DIAMOND FILMS AND COATINGS

Development, Properties, and Applications

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np NOYES PUBLICATIONS
Park Ridge, New Jersey, U.S.A.

Library of Congress Catalog Card Number: 92-35011
ISBN: 0-8155-1323-2
Printed in the United States

Published in the United States of America by
Noyes Publications
Mill Road, Park Ridge, New Jersey 07656

10 9 8 7 6 5 4 3 2 1

Library of Congress Cataloging-in-Publication Data

Diamond films and coatings : development, properties, and applications / edited by Robert F. Davis.
p. cm.
Includes bibliographical references and index.
ISBN 0-8155-1323-2
1. Diamonds, Artificial. 2. Diamond thin films. I. Davis, Robert F. (Robert Foster), 1942-
TP873.5.D5D52 1992
666'.88--dc20 92-35011
CIP

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Preface

The synthetic diamonds developed by industrial organizations in the 1950's and 1960's using a combination of high-pressure, high-temperature (HPHT) techniques are used primarily in cutting, grinding and polishing applications. However, a variety of potential applications for this material require thin films and coatings which cannot be produced by these methods. The results of much smaller efforts, simultaneous with the HPHT studies, in the United States and Russia and concerned both with the kinetics of the pyrolysis of various hydrocarbon-hydrogen mixtures and with the mechanisms of nucleation and growth of diamond on diamond seeds at low pressures were considered to be only of "academic" interest. However, the publication of micrographs of highly faceted and continuous diamond films, and confirming analytical data, in the Russian and, subsequently, in the Japanese scientific literature in the late 1970's and early 1980's catalyzed substantial activity in this field. This resulted in the development and use of a variety of deposition and characterization techniques to achieve and study diamond films and coatings.

The purpose of this book is to provide an in-depth examination of selected topics concerned with synthetic diamond. This unique material has been considered from the perspectives of historical development, its properties, the latest in scientific results regarding its growth and characterization and present and future applications.

The eight chapters of this book are authored by experts in their fields. The initial chapter by Yoder provides an applications-related cornerstone for the book. Tables of all the major properties of diamond are given in conjunction with discussions concerned with the importance of these

properties to the present and potential employment of this material. Having determined the need for synthetic diamond, the subsequent chapter by Nassau describes the considerable efforts to develop this material with an emphasis on the high-temperature, high-pressure research. The remainder of the book is concerned with diamond materials grown primarily from the vapor phase. Pehrsson, Celii and Butler address the important issue of the chemical mechanisms occurring within the gas phase which ultimately allow the deposition of this material under non-equilibrium conditions on various substrates. The various methods and experimental conditions within which one can obtain the proper gas-phase chemistry and resulting diamond films is described by Koba. Lux and Haubner describe the market potential and current applications of diamond in terms of wear resistant coatings for a variety of products. The chemical, physical and microstructural characterization of the low pressure diamond materials was used initially to convince the skeptics of its existence. Subsequently it was used to determine the nature of the deposited material and to provide information for the optimization of the particular growth method. The chapter by Zhu, Kong and Glass provides an in-depth review of the methods and results of this significant effort. Applications of diamond films and coatings are now being realized. In the final two chapters, Plano, Pinneo and Das have taken the information content in the book full circle with their discussion regarding both the identification of the relevant properties which affect the development of nonelectronic and electronic applications for diamond films and the future research necessary for property enhancement. Extensive lists of reviews, research papers and bibliographies at the end of each chapter also provide resource materials for more detailed study.

Numerous individuals have contributed and assisted in the preparation of this book. I wish to express my appreciation firstly to the authors and their employers who contributed considerable effort, time and facilities for the generation of each chapter. I am also especially indebted to Jeff Glass who provided numerous suggestions, assistance and author contact. I also appreciate the patience and continual encouragement of George Narita, Executive Editor of Noyes Publications, during the completion of all the tasks involved in the editing of this book. Last but not least, I wish to extend my special thanks to my wife, Jan, and daughter, Leona, for their patience and for the time I could not spend with them during this endeavor.

Raleigh, North Carolina
September, 1992

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Notice

Contents

1

Diamond Properties and Applications

MAX N. YODER

1.0 THE CRYSTALLINE STRUCTURE OF DIAMOND

Sir Isaac Newton was first to propose that diamond was organic. His suppositions were drawn from careful measurements of the indices of refraction. In 1772 the French chemist Antoine L. Lavoisier found that the products of diamond combustion behaved as, and most assuredly were, solely carbon dioxide. The English chemist Smithson Tennant conducted an experiment in which he mixed equal amounts of diamond, graphite, and coal together with equal amounts of saltpeter in separate respective closed chambers. He determined that the ignition and burning of each produced equal amounts of "bound air". Having thus established that all three materials were composed of the same element, their differences remained intriguing until the advent of x-rays and the ingenuity of the famous father and son Bragg duo—Sir William Henry and Sir William Lawrence. They found carbon to embody three separate structures: cubic, hexagonal, and amorphous. Natural diamond actually consists of approximately 99% carbon 12 and 1% carbon 13. As seen later, were it not for this isotropic impurity, the thermal conductivity of diamond would be even higher than its already unmatched value.

From these humble beginnings our knowledge of the properties of diamond have increased markedly. From this knowledge and the recent introduction of artifact diamond films, our ability to efficaciously apply diamond to the technological requirements of the modern age is gaining momentum.