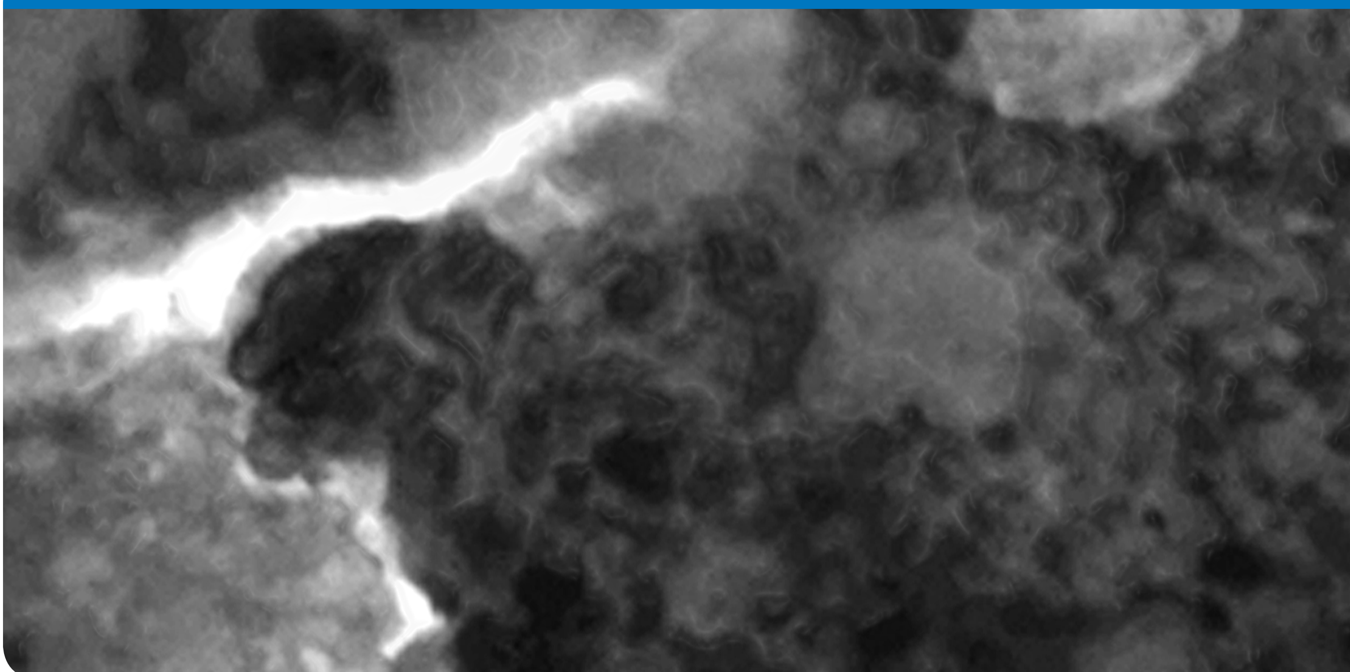


nanoDynamic Mode

Nanoscale Dynamic Mechanical Testing for Hysitron PI Series PicoIndenters

Traditional analysis techniques for nanomechanical testing assume elastic-plastic material behavior. However, this does not accurately describe the response of time-dependent materials that benefit from dynamic characterization. Bruker has developed the nanoDynamic™ in-situ testing option for the Hysitron® SEM and TEM PicoIndenter® instruments as a solution for measuring the properties of such materials.

Bruker's nanoDynamic Mode Features

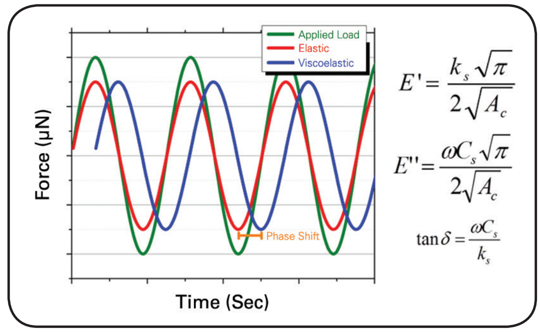
- Powerful CMX algorithms that provide a truly continuous measurement of hardness, storage modulus, loss modulus, complex modulus, tan-delta, etc. as a function of contact depth, frequency, and time
- In-situ fatigue testing that elucidates phenomena that lead to device failure
- A universally applicable technique for the thorough nanoscale characterization of materials, from ultra-soft hydrogels to hard coatings
- Enhanced dynamic characteristics and a dynamic testing range (1 Hz to 300 Hz), enabling increased accuracy and applicability on the broadest range of materials
- A flexible graphical user interface for rapid test setup, execution, and increased data analysis and reporting capabilities
- Coupled AC and DC force modulation for reliable and quantitative nanoscale dynamic characterization from the initial surface contact
- Direct control of the load amplitude rather than operation via displacement amplitude feedback loop
- Drift correction capabilities for maximum accuracy during long test cycles

Testing Routines

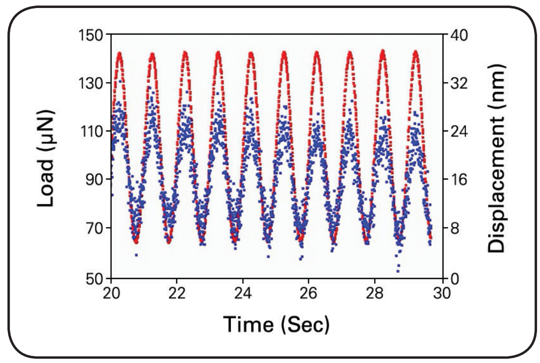
The nanoDynamic Mode offers several testing routines where a sinusoidal force is applied to a sample and the resultant displacement amplitude and phase shift are measured using lock-in amplification techniques. The dynamic response of a material is obtained using established dynamic mechanical analysis theory, which ultimately yields accurate measurements of the material's stiffness and damping properties at the nanoscale. From this, the storage (E') and loss (E") moduli can be calculated, as can their ratio and tan delta. This technique has also been expanded to include additional testing modes for characterizing creep and fatigue.

TriboScan Control Software

The system's TriboScan™ control software incorporates a flexible and intuitive graphical user interface to speed test setup and execution and enhance data analysis and plotting capabilities. Drift correction routines enable tests of prolonged duration, such as creep.



Schematic of sinusoidal force and resultant displacement data as measured using nanoDynamic Mode. Equations for storage (E') and loss (E") modulus are given on the right.

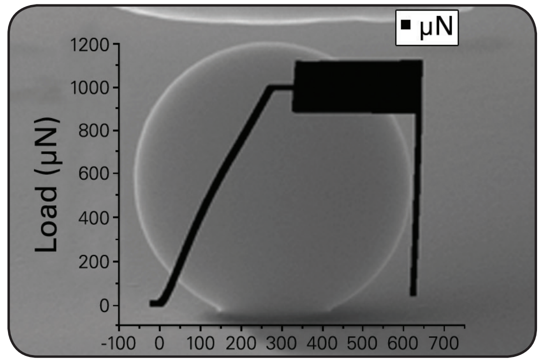


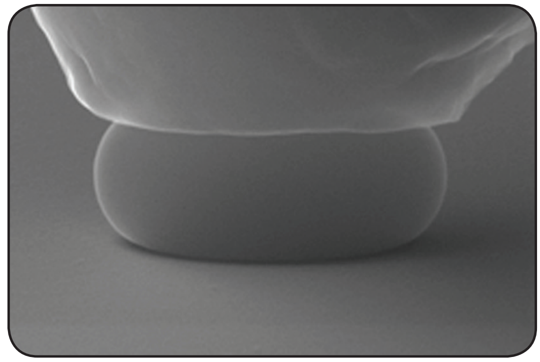
A plot of the applied load amplitude (red) and resulting displacement (blue) data from a 1 Hz dynamic loading test on a metallic thin film.

Dynamic Testing in the SEM

Coupling of high-resolution SEM imaging with force-displacement measurement dramatically increases the understanding of how, when, and why materials deform. This understanding is also enhanced through the use of advanced characterization, allowing a more complete description of the structure-property relationships that are fundamental to materials science. It allows for specific structures, such as particles, pillar, or specified grain orientations, to be targeted. Ultimately, it allows real-time observation of the material under deformation.

Traditionally, that deformation has been performed under a user-specified DC load. Now, with nanoDynamic Mode for the SEM PicoIndenter, the stiffness and damping under AC loading conditions can be collected continuously throughout the testing cycle. This provides a complete profile of the hardness and modulus as a function of depth or time. Other applications include the complete evolution of the strength of particles or nanostructures before, during, and after deformation events. Additionally, nanoDynamic Mode provides a means for imposing high-cycle fatigue stresses on nanostructures with the ability to apply large sinusoidal loads at frequencies up to 300 Hz, representing a new avenue of research for in-situ nanomechanical testing.



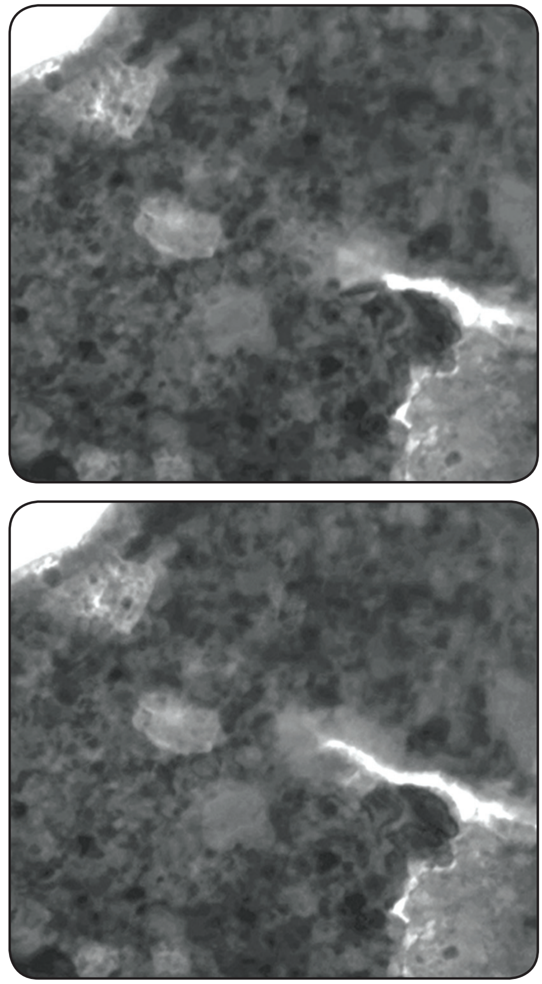


Silica particle compression with 1 mN DC, 100 µN at 10 Hz AC load. Particles shown exhibit viscoplastic creep under load.

Dynamic Testing in the TEM

Nanoscale mechanical testing inside transmission electron microscopes (TEMs) provides another level of insight into material deformation phenomena.

Correlating dislocation movement, shear banding, fracture or phase transformations observed in the TEM imaging with the force and displacement data provided by the Hysitron PI 95 has traditionally been accomplished using a user-specified DC load. This type of testing is sufficient to perform compression, tension, or bending tests to acquire quantitative nanoscale mechanical data. However, it is inefficient when many cycles are desired, such as for fatigue measurements. With nanoDynamic Mode, cyclic loading up to 300 Hz can be applied to your sample, measuring the stiffness as a function of time. Now cyclic fatigue properties can be measured and correlated to your imaging information.



TEM Images of stress-assisted crack growth in a metallic thin film subjected to a tensile fatigue stress. Note the void formation leading to crack initiation (stage I fatigue, top image) followed by crack growth (stage II fatigue, bottom image).

TEM Data Generated in Collaboration with:

Sandia National Laboratories

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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