P-1-15

Comparison of PECVD and RTCVD CESL Nitride Stressor in Reliability and Performance Improvement for High-k/Metal Gate CMOSFETs

Kyong Taek Lee[1], Chang Yong Kang[2], Seung-Ho Hong[1], Hyun-Sik Choi[1], Gil-Bok Choi[1], Jae Chul Kim[1], Seung-Hyun Song[1], Rock-Hyun Baek[1], Min-Sang Park[1], Hyun Chul Sagong[1], Sung Hwan Sakong[3], Sung-Woo Jung[3], Ho Kyung Park[2], Hyung Sang Hwang[4], Byoung Hun Lee[2] and Yoon-Ha Jeong[1]

[1]*Dept. of Electronic and Electrical Engineering, Pohang University of Science and Technology (POSTECH), Korea*

[2]*SEMATECH, 2706 Montopolis Drive, Austin, TX 78741, USA , [3]NCNT, Korea, [4]GIST, Korea*

TEL:(82)54-279-2897 , Fax:(82)54-279-2903 , herolkt@postech.ac.kr

1. Introduction

Mobility enhancement by process induced strain has become a dominant approach beginning with the 90nm technology node [1-2]. Among all the feasible approaches to stress engineering methods using SiGe and SiC substrates, strained spacers, strained gates, etc., a nitride contact etch stop layer (CESL) is a method most widely used due to its relative simplicity and large performance gains as demonstrated by several groups [3-4].

Thermally deposited SiN films tend to induce more tensile stress [2]. Therefore, a rapid thermal chemical vapor deposition (RTCVD) CESL nitride device can improve performance of NMOSFETs although it is hard to apply due to high temperature process. In this work, we investigated the influence of RTCVD nitride CESL on device performance and reliability by comparing it with tensile stressed PECVD CESL devices.

2. Experiments

The conventional high-k transistor process flow used in this study is shown in Fig. 1. The 3nm HfON films were deposited using the atomic layer deposition (ALD) method, followed by post-deposition annealing in NH_3 ambient. Then, 10nm ALD TiN/100nm poly-Si electrode stack was deposited. Oxide/nitride double sidewall spacers were formed after the halo/extension formation. Source/drain (S/D) activation and post-metallization annealing were then performed. To exclude stress that may be induced by silicide formation, the silicidation process was omitted. To study the effect of CESL, two different CVD methods plasma-enhance chemical vapor deposition (PECVD) and rapid thermal chemical vapor deposition (RTCVD) nitride layers were used in both nMOSFET and pMOSFET devices.

3. Results and Discussion

The I_{on}-I_{off} characteristics for nMOS and pMOS devices with PECVD and RTCVD CESL nitride as a function of thickness are shown in Fig. 2. In NMOS, the I_{on} of the RTCVD CESL nitride devices exhibit higher than the PECVD CESL nitride devices. In addition, in case of the RTCVD CESL, I_{on} is increased as thickness of CESL nitride increase. For pMOSFETs, however, no difference in I_{on}-I_{off} characteristics was observed. In transconductance comparisons as shown in Fig. 3, the RTCVD devices show higher $G_{m.max}$ indicating that the RTCVD CESL induced more tensile stress. In addition, $G_{m.max}$ became bigger in the RTCVD samples with increasing the thickness of the CESL nitride. These results were consistent with the data showing that the mobility of NMOS in the RTCVD CESL is greater than in the PECVD cases (Fig. 4). No differences in capacitance-voltage (CV) curve were observed between PECVD and RTCVD, indicating that equivalent oxide thickness (EOT) and threshold voltage (V_{th}) were not affected by the stressor layers (Fig. 5).

Fig. 6 shows comparison of $G_{m.max}$ / $G_{m.max\_cont}$ between tensile stressed PECVD CESL and RTCVD CESL devices. In the tensile stressed PECVD, the mobility improvement was increased as gate length decreased. However, unlike tensile PECVD, the mobility improvement of 100nm RTCVD CESL was maximized around 0.15 ~ 0.3μm. Due to process related effect, I_{cp} of tensile stressed PECVD CESL devices was higher than in those with the reference PECVD nitride layers (Fig. 7). However, the charge pumping data for the RTCVD CESL nitride stressor was lower than in those with reference PECVD films (Fig. 8). In addition, as thickness of nitride films increase, both of PECVD and RTCVD exhibit lower I_{cp}. In case of PECVD CESL nitride films, extra hydrogen can diffuse into the channel region and passivate dangling bonds at the interface with Si, which in turn decreases the interface state density [5]. In the other case, high temperature RTCVD nitride has lower hydrogen concentration because as no plasma is employed, it is harder to break the N-H bonds [6]. Therefore, the cause of lower charge pumping current in the RTCVD CESL device does not appear to be due to hydrogen passivation. For the RTCVD nitrides, it is believed that HfON and interface layer become more robust and cure dangling bond because the nitride film was deposited under higher thermal budget. These characteristics were similar even in long channel devices (Fig. 9).

Low frequency noise measurement with PECVD and RTCVD are shown in Fig. 10. The normalized 1/f noise can be generally expressed as

$$S_{Id} / I_d^2 \propto N_t,$$

where N_t is the trap density in the HfON and interfacial layer [7-8]. The RTCVD nitride device shows lower 1/f noise than PECVD sample indicating that lower defect in HfON and interface layer.

Fig 11 shows saturation current (I_{dsat}) degradation induced by HCI with different CESL nitrides. Under a high voltage stress, the thicker PECVD CESL device shows higher I_{dsat} degradation compared to 50nm PECVD CESL devices. Such a greater degradation in the thicker PECVD nitride device is believed to be caused by a higher rate of breakage of hydrogen bonds in the interface region since these devices contains more hydrogen. However, in case of the RTCVD, the thicker devices exhibit lower I_{dsat} degradation. In addition, from the results on the PBTI stress, we observed the lowest I_{dsat} degradation in the 100nm RTCVD CESL device(Fig. 12). These results indicated that more robust HfON and interface layer by high thermal budget is primary cause of lower charge pumping current and enhanced stress immunity.

4. Conclusions

In this paper, we have presented a systematic study of device performance and reliability characteristics of MOSFETs with PECVD and RTCVD CESL nitride layers. Due to be more robust HfON and interface layer, the RTCVD CESL nitride devices showed better initial interface quality and stress immunity was observed. For CMOS integration, these results suggest that a higher temperature CESL nitride can provide more room for performance and reliability improvement.

Acknowledgements

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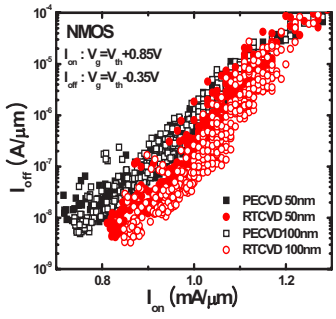
- Isolation & Well Formation
- Gate Stack Formation
- N & P LDD/Halo Implantation
- Nitride Spacer
- N+ & P+ SD Implantation
- S/D RTA
- No Silicidation for excluding silicide-induced stress
- CESL nitride (PECVD&RTCVD 50nm, 100nm)
- ILD TEOS & Contact Formation
- Metallization & Forming Gas Anneal

Fig 1. The process flow of a strained MOSFET using a CESL stressor. To exclude the stress that may be induced by the silicide formation, we omitted the silicidation process.



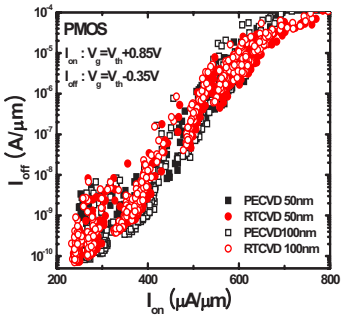


Fig 2. I_{on}-I_{off} performance comparison for (a) NMOS and (b) PMOS between PECVD CESL and RTCVD CESL as a function of thickness. In NMOS, the I_{on} of RTCVD CESL devices exhibit higher than PECVD CESL devices. In addition, in case of RTCVD CESL, Ion is increased as thickness of CESL SiN increase. However, no difference I_{on}-I_{off} characteristics of PMOS was observed

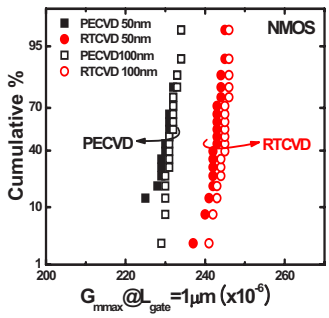


Fig 3. Cumulative plot of the $G_{m.max}$ with different CESL nitride. RTCVD devices show higher $G_{m.max}$ indicating that RTCVD CESL induced tensile stress.

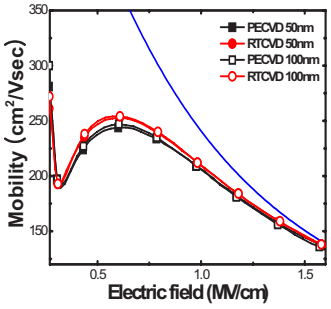


Fig 4. Mobility of NMOS with difference CESL nitride. The RTCVD CESL devices show slightly higher mobility.

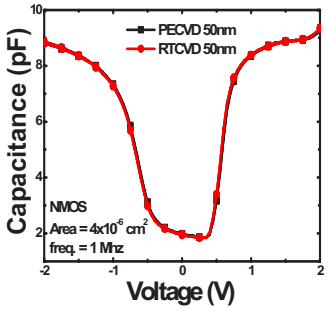


Fig 5. No differences in CV curve were observed between PECVD and RTCVD, indicating that equivalent oxide thickness (EOT) and threshold voltage (Vth) were not affected by the CESL nitride layers

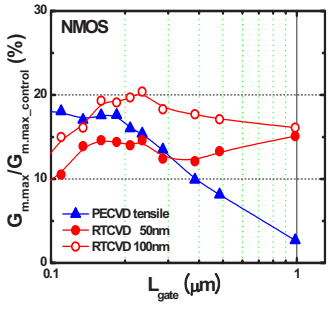


Fig 6. Comparison of $G_{m.max}$ / $G_{m.max\_cont}$ between PECVD tensile CESL and RTCVD CESL devices. Unlike PECVD tensile CESL, the mobility improvement of RTCVD CESL was maximized around 0.15 ~ 0.3μm

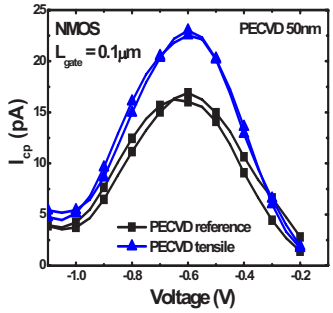


Fig 7. Comparison of I_{cp} with different PECVD CESL stressor nitride. I_{cp} in the PECVD tensile stressor devices was higher than in those with the reference nitride layers.

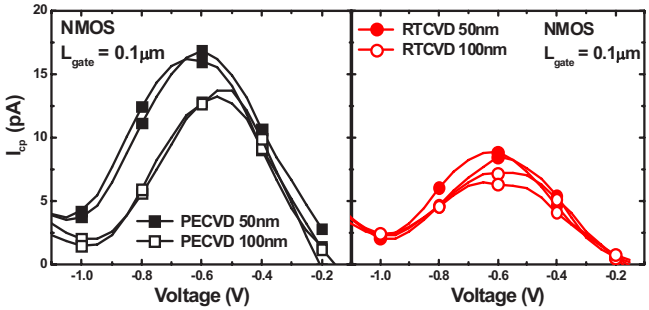


Fig 8. Comparison of I_{cp} with different CESL nitride. The RTCVD CESL devices exhibit lower charge pumping current than PECVD device which in turn lower interface charge trap density. In addition, both of PECVD and RTCVD devices decrease I_{cp} as thickness decrease.

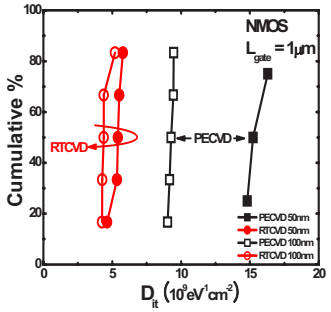


Fig 9. Comparison of D_{it} in gate length 1μm NMOS with different CESL elements. In long channel device, RTCVD samples also show lower interface charge trap density than PECVD samples

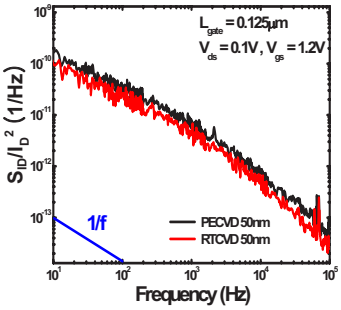


Fig 10. Low frequency noise measurement at V_{ds} = 0.1V and V_{gs} = 1.2V with PECVD and RTCVD CESL devices.

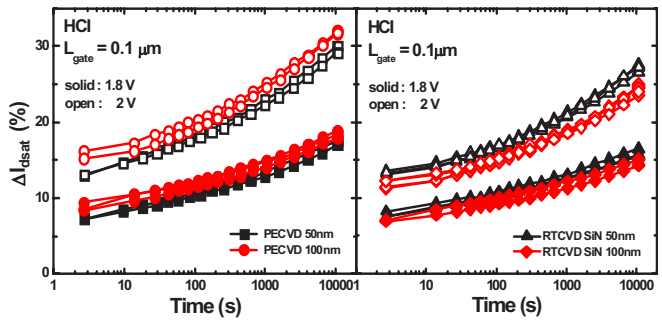


Fig 11. Comparison of ΔI_{dsat} with different CESL nitrides. Under a high voltage stress, the thicker PECVD CESL device shows higher I_{dsat} degradation compared to 50nm PECVD CESL devices. However, in case of RTCVD, thicker devices exhibit lower I_{dsat} degradation.

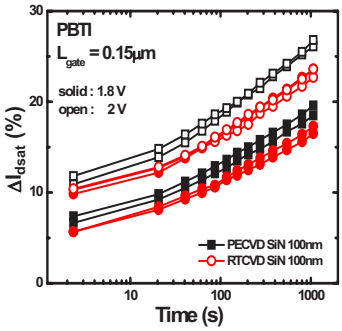


Fig 12. Comparison of ΔI_{dsat} in nMOS between PECVD and RTCVD CESL devices. The PECVD CESL devices show significant I_{dsat} degradation compared to RTCVD CESL devices.

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