Influence of the 5 Å TaN_x Interface Layer on Doped Metal Oxide High-k Dielectric Characteristics

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Metal oxides such as Ta_2O_5, HfO_2, ZrO_2, Y_2O_3 and Al_2O_3 are potential candidates to replace thermal SiO_2 as the gate dielectric material for future generations of MOS transistors. There are several drawbacks in these materials. For example, they have high leakage currents after being processed through a high temperature. In addition, when they are prepared into thin films, the apparent dielectric constants (k's) decrease drastically with the decreasing thickness.

Recently, authors and other researchers reported that the high leakage current of the high temperature annealed metal oxide is caused by the formation of the poly-crystalline phase. The leakage current can be reduced if the film is kept in amorphous phase, e.g., by doping it with a third element. The amorphous-to-polycrystalline transition temperature decreases with the doping process [1,2]. The apparent k value of the doped film could be higher than those of the undoped films [1,2,3].

The decrease of the apparent k value is contributed by the formation of a thin interface layer at the silicon substrate contact area, which has a much lower k value than that of the bulk film. The interface formation is unavoidable in most cases [4]. This is especially true when the film is deposited from a thermodynamically non-equilibrium process, such as sputtering or plasma enhanced chemical vapor deposition. The interface layer formation can be hindered if a thin inert film is inserted between the metal oxide and the silicon substrate. In this paper, we investigate the effectiveness of applying a thin tantalum nitride film (TaN_x), i.e., 5 Å, as the interface layer to slow down the deterioration of the dielectric properties of the sub 10 nm thick doped tantalum oxide (TaO_x) film.

The 5 Å thick TaN_x film was sputter deposited on a HF pre-cleaned P-type (100) silicon wafer. The Hf- or Zr-doped TaO_x film was subsequently co-sputtered from two separate targets, i.e., Ta and Hf or Zr, in Ar/O_2 within the same chamber without breaking the vacuum. The sample was annealed in a quartz tube at 600°C for 60 minutes or 700°C for 10 minutes under O_2. The film was fabricated into the metal-oxide-semiconductor (MOS) capacitor using sputtered aluminum dots as electrodes. The post-metal annealing was done at 300°C for 30 minutes under N_2 or forming gas. The dielectric properties were determined from C-V and I-V measurements. The film's material properties were determined by ellipsometer, SIMS, TEM, and ESCA.

Figure 1 shows that the leakage current of the Hf-doped TaO_x film is decreased with the insertion of the TaN_x film. The reduction of the leakage current is enhanced with the increase of the Hf content in the film. For the undoped TaO_x film, this effect is not obvious.

Figure 2 shows that the apparent k value of the film is increased with the existence of the interface layer. The increase may be partially contributed by the decrease of the capacitor size since the sample with the TaN_x interface layer has a smaller footage than that without the interface. The phenomenon that the lightly doped film has a higher k value than those of other films is preserved with the existence of the TaN_x interface layer.

Figure 3 shows that the undoped TaO_x film has abrupt breakdowns at both highly positive and negative bias conditions while the film with the TaN_x interface layer does not have the breakdowns. Separately, authors also observed that the shift of flat band voltage increases with the addition of the TaN_x interface layer. Therefore, the interface layer brings extra fixed charges to the structure, which can only partially be removed with an extended annealing time.

Reference

1. Y. Kuo, J.-Y. Tewg, and J. P. Donnelly, "Dopant Effects on TaO_x-Based High k Dielectric Films," *Procs. Intl. Semiconductor Technol. Conf.,* ECS, 2001-17, 324-327, 2001.
2. Y. Kuo, J. Lu, P. C. Liu, F. M. Daby, and J.-Y. Tewg, "Influence of the Nanometer Thick Interface Layer to Electrical Properties of the sub 10nm Doped Metal Oxide High k Dielectrics," IEEE 2nd NANO 2002 Symp. Procs., 251-253, 2002.
3. R. F. Cava, W. F. Peck, Jr., and J. J. Krajewski, *Nature*, 377, 215, 1995.
4. K. J. Hubbard and D. G. Schlom, "Thermodynamic Stability of Binary Oxides in Contact with Silicon," *J. Mat. Res.*, **11**(11), 2757-2776, 1996.

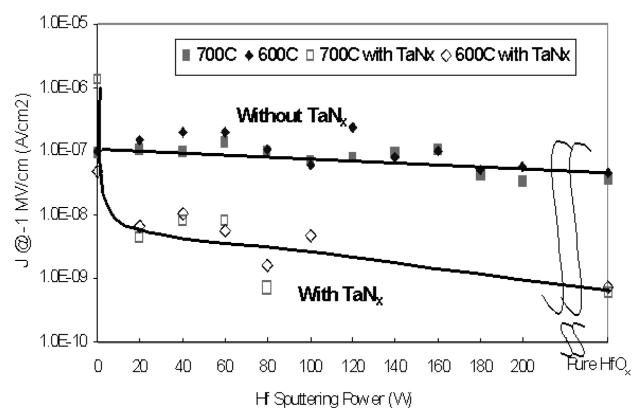

Figure 1. Leakage Current of Hf-Doped TaOx Films with and without the 5 Å TaN_x Interface Layer.

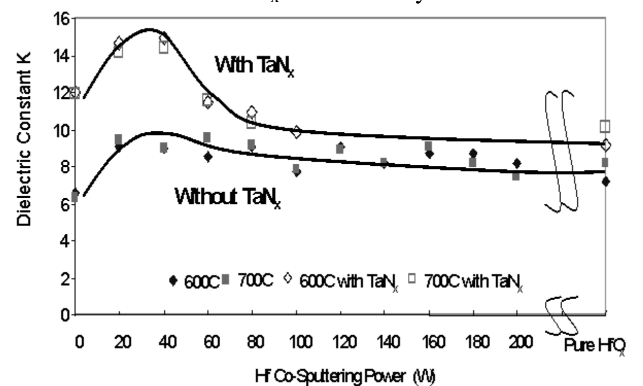

Figure 2. Apparent k Value of Hf-Doped Films with and without the 5 Å TaN_x Interface Layer.

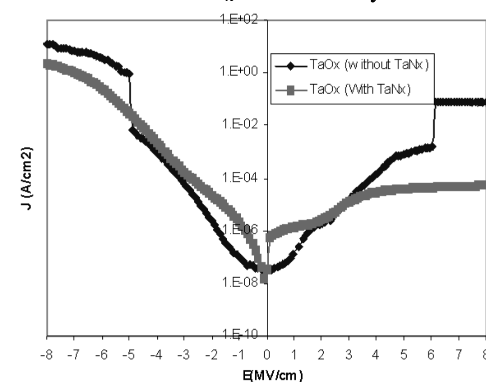

Figure 3. Current vs. Voltage Curved of TaOx Films with or without the TaN_x Interface Layer.