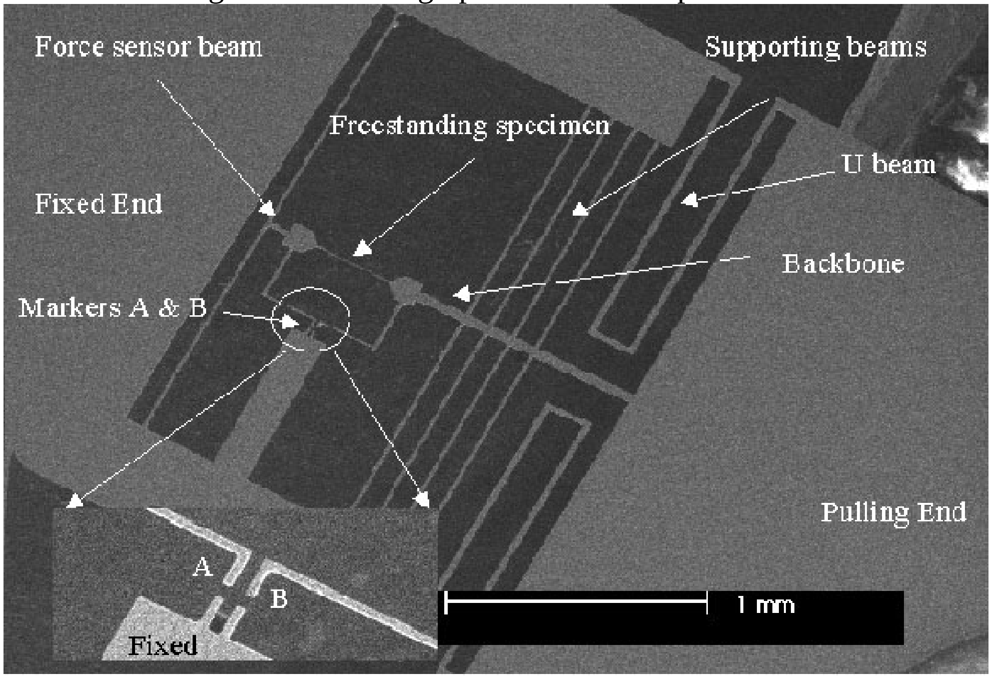

FIG. 2. TEM image of 30-nm-thick freestanding aluminum film specimen.