Preface

Nanoscience and nanotechnology have continued to grow at a rapid pace since their emergence a few decades ago. Nanostructured materials ranging from zero-dimensional, one-dimensional and two-dimensional to bulk nanomaterials are central to nanotechnology. It is crucial these days to find more cost-effective and versatile methods of fabrication and synthesis to compete with existing technologies. There is a tremendous amount of interest in chemical or electrochemical approaches for the discovery and development of novel nanostructured materials and applications. Electrochemical deposition or electrodeposition has been widely used for years in the plating industry for anti-corrosion and decorative applications in metals and alloys. It is a cost-effective, flexible and capable method for producing a variety of materials. Given these characteristics, the basic understanding of electrodeposition has been considerably enhanced over the last few decades, and it has been successfully downscaled for use in the deposition of a wide range of nano-sized materials with outstanding functional and mechanical properties.

The importance of electrodeposition in nanoscience and nanotechnology, and in particular in the development of nanostructured materials, has been widely acknowledged in recent decades, and further progress is certainly inevitable. Interest in the technology and the exploitation of its potential by both the academic and industrial sectors is anticipated in the coming years. Therefore, I felt it was essential to collect the most important advances and findings in the field of electrodeposition of nanostructured materials in the form of a monograph. Having more than 15 years of research experience on the electrodeposition of coatings and nanostructures, I came to the idea of a book covering the electrodeposition of nanostructured materials from fundamental principles to the most recent progress. This book is prepared to disseminate the major factors and principles of electrodeposition towards the fabrication of nanostructured materials as a unique reference. I outlined the pathways of this strategy as mentioned.

The book starts with the fundamental aspects of nanostructured materials, and develops the principles of electrochemistry, followed by the basics of electrodeposition. It then discusses a number of the most interesting electrodeposited nanostructured materials. Specifically, Chap. 1 gives an overview of the principles

of materials science and nanostructured materials. A general discussion of the basic structures of materials from atoms, atomic binding, physics of solid state materials or condensed matter physics, the band theory of solids and crystallography, classification of nanostructured materials, the dimensionality and quantum size effect in nanostructures, and the electronic properties of three types of nanostructures is expanded in detail. Chapter 2 deals with the principles of electrochemistry in materials science. The electrochemical aspects of electrodeposition are central to process control and development. Three concepts are covered: equilibrium electrochemistry, dynamic electrochemistry and instrumental electrochemistry. In Chap. 3, I explain the fundamentals of electrodeposition, including the principles of electrolysis, electrodeposition cells, nucleation and growth of electrodeposits, basics of overpotential (OPD) and underpotential (UPD) deposition, methods of characterizing the initial stages of electrodeposition, and electrodeposition through the application of external stimuli such as magnetic or ultrasound forces. Chapter 4 deals with electrodeposited two-dimensional (2D) and three-dimensional (3D) meso- and nanostructures. UPD is associated with 2D and OPD is related to 3D nucleation and growth. Free-standing metal or alloy mesocrystals and nanostructures on a substrate and multiple 3D nuclei and consequent coalescence for film are described. Template electrodeposition for the fabrication of nanowire arrays is explained in Chap. 5. The most common templates will be exploited, and electrochemical deposition mechanisms by means of direct current, pulse current and alternating current will be discussed. Recent progress in electrodeposited magnetic nanowires including metal and alloy, multilayered, core–shell and diameter-modulated nanowires are presented. Chapter 6 deals with electrocrystallization at the nanoscale. In this chapter, I focus on pulse electrodeposition; principles and important particulars will be discussed, including a comparison of Ni nanocrystalline films electrodeposited by direct and pulse techniques. Metal matrix–particulate nanocomposites are the topic of Chap. 7. Co-electrodeposition of metal matrix with particulates involves the electrochemical fundamental where mass transport and kinetics play important roles. Various theoretical models and the most important factors of co-electrodeposition will be discussed and compared in an example system: nickel–carbon nanotube nanocomposite coatings. Lastly, Chap. 8 concerns particular methods and techniques of electrodeposition of nanostructures, including scanning tunneling microscopy (STM)-assisted electrodeposition, lithographically patterned nanowire electrodeposition, electrodeposition of mesoporous films from lyotropic liquid crystals and electrodeposition of nanostructures by galvanic displacement. This book will be useful for different groups of readers, from academics or technologists, researchers and graduate students, to engineers and professionals, enabling the correlation of the principles of electrodeposition with their use in developing new strategies for the fabrication of numerous cutting-edge nanostructures. This book can also be used as a textbook for undergraduate and graduate students in related disciplines.

I have attempted to discuss the most promising electrodeposited nanostructured materials, with an emphasis on those for which we have direct research experience. Therefore, so many people have helped to make this book possible, and I am

sincerely indebted to them. I am grateful to my mentors and colleagues in the past and present, including Prof. Walther Schwarzacher, Prof. Laurie Peter, Prof. Simon Bending, Prof. Alain Nogaret, Prof. Mohammad Ghorbani, Prof. Azam Irajizad, Dr. Alexander Samardak, Dr. Alexey Ognev and his colleagues for their advice and fruitful collaboration on many topics of this book. I am also very thankful to all members of my research group at Sahand University of Technology for their cooperation, their efforts, constant research work and encouragement, in particular Mr. Hamed Cheshideh, Mr. Seyed-Majid Peighambari, Mr. Ali Fardi-Ilkhichy, Mr. Amin Pourandarjani, Ms. Sanam Abedini, Mr. Seyed-Mehdi Janjan, Mr. Farhad Daneshvar-Fattah, Mr. Mohammad-Reza Sanaeian, Ms. Masoumeh Nadi, Ms Soheila Beheshti, Mr. Mehdi Hadizadeh, Ms. Katayun Alipour, Mr. Navid Alinedjaidian, Mr Alireza Sarshar-Noshar, Ms. Saedeh Barzegar, Mr. Hossein Firouzi, Mr. Enayatollah Panahi, Ms. Aysan Hadighe-Rezvan, Mr. Sajjad Nasiri-ahmadabad, Ms. Rana Mahmoodi, Ms. Mina Abdollahzadeh and so many others that I may have forgotten. In addition, the financial support and research grants from the Research Affairs of Sahand University of Technology, Iranian Ministry of Science, Research and Technology, the Iran Nanotechnology Initiative Council and others are acknowledged.

I would very much welcome any comments and discussions from peers in this field for further development and improvement of this book.

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