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Improvement of Interfacial Characteristics and Reliability in Poly/SiON Gate Stack by Catalytic Effect of Hafnium Incorporation Technique

T. Shimizu, Y. Arayashiki, S. Inumiya, K. Nakajima, T. Aoyama, K. Eguchi
Process & Manufacturing Engineering Center, Semiconductor Company, Toshiba Corporation
8 Shinsugita-cho, Isogo-ku, Yokohama, 235-8522 Japan
Phone: +81-45-776-5422, Fax:+81-45-776-4106, E-mail: takashi5.shimizu@toshiba.co.jp

1. Introduction

Improvement of MOSFET performance by EOT (Effective Oxide Thickness) scaling in gate dielectric film is limited to about 1-2nm. Therefore, other additional technique except for EOT scaling is needed.

It is reported that incorporation of Hafnium to gate poly-Si/SiON interface is an effective method to improve MOSFET performance [1, 2]. A small amount of Hf at poly-Si/SiON interface can control threshold voltage (*Vth*) of MOSFET to keep the channel dopant concentration lower. Accordingly, degradation of effective mobility (*ueff*) caused by impurity scattering is suppressed and the drain current (*Id*) increases.

This Hf incorporation technique has been explained from the view point of work function control by Fermi-level pinning at Poly-Si/SiO_2 or Poly-Si/SiON interface [1-3]. On the other hand, it's well known that Hf has strong catalytic effect for oxygen activation. But the impact of catalytic effect caused by Hf incorporation technique on gate dielectric characteristics has not been reported.

In this report, we focus on the catalytic effect of Hf incorporation technique and investigate the effect on interfacial properties and reliability of SiON dielectric film.

2. Experiments

N- and P-type MOSFETs were fabricated on a (100) Si substrate using standard CMOS process. These MOSFETs have Poly-Si/Hf/SiON gate stack with various amount of Hf and channel dopant.

Sub-monolayer Hf was deposited on plasma nitrided SiON film (2nm) surface, using PVD process. Process flow and schematic diagram of this gate stack is shown in Fig.1.

We studied Hf amount dependence on MOSFET characteristics (*Vth*, *Id*, *ueff*). Furthermore, interfacial trap density (*Dit*) was evaluated from high and low frequency C-V characteristics. And NBTI lifetime was extracted from accelerated test at 105C.

In order to clarify Hf catalytic effect, we studied oxide regrowth in the case of Hf incorporated SiO_2 film. We carried out annealing in 5Torr O_2 ambient at 900C for SiO_2 films having various amount of Hf. And the change of film thickness was measured by XPS after the annealing.

3. Results and Discussion

Figure 2 shows the relation between channel I/I dose and *Vth*. It's clear to be able to set the channel I/I dose lower by the Hf incorporation. Fig.3 shows the relation between *Id* and Hf amount. With larger amount of Hf, *Id* is found to become higher for any target *Vth*.

For either N- and P-type MOSFETs, Hf incorporated sample has higher mobility as compared to no Hf sample which has same *Vth* tuned by channel impurity dose as shown in Fig.4. In the case of larger Hf amount, improvement of mobility is due to lower impurity scattering. However, it should be noted that Hf incorporated sample has higher mobility even at high electric field only in NMOS. In order to clarify the root cause of large mobility at high electric field in NMOS, we measured *Dit*. Fig.5 shows that *Dit* near the mid gap decreases with the increase of Hf amount. These results indicate that charged trap states affect the mobility at high electric field in NMOSFET. In PMOS, these interface trap states near the mid gap is barely filled at high electric field and not affect the mobility. It's found that Hf incorporation technique has additional effect to improve interfacial characteristics.

Next, we examine NBTI which is sensitive to interface characteristics. Fig.6 shows NBTI lifetime with various amount of Hf. Lifetime is found to be drastically extended by Hf incorporation technique. It is known that NBTI is caused by desorption of hydrogen from interfacial silicon dangling bond, which also originate interface trap [4]. Therefore, the longer NBTI lifetime result from the improvement of interfacial characteristic by Hf incorporation technique.

It is well known that Hf has catalytic effect. The catalytic effect activates oxygen molecular to radical atom. We think this catalytic effect is related to the interfacial characteristic of SiON/Si substrate. To clarify this catalytic effect by Hf in this gate stack structure, we examined behavior of oxide regrowth with Hf incorporation. Fig.7 shows thickness increase of oxide with Hf in low pressure oxidation ambient at 900C. Increase of oxide thickness is found to be enhanced with Hf amount deposited on the SiO_2 film. This result indicates that radical oxygen is generated by catalytic effect of Hf and it enhances oxidation rate of Si substrate.

From these results, we think that adsorbed oxygen (O_2, H_2O etc.) at SiON film surface or excess oxygen in SiON film is activated by Hf and it oxidize silicon dangling bond at SiON/Si interface in actual CMOS process (Fig.8).

4. Conclusions

It was found that Hf incorporation technique has not only the known effect of *Vth* control but also the effect of improvement in interfacial characteristic. This improvement of interfacial characteristic enhances effective mobility in NMOSFET and extend NBTI lifetime drastically.

References

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[2] H. Nakamura *et al*., VLSI Symp. Dig., **198** (2006)
[3] C. Hobbs *et al*., VLSI Symp. Dig., **9** (2003)
[4] N. Kimizuka et al., VLSI Symp. Dig., **92** (2000)

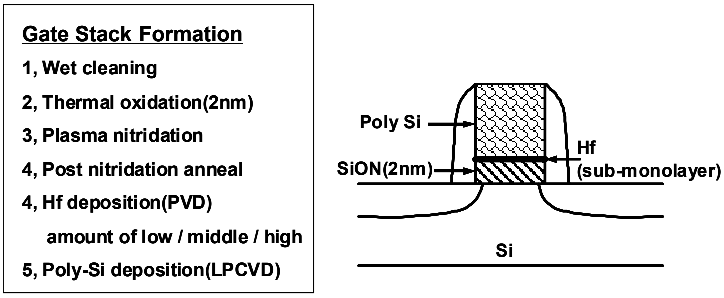


Fig.1. Process flow and schematic diagram of Hf incorporated Poly-Si/SiON gate stack.

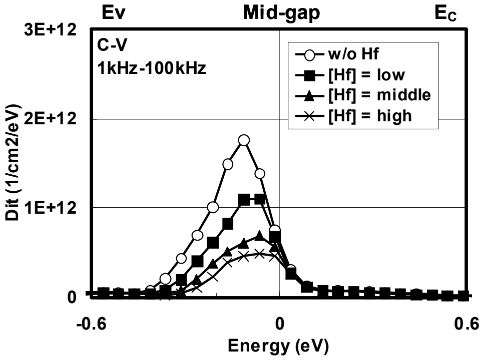
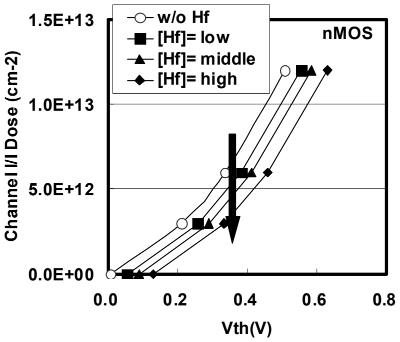
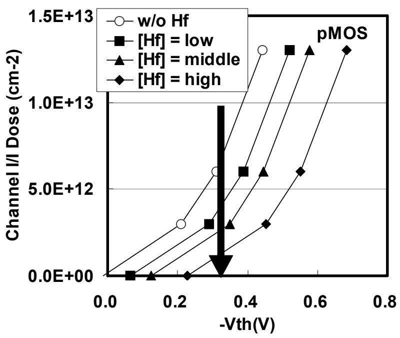


Fig.5. Surface energy dependence of Dit with various [Hf].



(a)NMOS



(b)PMOS

Fig.2. The relation between Channel I/I dose and Vth with various [Hf].

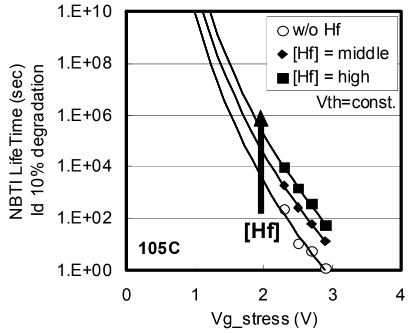
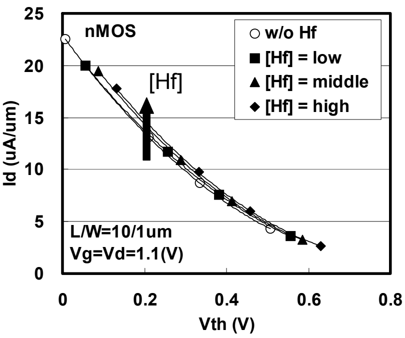
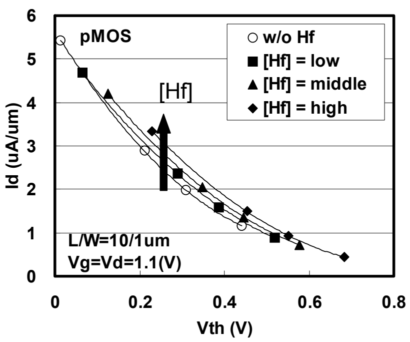


Fig.6. NBTI lifetime with various [Hf].



(a)NMOS



(b)PMOS

Fig.3. Vth dependence of Id with various [Hf]. (a)NMOS, (b)PMOS .

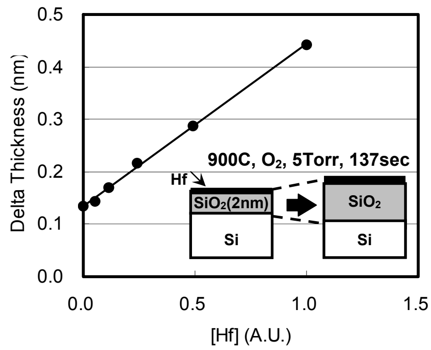
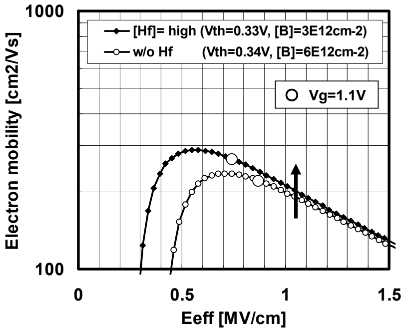
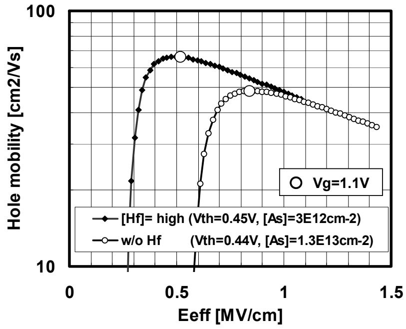


Fig.7. Thickness increment after anneal in oxygen ambient with Hf.



(a)electron



(b)hole

Fig.4. Electron and Hole mobility in inversion layer for with and without Hf at same Vth.

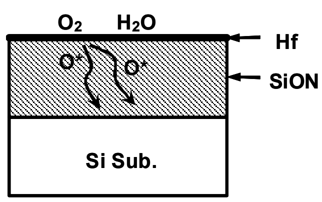


Fig.8. Schematic model of generation of radical oxygen due to the catalytic effect of Hf.