Introduction

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Since its commercialization early in the 20th century, indentation testing has played a key role in the development of new materials and understanding their mechanical behavior. Progress in the field has relied on a close marriage between research in the mechanical behavior of materials and contact mechanics. The seminal work of Hertz laid the foundations for bringing these two together, with his contributions still widely utilized today in examining elastic behavior and the physics of fracture.[1] Later, the pioneering work of Tabor, as published in his classic text *The Hardness of Metals*, expanded this understanding to address the complexities of plasticity.[2]

Enormous progress in the field has been achieved in the last decade, made possible both by advances in instrumentation, for example, load and depth-sensing indentation and scanning electron microscopy (SEM) and transmission electron microscopy (TEM) based in situ testing, as well as improved modeling capabilities that use computationally intensive techniques such as finite element analysis and molecular dynamics simulation. The purpose of this special focus issue is to present recent state of the art developments in the field.

The idea for the special focus issue was born at the *International Symposium on Indentation Behavior of Materials* in Hyderabad, India, February 2008. The conference focused on recent developments in indentation testing, in general, and its importance in modern materials research and advanced materials development. The plenary talk, given by Professor Ian Hutchings, chronicled the contributions of the late Professor David Tabor's seminal work in the field, and its long reaching importance. Professor Hutchings has transcribed that presentation into a historical overview that appears as the lead paper of this issue. Those of us working in the field owe a great deal to Professor Tabor for his insight and early leadership, which is apparent by the numerous times his work is referenced in this volume.

The sheer number of papers that were offered for the issue—more than 100—attests to the vitality of the field, which has advanced both on experimental and theoretical fronts. Although many of the concepts in indentation mechanics are rudimentary, the mathematical complexity of elastic, plastic, and time dependent deformation has in many instances eluded closed-form solutions. Thus, as amply illustrated in the issue, more advanced techniques such as finite element and neural network analysis have been brought to bear to further advance our understanding. In addition, with the advent of nanoindentation instrumentation and small-scale testing techniques, the size of many indentation contacts has been reduced to a range that overlaps what can be achieved in atomic simulations. As such, molecular

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dynamics has become a valuable tool for studying the physics of small-scale deformation processes, with experiment and simulation often exploring exactly the same length scales.

This is the third in a series of focus issues published in *Journal of Materials Research (JMR)* on the subject of indentation. Since its inception in 1986, *JMR* has been and continues to be a leader in publishing cutting-edge indentation research. The classic Doerner-Nix paper on nanoindentation appeared in Volume 1[3] and the most cited paper in *JMR* history for determining hardness and elastic modulus from indentation experiments by Oliver and Pharr appeared in Volume 7[4] of the journal. Since then, many other seminal papers in the field have been published in *JMR*. The first focus issue, which appeared exactly a decade ago (1999), focused on *"Nanoindentation: From Angstroms to Microns."*[5] At that time, the field of nanoindentation was just maturing, with many of the key problems associated with elastic-plastic deformation being worked out to the point that absolute measurements of hardness and elastic modulus were becoming routine, and the focus in nanoindentation research was shifting away from technique development to its use in studying and characterizing thin film and small-volume deformation phenomena. Five years later (2004), another focus issue dealt with *"Fundamentals and Applications of Instrumented Indentation in Multidisciplinary Research,"* shifting the paradigm from small-scale testing to instrumented indentation testing at any length scale.[6] The current issue focuses on indentation as a general tool for advancing our understanding of mechanical behavior, whether or not the tests were conducted in an instrumented fashion.

It is clear from the titles of the contributions in this issue that new areas for indentation testing are rapidly emerging. One is in biomaterials, wherein the properties of hard materials such as teeth, bone, and fingernails as well as the behavior of soft tissues are being conveniently probed and characterized by indentation techniques. Moreover, using small scale testing by means of nanoindentation and similar AFM-based techniques, the properties of individual cells are being measured and quantified. Several of the papers in this issue address these new frontiers.

Another area of evolving importance is the time-dependent deformation characteristic of viscoelastic and viscoplastic materials. Techniques and analysis procedures for assessing these properties in polymers and other similar materials have recently been developed to unprecedented levels of sophistication using quasi-static and dynamic methods. These have proven important not only in the study of classic viscoelastic materials like polymers, but also soft biological materials and tissues.

Indentation testing has also proven of enormous value in the characterization of size effects in plastic deformation. The classic "indentation size effect," or ISE, is probably the most well-known and well-documented of all size effects, largely due to the fact that nanoindentation can accurately probe and quantify it at the submicron length scales where the effect becomes measurable and important. However, such measurements are not without ambiguity in interpretation, and for this reason, research into indentation size effects is still vigorous, with many of the papers in the current issue addressing key experimental and theoretical issues. Nanoindentation has also facilitated the study of several fundamental plastic deformation phenomena such as the nucleation of dislocations in crystalline materials associated with pop-in and the basic deformation processes that control deformation of glassy metals by unstable shear band formation and propagation. Several contributions in this issue deal with these phenomena.

The editors would like to express their deep appreciation to two special groups without whom this issue would not have been possible. First, our sincere thanks to the numerous authors and reviewers for their contributions, especially for the quick turnaround of revisions and reviews that was needed to complete the issue on time. Second, we are particularly grateful to Gordon Pike, Eileen Kiley Novak, Linda Baker, and all the rest of the *JMR* staff for their dedicated efforts in making this issue a reality. It was *truly* a delight to work with them.

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