Preface

Thin films and nanostructures have a wide spectrum of applications such as microelectronics, optoelectronics, solar cells, flat panel displays, wear-resistant coatings, data storage media, sensors, micromechanical system (MEMS), and biological implants. Considering the huge number of publications in this field, it is not difficult to imagine how important this field is. Nevertheless, an understanding on the growth mechanism of thin films and nanostructures surprisingly lags behind. There are many puzzling phenomena regarding the growth of thin films and nanostructures, which cannot be explained by the textbook knowledge. In order to make a scientific, systematic, and efficient approach to this important area, the highest priority would be to understand the underlying principle of the microstructure evolution of thin films and nanostructures as well as the puzzling phenomena.

This effort should start with asking 'Why?' followed by the effort to answer the question. This is a typical way scientific progresses are made. By doing so, 'How?' can be approached most systematically and efficiently with trials-and-errors being minimized. This book will focus on 'Why' as to the puzzling microstructure evolutions of thin films and nanostructures.

The first question was "Why can diamond be synthesized at low pressure where graphite is more stable?" This question is answered based on the thermodynamic and kinetic concepts in Chap. 5. The next question was "Why do diamond crystals and porous skeletal soot deposit respectively on Si and Fe substrates under the same processing conditions?" The related figure is Fig. 6.1 of Chap. 6. Another question was "How is it possible that deposition of less stable diamond and etching of stable graphite occur simultaneously?" This puzzling phenomenon, which was experimentally observed, appears to violate the second law of thermodynamics. It turned out that these questions could not be answered with any conventional theory of crystal growth, where diamond films grow by individual atoms, in the textbook. Instead, these questions could be answered by a new growth mechanism, where diamond films grow by charged nanoparticles generated in the gas phase. It is a paradigm-shifting discovery about the growth mechanism of diamond films. Besides, this mechanism turns out to be very general in other chemical vapor deposition processes.

In other words, many thin films and nanostructures synthesized in the gas phase grow by non-classical crystallization, which has been studied recently and extensively in solution especially in biomineralization. Although non-classical crystallization is a relatively new and revolutionary concept in crystal growth, it has now become quite established that a few related books have been published and its tutorial and technical sessions have been included respectively in the spring meetings of Materials Research Society and European Materials Research Society in 2014. With the establishment of non-classical crystallization, many crystals that were believed to grow by atomic, molecular, or ionic entities turn out to grow actually by nanoparticles.

Chapter 1 is the general introduction of non-classical crystallization and its relation with the growth mechanism of thin films and nanostructures. Chapters 2–4 treat respectively thermodynamics of CVD, nucleation and growth, which are some fundamental concepts for the classical theory of crystal growth. For educational purposes, there are some questions for undergraduate seniors or graduate students to think upon before reading any further. Nevertheless Chaps. 2–4 contain some essential knowledge to understand Chaps. 5–7, linking the basic knowledge to non-classical crystallization of thin films and nanostructures. Chapter 5 covers the thermodynamic and kinetic concepts to explain the diamond synthesis at low pressure. Chapter 6 covers the diamond growth mechanism based on the theory of charged nanoparticles. Chapters 7–12 cover the extension of the theory to other systems. Chapter 13 deals with the charge-enhanced kinetics. Chapter 14 deals with the implications and applications of this new understanding.

I like to thank my former and present collaborators and students for their efforts to study the growth mechanism of thin films and nanostructures. I am indebted to Profs. Miyoung Kim, Seungwu Han, Heungnam Han, Seonghyeon Hong, Kibum Kim, and Jungjoong Lee in my department for their fruitful discussion and comments. I express my sincere gratitude to Dr. J. Cahn formerly at the National Institute of Standards and Technology, Prof. M. Hillert formerly at the Royal Institute of Technology, Prof. S. Iijima at Meijo University, Prof. J.K. Lee formerly at Michigan Technological University, Prof. I. Sunagawa formerly at Tohoku University, Prof. P. Bennema formerly at Nijmegen University, Prof. T. Yoshida formerly at the University of Tokyo, Prof. P. Roca i Cabarrocas at Ecole Polytechnique, Profs. K. Ostrikov and A.B. Murphy at CSIRO for fruitful advices, discussions and comments. I thank my graduate students, Jihye Kwon, Daseul Kim, Taeyoung Kim, Jonghwan Park, and Jungwoo Yang for their help in preparation of the manuscript related to drawing figures and references. Finally, financial support for the recent work from the Global Frontier R&D Program (2013M3A6B1078874) in Center for Hybrid Interface Materials, the National Research Foundation of Korea (NRF) Grant funded by the Government (MSIP) (No. 2015R1A5A1037627), and the Asian Office of Aerospace Research and Development (AOARD) of AFOSR is greatly appreciated.

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Springer

http://www.springer.com/978-94-017-7614-1

Non-Classical Crystallization of Thin Films and
Nanostructures in CVD and PVD Processes
Hwang, N.M.
2016, XII, 332 p. 229 illus., 64 illus. in color., Hardcover
ISBN: 978-94-017-7614-1