Electrical Properties of Tantalum Oxide Films on Plasma Nitrided Silicon Substrates
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As the feature size of ULSI circuits shrinks, thinning of gate oxide is necessary for maintaining the long channel effect. According to the 1999 ITRS, sub 0.1μm MOSFET requires an equivalent oxide thickness (t_{eq}) between 1.0 ~ 1.5 nm. Consequently, high k materials such as Ta_2O_5, TiO_2, ZrO_2, HfO_2, and BST are considered to substitute for SiO_2. Tantalum oxide (Ta_2O_5), which has been widely investigated in the past decade, is a promising candidate for gate dielectrics. However, Ta_2O_5 would react with the Si substrate and form an interfacial layer SiO_2. As a result, the series capacitance lowers the dielectric constant, and makes it difficult to reduce t_{eq} to 1.0 nm. In our work, The Ta_2O_5 films were grown on bare Si and plasma nitrided Si substrates by reacting penta-ethoxy-tantalum [$Ta(OC_2H_5)_5$] with oxygen at 450 ^oC. The nitrided Si substrates are made by treating the surface with N_2O plasma or NH_3 plasma at 50W for 10 min. The process of nitrogen incorporation can be achieved at temperature as low as 450 ^oC. After deposition, the samples were annealed in oxygen furnace (FO) at 650 ^oC and 800 ^oC for 30min.

Si substrates after plasma nitridation were characterized by X-ray photoelectron spectroscopy (XPS). Figure 1 shows the XPS spectra of N 1s, and Si 2p core levels for the plasma N_2O and plasma NH_3 treated Si surfaces. One sees that plasma NH_3 nitridation appears to have a higher nitrogen content than plasma N_2O. The binding energy difference between the two Si 2p peaks is 4.4eV for plasma N_2O sample, whereas 3.6eV for plasma NH_3 sample. The splitting between the two Si 2p peaks could be attributed to the different nitrogen contents.

Table 1 depicts the dielectric constant, tangent δ, and flat band voltage change (ΔV_{fb}) from measured C-V curves. It is obvious that the dielectric constant of Ta_2O_5 deposited on nitrogen passivated Si is higher than that of bare Si. Moreover, the ΔV_{fb}, which is measured by double voltage sweep, is much smaller in as-depsited Ta_2O_5/nitrided samples than as-depsited Ta_2O_5/Si samples. However, ΔV_{fb} is worse after FO annealing at 800^oC. In addition, The tangent loss (tanδ) is reduced after FO treatments, especially in Ta_2O_5/nitrided samples.

Figure 2 shows the I-V curves measured on positive bias of Ta_2O_5/N_2O nitrided Si, Ta_2O_5/NH_3 nitrided Si samples with various heat treatments. The leakage currents are reduced after FO annealing either at 650^oC or 800^oC. But the Ta_2O_5/N_2O nitrided samples suggest a better leakage current characteristic than Ta_2O_5/NH_3 nitrided ones. Therefore, we surmise that the Ta_2O_5/NH_3 nitrided samples might contain a higher hydrogen content, which acts as electric carriers for electron transportation in the dielectrics.

In conclusion, we propose the method of low-temperature plasma N_2O or NH_3 nitridation on Si substrates. The Ta_2O_5/ nitrided Si samples shows better electrical properties than Ta_2O_5/ non-nitrided Si samples. In order to reduce t_{eq} for gate dielectrics, Ta_2O_5 on plasma nitrided Si substrates shall be a good candidate for sub micron CMOS devices.

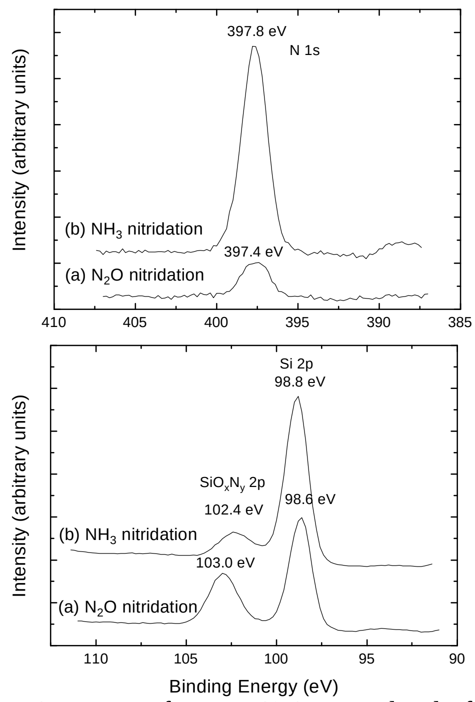

Fig. 1. XPS spectra of N 1s, Si 2p core levels for the plasma (a)N_2O and (b)NH_3 nitrided Si samples

		ε	tanδ	ΔV_{fb}
Ta_2O_5/Si	as-dep	9.15	0.08	1.88
	FO 650 ^oC	12.98	0.05	0.05
	FO 800 ^oC	13.22	0.06	0.49
Ta_2O_5/N_2O nitrided Si	as-dep	17.32	0.13	0.02
	FO 650 ^oC	14.02	0.04	0.05
	FO 800 ^oC	12.97	0.02	0.33
Ta_2O_5/NH_3 nitrided Si	as-dep	15.00	0.09	0
	FO 650 ^oC	17.41	0.002	0.01
	FO 800 ^oC	13.63	0.002	0.52

Table. 1. Data extracted from C-V curves of (a) Ta_2O_5/N_2O nitrided Si, (b)Ta_2O_5/NH_3 nitrided Si samples

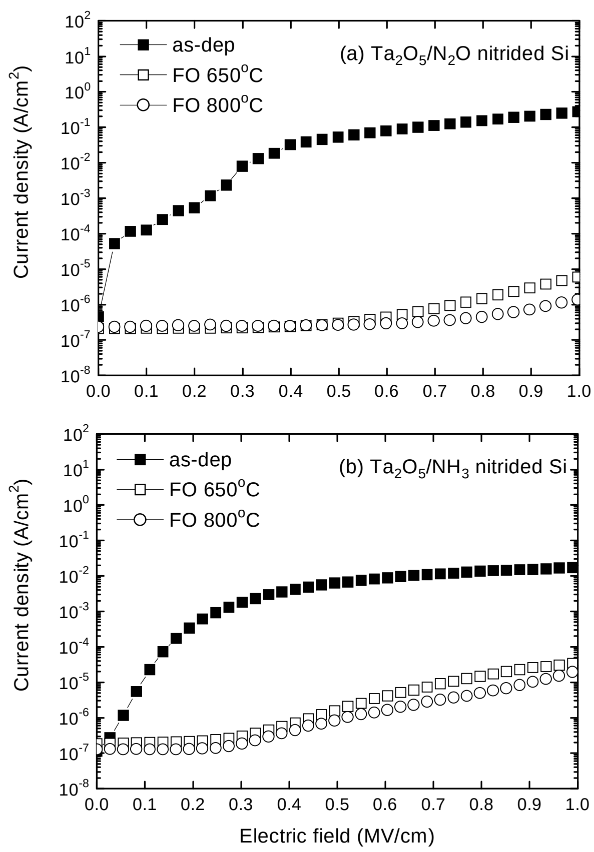

Fig. 2. I-V curves of (a)Ta_2O_5/N_2O nitrided Si, and (b)Ta_2O_5/NH_3 nitrided Si before and after heat treatments.