P-1-14

Extended Abstracts of the 2011 International Conference on Solid State Devices and Materials, Nagoya, 2011, pp34-35

Enhanced Sidewall Growth (ESG) process: towards PEALD with conformality above 100%

Shintaro Ueda, Atsuki Fukazawa, Hideaki Fukuda, and Nobuyoshi Kobayashi
ASM
23-1-6, Nagayama, Tama-Shi Tokyo, 206-0025, Japan
Phone: +81-42-337-6314 E-mail: ueda@asm.com

1. Introduction

Plasma Enhanced ALD (PEALD) can deposit conformal dielectric films into deep trenches at 100ºC [1]. In this work, we report the Enhanced Sidewall Growth (ESG) process: a modified PEALD SiO_2 process providing a step-coverage > 100% with an accurate control of the ratio sidewall/top thickness (Fig.1). We also discuss the ESG mechanism which is based on ion-assisted surface reactions. Feasibility of this process is demonstrated for different applications.

2. Experimental

PEALD SiO_2 was performed in a single-wafer reactor with parallel plate electrodes where RF power of 13.56 MHz was applied. One cycle of ESG process consists of PEALD SiO_2 deposition and C1 plasma irradiation (Fig.2). In this process, an aminosilane was used as a Si precursor with O_2 as a reactant gas and C1 which consists of $C_xN_yH_x$ with arbitrary x, y and z numbers. The gas pulse was controlled with a switching valve, and the reactor pressure was maintained at constant pressure by feeding Ar and He carrier gases. Deposition was carried out between 100ºC and 400ºC. PEALD SiO_2 was performed by repeating a few-second process cycle, where the chemisorbed Si precursor was oxidized by O_2 plasma to form SiO_2.

3. ESG results and mechanism

The ratio of sidewall/top film thickness (S/T) was evaluated on isolated trenches by changing C1 plasma irradiation time and RF power from 0 W to 800 W (Fig.3). Without RF power during C1 supply, S/T ratio stayed around 1.0, which corresponds to the conformal deposition by PEALD SiO_2. When the RF power was applied, the S/T ratio increased linearly with the C1 plasma irradiation time. When the C1 plasma irradiation with twice RF power was added after each PEALD SiO_2 cycle, S/T reached 1.9. The anisotropic shape is not due to the sputtering of C1 plasma, because the conformal shape of PEALD SiO_2 did not change by the C1 plasma irradiation with same PEALD cycle numbers after the PEALD SiO_2 process. The film thickness linearly increased with the cycle number, and S/T ratio was compared between ESG and PEALD SiO_2 (Fig.4). The S/T ratio of 1.7 was not changed by the cycle numbers in ESG process. This indicates that SiO_2 films growth was anisotropically suppressed by inserted C1 plasma irradiation after each PEALD SiO_2 cycle. A hypothesis is that the SiO_2 top surface is covered with inhibitors after ion bombardments during C1 plasma irradiation at each ESG cycle. FT-IR spectra were compared between PEALD SiO_2 and ESG films where the intensity was normalized by film thickness (Fig.5). The Si-OH peak at 935 cm^{-1} was clearly observed in PEALD SiO_2 film, whereas the peak disappeared in ESG film. The Si-N peak was not observed in ESG film so that film nitridation is not present in a significant way. Additionally the intensity of Si-OH between 3000 and 3800 cm^{-1} also reduced in ESG film. Based on these results, we propose a mechanism in order to explain the ESG process that is basically ion-assisted surface reaction (Fig.6). In PEALD SiO_2, absorbed Si precursor on SiO_2 is oxidized after each chemisorption step. It is thought that hydroxyl groups on SiO_2 were chemisorption sites for Si precursor in which amine groups were included [2]. The SiO_2 profile can be controlled by ESG process because ion-assisted reaction preferably proceeds at the top and bottom trenches.

4. Applications for ESG

The gap-filling profiles into Si trenches are compared between PEALD SiO_2 and ESG films. There was a little pattern loading effect on top films thickness between isolate and dense trenches (Fig.7). Filling capability of ESG was significantly higher than PEALD SiO_2. Moreover, no seam was observed in ESG film after dipping into diluted 1% HF water (Fig.8). The ESG process was applicable to the spacer deposition onto photoresist patterns by reducing the RF power to prevent O_2 plasma damage (Fig.9). In the ESG process, the films thickness can be precisely controlled with an excellent within wafer uniformity. These properties are important for the critical dimension control in Spacer Defined Double Patterning (SDDP).

5. Conclusions

We developed the Enhanced Sidewall Growth (ESG) in order to reach conformality above 100%. The ESG process controls the ratio of sidewall/top >1.0 and the film thickness is also controlled at a nano level. These specifications were confirmed at temperatures from 100ºC to 400ºC. A proposed mechanism for anisotropic film growth is the ion-assisted surface reaction on SiO_2 during C1 plasma irradiation. This SiO_2 process enables a nano level film formation without damage for various applications, for example gap-filling, SDDP, TSV and so on.

6. References

[1] A. Sherman, U.S. patent 6,616,986, 2001
[2] T. Blomberg, R. Matero, S. Haukka, and A. Root: Mater.Res.Soc.Symp.Proc.Vol.1066, 2008.

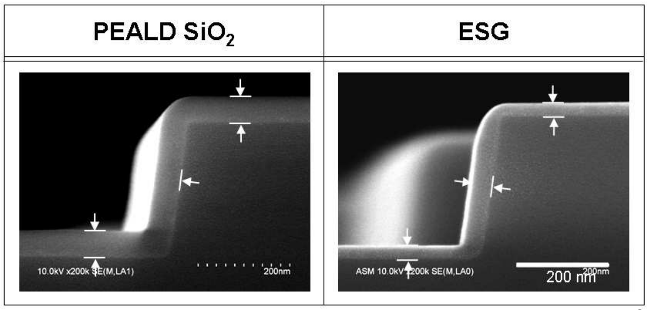

Fig.1 Step coverage comparison between PEALD SiO_2 and ESG films

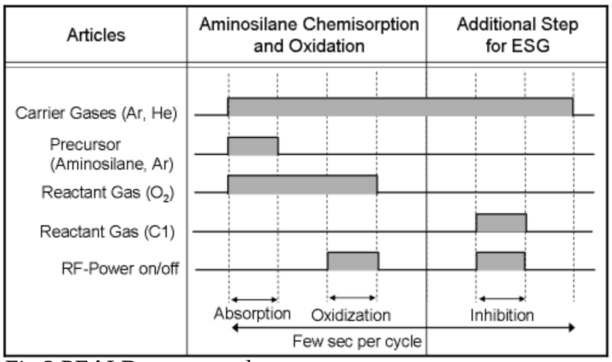

Fig.2 PEALD reactor and process gases.

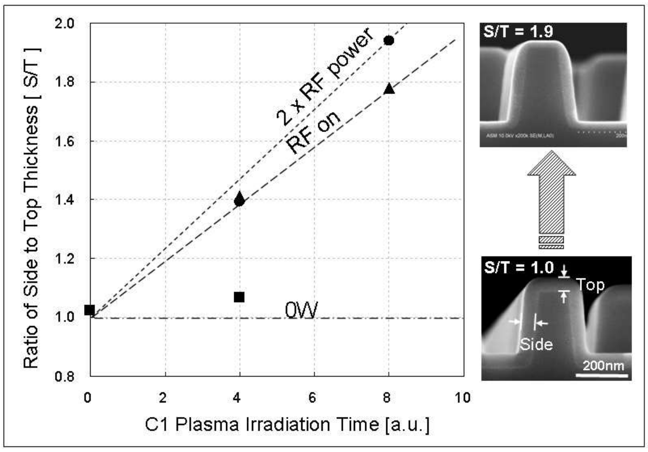

Fig.3 One process cycle consisted of several steps for ESG process

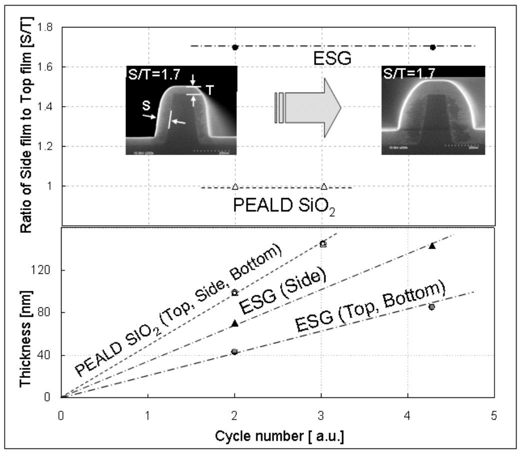

Fig.4 Thickness ratio (S/T) and film thickness as a function of ESG cycle number.

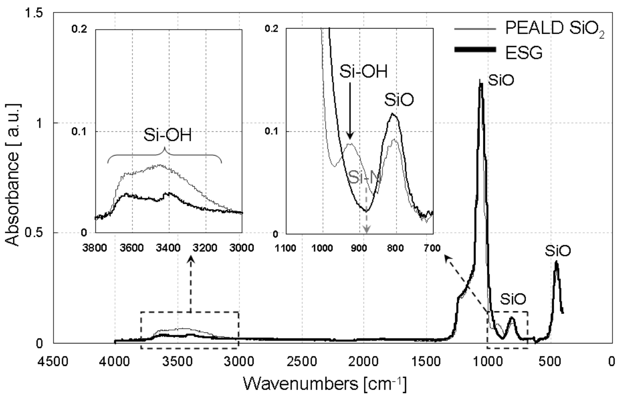

Fig.5 Comparison with FT-IR spectra between PEALD SiO_2 and ESG.

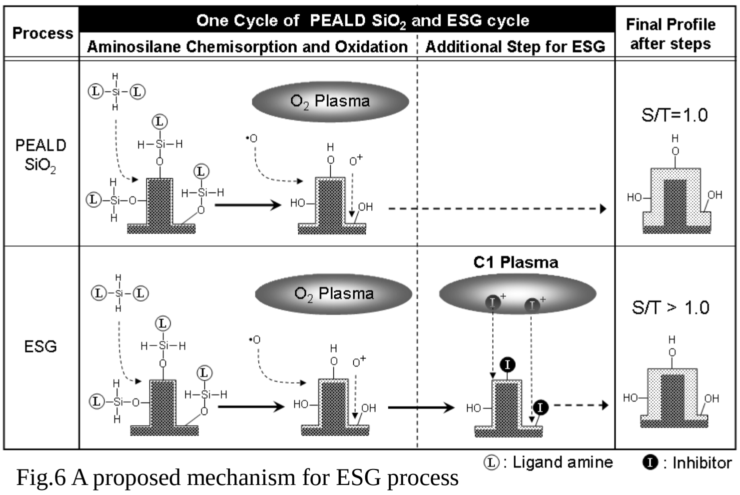

Fig.6 A proposed mechanism for ESG process

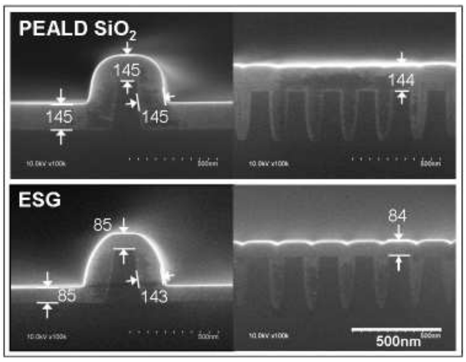

Fig.7 Gap-filling film profiles over Si trenches between PEALD SiO_2 and ESG films.

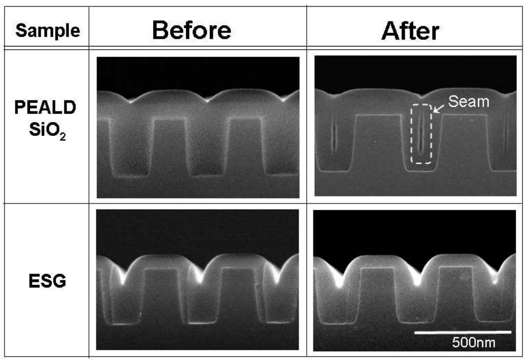

Fig.8 Wet etching evaluation by 1%HF.
Seams formed in the middle of the trench with PEALD SiO_2 during HF dip.

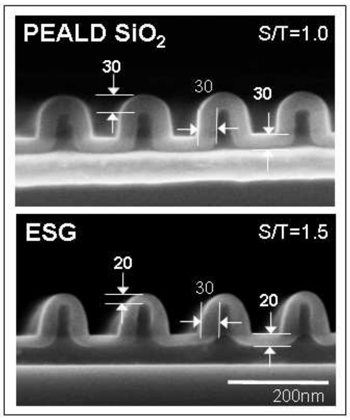

Fig.9 SiO_2 deposition on the photoresist patterns at temperatures below 100ºC.