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Effect of Plasma Nitridation on the Conduction Mechanism of Ta_2O_5 Gate Dielectric

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1. Introduction

Although Ta_2O_5 has been investigated in terms of MOS gate dielectric applications, it is difficult to obtain an equivalent oxide thickness of less than 2nm with acceptable leakage current [1]. Since an approximately 1nm-thick interfacial SiO_2 layer is necessary to minimize interface state density and the intermixing of silicon and Ta_2O_5, the dielectric constant of Ta_2O_5 is not sufficient to obtain an equivalent dielectric thickness of less than 2nm. It has been reported that the dielectric constant of Ta_2O_5, when deposited on a Ru layer was significantly improved by rapid thermal nitridation [2]. Recently, we have reported excellent electrical characteristics of TaO_xN_y gate dielectric prepared by NH_3 nitridation [3,4]. In this paper, we have investigated the conduction mechanism of TaO_xN_y prepared by remote plasma nitridation.

2. Experiment

After standard cleaning of Si wafer, a 1nm thick SiO_2 layer was grown by plasma oxidation in order to reduce the interface state density between Si and Ta_2O_5. A 9-nm thick Ta_2O_5 was deposited at 400°C using O_2 and $Ta(OC_2H_5)_5$ source. Remote plasma nitridation in N_2 ambient was performed at 400°C for 2min. After a 200nm-thick gold deposition by e-beam evaporator, MOS devices with a gate area of $9\times10^{-6}cm^2$ were defined by photolithography and etching. A standard post-metallization annealing in forming gas was performed at 400 °C.

3. Results and Discussion

Fig.1 shows the C-V characteristics of both as-deposited Ta_2O_5 and nitrided sample. Flatband voltage shift of 200mV was observed due to the nitridation. As shown in Fig.2, the current density of plasma nitrided sample is slightly higher than that of as deposited sample. The physical thickness of samples were confirmed by X-ray reflectivity as shown in Fig. 3. The thickness of as-deposited Ta_2O_5 and that of nitrided sample were 98 Å and 97 Å, respectively. The improvement of capacitance by nitridation as shown in Fig. 1 can be explained by high dielectric constant of nitrided samples.

Using XPS analysis, O1s energy loss spectra and the valence band spectrum was obtained as shown in Fig. 4. Based on this data, we can calculated the energy gap and the valence band offset to Si substrate.

To estimate conduction mechanism, the I-V characteristics as shown in Fig. 2 were redrawn as shown in Fig. 5. For as-deposited sample, an accurate fitting of I-V characteristics can be obtained by trap assisted tunneling model. Using trap assisted tunneling model, the trap energy barrier height of as-deposited sample was approximately 1.53eV. In contrast, the I-V characteristics of nitrided samples cannot be explained by trap assisted tunneling model [5]. Using Poole-Frenkel model, we can explain I-V characteristics of nitrided samples as shown in Fig. 6.

To confirm the Poole-Frenkel model, the temperature dependence of I-V characteristics was measured as shown in Fig. 7. For different bias condition such as 2.3V and 1.9V, the Poole-Frenkel model can explain the leakage current. Based on fitting of experimental data, the trap energy barrier height of 0.68eV was obtained. By adjusting trap energy barrier height, we have estimated I-V characteristics as shown in Fig. 8. With decreasing trap energy barrier height, a significant increase of leakage current was observed.

Based on the results of Fig. 4, 5, and 7, the band diagrams and trap energy barrier height of as-deposited Ta_2O_5 and nitrided sample were drawn as shown in Fig. 9.

4. Conclusion

Although nitridation of ultrathin Ta_2O_5 increases dielectric constant, we found a degradation of leakage current. Compared with as-deposited Ta_2O_5 which exhibits trap-assisted tunneling, nitrided Ta_2O_5 exhibits Poole Frenkel conduction which was confirmed by temperature dependence and field dependence. The nitridation of Ta_2O_5 modify bandgap and trap barrier height. Although the nitridation of high-k gate dielectric improves thermal stability and minimizes the growth of interfacial oxide layer, the optimization of process conditions is necessary to minimize the degradation of leakage current [6].

Acknowledgement

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References

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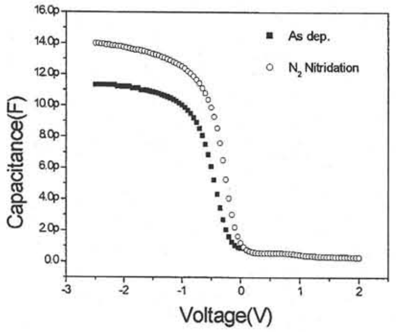

Fig.1 The C-V curves of bot samples

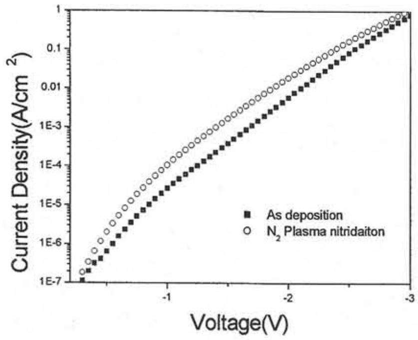

Fig.2 The J-V curves

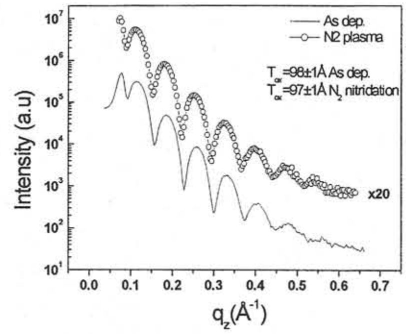

Fig.3 X-ray reflectivity of the two samples.

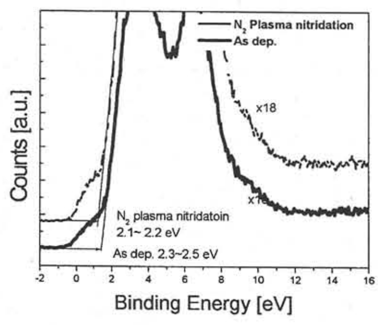

Fig.4(a) Valence band spectrum of both samples

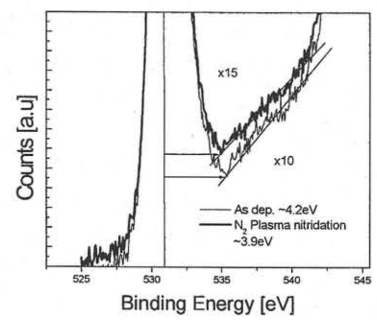

Fig4.(b) Energy loss spectra of $O1_s$ for both samples

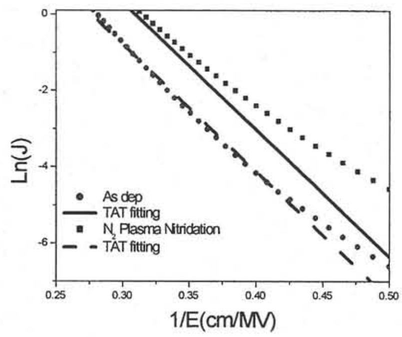

Fig.5 TAT fittings for both samples

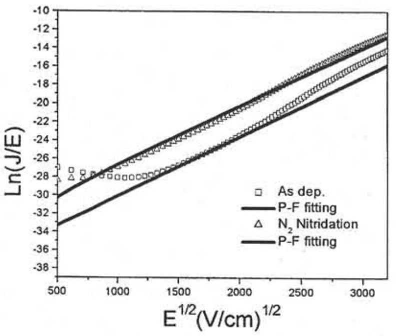

Fig.6 P-F fitting (Ln(J/E) Vs. $E^{1/2}$) of both samples.

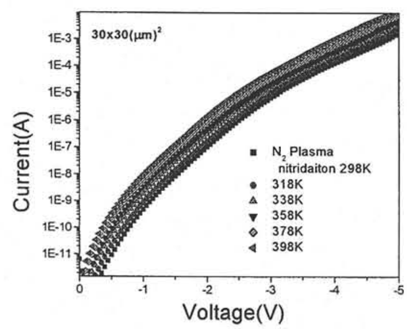

Fig.7(a) JV curves with various temperatures

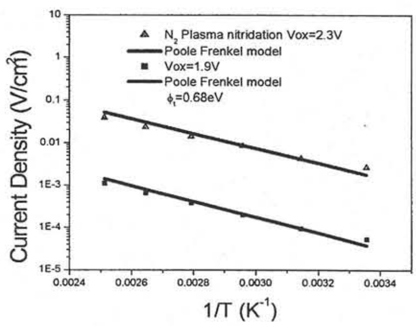

Fig.7(b) J vs. inverse temperature at the V_{ox} 1.9 and 2.3V

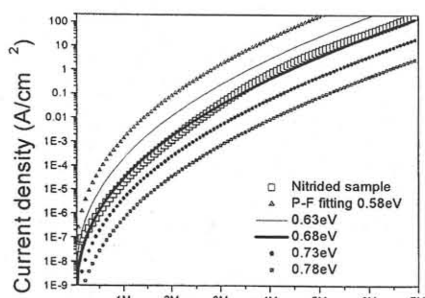

Fig.8 P_F fittings with various ϕ_t of nitrided sample

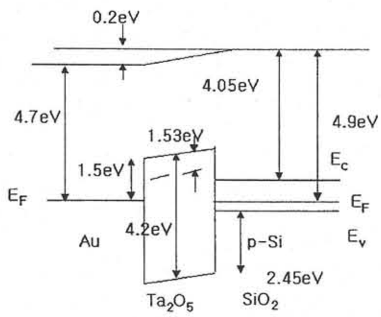

Fig.9(a) Band diagram of as dep. sample

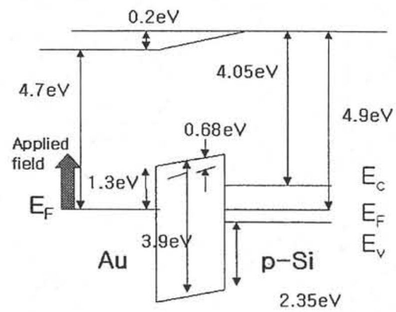

Fig.9(b) Band diagram of nitrided sample