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Effects of Nitrogen in HfO_2 Gate Dielectric on the Electrical and Reliability Characteristics by N_2 plasma

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HfO_2 and ZrO_2 have received much attention and studied as possible candidates for high-*k* gate materials because of their modest dielectric constants and wide bandgap. However, these materials have weak resistance to oxygen diffusion, which causes growth of interfacial SiO_2 during high temperature annealing[1,2]. Recently, there have been several reports on incorporating nitrogen into high-*k* materials to improve thermal stability of high-k gate dielectric[3,4]. The high-*k* dielectric nitrated by NH_3 is known to reduce EOT and leakage current density. However, it also causes an increase of an interface trap density.[5]. Therefore, nitrogen (N_2) is necessity to use instead of NH_3 in plasma treatment to improve electrical properties. In this work, nitrogen incorporation into HfO_2 films was investigated for gate dielectric applications.

After standard cleaning of p-type Si (100) wafers, 5 nm thick-HfO_2 films were deposited by plasma-enhanced chemical vapor deposition using hafnium tertiary-butoxide ($Hf[OC(CH_3)_3]_4$) as the precursor in the absence of O_2. The deposition conditions were performed at a temperature of 300℃, a pressure of 0.5 Torr and an RF power of 40 W. The precursor was vaporized in a bubbler maintained at 30℃ and was carried to the reactor using argon (purity 99.9999 %) as the carrier gas. The surface of the cleaned Si substrates (bottom-side of HfO_2) and top-side of HfO_2/Si were treated at 300°C by N_2 plasma at 70 W for 10 min. The HfO_2 dielectrics with and without N_2 plasma treatment were annealed at 700°C for 1 min in an N_2 ambient. A TaN film with 200 nm thickness was then deposited by a dc reactive sputtering with a dc power of 100 W at room temperature in nitrogen ambient. After patterning the electrode, the samples were annealed at 900°C in N_2 (purity 99.9999 %) for 1 min.

Figures 1 show AES depth-profiles of HfO_2 dielectrics deposited at 300℃ after N_2 plasma annealing, Nitrogen of approximately 8 atom % in samples treated by N_2 plasma at 70 W was accumulated at the HfO_2/Si interface. As shown in Fig. 2, N_2 plasma-treated HfO_2 films exhibited an improvement of EOT and leakage current density compared with samples without plasma treatment. The capacitors treated by both sides of HfO_2 films exhibited the lowest EOT and leakage current density of approximately 1.5 nm and 1.8 x 10^{-5} A/cm^2 at -1.5 V, respectively. The interface trap density (D_{it}) of HfO_2 capacitors treated by N_2 plasma as a function of applied voltage was shown in Fig. 3. D_{it} was obtained at mid-gap values consisting with the transition region of depletion and inversion. D_{it} in a N_2 plasma treated HfO_2 capacitors was similar to that of fresh-HfO_2 capacitors and remains constant at approximately 1.3 x 10^{11} cm^{-2}eV^{-1}. This result suggested that a N_2 plasma treatment in a HfO_2 gate dielectric did not influence on the interface characteristics compared with NH_3 plasma treatment.

The bottom, top, and both side of HfO_2 gate dielectrics were treated by N_2 plasma to improve a thermal stability of hafnium-based gate dielectrics. The HfO_2 films treated at both sides by N_2 plasma exhibited the lowest EOT and leakage current density, and comparable interface charge density to films without plasma treatment. A N_2-plasma treatment in a HfO_2 gate dielectric is a promising technique to give a good reliability in a high-k gate dielectric.

References

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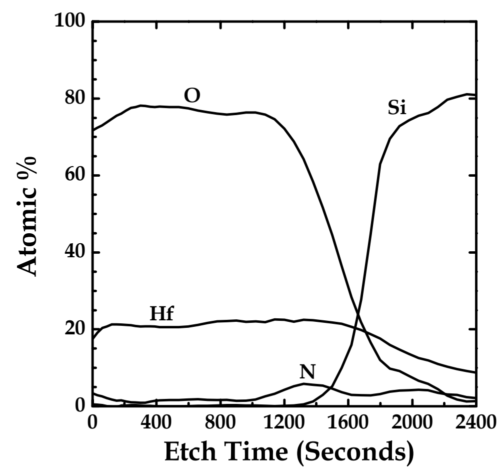

Fig. 1 AES depth-profiles of HfO_2 films on the surface of Si (100) treated by N_2 plasma at 70 W.

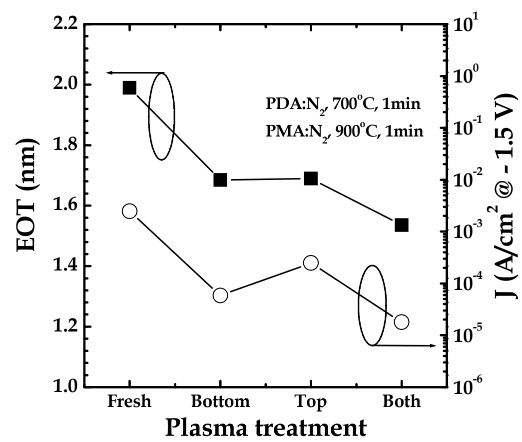

Fig. The variation of EOT and leakage current density in TaN/HfO_2/Si capacitors treated by N_2 plasma.

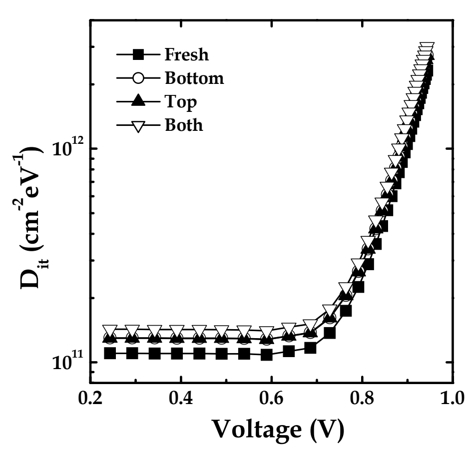

Fig. 3 Interface trap density of HfO_2 capacitors treated by N_2 plasma as a function of applied voltage.