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Characteristics of SiO_2 Film Grown by Atomic Layer Deposition as the Gate Insulator of Low-Temperature Polysilicon Thin-Film Transistors

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Abstract. SiO_2 films were prepared by atomic layer deposition (ALD) technique, and their physical and electrical properties were characterized for being applied as a gate insulator of low-temperature polysilicon thin-film transistors. ALD SiO_2 films were deposited at 350–400 °C using alternating exposures of SiH_2Cl_2 and O_3/O_2, and the characteristics of the deposited films were improved with increasing deposition temperature. The ALD films deposited at 400 °C exhibited integrity, surface roughness and leakage current better than those of the conventional plasma-enhanced chemical vapor deposition (PECVD) films.

Introduction

SiO_2 has been one of the most popular gate insulators for low-temperature polysilicon (LTPS) thin-film transistors (TFT). The gate insulator SiO_2 film with excellent physical and electrical properties should be prepared at lower temperatures than 400°C. Plasma-enhanced chemical vapor deposition (PECVD) method has been used for this purpose; however, the properties of the SiO_2 film and the Si/SiO_2 interface are serious issues for LTPS-TFT devices [1]. Recently, atomic layer deposition (ALD) technique attracts much interest in semiconductor manufacturing, because the uniform thin films with excellent properties can be deposited by this method even at lower temperatures than conventional CVD. ALD process consists of self-limited surface reactions, where the substrate surface is alternatively exposed to the different precursors [2, 3]. In addition, thermal ALD process does not need plasma, so the gate insulator prepared by ALD method is expected to reduce interfacial charges between Si active layer and gate insulator. However, there has been no report on the ALD gate insulator for LTPS-TFT applications.

In previous work, we deposited SiO_2 films by ALD technique using alternating exposure of SiH_2Cl_2 and O_3/O_2 [4]. In this work, we evaluate ALD SiO_2 films as the gate insulator of LTPS-TFT. The physical and electrical characteristics of ALD SiO_2 films deposited at below 400°C were compared with those of PECVD SiO_2 films.

Experimental Procedure

Dichlorosilane (SiH_2Cl_2) and O_3/O_2 were used as the precursors. O_3 was generated by corona discharge inside the delivery line of O_2, and the concentration of O_3 was approximately 8.6 at % of O_2. N_2 was used as the purging gas between the pulses of precursors. Boron-doped Si (100) wafers were used as the substrate for the ALD of SiO_2. The native oxide on Si wafers was removed by buffered oxide etch (BOE) solution composed of HF and NH_4F. Table 1 shows the processing conditions of wet oxidation and PECVD of SiO_2 films. The thickness of SiO_2 films grown by various methods was fixed at 75 nm, and the thickness variations were below 5 nm.

Table 1. Process conditions of various SiO_2 thin films used in this study.

Deposition Method	Precursor	Processing Temperature (°C)
Wet Oxidation	H_2O/O_2	900
PECVD	SiH_4, N_2O	400
ALD	SiH_2Cl_2, O_3/O_2	350–400

The thickness and refractive index of deposited films were measured by using an ellipsometer. An X-ray photoelectron spectroscopy (XPS) system was utilized for composition analysis, and an atomic force microscope (AFM) system was used for measuring surface roughness. The wet etch rate of the deposited films was evaluated in a diluted HF solution (1000:1). Leakage currents through various SiO_2 films were measured by utilizing metal-oxide-silicon (MOS) structure. Al electrodes were formed by thermal evaporation method with a shadow mask, and then the MOS structure was annealed at 400°C for 1 hr in a H_2(3%)/Ar ambient.

Results and Discussion

Figure 1 shows the changes of the growth rate and the refractive index of ALD SiO_2 film with varying deposition temperatures ranging from 350 to 400°C. The exposure of SiH_2Cl_2 and O_3/O_2 were maintained at 5.0×10^9 L. The growth rate was 0.17 nm/cycle at 350°C, and increased to 0.20 nm/cycle and 0.21 nm/cycle as the substrate temperature increased to 375°C and 400°C, respectively. The refractive index also increased gradually with increasing the temperature, and reached to 1.46±0.01 at 400°C, which is the same with the value of stoichiometric SiO_2.

XPS analysis was performed to obtain the chemical composition of the prepared films as shown in Table 2. The stoichiometry of the ALD film was almost the same with the films prepared by other methods. The Cl content of the ALD film is due to SiH_2Cl_2, and decreased from 0.16 to 0.09 at.% with increasing deposition temperature.

The wet etch rates of the films were estimated with a diluted 1000:1 HF solution to investigate the density and integrity of the films. The obtained results are shown in Fig. 2. The film prepared by wet oxidation exhibited the lowest rate of 2.5 nm/min, and the PECVD film showed 6 nm/min. The wet etch rate ALD films decreased with increasing deposition temperature, and showed lower etch rates as compared with PECVD films at the deposition temperatures of 375 and 400°C.

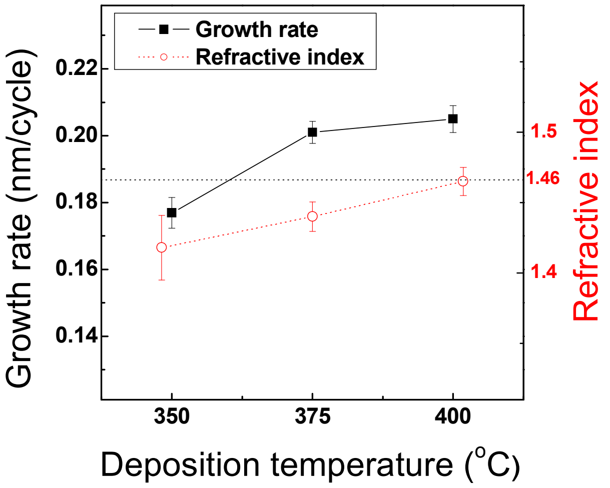

Fig. 1. Growth rate and refractive index of the ALD SiO_2 films as a function of deposition temperatures at a fixed SiH_2Cl_2 and O_3/O_2 exposures of 5.0×10^9

Table 2. Atomic concentrations of various SiO_2 thin films determined by XPS.

Method	O 1s[at.%]	Cl 2p[at.%]	Si 2p[at.%]
Wet Oxidation	62.36	-	37.64
PECVD	64.80	-	35.20
ALD (350°C)	63.47	0.16	36.37
ALD (375°C)	63.69	0.15	36.16
ALD (400°C)	63.65	0.09	36.26

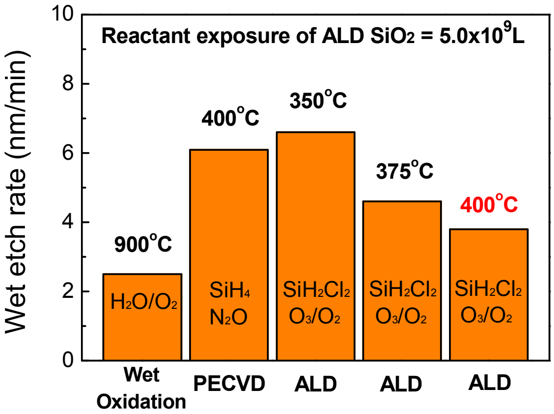

Fig. 2. Wet etch rate of SiO_2 thin films in a dilute HF solution.

The root-mean-square (RMS) values of surface roughness of various SiO_2 films are shown in Fig. 3. The RMS roughness values of the SiO_2 films prepared by wet oxidation and ALD (400°C) were 0.15 nm and 0.24 nm, respectively, which are much smaller than 3.07 nm obtained from PECVD films. This result indicates the ALD film had a much smoother surface morphology than conventional PECVD films owing to the self-limiting nature of ALD reaction mechanism. On the other hand, PECVD films are grown by the three-dimensional island growth mode, resulting in rough surface morphology.

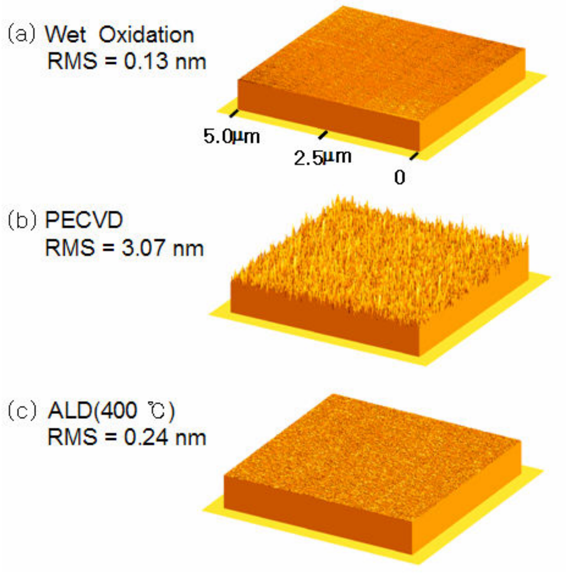

Fig. 3. Surface morphologies of various SiO_2 films.

The I-V characteristics were measured to evaluate electrical properties of ALD SiO_2 films. As shown in Fig. 4, wet oxidation films showed the lowest leakage current (0.95nA/cm^2) at a fixed electrical field, 3 MV/cm. The leakage current of ALD films decreased abruptly with increasing the deposition temperature. The ALD film deposited at 400°C showed 6.78 nA/cm^2 at 3 MV/cm, which is lower than that of PECVD films (20.68 nA/cm^2).

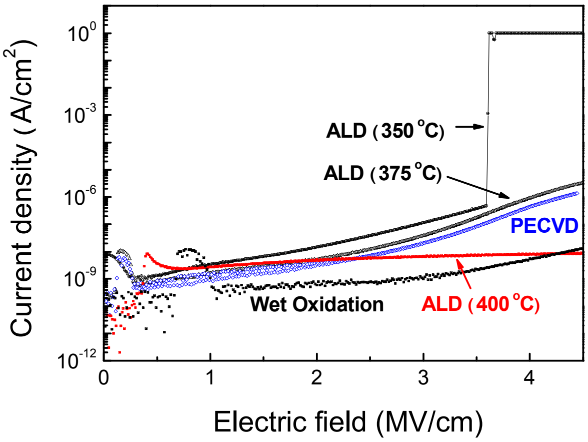

Fig. 4. Current-voltage characteristics of various SiO_2 thin films

Conclusions

Silicon oxide thin films were prepared by the ALD method using SiH_2Cl_2 and O_3/O_2 as the precursors at temperatures ranging from 350 to 400°C. The growth rate and refractive index of ALD films increased gradually with increasing the deposition temperature, and refractive index reached 1.46 at 400°C, which is the same with the value of the stoichiometric SiO_2. ALD SiO_2 films deposited at 400°C exhibited stoichiometry, wet etch rate, surface morphology and leakage current superior to PECVD SiO_2 films.

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