VLSI Electronics Microstructure Science

Volume 8

Plasma Processing for VLSI

Edited by

Norman G. Einspruch

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Preface

The use of plasmas in semiconductor processing until recent years was limited to photoresist stripping and metal sputtering. In the early 1970s, plasma deposition of silicon nitride for use as a topside passivation layer was added. The more recent revolutionary explosion in plasma processing has been spurred on by the etching requirements for high-resolution pattern formation, a constantly improving vacuum technology, lower chemical processing costs, and even a reduced environmental impact caused by the elimination of wet-chemical etching and the subsequent decrease in acid-disposal problems. A natural extension of this last point would be the replacement of acid cleans by plasma scrubbing and cleaning systems.

The subject matter of this volume extends beyond what most would expect to find (etching), since it includes parts on advanced deposition of materials for metallization and lithographic methods that use plasmas as exposure sources and for multiple resist patterning and a part on new and improved device structures made possible by anisotropic etching. The discussion of the utilization of plasmas for general semiconductor processing is, of course, even more extensive because this volume covers subjects thought to be directly related to silicon VLSI processing.

Chapter 1 is a brief history of plasma processing written by Donald L. Tolliver, who discusses some of the early developmental high points and more recent trends for VLSI. The rest of the volume is organized somewhat as a processing sequence would be. Deposition techniques for VLSI are discussed by Ronald S. Nowicki (sputtering metals for metallization and contacts), Dennis W. Hess (plasma-enhanced chemical vapor deposition of metals and silicides), and T. B. Gorczyca and B. Gorowitz (plasma-enhanced chemical vapor deposition of dielectrics). The part on lithography, which starts with the contribution from James B. Kruger and his colleagues Michael M. O'Toole and Paul Rissman, summarizes the limitations of single-layer resist and discusses the high-resolution trilayer resist system. Pulsed x-ray sources for submicrometer x-ray lithography are covered by D. J. Nagel, and Andrei N. Petelin and Michael G. Ury describe high-intensity deep-UV sources for, among other applications, the flood exposure of PMMA for the high-resolution resist system originally proposed by Burn J. Lin in 1975. The part on etching should be extensive enough to emphasize plasma etching's importance as a constantly evolving method for forming high-resolution patterns. The methods discussed in this section are quite varied, ranging from the high-pressure techniques discussed by Donald L. Smith to ion-beam etching using reactive gases detailed by B. A. Heath and T. M. Mayer. A very extensive discussion of the methods used to etch a wide range of materials by using low-pressure reactive ion etching has been contributed by Bernard Gorowitz and Richard J. Saia. R. E. Lee describes the uses of inert-gas ion milling, a technique widely used to etch metals and metal oxide patterns. The theory and mechanisms of plasma etching are described by the AT&T Bell Laboratories group (Daniel L. Flamm, Vincent M. Donnelly, and Dale E. Ibbotson). William R. Harshbarger's contribution on diagnostics and end-point detection emphasizes the control function requirements for plasma etching, because in contrast to wet etching, in which complete layer-to-layer chemical selectivity is achievable, physical erosion occurs during most plasma-etching processes. Y. Horiike describes a number of new etching techniques being developed at Toshiba Corporation. The last chapter in this volume, by T. Paul Chow, covers a number of new device structures made possible by anisotropic etching. Included are the plasma techniques being used as a new tool to produce novel devices in the submicrometer region.

Reflection on the significance of plasma processing leads one to believe that the techniques described in this volume will continue to evolve, bringing about even further improvements in VLSI processing, which will, in turn, enable the semiconductor industry to produce more function at lower cost than is presently achievable.

DALE M. BROWN

Contents

Chapter 1 The History of Plasma Processing

Donald L. Tolliver

Part A DEPOSITION

Chapter 2 Sputtering for VLSI

Ronald S. Nowicki

Chapter 3 Plasma-Enhanced Chemical Vapor Deposition of Transition Metals and Transition Metal Silicides

Dennis W. Hess

Chapter 4 Plasma-Enhanced Chemical Vapor Deposition of Dielectrics

T. B. Gorczyca and B. Gorowitz

Part B LITHOGRAPHY

Chapter 5 Trilayer Resist

James B. Kruger, Michael M. O'Toole, and Paul Rissman

Chapter 6 Plasma Sources for X-Ray Lithography

D. J. Nagel

Part C ETCHING

Chapter 11 **Ion-Beam Etching (Milling)**
R. E. Lee

Chapter 12 **Reactive Ion-Beam Etching**
B. A. Heath and T. M. Mayer

Chapter 13 **Plasma Diagnostics and End-Point Detection**
William R. Harshbarger

Chapter 14 **Emerging Etching Techniques**
Y. Horiike

Chapter 15 **Advanced Device Structures Fabricated with Anisotropic Dry Etching**
T. Paul Chow

Chapter 1

The History of Plasma Processing

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I. INTRODUCTION

In the rapidly growing industry of semiconductor microelectronics, it is often difficult for present-day workers to have a perspective on how specific technologies have evolved within their industry. Plasma technology or dry etching technology is one of the newer requirements in semiconductor wafer manufacturing that has seen significant implementation in the last 10 years. As an introduction and an overview to the general subject of this volume, this chapter attempts to track the subject of plasma processing in the microelectronics industry over the last 15 years.

II. EARLY DEVELOPMENTS

A. Ashing of Photoresists

The ashing of photoresists was the initial process that was implemented in various manufacturing lines as early as 1968. Figure 1 shows one of the early reactor designs introduced as a low-temperature asher by Tracerlab. Bipolar integrated circuits was emerging as a viable addition to volume manufacturing, and engineers were searching for advances to improve the manufacturing process. Wet chemical stripping was both costly and inefficient. The new concepts of dry stripping of resists appeared to provide a natural improvement as well as a novel idea in the resist-removal process. Irving [1] reported on the potential use of plasma ashing to remove photo resist at the 1968 Kodak Photoresist Seminar. What was noted then as a possible manufacturing problem was not easily communicated or understood by many workers in wafer processing in 1968. The earlier KMER® photoresists produced by Eastman Kodak Company were used in routine manufacturing during this period. The inorganic residuals, primarily tin, that were left behind when the resist polymer was removed were not easily detected or subsequently removed after the ashing process. Little knowledge or under-

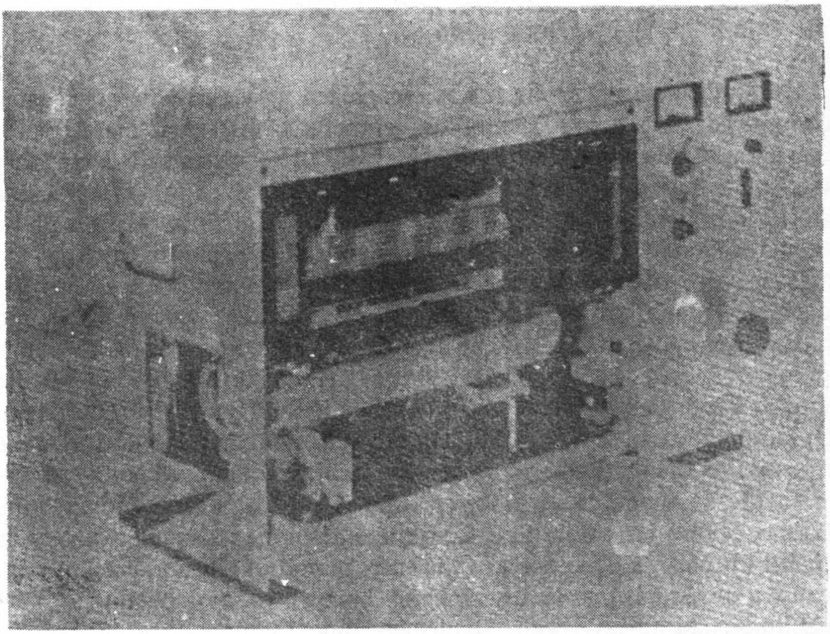

Fig. 1. Low-temperature asher LTA600J. (Courtesy of LFE Corporation.)

standing of the actual plasma process or its results was on hand when the process was introduced. By 1969, enough severe device degradation and product loss had occurred to cause most users to completely eliminate the use of plasma ashing until 1972 or 1973. Not enough characterization and evaluation had taken place prior to the introduction of the process to manufacturing. What originally was conceived to be an essentially clean, inert, and passive method of organic film removal from the semiconductor surface turned out to be a highly reactive and selective removal process for negative photoresist. The trade-offs were enormous. Although plasma ashing has regained much of its original popularity in numerous manufacturing areas, the process is still subject to periodic failures due to misuse of the application or lack of good in-process control procedures. Even as late as 1983 some hesitance on the part of process engineers is noticeable with respect to full implementation of ashing in advanced manufacturing areas. Further mention of the use of plasma ashing will be included in Subsection III.F. Designs and applications of both processes and equipment have undergone significant change.

B. Thin-Film Plasma Deposition

Thin-film plasma deposition was recognized very early, before plasma etching needs, as a new source of low-temperature dielectric materials for passivation of integrated circuit surfaces. Figure 2 shows an early laboratory model of a silicon nitride deposition system developed in 1970. Plasma deposition of organic thin films was inherent in the chemistry of gas phase plasma reactions. In the early 1970s, silicon nitride depositions from plasma reactions were of high interest technically in that methods to provide acceptable silicon nitride depositions conventionally were restricted to temperatures above 700°C. By the end of 1972, no commercially available systems provided either plasma deposition of silicon nitride *or* low-pressure chemical vapor deposition of silicon nitride (LPCVD). The properties of high-temperature silicon nitride films were well enough understood to make the possibility of low-temperature deposition of silicon nitride highly attractive to the semiconductor industry prior to 1973. Silicon dioxide, the mainstay of dielectric thin films for semiconductor processing, was not in demand for plasma deposition in the early period of plasma development because a strong position in atmospheric chemical vapor deposition (CVD) capabilities had already been established by low-temperature passivation technology [2].

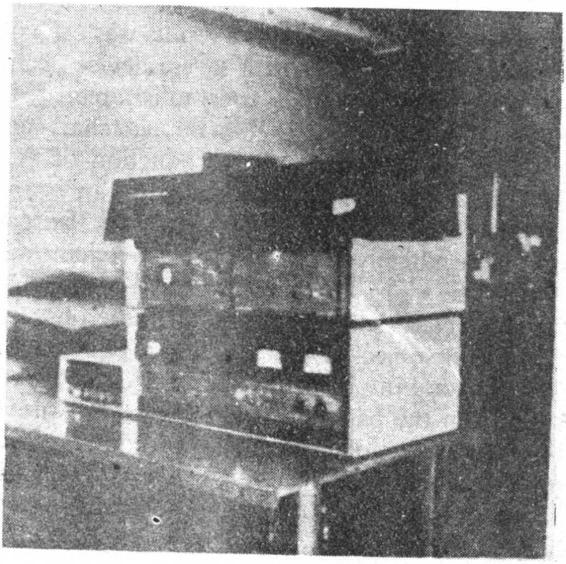

Fig. 2. Experimental plasma nitride deposition, 1970. (Courtesy of IPC Corporation.)

C. Plasma Etching of Thin Films

Plasma etching of thin films for semiconductor manufacturing was the newest and least understood of the possible plasma applications being discussed in the 1968 – 1971 period. In spite of all the growth and equipment manifestations that have occurred during the last 10 years, it should be understood that the products required for semiconductor customers dictate the process and equipment requirements. No one simply wanted dry process technology; it became a mandatory addition to the process for survival in the business of advanced integrated circuit manufacturing.

From a historical perspective, the early interest (prior to 1972) in plasma etching was minimal since variations of thermally grown or deposited silicon dioxide and aluminum were the only significant materials that required etch proceses in the mainstream of semiconductor manufacturing. Through 1972 and into 1973, these applications were adequately handled by wet chemical processes.

III. INTRODUCTION OF PLASMA PROCESSING TO SEMICONDUCTOR MANUFACTURING, 1971 – 1978

Plasma processing, and particularly plasma etching by 1972, was beginning to be recognized because of the emergence of NMOS technology; *n*-channel silicon gate MOS (NMOS) was the primary technology that produced dynamic random access memories and logic circuits such as microprocessors. When this technology began to transfer from the laboratories and development lines to full-scale production lines, the realities of etching silicon nitride layers and polycrystalline silicon films had to be dealt with. Among all other process demands in the 1970s and into present-day plasma etch applications, silicon nitride and polycrystalline silicon etching have provided the majority of the etch requirements in advanced manufacturing for plasma technology. The etching demands have certainly changed and new films and processes have been added, but the basic need for a highly dependable etch process for silicon nitride and polysilicon has not diminished.

A. Applications to Silicon Nitride and Polysilicon

Because of the significance of these etching applications, it is appropriate at this point to describe briefly and review the application of plasma etching to MOS silicon nitride and polysilicon etching. Plasma processing was