SILICON NITRIDE AND SILICON DIOXIDE THIN INSULATING FILMS

Edited by

The Electrochemical Society
Founded in Philadelphia 1902
Incorporated 1930

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PROCEEDINGS OF THE SYMPOSIUM ON

SILICON NITRIDE AND SILICON DIOXIDE THIN INSULATING FILMS

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DIELECTRIC SCIENCE AND TECHNOLOGY AND ELECTRONICS DIVISIONS

Proceedings Volume 97-10

THE ELECTROCHEMICAL SOCIETY, INC.,
10 South Main St., Pennington, NJ 08534-2896

Published by:

The Electrochemical Society, Inc.
10 South Main Street
Pennington, New Jersey 08534-2896, USA

Telephone (609) 737-1902
Fax (609) 737-2743
e-mail: ecs@electrochem.org
Web site: http://www.electrochem.org

ISBN 1-56677-137-4

Printed in the United States of America

STRESS AND BONDING CHARACTERIZATION OF PECVD SILICON DIOXIDE FILMS

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The presence of hydrogen-related impurities and the resulting stress instability of chemical vapor deposited (CVD) silicon dioxide films is an important issue in microelectronics. By observing the stress behavior and bonding nature of oxide films simultaneously, insight is provided into the possible physical causes of stress. The bonding nature and stress behavior of relatively low-temperature, high-rate deposited silicon dioxide films were investigated. Depending on the type and concentration of impurities, both reversible and irreversible bond reconstruction were observed upon annealing such films. Concomitantly, both reversible and irreversible changes in stress were observed in the annealed films. The reaction of strained Si-O bonds with moisture and a corresponding near-neighbor Si-OH formation, along with hydrogen-bonded moisture, were found to be primarily responsible for stress instability in these films. Moisture was found to play an important role in Si-O bond strain relief. Annealing the films in a steam ambient or capping the film with a thin moisture barrier material are shown to improve stress stability considerably.

INTRODUCTION

Stress in silicon dioxide films is an important issue in microelectronics and becomes more so as the wafer size continues to increase. Oxide films with moderate compressive stress are desirable to partially compensate tensile stress in the metal interconnects, thus avoiding film cracking. Different types of impurities incorporated during deposition affect the stress behavior of these films. It is important, therefore, to identify incorporated impurities and to understand their impact on film stress, especially for low-temperature, high-rate deposited silicon dioxide films. Excessive stress can cause cracking or delamination of the dielectric film and the formation of voids and notches in metal interconnects [1]. To prevent diffusion of shallow junctions, interdiffusion of metals in multi-level metallization systems, and hillock formation on aluminum metal lines, there has been a continuous move toward low temperature processes for dielectric deposition [2].

Even though PECVD produces films at reasonably low temperatures, the incorporation of impurities may make the film properties less than desirable. The most common impurities incorporated into silicon dioxide are Si-H and silanol (Si-OH). By choosing appropriate deposition conditions, PECVD films can be deposited with compressive stress values varying over a wide range [3]. However, the stability of film stress during the several thermal excursions normally associated with a fabrication process, as well as during aging is very important. The stability of different types of impurities during film aging or annealing needs to be fully investigated to gain a better understanding of their effects on stress behavior. This will help in the development of a clear cause and effect relationship between the two, which may point to ways for more precisely controlling stress in these films.

The effects of annealing and aging on the behavior of CVD oxide films have been studied since the 1970s [4,5]. However, the effects of aging and the resulting changes in chemical bonding in CVD oxide films have only recently been studied in detail [6]. Even though moisture has been reported to be responsible for changes in film stress during aging, no detailed study has been reported so far which correlates the change in stress with changes in the bonding nature and impurity content of the films [5].

The stress behavior of PECVD oxides vary during annealing and/or aging depending on the impurity content in the material. In the work reported here, concurrent FTIR and stress studies on low-temperature, high-rated deposited silicon dioxide films were performed in order to establish a cause and effect relationship between the two. From the FTIR and stress study results, the impurities involved, their impact on stress, and their chemical bonding stability during annealing and/or aging were identified. In light of the results of this bonding and stress behavior study, different techniques for improving the stability of low-temperature, high-rate deposited silicon dioxide films were determined.

EXPERIMENTAL

A Plasma-Therm model Shuttle-Lock SLR 700 PECVD system was used for all film depositions. In this system, the reactant gases are delivered through a showerhead type powered electrode. The deposition parameters used are shown in Table 1. P-type, <100>, 125 mm diameter, 650 μm thick silicon wafers were used as substrates for all films on which stress measurements were performed. For the FTIR study, all the oxide films were 1 μm thick and were deposited on substrates cut from 75 mm diameter, 360 μm thick, double-side polished, lightly-doped, p-type silicon wafers. For the specified deposition parameters, the deposition rate was about 1000 Å/min and changed negligibly with deposition temperature. The films were annealed at temperatures in the range of 250-400°C. Unless otherwise noted, all annealing was performed in a Labline Instruments oven in a nitrogen ambient at atmospheric pressure for 30 minutes.

A Nanospec model CTS 102 system was used to measure film thickness. A Mattsons Research Series FTIR system with a resolution of 4 cm^{-1} in the mid-IR range (400-4000 cm^{-1}) was used to study the bonding characteristics and impurity content of the material. This system uses a deuterated triglycine sulphate (DTGS) detector operating at room temperature

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