Synthetic Diamond: Emerging CVD Science and Technology

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This book provides a “serious assessment of CVD diamond science and technology.” It has sixteen chapters divided between five separate sections and includes an index. Twenty-one well known authors in the field contribute their work. The book is directed at upper-level university students, academic researchers, industrial scientists and engineers, and business people who are interested in or involved with R&D, manufacture, or application of chemical vapor deposited (CVD) diamond.

CVD diamond has been of interest to the general public and the scientific research community for a number of years. The possibility of large technological payoffs in electronics, optical devices, wear parts, and tooling has led to the development of a great deal of information and experience on the subject of CVD diamond. Thousands of papers, reports, and news articles have been written and an interested individual would have to plow through a great deal of material before getting a feel for the field. Several reviews have been written to improve information access but few, if any, have had the breadth and scope of this book. From this one source, it is possible to get a background, a tutorial on the current state, an economic analysis, and a view of the future of the field.

The book is organized logically and includes a comprehensive index at the end. The chapters are: The Vision of Diamond as an Engineered Material; Development of Low-Pressure Diamond Growth in the United States; Summary of Research on Diamond Growth from the Gas Phase in Russia; Development of Diamond Science and Technology in Japan; Development and Status of Diamondlike Carbon; Growth of Diamond by CVD Methods and Effects of Process Parameters; Vapor Phase Diagnostics in CVD Diamond; Mechanisms for CVD Diamond Growth; Physical, Chemical, and Microstructural Characterization and Properties of Diamond; Diamond Electrical Properties and Electronic Device Behavior; Optical Properties and Optoelectronic Applications of Diamond; Tribology and Wear Behavior of Diamond; Industrial Applications of Single-Crystal Diamond; Technological Applications of CVD Diamond; A Comparative Assessment of CVD Diamond Manufacturing Technology and Economics; and CVD Diamond Markets in the 21st Century. One of the editors, Spear, said that every effort was made to ensure that the chapters were written so they could be read easily from one to the next. Additionally, the reader is periodically directed from a generally covered topic in one chapter to a more thorough presentation in another. The chapters are also written so they can stand alone if necessary. This resulted in some minor overlap but typically only in their introductory sections.

It is refreshing to read about the technical development of this field of research as told by the individuals who made such large personal contributions to the field. The chapter contributed by Angus on the development of low-pressure diamond growth in the United States includes personal pictures and drawings of original apparatus. Angus reviews the seemingly inexplicable delay in the acceptance and further development of diamond technology in the late 1960s and early 1970s. However, he does not include his own story of why he had to drop diamond research at a time when great success seemed at hand. One highlight of Fedoseev’s summary chapter on CVD diamond growth from the gas phase in Russia is the description of a material invented in his laboratory called “polycruster diamond films.” I held one of these films a number of years ago. It was remarkable in that it had been deposited on a flexible steel sheet and did not spall off under mild flexure. The chapter by Setaka on the history of the development of diamond science and technology is one of the few instances where an overview of work on all aspects of diamond synthesis in Japan has been presented. Many innovations in CVD diamond deposition originated with Japanese work such as microwave plasma, hot filament, welding torch, etc. More important, if the NIRIM group had not reported its successes, then the book currently under review would not have been written nor would the worldwide interest in CVD diamond have occurred. One important fact brought out is the early use by the NIRIM group of Raman spectroscopy to examine their diamond films. This technique is still the best method to determine the presence and nature of diamond in thin films. Japanese work on high-pressure and shock wave methods of diamond and cubic boron nitride synthesis are also included. The historical accounts of the development of CVD diamond are interesting and serve as a warning to technologists in other fields. Research has fluctuated wildly in this field for many years, but only in the last ten years has serious attention been paid to the subject. How many other areas of research are currently drifting through the backwaters of attention only to be “rediscovered” 20 or 30 years from now?

A chapter on the development and status of diamond-like carbon (DLC) was contributed by Grill and Myerson. It may seem odd to have a chapter in a book on diamond about a material that is noncrystalline and has physical properties that vary between those of hydrocarbon polymers and diamond. However, DLC plays an important part in CVD diamond technology in addition to its own applications because of its use as an interfacial and nucleation layer. DLC is also the frequent product of failed diamond deposition experiments. Spear and Frenklach review and expand upon their mechanisms for CVD diamond growth in their chapter. Their presentation replies to problems and questions that have been brought up in print and at conference by Harris and others concerning diamond growth mechanisms. Included in their chapter is a short tutorial on hydrocarbon pyrolysis.

The chapter on the physical, chemical, and microstructural characterization and properties of diamond was contributed by van Enckevort. Unlike earlier works, the properties of CVD diamond have been reviewed with those of natural and high-pressure syn-
thetic diamond. There has been a need for many years to contrast and compare CVD diamond with the other forms of diamond. The chapter on the tribology and wear behavior of diamond by Gardos is the most voluminous of the book. This extensive chapter will likely become the starting point of most future discussions on the nature of wear on the CVD diamond surface. Opportunities exist for polycrystalline CVD diamond where single crystal diamonds are now being used. A chapter on the industrial applications of single-crystal diamonds was contributed by Seal. His credentials include being on the team that prepared the most exclusive diamond product ever made, the nearly $\frac{1}{2}$ in. (1.9 cm) diameter single-crystal natural diamond window used on the Pioneer Venus interplanetary probe.

The first 14 chapters of the book lead up to a comparative assessment of CVD diamond manufacturing technology and economics by Busch and Dismukes and an examination of CVD diamond markets in the 21st century by Russell. Taken together, these last two chapters could be the most crucial part of the book for scientists and engineers who need to sell or defend their research to management. It is a historical fact that organizations have invested millions of dollars on CVD diamond research and development without knowing either the true costs or the value of the payoff. These data are now becoming more critical when deciding research and funding plans and opportunities.

The book stays fairly focused on the science and technology of CVD diamond. Some work on single-crystal natural and high-pressure synthetic and shock wave diamond is included with a brief mention of cubic boron nitride. These excursions show the technological framework in which CVD diamond research is located. Beginning or active researchers will appreciate the areas for further research that are provided by the authors of many chapters. The book did have a few small flaws. I noticed a couple of minor typographical errors and there was some tendency to be self-referent; however, these typically did not detract from the presentation. This book will be compared by some with *Diamond Films and Coatings* [1]. The two books do share two contributors but this one covers a great deal more territory. The range and depth of material presented from history to technology to business concerns makes this a comprehensive work and one that will clearly be used as a reference source for many years to come.

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