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Advanced *In Situ* TEM Nanomechanical Testing Options with the PI-95

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In situ transmission electron microscope (TEM) mechanical testing with the Hysitron PI-95 (Bruker Nano Surfaces, Minneapolis, MN, USA) encompasses a variety of techniques that provide unprecedented detail into fundamental deformation mechanisms. This is done by combining the high-resolution force and displacement sensing and actuation capabilities of the PI-95 with the impressive imaging and characterization capabilities of the TEM, which can occur simultaneously in real time. Nanoscale volumes of material can be deformed while quantifying the force-displacement response and, with appropriate analysis, the stress-strain response. This is not only suitable for nanomaterials like particles and wires, but also through careful sample preparation, selected regions of a larger microstructure.

Several advanced options are available to add a new dimension to the already impressive base system capabilities. Three exciting options are nanoScratch, nanoDynamic mode, and the electrical push-to-pull (E-PTP). The nanoScratch module utilizing a 2D MEMS based transducer to allow simultaneous measurement of the normal and lateral forces and displacements during the experiment. A piezoelectric actuator is used for the lateral actuation, which enables the in situ study of tribology, wear and friction [1]. Figure 1 shows an example of a nanoScratch test on olivine [2]. The nanoDynamic module allows an oscillation to be superimposed on top of the quasi-static loading, which enables continuous tracking of contact stiffness and, with high enough amplitude, in situ fatigue testing [3]. Lastly, the push to pull device allows compressive force to be converted into a tensile test, which can accommodate individual nanowires or liftouts. The electrical push-to-pull device is shown in Figure 2. This is similar to the basic PTP device, but also adds contact pads for a four-wire electrical test, enabling simultaneous current-voltage characterization of a material [4].

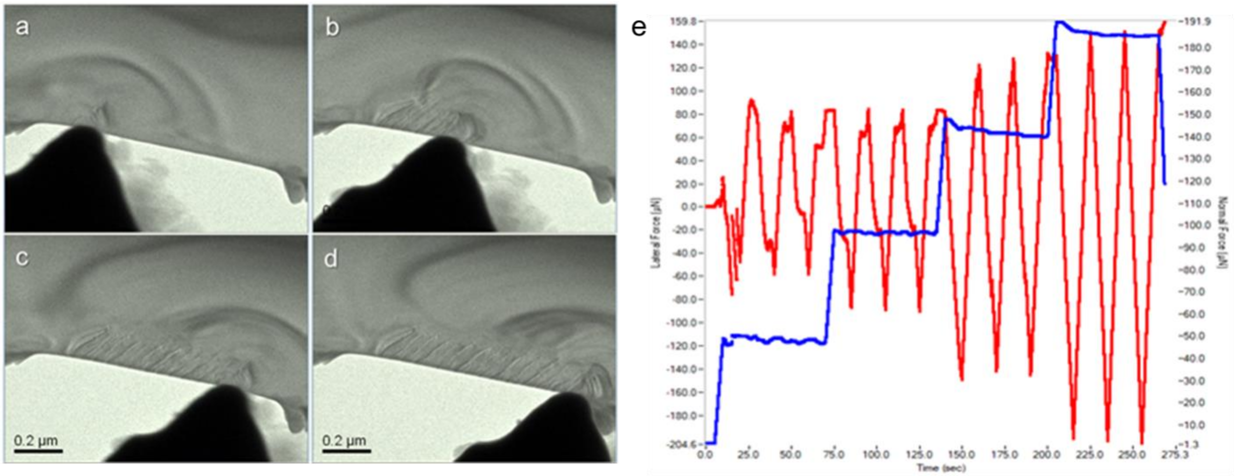

Figure 1. Development of symmetric array of defects along the wear path in olivine sample after (a) 3rd pass (b) 6th pass, (c) 9th pass and (d) 12th pass and the corresponding normal and lateral force versus time (e), where the normal force is progressively ramped every three cycles.

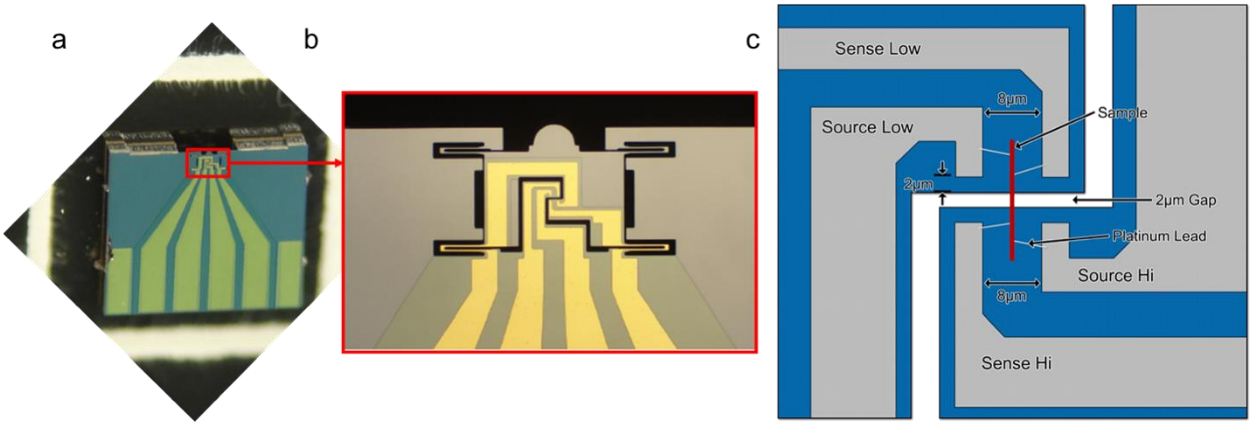

Figure 2. Electrical push to pull device shown in low magnification (a). The functional region is shown with enhanced magnification as an optical microscope image in (b) and a schematic showing the different leads in (c).

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