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Effects of N-rich TiN Capping Layer on Reliability in 20nm Gate-Last High-k/Metal Gate MOSFETs

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One of the major challenges for the gate-first approach in high-k/metal-gate (HK/MG) transistor fabrication is finding the gate stacks that can survive high temperature annealing (typically over a thousand degrees, °C) and compatible with strain techniques. As transistor size scales down, it becomes hard to find the metals which can endure 1000°C or the high annealing temperature without the metal work function shift that causes performance degradation. Therefore, a gate-last technology where high temperature process has been decoupled from the metal gate processing has been introduced [1]. However, reliability concern is becoming severe, since gate stack can't suffer enough thermal treatment [2].

In this paper, time-dependent dielectric breakdown (TDDB) and bias temperature instability (BTI) of transistors fabricated in 20nm HK/MG gate-last technology are studied with focus on nitrogen enrichment inside the HK/MG stack and its reliability effects.

Experimental results and Discussions

Nitridation in HK to reduce oxygen vacancy is one of candidate methods for improving reliability in HK/MG technology [3]. However, to prevent N_2-induced defect generation leading to extra NBTI degradation, it is desirable that nitrogen should be concentrated in the bulk HfO_2 while interface layer (IL) is nearly nitrogen free. To attain such stack, deposition of N-rich TiN capping layer versus plasma nitridation (PN) was used as N_2 curing methods are compared in this study (in Fig.1). N-rich TiN deposition hardly affects the IL because the nitrogen is mostly contained within TiN capping layer. From the X-ray photoelectron spectroscopy (XPS) depth profile (in Fig. 2), the N-rich TiN capping layer sample shows the high nitrogen concentration in the high-k layer but the concentration is low in the IL. The samples fabricated with N-rich TiN capping layer shows negligible difference in gate leakage current compared to the reference (no nitridation) sample while PN sample shows a noticeable increase (shown in Fig. 3) at the given Tinv thicknesses. As indicated above, the sample by PN is supposed to have more defects, resulting in the more gate leakage, due to N injected into IL. On the other hand, N-rich TiN capping layer itself only affects the gate stack with no influence on the IL. Hence, there is no difference of oxide defects and gate leakage current in this study.

Fig. 4 shows that NBTI on the sample with N-rich TiN capping layer has a slight increase in V_{th} shift(ΔV_{th}) compared to the reference sample; however, it can still surpass 10yr lifetime reliability goal. The PN sample has >2x higher degradation than the reference. We speculate that the plasma-enhanced nitrogen results in more defects on IL due to plasma damage. In case of PBTI (shown in Fig.5), ΔV_{th} for the N-rich TiN capping layer and PN samples showed large reduction compared to the reference. It is attributed to the nitrogen passivation of defects (known as Oxygen vancancies) in the high-k bulk layer. Fig. 6 shows that TDDB characteristics of the nFET regardless of N-rich TiN capping layer and PN have also more improved over the reference. However, PN technique has limitations to simultaneously meet TDDB and BTI. In conclusion, N-rich TiN capping layer can be optimized to meet both BTI/TDDB reliability requirements without increase in the gate leakage current.

Reference

[1] D. Hisamoto, et al., *IEEE TED*, vol. 47, no. 12, 2000
[2] Y. –L Yang, et al., *IEEE EDL*, vol. 33, no. 8, 2012.
[3] C. Choi, et al., in *VLSI Symp. Tech. Dig*., 2004.

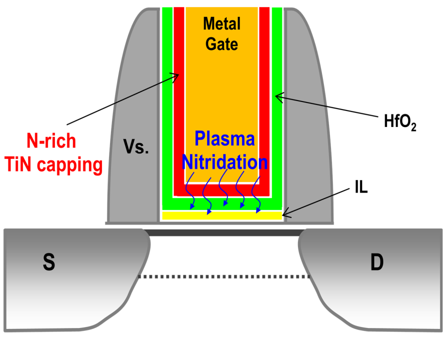

Fig. 1. Schematic diagram of 20nm gate-last HK/MG MOSFETs with N-rich TiN capping or plasma nitridation.

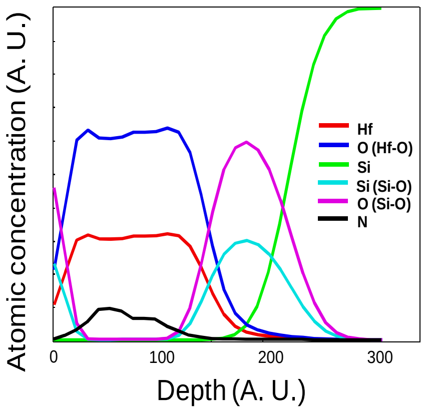

Fig. 2. XPS depth profile of HK/IL+Si stack by N-rich TiN method sample.

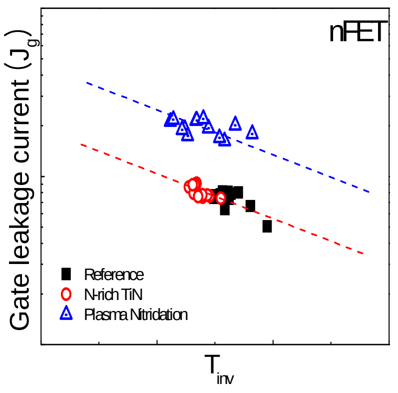

Fig. 3. Comparison of gate current density shows that N-rich TiN capping layer induces no significant difference compared to the reference.

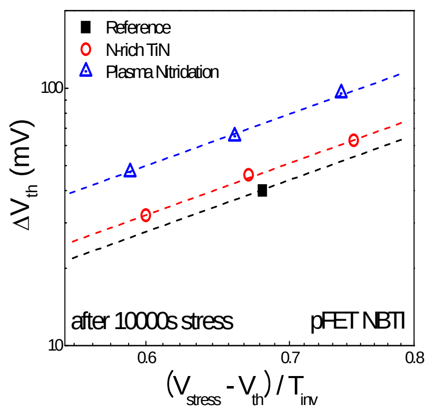

Fig. 4. A slight difference between the sample with N-rich TiN capping layer and the reference.

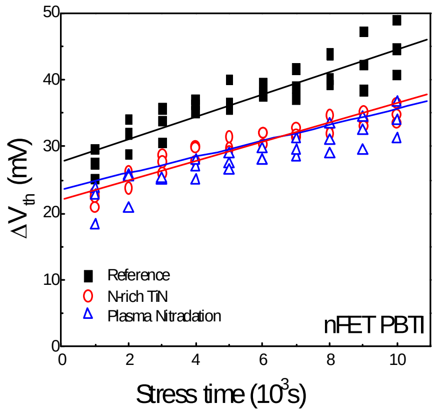

Fig. 5. N-rich TiN capping layer decreases ΔV_{th} significantly due to nitrogen passivation.

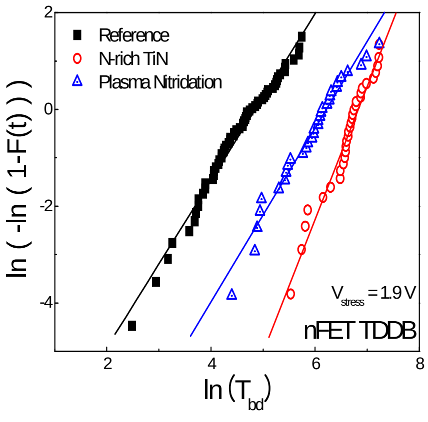

Fig. 6. Comparison of TDDB characteristics between N-rich TiN capping layer and PN method.