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Improved J-E Characteristics and Stress Induced Leakage Currents (SILC) in Oxynitride Films Grown at 400°C by Microwave-Excited High-Density $Kr/O_2/NH_3$ Plasma

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1. Introduction

Future ULSI technology dictate the lowering of process temperatures, in order to realize ultra shallow junctions, precise dopant profile control and System On Glass (SOG) fabrication, for example. However, lowering the conventional growth temperature (900°C-1000°C) of gate oxides, below 550°C, results an unacceptable reduction of growth rate and poor SiO_2 electrical characteristics, i.e., degradation in their insulation and reliability properties. This work concerns oxynitride (SiON) films, which are considered to be candidates for the next generation gate insulators[1][2], due to their lower gate leakage currents and lower stress induced leakage currents (SILC) with respect to SiO_2 films. This is important, in particular, in nonvolatile flash memories, which must retain information after many program/erase cycles. In this work, we have grown oxynitride films at 400°C which is significantly lower temperature than that used in the conventional methods. This is done by using microwave-excited high-density $Kr/O_2/NH_3$ plasma. It has been demonstrated that high integrity silicon dioxide and silicon nitride films can be grown by this plasma technique[3][4]. The results presented below, show that the oxynitride films which were grown at 400°C, exhibit lower gate leakage currents and lower stress induced leakage currents (SILC), with respect to oxide films grown by conventional dry oxidation at 1000°C. This enables to extend the scaling limits of tunnel insulators for flash memories.

2. Experimental

MOS capacitors [phosphorus-doped poly-Si/SiON/Cz n-type (100) Si 3-5 Ω cm] were fabricated in order to evaluate the electrical properties of the oxynitride films. The oxynitride films are grown at 400°C in $Kr/O_2/NH_3$ microwave-excited high-density plasma system[5]. The partial pressure ratio of $Kr/O_2/NH_3$ mixing gas was 96.5/3/0.5. The total pressure in the growth chamber was 1 Torr. MOS capacitors with oxide films grown by conventional thermal oxidation (Dry 1000°C) were made for comparison of the electrical properties. Film thicknesses (Ti) were determined from the accumulation region of the capacitance-voltage (C-V) characteristics, measured at 100kHz.

3. Results and Discussion

Fig. 1(a) shows secondary ion mass spectrometry (SIMS) depth profile of 8nm-thick oxynitride film grown by the $Kr/O_2/NH_3$ plasma. Nitrogen incorporated in the grown film was piled up in the oxynitride/Si interface. The oxynitride film thickness as a function of the NH_3 mixing partial pressure (x%) is shown in Fig. 1(b), exhibiting reduction in Ti with increasing nitrogen content. The growth time per sample was 10min. In Fig. 2 the interface trap densities (Dit) of two $Kr/O_2/NH_3$ oxynitride films and a dry thermal oxide film are compared. The results show that with respect to SiO_2, high NH_3 partial pressure (2%) produces over three times interface trap density, while the low NH_3 content (0.5%) yielded only 30% more Dit. This is the reason that the following data present results only for NH_3 partial pressure of x=0.5%. Fig. 3(a) shows the substrate injection J-E characteristics of the oxynitride and oxide films. The leakage current density of the oxynitride film (400°C) is lower than that of the thermal oxide film (1000°C). The Fowler-Northeim (F-N) plot of these J-E curves is shown in Fig. 3(b). The slopes and barrier heights of the two films are comparable, and their values are very close to that of ideal SiO_2. Fig. 3(c) shows that the gate injection J-E characteristics of the oxynitride film, exhibit comparable or slightly lower leakage currents than that of the silicon dioxide film. Fig. 4 shows stress induced substrate injection leakage currents (SILC) measured at 6MV/cm, of the oxynitride and silicon dioxide films. The stress current is $1A/cm^2$. The SILC of the oxynitride film (400°C) is noticeably lower than that of thermal oxide film (1000°C). It also exhibits slightly lower slope, reflecting on the robustness of the oxynitride film.

4. Conclusions

A significant reduction in the growth temperature of the oxynitride films down to 400°C yielded lower leakage currents and lower stress induced leakage currents (SILC) with respect to SiO_2 films grown by conventional dry oxidation at 1000°C. This demonstrates the potential of the oxynitride films for use as gate insulators in future MOS devices. Specifically, their use in nonvolatile memories can improve the data retention capabilities.

Acknowledgement

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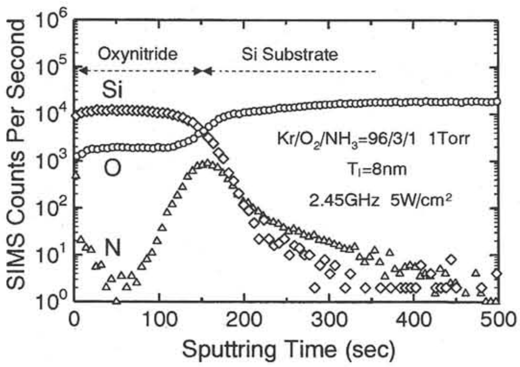

Fig. 1(a) SIMS depth profile of oxynitride film grown by $Kr/O_2/NH_3$ plasma

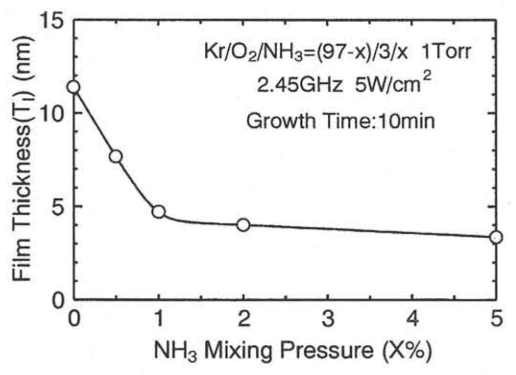

Fig. 1(b) Film thickness as a function of the NH_3 mixing pressure

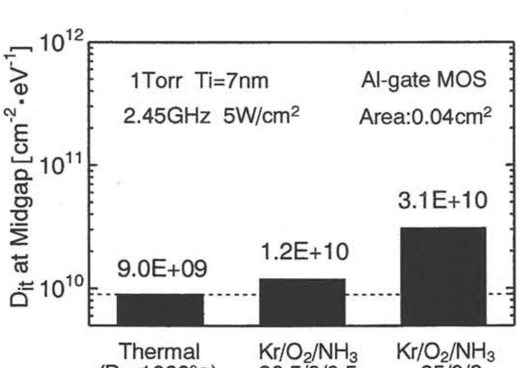

Fig. 2 Interface trap density (Dit) of the oxynitride films grown by $Kr/O_2/NH_3$ plasma, and of oxide film grown by dry thermal oxidation

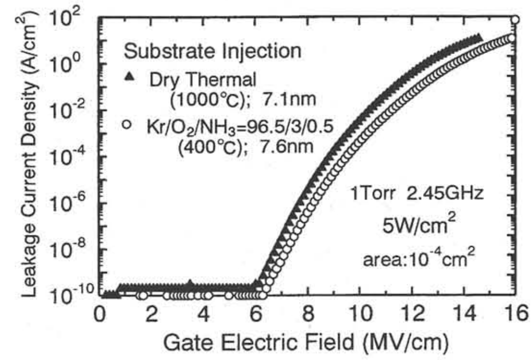

Fig. 3(a) J-E characteristics (substrate injection) of MOS capacitors, one with gate oxynitride film grown by $Kr/O_2/NH_3$ plasma, and another with conventional dry thermal gate oxide film

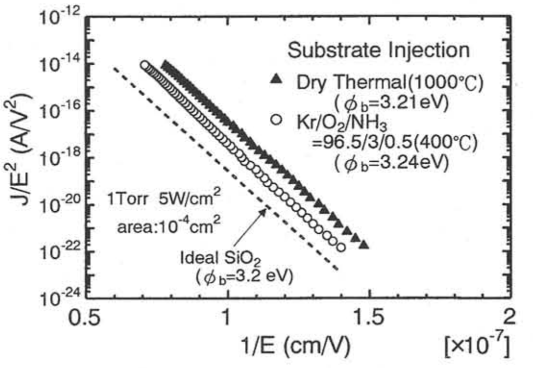

Fig. 3(b) Fowler-Northeim (F-N) plot of J-E characteristics (substrate injection) of Fig. 3(a)

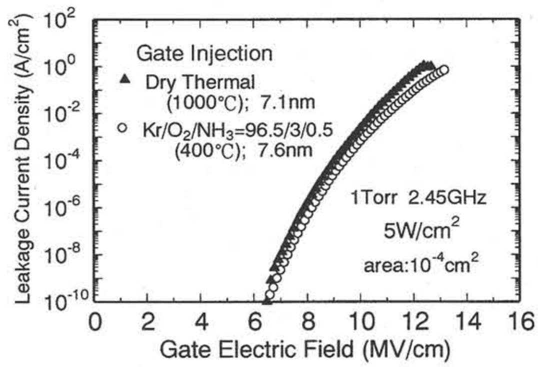

Fig. 3(c) J-E characteristics (gate injection) of MOS capacitors, one with gate oxynitride film grown by $Kr/O_2/NH_3$ plasma, and another with conventional dry thermal gate oxide film

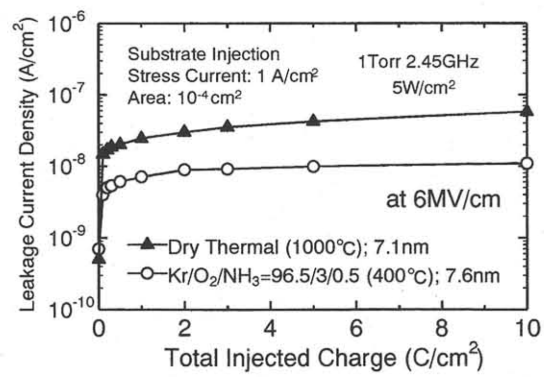

Fig. 4 SILC properties (substrate injection) of MOS capacitors, one with gate oxynitride film grown by $Kr/O_2/NH_3$ plasma, and another with conventional dry thermal gate oxide film