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Impacts of SiN Deposition Conditions on NMOSFETs

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1. Abstract

Although SiN capping could dramatically enhance device performance, a high amount of hydrogen species contained in the SiN capping may aggravate hot-carrier reliability. In order to alleviate this shortcoming, we vary the deposition conditions of SiN film and investigate their impacts on the device performance. We found that devices with nitrogen-rich SiN film have larger tensile stress and thus effectively boost the device mobility. Moreover, the resistance to hot-carrier degradation is also improved due to less hydrogen diffusion from the capping layer.

2. Introduction

Channel strain engineering such as eSiC [1] and SiN capping [2-4] for NMOSFETs mobility enhancement has been pursued aggressively in scaled CMOS devices. Among these methods, SiN capping technique has received much attention because it is easily implemented in modern IC technology. However, abundant hydrogen species generated during the SiN deposition process may diffuse into the channel region, causing hot-carrier reliability issue [3]. Recently, the insertion of a buffer layer below the SiN capping has been proposed to restore the reliability without compromising device performance [4]. In this work, the composition of SiN film is varied by using different gas flow rate for SiN deposition. The stress effect and hot-carrier reliability on these fabricated devices were investigated.

3. Device Fabrication

The NMOSFETs used in this study were with 3 nm thermal oxide and 150 nm poly-Si layer as the gate electrode. SiN film and TEOS passivation were deposited by PECVD and the thickness was fixed at about 300 nm, as shown in Fig. 1. In this work, we evaluated devices with three different types of SiN films using $SiH_4/NH_3/N_2$ gas mixtures at 300°C (denoted as SiN-1, SiN-2, and SiN-3 splits), as shown in Table 1. The devices with TEOS passivation were fabricated for reference (denoted as TEOS split).

4. Results and Discussion

Using stress measurement, we confirmed that the stress is tensile in nature with a magnitude of around 100, 300, and 500MPa for SiN-1, SiN-2, and SiN-3 split, respectively. From Table 1, it can be seen that the tensile stress increases with increasing N_2 flow rate. Fig. 2 compares transconductance (Gm) enhancement for all splits with W/L=10/0.4μm. It can be seen that the Gm of SiN-3 split depicts the largest increase among all samples, while the SiN-1 split shows comparable Gm with the TEOS split, while the SiN-2 split falls between that of SiN-1 and SiN-3 splits. Similar enhancement trend in drive current is also observed, as shown in Fig. 3. These electrical results are consistent with the results of film stress measurement listed in Table 1. Fig. 4 shows Gm_{max} on the nitride as a function of film stress. A linear dependence is observed in this figure. Fig. 5 shows the percentage increase of Gm for all SiN capping samples, compared with the TEOS controls, as a function of channel length. These results demonstrate that Gm enhancement ratio increases with decreasing channel length, a feature characteristic of uniaxial strain by SiN capping. *C-V* characteristics for all samples coincide altogether, as shown in Fig. 6, indicating that the above-mentioned results are not caused by oxide thickness difference.

The subthreshold characteristics and extracted subthreshold swing are shown in Fig. 7 and Fig. 8, respectively. We can see that subthreshold swing of all SiN capping splits depicts similar value and is slightly lower than that of TEOS control. This is ascribed to the hydrogen species contained in the SiN that tend to passivate the interface states, resulting in better subthreshold swing among the splits. This is evidenced form the charge pumping current (Icp) as shown in Fig. 9. All SiN capping splits have lower Icp than TEOS controls. Moreover, SiN-3 split depicts the largest Icp among all SiN capping splits, indicating that Icp seems to increase slightly with N_2 flow rate. Since N-H bonds are thermally more stable than Si-H bonds [5], hydrogen atoms tend to bond with nitrogen for nitrogen-rich film. This may result in less diffusion of hydrogen species from the SiN to the oxide/channel interface. As a consequence, the SiN-3 split has a slightly higher interface than the other two SiN-capping splits.

Next, we turn our attention to hot-carrier characteristics. Fig. 10 shows the threshold voltage shift (ΔV_{th}) and increased interface state generation (ΔN_{it}) as a function of stress time for all splits. We can see that SiN-1 split depicts the worst degradation in terms of the largest ΔV_{th}. By contrast, SiN-3 split apparently shows much improvement in this aspect, although its maximum tensile stress accounts for the best performance gain among the three SiN capping splits. It is well known that the breaking of Si-H bonds at the interface is one of the major reasons responsible for the hot-carrier degradation. The abundant hydrogen species contained in the SiN definitely aggravate the reliability [3]. Less Si-H bonds for nitrogen-rich SiN-3 split, as evidenced from Fig. 9, account for the hot-carrier reliability improvement.

5. Conclusion

In this work, we fabricated strained channel NMOSFETs with three types of SiN capping by varying the N_2 gas flow rate during the deposition. Tensile stress would be increased by increasing the N_2 gas flow rate and thus the device performance could be boosted, especially in short-channel devices. In addition, devices with nitrogen-rich SiN capping show better hot-carrier reliability, which is ascribed to less H diffusion from the SiN layer.

Acknowledgments

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References

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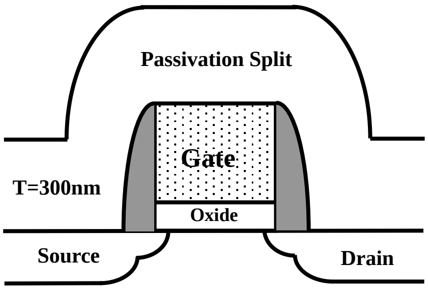

Fig. 1 Schematic structure of fabricated devices with different types of passivation, and the thickness is fixed at about 300 nm.

	SiH_4 (sccm)	NH_3 (sccm)	N_2 (sccm)	Stress (MPa)
SiN-1	50	6	50	99
SiN-2	50	6	100	300
SiN-3	50	6	1000	498

Table 1 Gas flow rate and mechanical stress for different nitride films deposited by PECVD.

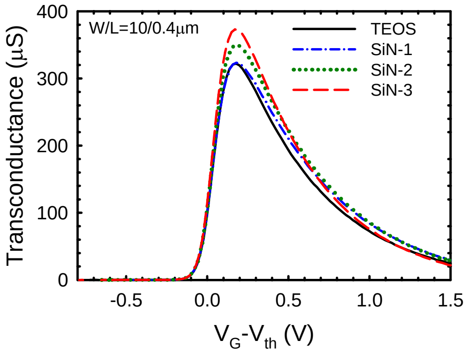

Fig. 2 Gm versus V_G-V_{th} for all splits of NMOSFETs.

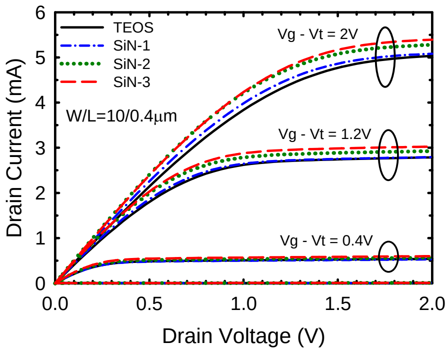

Fig. 3 Output characteristics of NMOSFETs for all splits.

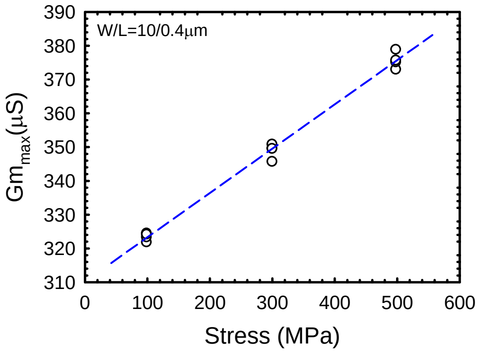

Fig. 4 Dependence of NMOSFETs performance on the nitride film stress.

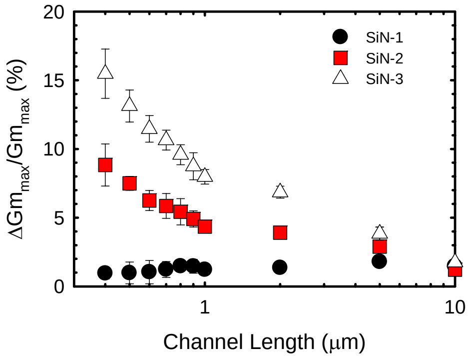

Fig. 5 Gm increase versus channel length for devices with SiN film with respect to TEOS controls.

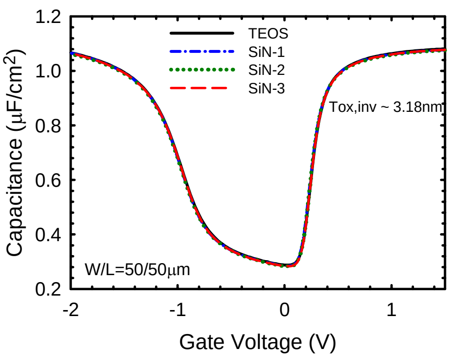

Fig. 6 *C-V* characteristics for all splits, showing almost identical curves.

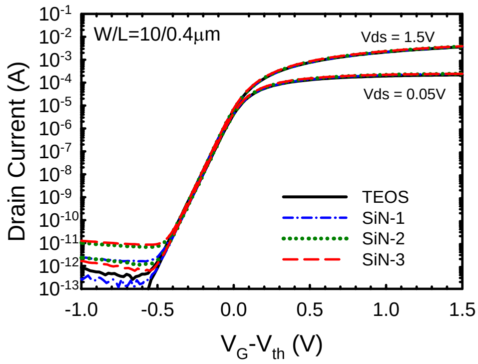

Fig. 7 Subthreshold characteristics of NMOSFETs for all splits with W/L=10/0.4μm.

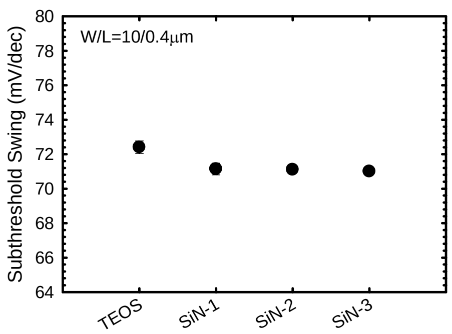

Fig. 8 Subthreshold swing of NMOSFETs for all splits with W/L=10/0.4μm.

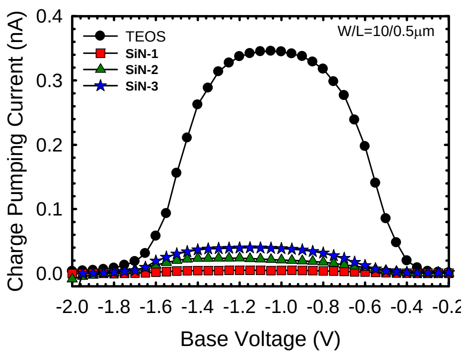

Fig. 9 Charge pumping current for all splits with pulse amplitude of 1.5V and frequency of 1MHz.

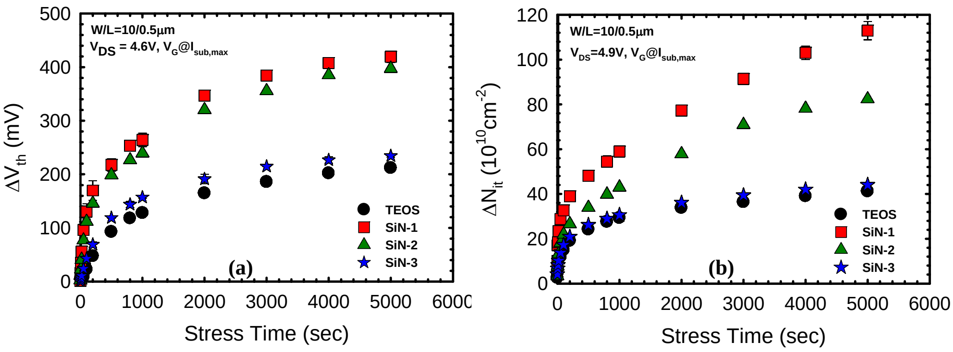

Fig. 10 (a)Threshold voltage shift, and (b) increased interface state generation as a function of stress time for all splits. Devices with W/L of 10/0.4μm were stressed at V_{DS}=4.6V, and V_G at maximum substrate current. Each datum point represents the mean measurement results of three devices.