MATERIALS CHARACTERIZATION SERIES

SERIES EDITORS: C. Richard Brundle and Charles A. Evans, Jr.

材料表征原版系列丛书

硅加工中的表征

CHARACTERIZATION IN Silicon Processing

Yale E. Strausser

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CHARACTERIZATION IN SILICON PROCESSING

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MATERIALS CHARACTERIZATION SERIES
Surfaces, Interfaces, Thin Films

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Characterization of Optical Materials, Gregory J. Exarhos

Characterization of Tribological Materials, William A. Glaeser

Characterization of Organic Thin Films, Abraham Ulman

Preface to the Reissue of the Materials Characterization Series

The 11 volumes in the Materials Characterization Series were originally published between 1993 and 1996. They were intended to be complemented by the *Encyclopedia of Materials Characterization*, which provided a description of the analytical techniques most widely referred to in the individual volumes of the series. The individual materials characterization volumes are no longer in print, so we are reissuing them under this new imprint.

The idea of approaching materials characterization from the material user's perspective rather than the analytical expert's perspective still has great value, and though there have been advances in the materials discussed in each volume, the basic issues involved in their characterization have remained largely the same. The intent with this reissue is, first, to make the original information available once more, and then to gradually update each volume, releasing the changes as they occur by on-line subscription.

C. R. Brundle and C. A. Evans, October 2009

Preface to Series

This Materials Characterization Series attempts to address the needs of the practical materials user, with an emphasis on the newer areas of surface, interface, and thin film microcharacterization. The Series is composed of the leading volume, *Encyclopedia of Materials Characterization*, and a set of about 10 subsequent volumes concentrating on characterization of individual materials classes.

In the *Encyclopedia*, 50 brief articles (each 10 to 18 pages in length) are presented in a standard format designed for ease of reader access, with straightforward technique descriptions and examples of their practical use. In addition to the articles, there are one-page summaries for every technique, introductory summaries to groupings of related techniques, a complete glossary of acronyms, and a tabular comparison of the major features of all 50 techniques.

The 10 volumes in the Series on characterization of particular materials classes include volumes on silicon processing, metals and alloys, catalytic materials, integrated circuit packaging, etc. Characterization is approached from the materials user's point of view. Thus, in general, the format is based on properties, processing steps, materials classification, etc., rather than on a technique. The emphasis of all volumes is on surfaces, interfaces, and thin films, but the emphasis varies depending on the relative importance of these areas for the materials class concerned. Appendixes in each volume reproduce the relevant one-page summaries from the *Encyclopedia* and provide longer summaries for any techniques referred to that are not covered in the *Encyclopedia*.

The concept for the Series came from discussion with Marjan Bace of Manning Publications Company. A gap exists between the way materials characterization is often presented and the needs of a large segment of the audience—the materials user, process engineer, manager, or student. In our experience, when, at the end of talks or courses on analytical techniques, a question is asked on how a particular material (or processing) characterization problem can be addressed the answer often is that the speaker is "an expert on the technique, not the materials aspects, and does not have experience with that particular situation." This Series is an attempt to bridge this gap by approaching characterization problems from the side of the materials user rather than from that of the analytical techniques expert.

We would like to thank Marjan Bace for putting forward the original concept, Shaun Wilson of Charles Evans and Associates and Yale Strausser of Surface Science Laboratories for help in further defining the Series, and the Editors of all the individual volumes for their efforts to produce practical, materials user based volumes.

C. R. Brundle *C. A. Evans, Jr.*

Preface to the Reissue of *Characterization in Silicon Processing*

When this volume was originally released in 1993 the chapters dealt with materials and manufacturing processes in the state of the art wafer fabrication facilities of the day. Mature fabs today still use many of those materials and processes, though state of the art fabs of today also include both different materials (e.g., Cu interconnects, organic dielectrics) and processing steps which did not exist then. After the reissue of this volume in a form close to the original, updates covering the changes that have occurred will be made and released as on-line downloads as they are completed.

C. R. Brundle and C. A. Evans, October 2009

Preface

This volume has been written to aid materials users working with silicon-based semiconductor systems. Materials problems arise in all stages of semiconductor device production: research and development of new processes, devices, or integrated circuit technologies; new process equipment definition and new process start-up; operation of state-of-the-art processes in wafer fabrication facilities; and throughout the life of each wafer fabrication process.

These materials problems are sometimes investigated using only electrical tests, but they can often be more clearly identified by using an appropriate selection of materials characterization techniques. However, the research and development scientists and engineers who work with new technologies and define or implement new processes are typically not experts in these techniques. This volume, and indeed the Materials Characterization Series, is intended to help the nonspecialist determine the best selection of techniques for a surface- or thin film materials-based problem.

This volume should be used in conjunction with the lead volume of the series, *Encyclopedia of Materials Characterization*, which defines boundary conditions for fifty widely used surface and thin-film materials characterization techniques. Each technique description discusses

- the type of information to be obtained about a sample
- appropriate samples and required sample preparation
- limitations and hardware requirements with regard to spatial resolution, compositional resolution, and sensitivity
- time required for an analysis
- destructiveness to the sample
- other important characteristics of the technique.

Each technique description also lists authoritative references for further research. The descriptions are succinct and do not discuss operation of the instruments or lengthy derivations of basic principles. They are jargon-free guidelines to aid the nonspecialist in understanding the type of information a technique provides and in selecting the appropriate technique to solve a problem.

This volume approaches materials characterization from the materials properties, processing, and problems point of view. It discusses typical materials and processes used in the manufacture of today's silicon-based semiconductor devices and

provides examples of typical problems encountered in the real silicon-processing world and their identification and characterization using techniques described in the *Encyclopedia*.

The organization of the chapters in this volume is similar to the process flow of a wafer. Each material commonly used in silicon integrated circuit manufacture is the topic of a chapter, including epitaxial silicon (including silicon-germanium alloys), polycrystalline silicon, metal silicides, aluminum and copper conductors, tungsten conductors, and barrier films. Dielectric films are not covered. Each chapter discusses a typical process history of the material—deposition, thermal treatment, lithography, etc.—and the desired properties of the material, with examples of common problems seen in producing materials having the desired properties. These examples illustrate the application of appropriate characterization techniques to solve the problems.

The fifty techniques discussed in the *Encyclopedia* are the most widely used for a broad range of materials problems. Some of these techniques are seldom used in characterizing silicon-based semiconductor materials, and some techniques specific to semiconductor characterization are not included in the *Encyclopedia*. For these reasons, an appendix is provided in this volume that contains pertinent summary pages taken from the *Encyclopedia* plus lengthier descriptions of the important semiconductor-specific methods not covered in the *Encyclopedia*.

This volume is not sufficient to make one an expert in any of the materials characterization techniques ("a little knowledge is a dangerous thing"). Its purpose is to guide one in determining which techniques to be aware of and approach first in problem-solving. Further information to help solve a materials-based problem may be obtained from the references at the close of each chapter and from experts who use characterization techniques to solve problems. (Experts are employed in the materials characterization organizations of large companies and in independent analytical service laboratories.)

I would like to acknowledge the contributions of a number of people in the preparation of this volume. Dick Brundle, the Series editor has helped beyond the call of duty in many ways. He has been patient and persistent and he has assisted in much of the editing. Gary McGuire pitched in at a time when I was unavailable and proofread all the chapters in draft form, making suggestions for improvements. Penny Strausser, my wife, was helpful in every way possible—discussing ideas, proofreading, typing—and was forgiving of my time. Finally, I thank the authors of the individual chapters for being patient and for seeing this through.

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Application of Materials Characterization Techniques to Silicon Epitaxial Growth

C. I. DROWLEY

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1.1 Introduction

Silicon epitaxial growth has emerged as a major process technology for VLSI circuit production during the last decade. Prior to that time, silicon epitaxial growth technology had been used primarily for bipolar IC, discrete device, and power device applications. The ability to reduce latchup in CMOS circuitry by growing a lightly doped epitaxial layer (for the active device region) over a heavily doped substrate (which provides a low-resistance shunt path for substrate currents, and thus suppresses turn-on of parasitic devices) has led to the adoption of epitaxy for high-volume CMOS processes.[1] Silicon epitaxial growth is also a critical process for the production of high-performance circuits incorporating both bipolar and CMOS devices (i.e., BiCMOS technology).[2]

Epitaxial growth applications have expanded to include the selective epitaxial growth of silicon on patterned substrates. Selective epitaxy has been demonstrated on a number of VLSI structures. Some examples of such selective growth applications are the creation of low-encroachment isolation,[3, 4] elevated MOS source/drain formation,[5] and DRAM cells.[6, 7] Three-dimensional structures such as folded CMOS inverters have also been fabricated.[8]