Available online at www.sciencedirect.com
SCIENCE DIRECT®
Microelectronic Engineering 82 (2005) 129–135
MICROELECTRONIC ENGINEERING
www.elsevier.com/locate/mee

Profile control in high aspect ratio contact hole etching by a capacitively coupled plasma source

T.F. Yen [a], K.J. Chang [a], K.-F. Chiu [b,*]

[a] ProMOS Technologies Inc., Hsinchu, Taiwan
[b] Department of Materials Science and Engineering, Feng Chia University, 100 WenHwa Road, Taichung 407, Taiwan

Received 24 March 2005; received in revised form 20 June 2005; accepted 5 July 2005
Available online 28 July 2005

Abstract

Two types of masking methodologies for high aspect ratio deep contact hole etching, photo-resist (PR) masks only and poly-silicon hard masks (poly-HM), have been applied and studied. In order to understand the variation of plasma chemistries, the optical emission spectroscopy has been used to characterize the reactions of plasma etching. A novel technique for bowing-free 0.1-μm deep contact hole etching using either PR or poly-HM has been developed. It has been demonstrated that a straight vertical profile of deep contact hole can be obtained by controlling two process factors: polymer deposition rates and ion extraction energy. The step-by-step control of top and bottom powers in the capacitively coupled plasma has been found to be an effective method to avoid profile bowing and tapering in the etching process. The deep contact holes with aspect ratio >30 and profile angle of 89.8° have been obtained.

Keywords: High aspect ratio; Contact hole etching; Vertical profile; Capacitively coupled plasma

1. Introduction

The demands for more cost effective manufacturing of dynamic randomly access memories (DRAM) have ever been increasing. To meet the requirements, the feature sizes of the devices scales down whereas the heights (depths) of storage node capacitor increase to compensate for the for higher capacitance criteria. In fact, in stack DRAMs, the metal aspect ratios of metal contacts and storage nodes have reached 30. Due to the scaling down of feature sizes, the exposure wavelength of the light source for sub 90-nm photolithography has been reduced from 248 to 193 nm to better control the critical dimension. In the mean time, the thickness of photo resists decreases for higher expose accuracy. The thinner photo resists may not have enough photo-resist etching resistance. The hard

* Corresponding author. Tel.: +886424517250x5336; fax: +886424510014.
E-mail address: kfchiu@fcu.edu.tw (K.-F. Chiu).

0167-9317/$ - see front matter
doi:10.1016/j.mee.2005.07.001

mask processes are, therefore, introduced to address the photo resist thinning issue. However, for both photo resist and hard mask processes applied in high aspect ratio (>20) contact etching, profile bowing is almost inevitable. Studies on the mechanisms of profile bowing in high aspect ratio contact etching is, therefore, of great interest and importance [1,2]. By better understanding of the mechanisms, straight vertical etch profiles may be obtained.

Some recent studies have shown that it is important to control the balance of radical and ion fluxes in perfluorocarbon gas plasma, in order to obtain high photo resist etch selectivity and bowing-free contact profile [3–6]. Investigations on plasma chemistries have shown that surface polymerization, and the density of CF_2 and CF_3 radicals influence the etch rate of dielectric layer and therefore determine the etching selectivity. It is beneficial to properly maintain the balance between the radicals (such as CF_2 and CF_3) to obtain a vertical etched profile [7].

In this study, we reported that the deep contact hole etching processes using photo resist masks and using poly silicon hard masks exhibited different plasma chemistries, and therefore the induced profile bowing is also different. Understanding the mechanisms of polymer formation provided the information for controlling straight etching profile. The comprehensive results showed the plasma gas chemistries and ion incident trajectories influenced the etching processes deeply. A novel process for vertical deep contact hole etching has been developed and demonstrated. Well controlled polymer deposition and ion incident trajectories have been achieved using step-by-step tuning of plasma power. Straight vertical profiles of deep contact holes with aspect ratio >30 can be obtained.

2. Experimental

Two test wafers were separated into two groups. One used 3000-Å thick poly-silicon hard masks (poly-HM) on TEOS-type SiO_2. The other test wafers utilized 3900-Å thick photo-resist mask (PR-M) on BARC-type SiO_2. The critical dimension (CD) of the holes is 0.12 μm for both PR and poly-HM wafers. The etch properties and mechanisms for both types of wafers were investigated. All the wafers were processes in a Helium cooled capacitively coupled plasma (CCP) etch reactor [8] with the processing temperatures of 60/60/−15 °C for the top electrode/wall/bottom electrode, respectively. During the plasma process, the working pressure was 15 mTorr. The working gas was a mixture of high purity $C_5F_8/O_2/Ar$ with flow rates of 12–15, 10–20 and 200–500 sccm, respectively. The electrodes were powered by power supplies with frequencies of 60 MHz for the top electrode and 2 MHz for the bottom electrode. The power suppliers can be tuned step-by-step to give powers up to 1800 W (top) and 2000 W (bottom). The etch profiles at different processing times were examined. The profile tapering, necking and bowing of the deep contact holes were observed for both poly-HM and PR-M wafers. In order to precisely define the profile quality in both poly-HM and PR-M samples, effective and comprehensive profile parameters should be designed. A statistical method was applied for this purpose. First, two assumptions were made: (1) on a wafer, different holes with the same etching time have the same profile parameters; (2) for different etching time, the profile parameters change accordingly. All possible parameters were chosen and defined in Table 1 and Fig. 1. A series of experiments and statistical analysis were carried out and based on the results the effective profile parameters were clearly defined. Cross-sectional micrographs of the etched contact holes were taken by scanning electron microscope (SEM) to identify the profile quality. For each testing groups, 50 wafers have been processed. For each wafer, five measurement sites from wafer edge to center were randomly chosen. After cross-sectional cut, there were five contact holes at each site. Among them, the cross-sections of two best cut holes (1p and 2p) were used for SEM observation and profile parameter determination.

The optical emission spectra (OES) of the plasma at the initial and ending stages of etching were recorded to analyze the plasma chemistries. The OES scanning wavelength ranged from 200 to 800 nm, with the photo-multiplier tube (PMT) ratio of 40%.