MATERIALS PROCESSING THEORY AND PRACTICES

Volume 4

Series Editor F.F.Y. Wang

dry etching for microelectronics

Volume Editor

R. A. Powell

north-holland

DRY ETCHING
FOR MICROELECTRONICS

MATERIALS PROCESSING – THEORY AND PRACTICES

VOLUME 4

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DRY ETCHING FOR MICROELECTRONICS

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INTRODUCTION TO THE SERIES

Modern technological advances place demanding requirements for the designs and applications of materials. In many instances, the processing of materials becomes the critical step in the manufacturing processes. However, within the vast realm of technical literature, materials processing has not received its proper attention. It is primarily due to the lack of a proper communication forum. Since the materials processing is intimately concerned with specific products, those who are experts have no need to communicate. On the other hand, those who are involved with a different product will develop, in time, the technology of materials processing when required.

It is the objective of this series, Materials Processing – Theory and Practices, to promote the dissemination of technical information about the materials processing. It provides a broad prospective about the theory and practices concerning a particular process of material processing. A material process, intended for one technology, may have an applicability in another. This series provides a bridge between the materials engineering community and the processing engineering community. It is a proper forum of dialogues between the academic and the industrial communities.

Materials processing is a fast-moving field. Within the constraints of time and printed spaces, this series does not aim to be encyclopedic, and all-inclusive. Rather, it supplies an examination of material processes by the active workers. The view will be, by necessity, subjective. But the view will include both near-term and long-term prospectives. It is the fondest hope of this general editor that the volumes in this series can serve as first reference books in the field of materials processing.

Franklin F.Y. WANG
Stony Brook, New York

PREVIOUS VOLUMES IN THE SERIES

1. Fine line lithography
   R. Newman, volume editor
2. Impurity doping processes in silicon
   F.F.Y. Wang, volume editor
3. Laser materials processing
   M. Bass, volume editor

PREFACE TO VOLUME 4

Over the last decade, dry or plasma-assisted etching has emerged as an indispensable tool for the manufacture of microelectronic circuits, replacing traditional wet chemistry for etching and pattern transfer. The present volume collects together, for the first time, a series of in-depth, critical reviews of important topics in dry etching. This topical format provides the reader with more specialized information and references than found in a general review article. In addition, it presents a broad perspective which would otherwise have to be gained by familiarity with a large number of individual research papers.

As interest in dry etching has steadily increased over the years, so too has the number of technical papers. Hundreds have now been published including many excellent reviews of a general nature. Unfortunately, in-depth treatments of specific dry etch topics have been rare. Topical reviews are particularly lacking for areas which are promising but in an early stage of development, such as dry processing of III–V compound semiconductors, as well as areas which have been under intense development but are highly proprietary, such as dry etching of refractory metal silicides. In addition, there are topics which have been discussed more or less openly by workers for many years, such as dry etching aluminum and aluminum alloys, for which an article reviewing past experimental results in light of our current theoretical understanding of the dry etch process would be of great value.

The present volume arose out of the desire to provide, in one place, up-to-date critical reviews of these and other important topics in dry etching. The treatment of each specific topic in this volume is, to my knowledge, the most in-depth review of that topic yet published. An additional unique feature of the present book is the inclusion of an extensive literature review of dry processing, compiled by search of computerized data bases. Consisting of over 800 citations, this bibliography is intended to augment the more specific, topical references found throughout each of the critical review chapters. A subject index at the end of the book allows ready access to the key points raised in each of the chapters.

Chapters 1–3 deal with dry etching specific materials of proven or projected importance in microelectronics: aluminum and aluminum alloys (chapter 1), refractory metals and their silicides (chapter 2), and III–V compound semiconductors (chapter 3). In each case, successful etching depends on understanding a variety of interrelated materials and processing issues. Although a great deal of effort has been directed in the past at dry etching aluminum-based metallizations such as AlSi(2%) and AlSi(2%)Cu(1–4%), the development of a suitable, production-worthy etch strategy continues to challenge both process engineer and equipment manufacturer. Compared to aluminum etching, much less has been publically reported for refractory metals and metal silicides such as Mo, W, $TiSi_2$, WSi_2 etc. However, this is an area of intense and often proprietary development, since these materials are top contenders to replace or augment polysilicon as interconnects and metallizations in next-generation VLSI devices. Although the use of III–V compound semiconductors such as GaAs, $Al_xGa_{1-x}As$ and InP in electro-optics and discrete solid-state microwave devices has a long history, plasma-assisted etching of these materials is relatively unexplored. This situation is rapidly changing due to developments in integrated optics and digital GaAs technology which have placed more stringent demands on pattern transfer and etching of these materials.

Rather than dealing with a specific class of materials, chapter 4 critically reviews the dry etch technology of reactive ion beam etching (RIBE) – its instrumentation, basic principles and applications. Although the most common manifestations of dry etching today are reactive ion etching (RIE), plasma etching, and ion beam milling, recent developments in RIBE make it a promising alternative for certain microelectronic applications.

It is important to point out that the present volume deals only with the use of plasmas for the *removal* of materials, i.e., dry etching and pattern transfer. The use of plasmas to *deposit* thin films such as by plasma-enhanced chemical vapor deposition (PECVD) is not treated in either the critical review chapters or the bibliography.

Finally, I would like to thank the series editor, Prof. F.F.Y. Wang for his encouragement and the editorial staff of North-Holland Physics Publishing for the courteous and efficient manner in which they handled all aspects of this project. I also wish to acknowledge M.L. Manion, Stauffer Chemical Company, Mountain View, California, who compiled the subject index to this volume.

Ronald A. POWELL
Palo Alto, CA, USA
April, 1984

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CHAPTER 1

PLASMA-ASSISTED ETCHING OF ALUMINUM AND ALUMINUM ALLOYS

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Contents

1. Introduction

Phenomenal advances in the design and fabrication of solid state devices and integrated circuits have occurred over the last two decades. Many of these advances have been made possible by the continual reduction in minimum feature size of individual circuit elements. Recent improvements in resist materials and exposure tools allow the printing of submicron patterns. Device fabrication, however, requires controllable transfer of these patterns into inorganic and organic film materials. Since liquid etching is limited to lateral dimensions on the order of 2 μm or greater, future, and indeed many current device designs, demand dry etching techniques.

Very large scale integration (VLSI) necessitates the interconnection of more than 10^5 devices per chip. Thus, a large portion of the chip area, more than 60% in some devices (Sinha, 1982), is taken up by interconnect layers. Currently, the most common metallization layer for electronic devices is aluminum or its alloys. Although pure aluminum presents a number of problems for VLSI (Learn, 1976), the most serious of these are electromigration and hillock formation. However, these problems can be alleviated by using aluminum–copper alloys. Thus, for the foreseeable future, aluminum or its alloys will certainly be used for at least one layer of metallization in integrated circuits.

In this chapter the chemical and physical processes occurring during the plasma-assisted etching of aluminum and its alloys are discussed. Since excellent reviews exist for sputtering of metal films (Vossen and Cuomo, 1978; Thornton and Penfold, 1978; Fraser, 1978; Waits, 1978), this topic will only be briefly mentioned here. The primary emphasis will be on mechanistic considerations and on effective use of the process latitude available for plasma-assisted aluminum etching.

1.1. Need for dry etching

Until the late 1970s, liquid etching was the preferred method of pattern delineation for thin films. Indeed, from a manufacturing standpoint, liquid