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Thin Solid Films 504 (2006) 117 – 120
thin solid films
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Integrated process of photoresist trimming and dielectric hard mask etching for sub-50 nm gate patterning

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Available online 2 November 2005

Abstract

Photoresist (PR) trimming for narrowing gate critical dimensions (CD) to sub-50 nm range is a known technique in polysilicon gate CMOS technology. However, the trend to replace polysilicon by a suitable metal such as TaN involves replacement of PR mask by a dielectric hard mask (HM) for providing tight CD and profile control in subsequent TaN etching. We have found that traditional selective etching of dielectrics on top of TaN film poses many challenges. Besides, PR trimming also should be tuned so that PR mask after trimming could match requirements of HM etching. By study and optimization of both PR trimming and HM etching in dipole ring magnetron etcher, we developed a production worthy processes for fabrication of sub-50 nm hard mask used for TaN gate etching in CMOS technology.

Keywords: Photoresist trimming; Hard mask; Sub-50 nm; Dipole ring magnetron

1. Introduction

Scaling critical dimensions (CD) of CMOS devices to sub-50 nm range poses great challenges for development of robust lithography and etching processes. Moreover, current DUV lithography capabilities are limited to 70–80 nm even with the introduction of advanced phase-shift masks (PSM); therefore, photoresist (PR) trimming process is becoming a mandatory step [1]. Next, a special feature of sub-50 nm TaN gate patterning is the need of dielectric hard mask (HM), as (PR) mask causes considerable CD gain during subsequent gate etch [2]. However, even etching of relatively thin HM presents a challenge, as etching process should find a balance between contradicting requirements of providing sufficient selectivity to thin PR and avoiding formation of excessive sidewall polymer resulting in CD gain. We found that usage of traditional selective fluorocarbon plasma for etching of HM on top of TaN results in large CD gain; therefore, O_2 should be added. However, etching with O_2-containing plasma created a problem of redeposition of Ta-containing by-products during over-etching step. Thus, two-step HM etching should be developed to satisfy contradicting requirements of main etch and overetch steps. Due to O_2 added in the main etch step, selectivity to PR will be low; hence, the PR trimming process should provide not only sub-50 nm CD but also retain sufficient PR thickness.

Usually PR trimming is performed in situ as a part of the polysilicon gate etching process [3]. This is well justified when gate etching is performed with PR mask. However, in our case, when gate material is TaN, it is reasonable to perform steps of PR trim and subsequent HM etching ex situ, in a specialized chamber.

Thus, in this study, we concentrated on the development of integrated ex situ PR trimming and dielectric HM etching in the dipole ring magnetron (DRM) chamber widely used by the industry.

2. Experimental

80-nm-thick SiO_2 HM was deposited by PECVD on either 8-in. bare silicon substrate or on silicon substrate with a layer of TaN. Lithography was performed in Nikon 248-nm DUV step and scan system with alternating PSM using DUV resist with

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doi:10.1016/j.tsf.2005.09.152

bottom organic antireflective coating (BARC). Post development CD were in the range of 80–85 nm. Integrated process of PR trimming and HM etching was performed in the Unity IIe 85DD DRM system from Tokyo Electron Ltd. DRM chamber is a single frequency (13.56 MHz) magnetically enhanced reactive ion etching (MERIE) system, where RF power is applied to the lower electrode (wafer chuck). The system has two identical DRM chambers. One of them is dedicated for dielectric etching and another for PR stripping and trimming. PR trimming and HM etching was followed by PR stripping in Mattson ICP (inductively coupled plasma) reactor where 1% of CF_4 was added to O_2 plasma for effective removal of sidewall by-products. Etching results were evaluated by scanning and transmission electron microscopes (SEM and TEM). Gate CD measurements were performed in Hitachi CD SEM, tilted view analysis was performed in SEMVision™ from Applied Materials, cross-section analysis was performed in JEOL FESEM JSM6700F, TEM and EDX (energy dispersive X-ray) analyses were performed in Philips CM 200FEG system with EDAX detector. Study of effects of various process parameters and optimization was performed by design of experiment (DOE) using statistical analysis software Cornestone™.

3. Results and discussions

3.1. Development of photoresist trimming process

To provide optimal performance of 248-nm lithography with PSM, PR thickness was reduced to 280 nm. Moreover, it was found that after lithography due to short range flare and some other effects the PR thickness tends to decrease with the dimension of the lines. PR thickness for lines with printed CD of 85 nm was 10% less comparing to PR thickness of large pads. Due to decrease of PR thickness in lines after lithography and taking into account low expected selectivity in HM etching, the highest priority in PR trimming development was to minimize loss of PR thickness in vertical direction during PR trimming. In other words in order to secure maximal remaining thickness of PR it is required to minimize the ratio of PR strip rate to PR trim rate. To be controllable and reproducible trimming rate should not be too high, so, it is desirable to dilute O_2 by less chemically active gas. It is known that dilution by N_2 in a low pressure plasma provided noticeable reduction of both vertical and lateral

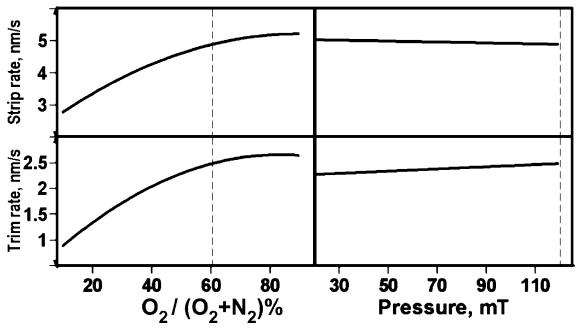

Fig. 1. Photoresist trim and strip rates versus pressure and O_2 percentage in the mixture of O_2+N_2. Vertical dashed lines show variable settings optimized for minimal strip rate/trim rate ratio.

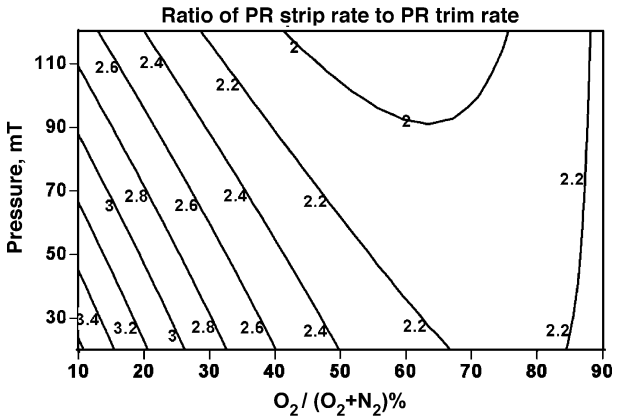

Fig. 2. PR strip rate/PR trim rate ratio as a function of pressure and O_2 percentage in the mixture of O_2+N_2.

etch rates of PR [4]. Thus, trimming, including BARC opening step, was performed in O_2+N_2 chemistry. The moment of BARC opening was controlled by spectral endpoint system monitoring CO (484 nm) line. Further PR trimming continued during BARC overetch step. It was found that during overetch, along with overall PR trimming, lines becomes narrowed at the bottom. We quantified this effect by the parameter called profile undercut value, calculated as the difference between maximal and minimal width of line profile (Fig. 4). Minimization of profile undercut was another priority of this development.

After some screening experiments further optimization of trimming parameters was performed using DOE in which variable factors were pressure and O_2 percentage in the mixture of O_2+N_2. The variation range of pressure was 20–120 mT, the range of O_2 percentage was 10–90%. Other parameters were kept constant: power at 125 W, chuck temperature at 40 °C, inter-electrode gap at 27 mm. We used quadric model for O_2 percentage (three levels of factor variation), and linear model for pressure (two levels of factor variation); interaction of both factors was included in the model as well. The responses investigated were PR strip rate (PR removal rate in vertical direction), PR trim rate for isolated lines (difference of line CD after lithography and CD after trimming divided by time), uniformity of trim rate across the wafer, PR strip rate/PR trim rate ratio and trim value/undercut value ratio. According to the chosen DOE plan six experimental runs were performed. After trimming, all wafers were measured in CD SEM followed by cross-section SEM analysis. For all DOE wafers printed lines with CD of 80–90 nm were trimmed down to a narrow range of 37–47 nm due to individual adjustment of overetch time for each wafer. Response data obtained were subjected to regression analysis and the etching model was generated.

The results of the analysis can be visualized in Figs. 1–3. Fig. 1 presents effect of the variables on PR strip and trim rates. As expected, both trim and strip rate go up significantly with O_2 percentage. Effect of pressure is not so strong but it is important that stripping rate decreases while trimming rate slightly increases with pressure. This creates a room for optimization of PR strip rate to PR trim rate ratio. Fig. 2 presents effect of the variables on the ratio of PR strip rate to PR trim rate. At a fixed O_2 percentage, the ratio of PR strip rate to PR trim rate