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Characteristics of Low Temperature High Quality Silicon Oxide by Plasma Enhanced Atomic Layer Deposition with In-situ Plasma Densification Process

Haiwon Kim[1,2], Zaretskiy Sergey[2], Seungwoo Shin[2], Wooduck Jung[2], Ryong Hwang[2], Jaeho Lee[2], Choonsik Jeong[2], Seongjin Park[2], Hanna Hwang[2], and Ilsub Chung[1]

[1]College of Information and Communication Engineering, Sungkyunkwan University, Suwon 440-746, Korea
[2]Research and Development group, Eugene Technology, Yongin 449-824, Korea

Silicon oxide (SiO_2) has played an important role in the semiconductor industries, such as gate dielectric, gate spacer, inter-poly dielectric, and liner layer in the shallow deep trench. However, as the device is scaled down, two main issues have appeared. One is a poor film step-coverage and the other is a high deposition temperature of SiO_2. Method of conventional low pressure chemical vapor deposition (LP-CVD) is limited in conformal films deposition on the higher density devices. To overcome this disadvantage, plasma enhanced atomic layer deposition (PEALD) method has been developed in recent years to deposit low temperature SiO_2. ALD process offers excellent film step-coverage with atomic level thickness control due to self-limited surface reaction [1] but it has suffered from adoption of the semiconductor devices because of lower films quality deposited at temperature below 500°C using carbon-containing precursor [2, 3].

In this work, in-situ O_2 plasma densification (DENSIFICATION) effect on SiO_2 that has been deposited by PEALD at temperature (< 400°C) was investigated. Fig.1 shows the deposition sequence of high quality low temperature SiO_2 films. The key point is that a SiO_2 deposition is followed by DENSIFICATION. High quality SiO_2 film was deposited using $SiH_2[N(C_2H_5)_2]_2$ [bis-diethylamino-silane] as the silicon precursor and plasma-activated O_2 as the reactant.

The deposition and DENSIFICATION temperatures were the same (375°C). The ALD cycle and DENSIFICAITON step pressures were 2torr and 0.15torr, respectively. The plasma powers of deposition and DENSIFICATION were 600watt and 1000watt, respectively.

DENSIFICAITON time was varied, and its effect on wet etch rate was studied. The wet etch rate (100:1 HF) decreased with increasing DENSIFICAITON process time (Fig.2) due to the residual impurities (mainly 'carbon') reduction in the SiO_2 film by oxygen radical [2]. The wet etch rates data of SiO_2 films deposited by various methods were presented. The characteristics of wet etch rate of high quality low temperature SiO_2 demonstrate lower than LP-CVD SiO_2 (LP HTO & LP TEOS) values (Fig.3). Fig.4 shows the leakage current density curves of SiO_2 with 4.9nm equivalent oxide thickness (EOT). The films were deposited by thermal oxidation (850°C), LP-CVD HTO (780°C), and low temperature PEALD with DENSIFICAITON. The electrical characteristics of abovementioned films were measured by using n+Si/SiO_2/n+Si structure. High doped n+ poly Si films were utilized as the top and bottom electrodes.

Dielectric breakdown of high quality SiO_2, LP-CVD HTO and thermal SiO_2 films occurred at 6.7V, 4.35V and 6.7V, respectively, under the positive bias condition on the n+ poly top electrode. From the simple calculation breakdown fields were around 13.5MV/cm, 9.0MV/cm and 13.5 MV/cm, respectively.

In conclusion, low temperature high quality SiO_2 with an excellent breakdown field and a lower wet etch rate compared to the high temperature LP-CVD SiO_2 has been deposited by PEALD with DENSIFICATION.

References

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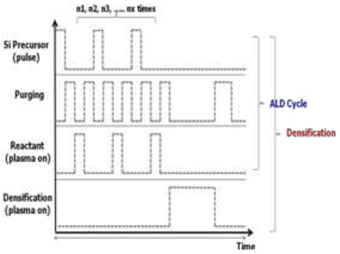

Fig.1. Deposition sequence of high quality low temperature SiO_2 films

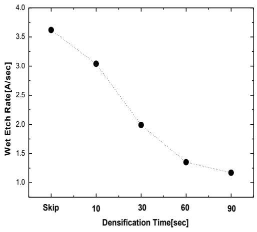

Fig.2. 100:1 HF wet etch rate of high quality SiO_2 as a function of plasma densification time.

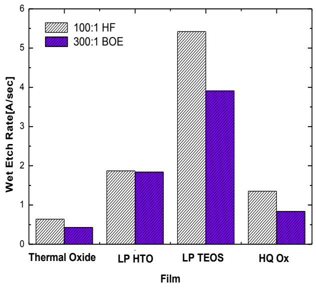

Fig.3. Wet etch rate of SiO_2 films deposited by various methods

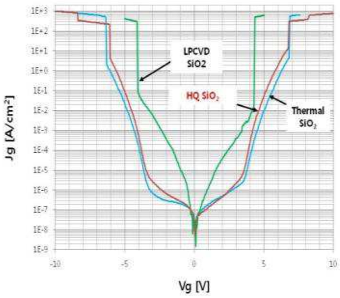

Fig.4. Leakage current density curves of SiO_2 films with 4.9nm EOT