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Characterization of Ultra Thin Oxynitride Formed by Radical Nitridation with Slot Plane Antenna Plasma

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1. Introduction

The oxynitride film is a promising candidate for thin gate dielectrics for downscaled CMOS logic devices of 100nm technology node and beyond. In this paper, a systematic study was performed on radical nitridation of thin SiO_2 films using microwave and slot plane antenna (SPA) plasma, which is based on the original work of Radial Line Slot Antenna (RLSA) by Ohmi et al [1].

2. Experiments

Figure 1 shows the feature of SPA plasma reactor. 2.45GHz microwave was introduced and distributed over the slot plane antenna to generate the uniform high density plasma just beneath the dielectric plate. Process gases were introduced by gas nozzles at the chamber wall. 200mm size wafer was put on the suscepter that can be heated to 500℃ by the resistive heater. N-type MOS capacitors were fabricated on p-type B doped silicon wafers (8-12Ω-cm). After RCA pre-cleaning, SiO_2 film (1.6nm thick) was thermally grown, and was nitrided by SPA plasma to form oxynitride. Plasma conditions are shown in Table I. After that, 300nm thick poly-Si was deposited and Phosphorous doped(4E20/cm^3) by $POCl_3$ annealing at 875℃. C-V and I-V characteristics were measured using HP4284 LCR meter and an HP4072A parametric tester. Two-frequency CV method[2] was used for CV analysis to extract equivalent oxide thickness (*EOT*) and flat band voltage (V_{fb}).

3. Results and Discussions

Figure 2 shows electron temperature (T_e) and electron density (N_e) of SPA plasma measured by Langmuir probe as a function of pressure, showing its unique feature of high plasma density with low electron temperature (1~1.4eV). Both T_e and N_e is pressure-dependent and become higher for lower pressure.

Figure 3 shows gate leakage current (J_g) and V_{fb} of both base oxide and nitrided samples as a function of *EOT*. In low-pressure(7Pa) condition, a large reduction of *EOT* (from 16A to 13A) was achieved by 20sec nitridation with small J_g increase, which indicates a substantial leakage reduction by ~1 order of magnitude compared with oxide of the same *EOT*. On the contrary, for longer nitridation, *EOT* shows turn-around and starts to increase in 40sec with V_{fb} negative shift, suggesting onset of radical oxidation/nitridation at the bottom interface. In high-pressure(67Pa), *EOT* reduction is smaller and the turn-around starts in 20sec, faster than low-pressure condition.

Figure 4 shows SIMS profile of these films. Although 40sec in high-pressure process shows higher nitrogen than 20sec in low-pressure, *EOT* is larger (less reduced by nitridation) than low-pressure. This can be explained by difference of oxygen behaviors for high and low-pressure processes. Figure 4b shows decrease of oxygen signal with proceed of nitridation, specially at nitrogen peak position, suggesting oxygen removal occurs by conversion of SiO bond to SiN bond. Although oxygen concentration is similar for high-pressure 40sec process and low-pressure 20sec, high-pressure process shows extended oxygen tail at the interface, suggesting an excess oxide (oxynitride) re-growth at the interface. Therefore, control of the oxygen behavior and suppression of this re-growth is the key to the *EOT* reduction.

Figure 5 shows I-V curves for various pressures. In low pressure, a great difference is observed between low bias(> −1V) and high bias region(< −1V). In high bias region, J_g decreases from 10sec until 40sec nitridation possibly due to oxide re-growth. On the contrary, in low bias region, the J_g increases until 40sec nitridation. The low bias leakage current is known to be related with interfacial and bulk traps [3]. The increase of J_g in low bias region is considered to be due to increased defect density at or in the vicinity of the interface possibly caused by plasma damage. High-pressure process has lower T_e and lower plasma damage than low-pressure process, though less advantageous for *EOT* reduction.

Figure 6 shows total gas flow rate dependencies of *EOT* and J_g behavior in low-pressure condition. This shows EOT reduction effect is strongly dependent on total gas flow and is greatly enhanced for higher gas flow rate. Longer gas residence time during process seems to

cause oxide re-growth at the interface. Therefore, the optimum process can be obtained by high pressure with increased total gas flow rate. J_g and V_{fb} characteristics of this process(130Pa) is also shown in Fig.3. In this process, J_g is not increased, but is suppressed together with EOT reduction, and V_{fb} shift was also suppressed until 40sec nitridation. In Fig.5c, low bias leakage current remains low and the damage can be neglected in this process.

4. Conclusions

Oxynitride thin films formed by SPA plasma was studied. Low-pressure process shows superior *EOT* reduction, but degraded interfacial properties than high-pressure condition. By using high gas flow rate and high-pressure process, we could achieve excellent oxynitride films(~1.3nm) with low leakage and no Vfb-shift.

References

[1] Katsuyuki Sekine, Yuji Saito, Masaki Hirayama and Tadahiro Ohmi, *J. Vac. Sci. Technol. A 17 (5), Sep/Oct 1999* p. 3129.

[2] Akiko Nara, Naoki Yasuda, Hideki Satake and Akira Toriumi, *Extended Abstracts of SSDM, 2000* p. 452.

[3] Andrea Ghetti, Enrico Sangiorgi, Jeff Bude, T.W.Sorsch and Gary Weber, *Technical Digest of the international Electron Devices meeting, 1999* p. 731.

Table I Nitridation Condition

Pressure	Gas Flow Rate	MW Power
7Pa(50mTorr)	Ar/N_2=1000/40sccm	1000W
67Pa(500mTorr)	Ar/N_2=1000/40sccm	1000W
130Pa(950mTorr)	Ar/N_2=2000/150sccm	1500W

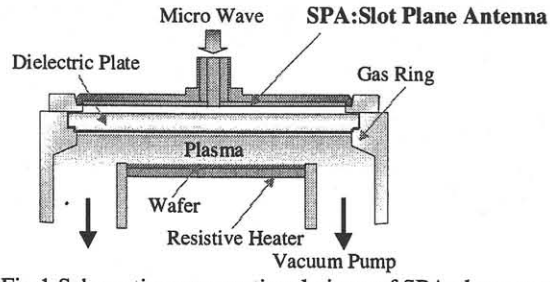

Fig.1 Schematic cross-sectional views of SPA plasma system

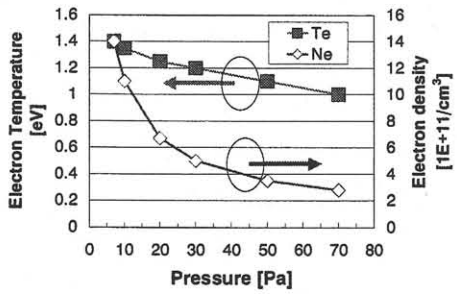

Fig.2 Electron temperature (T_e) and electron density (N_e) of Ar/N_2 plasma,Ar/N_2:1000/20, MW:1000W, Pressure:7Pa to 70Pa.

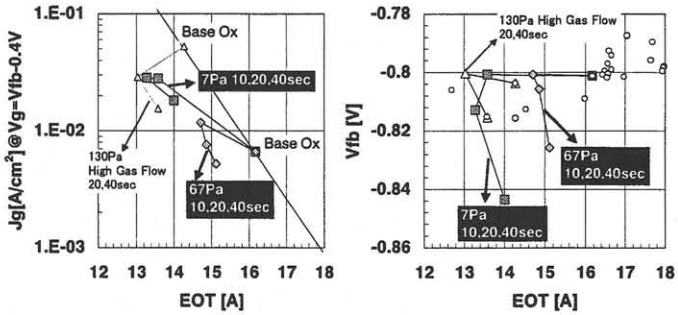

Fig.3 Jg and V_{fb} changes as a function of *EOT*. Capacitor area:2500cm^2. Circle point of V_{fb} graph means Reference oxide.

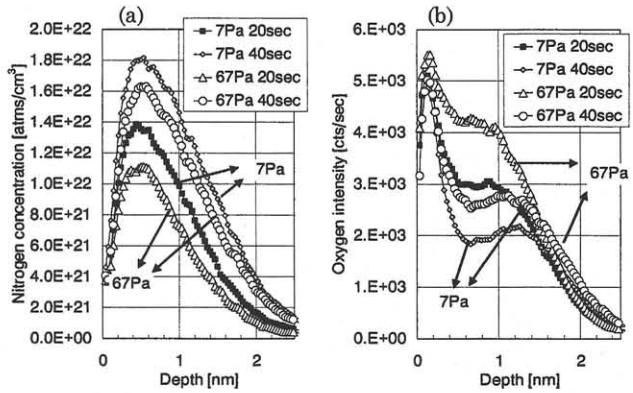

Fig.4 a,b SIMS profiles of nitrogen (a) and oxygen (b) on SPA oxynitride thin films. Base oxide thickness was 2.0nm.

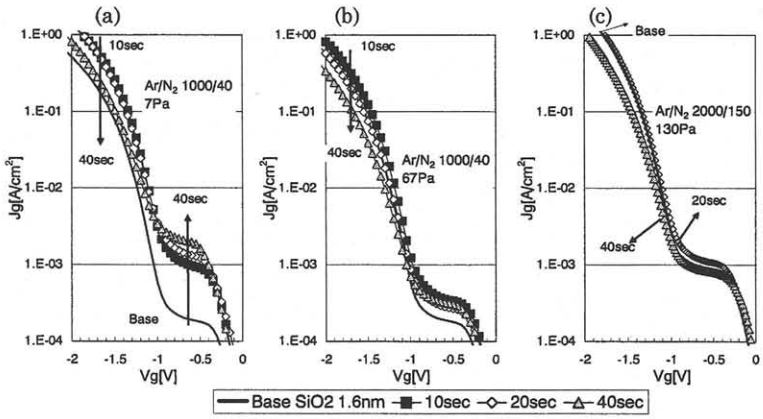

Fig.5 a,b,c I-V curve of various conditions. Capacitor: 2500um^2

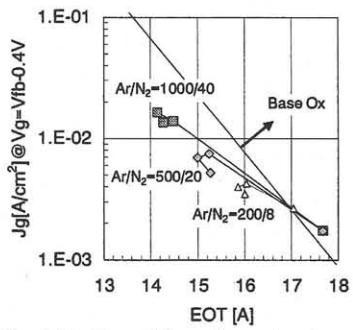

Fig.6 Total gas flow dependencies of *EOT* and *Jg* in low-pressure (7Pa). Capacitor area: 2500um^2