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Beyond Indentation Hardness and Modulus: Recent Advances in Nanoindentation Techniques: Part II

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This *JOM* special topic is a continuation of "Beyond Indentation Hardness and Modulus: Recent Advances in Nanoindentation Techniques: Part I," published in the November 2017 issue. The scope of this special topic is to review some of the recent advances in nanoindentation techniques for measuring various nanoscale mechanical properties.

Indentation-enabled micro-/nano-mechanical characterization on small-scale specimens provides powerful tools for probing some of the material properties that were once unattainable by conventional experimental methods. Recent advances in instrumentation permit in situ mechanical testing inside electron microscopes, with high spatial and temporal resolutions. The article titled "Indentation-Enabled In Situ Mechanical Characterization of Micro-/nano-Pillars in Electron Microscope" by Q. Guo et al. reviews recent developments in nanoindentation-enabled in situ mechanical testing in microscopes, with an emphasis on micro-/nano-pillars. Focus is placed on novel applications beyond simple compressive and tensile testing that have been developed in the past few years. Limitations and possible future research directions in this field are proposed and discussed.

Standard nanoindentation tests are already considered "high throughput" in comparison to many other mechanical testing techniques, such as tension or compression. However, the typical rates of indentation, $\sim$ tens of tests per hour, need to be significantly improved. Recent progress towards higher testing rates enables otherwise impractical studies requiring several thousands of indents, such as high-resolution nanoindentation mapping. However, care must be taken to avoid systematic errors in the measurement, including the selection of the indentation depth/spacing to avoid overlap of plastic zones, pile-up, and influence of neighboring microstructural features in the material being tested. Furthermore, since high loading rates are applied, strain rate sensitivity must also be considered. The review article "High Through-put Nanoindentation for Statistical and Spatial Property Determination" by Hintsala, Hangen, and Stauffer uses complementary standard nanoindentation measurement techniques to address these issues. Experimental applications of the technique, including mapping of welds, microstructures, and composites with varying length scales, along with studies on the effect of surface roughness on nominally homogenous specimens, are presented.

Furthermore, in the regular article titled "Investigation of Interface Bonding Mechanism of an Explosively Welded Tri-Metal Titanium/Aluminum/Magnesium Plate by Nanoindentation", Zhang et al. combined nanoindentation tests and associated microstructure analysis to investigate the interface bonding mechanisms of the Ti/Al/Mg cladding plate. The periodic wavy bonding interface between the Al and Mg plates has similar wavy shape but larger amplitude compared to the interface between the Ti and Al plates. The formation of the wavy interface was found to result from a severe deformation at the interface, which was caused by the strong impact or collision. The nanoindentation tests showed that the material hardness decreased with increasing distance from the bonding interface.

In summary, the ability to quantitatively characterize and tailor the mechanical properties of individual microstructures/phases/constituents/interfaces in bulk materials at the nanoscale, as well as thin films and low-dimensional materials, has been critical for making revolutionary advances in materials development. Recent advances in indentation-based

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mechanical testing have enabled quantitative characterization of more complex mechanical behaviors at the nanoscale. This special topic reviewed creep and stress relaxation behavior, strain-rate sensitivity, fracture toughness, interfacial adhesion, high-throughput property measurement, and in situ nanoindentation in electron microscopes.

The following articles being published under the special topic of "Beyond Indentation Hardness and Modulus: Advances in Nanoindentation Techniques: Part II" in the April 2018 issue (vol. 70, no. 4) of *JOM* can be accessed via the *JOM* page at http://link.springer.com/journal/11837/70/4/page/1.

- "Indentation-Enabled In Situ Mechanical Characterization of Micro-/nano-Pillars in Electron Microscope" by Q. Guo, X. Fu, X. Guo, Z. Liu, Y. Shi and D. Zhang;
- "High Through-put Nanoindentation for Statistical and Spatial Property Determination" by E.D. Hintsala, U. Hangen, and D.D. Stauffer;
- "Investigation of Interface Bonding Mechanism of an Explosively Welded Tri-Metal Titanium/Aluminum/Magnesium Plate by Nanoindentation" by T.T. Zhang, W.X. Wang, J. Zhou, X.Q. Cao, Z.F. Yan, Y. Wei, and W. Zhang.