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Dynamic Probing of Microstructure Evolution in Nanostructured Materials

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Microstructure evolution occurs in nanostructured materials through a wide range of mechanisms. Those strongly impact their mechanical behavior under external loading. Significant advances in dynamic in-situ electron microscopy [including both scanning electron microscopy (SEM) and transmission electron microscopy (TEM)] have recently emerged. They represent a new opportunity to investigate the response of nanostructured materials under various external stimuli which can be mechanical, thermal, electrical, irradiative and/or corrosive. The information provided by dynamic in-situ electron microscopy, in combination with materials modeling and simulations, will be the scientific underpinning to design nanostructured materials with tailored mechanical responses for future engineering applications.

The international symposium “Dynamic Probing of Microstructure Evolution in Nanostructured Materials” was held at the TMS 2015 Annual Meeting & Exhibition with the aim of understanding the mechanical behavior of materials at micro- and nano-scales. Emphasis was given to new in-situ mechanical spectroscopy techniques, integration of in-situ mechanical spectroscopy with materials modeling, and applications for nanostructured materials. Several exciting recent works were selected at this symposium to be published in this *JOM* issue.

Understanding the physics of the phase transition is critical for the design of materials with advanced properties. Numerous in-situ techniques, such as in-situ x-ray diffraction and neutron diffraction, have been applied to reveal phase transformations at the macroscopic level. The article by Liu et al., “In-situ TEM Nanoindentation Studies on Stress-Induced Phase Transformations in Metallic Materials,” reviews the progress of in-situ nanoindentation techniques coupled with TEM for identifying stress-induced phase transformations and microstructural evolutions at a sub-micron-length scale, and presents two typical examples: amorphous CuZrAl alloy and NiFeGa shape memory alloy.

Nuclear energy requires advanced materials with unprecedented performance under extreme radiation environments. Neutron and heavy ion irradiation generally induces voids in metallic materials, and continuous radiation typically result in void swelling and mechanical failure of the irradiated materials. The paper entitled “Radiation-Enhanced Absorption of Frank Loops by Nanovoids in Cu,” by Chen et al., reports on the structural evolution of Frank loops under cascades and addresses in detail the role of nanovoids in absorbing Frank loops by using molecular dynamics simulations. Results show that a standalone Frank loop is stable under cascades. When Frank loops are adjacent to nanovoids, the diffusion of a group of atoms from the loop into the nanovoids is accomplished via the formation and propagation of dislocation loops.

Materials containing a high density of interfaces are promising candidates for future energy technologies, because interfaces acting as sources, sinks, and barriers for defects can improve mechanical and irradiation properties of the materials. The paper entitled “Relaxation, Structure, and Properties of Semi-Coherent Interfaces,” by Shao et al. reviews the recent work combining atomistic simulations and defect theory to investigate the misfit dislocation network on the semi-coherent interfaces, and summarizes the mechanical properties as well as the irradiation properties of the interface in terms of the interaction between defects. Further understanding of the effect of interfaces on the mechanical behavior of nanostructured materials will promote the design and usage of materials with a vhigh density of interfaces under extreme environments.

Nan Li is the guest editor for the Nanomechanical Materials Behavior Committee of the TMS Materials Processing & Manufacturing Division (MPMD); and the coordinator of the topic Dynamic Probing of Microstructure Evolution in Nanostructured Materials in this issue.

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As the feature dimensions of modern devices are continuously getting smaller, the size-dependent mechanical properties of metals at small scales have been of great interest. Recently developed experimental techniques based on in-situ TEM and Laue micro-diffraction could provide a large amount of unprecedented information, but it still remains challenging to employ these techniques to track evolving dislocation structures in microscale samples. The article by Ryu et al., "Anisotropic Size-Dependent Plasticity in FCC Micropillars under Torsion," presents work using three-dimensional dislocation dynamics simulations to investigate the plastic response of single-crystalline metallic submicron pillars under torsion. With a new algorithm for dislocation nucleation at free surfaces, this work reveals an orientation-dependent size effect in plasticity and provides a detailed dislocation microstructure under torsion.

We thank the members of the TMS Nanomechanical Materials Behavior Committee for providing the ideas leading to the topic selection for this issue. We also thank the authors for contributing their best works to be published in this issue. We hope that this issue will benefit the nanomechanical materials community.

The following articles being published under the topic of Dynamic Probing of Microstructure Evolution in Nanostructured Materials provide excellent details and research on the subject. To download any of the papers, follow the url http://link.springer.com/journal/11837/68/1/page/1 to the table of contents page for the January 2016 issue (vol. 68, no. 1).

- "In-situ TEM Nanoindentation Studies on Stress-Induced Phase Transformations in Metallic Materials," by Y. Liu, H. Wang, and X. Zhang.
- "Radiation-Enhanced Absorption of Frank Loops by Nanovoids in Cu," by Y. Chen, X. Zhang, and J. Wang.
- "Relaxation, Structure, and Properties of Semi-Coherent Interfaces," by S. Shao and J. Wang.
- "Anisotropic Size-Dependent Plasticity in FCC Micropillars under Torsion," by I. Ryu W. Cai, W.D. Nix, and H. Gao.