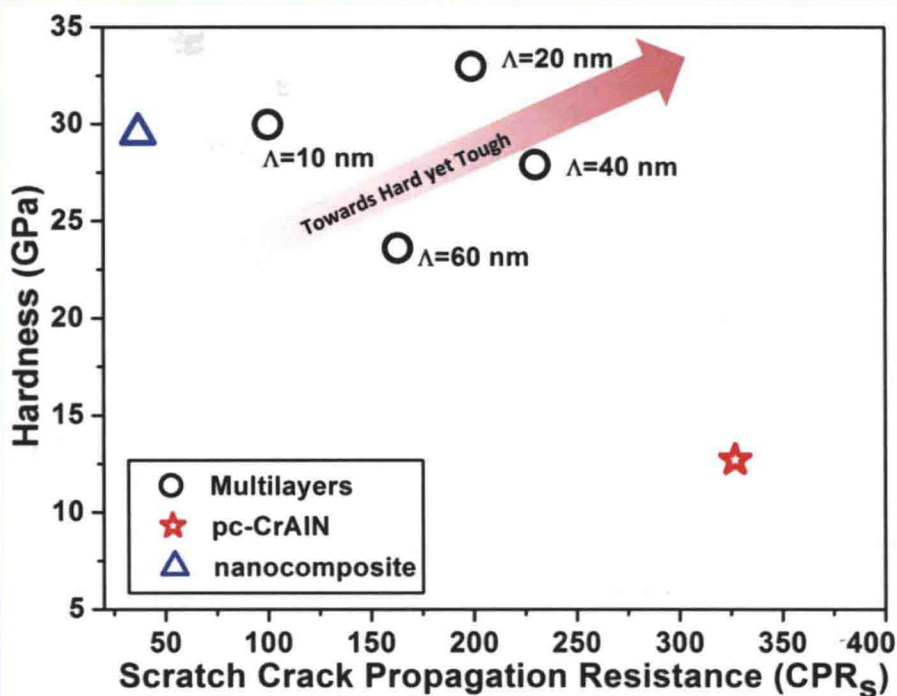


Thin Films and Coatings

Toughening and Toughness Characterization



Edited by Sam Zhang



CRC Press
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*Nanyang Technological University
Singapore*



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Thin Films and Coatings

**Toughening and
Toughness Characterization**

Advances in Materials Science and Engineering

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Sam Zhang

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Series Statement

ADVANCES IN MATERIALS SCIENCE AND ENGINEERING

Materials form the foundation of technologies that govern our everyday life, from housing and household appliances to handheld phones, drug delivery systems, airplanes, and satellites. Development of new and increasingly tailored materials is a key to further advancing important applications with the potential to dramatically enhance and enrich our experiences.

The *Advances in Materials Science and Engineering* series by CRC Press/Taylor & Francis Group is designed to help meet new and exciting challenges in the field of materials science and engineering. The books and monographs in the series are based on cutting-edge research and development, and thus are up to date with new discoveries, new understanding, and new insights in all aspects of materials development, including processing and characterization and applications in metallurgy, bulk or surface engineering, interfaces, thin films, coatings, and composites, to name just a few.

The series aims at delivering an authoritative information source to readers in academia, research institutes, and industry. The publisher and its series editor are committed to making this series the most comprehensive and accurate literary source to serve the materials' world and associated fields.

As the series editor, I would like to thank all authors and editors of the books in this series for their noble contributions to the advancement of materials science and engineering and to the advancement of humankind.

Sam Zhang

Preface

Cutting tools, drills, molds, and dies used in today's industries are likely made of high-speed steels, tungsten carbides, and so on. Applying a thin layer of ceramic coating could extend their service life up to many folds. However, if the coatings applied are only hard and not "tough" enough, chipping of the coatings occurs, which renders the coatings ineffective. Hardness of thin films and coatings has been sought after for years. Researchers have now realized that toughness is as important as hardness, if not more so, in all mechanical application areas. Toughening of films and coatings thus has attracted research attention worldwide, especially during recent years. Meanwhile, toughness measurement/characterization for thin films and coatings is still a pertinent research area although that for bulk materials has been classic. Thus, these two areas prompted me to gather forces and examine the most recent endeavors and results scattered across disciplines to formulate a logical chain of references, hence, the birth of this book *Thin Films and Coatings: Toughening and Toughness Characterization*.

As such, this book captures recent hardening, toughening and development in relation to the toughness measurement of thin films and coatings to provide a timely reference book for researchers to refer to and for newcomers to learn from. Being the first of its kind, this book provides the most recent developments in toughening of hard coatings and methodologies in the measurement of toughness of thin films and coatings.

This book is written in such a way that both novices and veterans will find it useful. Researchers in the materials fields, materials scientists, engineers, postgraduate students, especially those dealing with films and coatings, will find this book timely and useful.

The book contains nine chapters contributed by experts from Australia, China, Czech Republic, Poland, Singapore, Spain, and the United Kingdom. Chapter 1 presents the current status of hard-yet-tough ceramic coatings. Chapter 2 reviews various toughness evaluation methodologies for films and hard coatings, old and new. Chapter 3 focuses on nanoindentation determination of fracture toughness of coatings, and Chapter 4 further focuses on toughness and toughening mechanisms of porous thin films. Laser-treated surface toughness is dealt with in Chapter 5. Chapter 6 looks into the adhesions of the film/substrate interface while Chapter 7 focuses on resistance to cracking. Chapter 8 especially deals with characterization of coating adhesion strength. Finally, Chapter 9 looks specifically at sliding contact fracture phenomena.

Toughening and toughness measurement (of films and coatings) are two related, yet separate, fields of great importance in today's nanotechnology world. I dream that one day a technology will be developed such that a device/apparatus is available for toughness of thin films and coatings just like nanoindentation is to hardness of films and coatings. I hope that this book contributes to that aim along the way.

As with my other books, I paid special attention to be sure that enough details to the chapters were included by their respective contributing authors, noting that this book is one of the reliable resources for readers searching for knowledge. A book chapter is not a journal paper, thus it should be written in such a way that novices will find it a stepping stone to the field and veterans will find it a rich source of information for their research. I hope that I have achieved this.

I thank all the contributing authors for their painstaking work that finally resulted in this informative and timely book in the area of toughening and toughness measurement of films and coatings. Special thanks to the reviewers of the chapters who patiently went through the long chapters (one or two reviewers per chapter) to provide their professional critique, which enabled the authors to improve the chapters to their current form. Their professional contributions guaranteed the quality of the book. Last, but not least, I thank the staff at CRC Press, especially Allison Shatkin and Jennifer Ahringer, for their invaluable assistance throughout the endeavor that made the smooth publication of the book a reality.

Sam Zhang

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Editor



Professor Sam Zhang Shanyong, better known as Sam Zhang, earned his PhD in ceramics in 1991 from the University of Wisconsin-Madison, USA, and is a tenured full professor (since 2006) at the School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore. Professor Zhang serves as the founding editor-in-chief for *Nanoscience and Nanotechnology Letters* (USA) since 2008 and principal editor for *Journal of Materials Research* (USA) since 2003. He has been in processing and characterization of nanocomposite thin films and coatings for more than 20 years and has authored/coauthored more

than 290 peer-reviewed international journal articles, 11 books, more than 20 book chapters, and guest-edited more than 10 journal volumes. His books are

1. Sam Zhang (ed.), *Thin Films and Coatings: Toughening and Toughness Characterization*, CRC Press, Taylor & Francis Group, 2015.
2. Guojun Qi and Sam Zhang (eds.), *Handbook of Manufacturing Engineering and Technology*, Springer, 2014.
3. Sam Zhang (ed.), *Hydroxyapatite Coatings for Biomedical Applications*, CRC Press, Taylor & Francis Group, 784 pp., 2013, ISBN: 9781439886939.
4. Sam Zhang and Dongliang Zhao (eds.), *Aerospace Materials Handbook*, CRC Press, Taylor & Francis Group, 784 pp., 2012, ISBN: 9781439873298.
5. Sam Zhang (ed.), *Biological and Biomedical Coatings Handbook: Processing and Characterization*, CRC Press, Taylor & Francis Group, 2011, ISBN: 978-1-4398-4995-8.
6. Sam Zhang (ed.), *Biological and Biomedical Coatings Handbook: Applications*, CRC Press, Taylor & Francis Group, 2011, ISBN: 978-1-4398-4996-5.
7. Sam Zhang (ed.), *Nanostructured Films and Coatings: Mechanical Properties*, CRC Press, Taylor & Francis Group, 550 pp., 2010, ISBN: 9781420094022.
8. Sam Zhang (ed.), *Nanostructured Films and Coatings: Functional Properties*, CRC Press, Taylor & Francis Group, 422 pp., 2010, ISBN: 9781420093957.
9. Sam Zhang (ed.), *Organic Nanostructured Thin Film Devices and Coatings for Clean Energy*, CRC Press, Taylor & Francis Group, 254 pp., 2010, ISBN: 9781420093933.

10. Sam Zhang, Lin Li, and Ashok Kumar, *Materials Characterization Techniques*, CRC Press, Taylor & Francis Group, 344 pp., 2008, ISBN 9781420042948.
11. Sam Zhang and Nasar Ali (eds.), *Nanocomposite Films and Coatings—Processing, Properties and Performance*, Imperial College Press, UK, 628 pp., 2007, ISBN 978-1-86094-784-1.

His textbook *Materials Characterization Techniques* has been adopted by eight American universities and one European university: Purdue University, Department of Materials Engineering; New York University, Department of Biomaterials and Biomimetics; Louisiana State University, Department of Mechanical Engineering; California Polytechnic State University, Department of Materials Engineering; University of Missouri, Department of Chemical and Biological Engineering; Rutgers University-Camden, Department of Physics; Johns Hopkins University, Department of Materials Science and Engineering; and North Seattle Community College, Math, Science, and Social Sciences; and in Europe: University of Southern Denmark, Centre for Nanotechnology. This book was also translated into Chinese and published by the China Science Press in October 2010, and is adopted by many Chinese universities as a textbook.

Professor Zhang was conferred the title of honorary professor of the Institute of Solid State Physics, Chinese Academy of Sciences. He also holds guest professorship at Zhejiang University and Harbin Institute of Technology. He was featured in the first ever *Who's Who in Engineering Singapore* (2007), and featured in the 26th and 27th editions of *Who's Who in the World*. He became a fellow of the Institute of Materials, Minerals and Mining, United Kingdom, in October 2007. He has been invited to present plenary keynote lectures nearly 60 times at international conferences in Japan, the United States, France, Spain, China, Portugal, New Zealand, Germany, among others. He has also been invited by universities or industries to conduct short courses and workshops more than 20 times. He founded the biennial *International Conference on Technological Advances of Thin Films & Surface Coatings* conference series in 2002 and has been the chair of this very successful conference series ever since. Professor Zhang is also the founding president of the Thin Films Society.

Professor Zhang's research centers on the following four aspects: hard-yet-tough nanocomposite coatings for tribological applications, biological coatings and drug delivery application, electronic thin films, and energy films and coatings. On hard-yet-tough nanocomposite coatings alone, he has published approximately 50 journal articles. Professor Zhang's articles have been cited more than 4,860 times as of March 2015, citation per paper more than 17 times. His H-index is 38. An online live update of these data is available at Professor Zhang's researcher ID website: <http://www.researcherid.com/rid/A-3867-2011>. (Details are also easily accessible at his personal website <http://www.ntu.edu.sg/home/msyzhang>)

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