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Decoupling method of BTI component from hot carrier degradation in ultra-thin HfSiON MOSFETs

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1. Introduction

Hot carrier (HC) degradation is one of the most critical reliability issues as the channel length is reduced [1,2]. Another concern is Bias Temperature Instability (BTI). In addition to NBTI, PBTI is significant in high-k devices [3-5]. When applying HC stress to devices, BTI is also expected to occur [6] due to the vertical electric field. This effect would be more significant in high-k devices than SiON devices due to a large amount of pre-existing bulk traps. As a result, HC degradation is overestimated because of the combination of HC and BTI components. More accurate lifetime prediction becomes possible by decoupling the BTI component from HC degradation. In this study, we propose a new convenient method of decoupling HC degradation using the relation between gate current density and threshold voltage shift by BTI.

2. Method of decoupling HC degradation

It has been reported that the HC component can be decoupled from the NBTI component during the degradation under V_g=V_d stress by subtracting the NBTI degradation in long channel from the one measured in short channel devices [6]. However, we may overestimate the BTI component using this method, because BTI is sensitive to the vertical electric field and the field under HC stress is different from the one under BT stress (Fig.1, 2(a)).

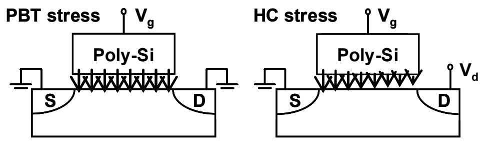

Fig. 1 Schematic illustrations of the electric field under PBT and HC stress.

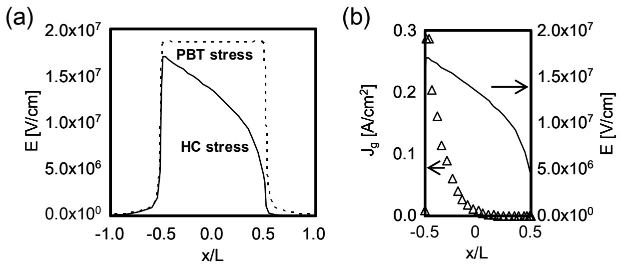

Fig. 2 (a) TCAD simulation result of the electric field under PBT and HC stress. (b) Gate current density (triangle) under simulated HC stress condition in (a). The experimental J_g-E data is used. L/W=0.14/5μm.

We focus on the gate current density (J_g). Fig.2(b) shows J_g distribution under HC stress by J_g-E measurement and the electric field simulation (Fig.2(a)). As shown in Fig.3(a), threshold voltage shifts (ΔV_{th}) at long stress time have little difference when exchanging source and drain in I-V measurements. This suggests that the degradation is not localized in source-side. So BTI degradation can be approximately monitored by averaging J_g. We propose a convenient decoupling method using the relation between ΔV_{th} and J_g. The procedure is shown in Fig.4. First, ΔV_{th}^{BTI} and J_g^{BTI} under BT stress are measured at several V_g. A relation between them introduced by fitting is given by

$$\Delta V_{th}^{BTI} = a\left(J_g^{BTI}\right)^b \qquad (1)$$

Then, ΔV_{th} (ΔV_{th}^{Total}) and J_g (J_g^{HC}) under HC stress are measured. The BTI component (ΔV_{th}^{BTI}) is estimated by substituting J_g^{HC} into the relation (1). The HC component (ΔV_{th}^{HC}) can be decoupled by subtracting the BTI component from the total degradation.

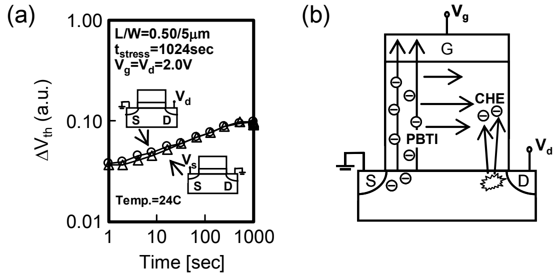

Fig.3 (a) Threshold voltage shift under V_g=V_d stress measured with exchanging source and drain on I-V measurement. Circle indicates V_d applied and triangle indicates V_s applied. (b) Schematic illustration of the degradation by PBTI and CHE.

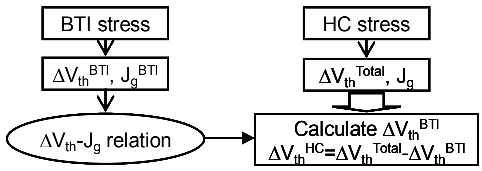

Fig.4 Characterization procedure of our new decoupling method.

3. Results and discussion

Decoupling of PBTI/HC components from HC degradation

Measurements were performed on n and pFETs with SiO_2/HfSiON/poly-Si gate stacks. The EOT of the gate dielectric is ~1.5nm. The channel length and width are 0.11-0.5μm and 5μm, respectively.

PBTI characteristics with different gate bias voltages are shown in Fig.5. Fig.6 shows the J_g dependence of ΔV_{th}. Their relation is well fitted by the power-law. We estimated the channel length dependence of PBTI (Fig.7) to use the relation between ΔV_{th} and J_g into different channel length samples. As shown in Fig.7(b), PBTI doesn't have significant channel length dependence. Fig.8(a) shows the stress time dependence of HC degradation and its PBTI and HC components decoupled by the method described above. Fig.8(b) shows the channel length dependence of the decoupling result of HC degradation on different channel length nFETs. The HC component becomes larger as channel length is reduced, while PBTI stays mostly unchanged. These features are consistent with the channel length dependences of HC and PBTI in SiON devices, respectively [6].

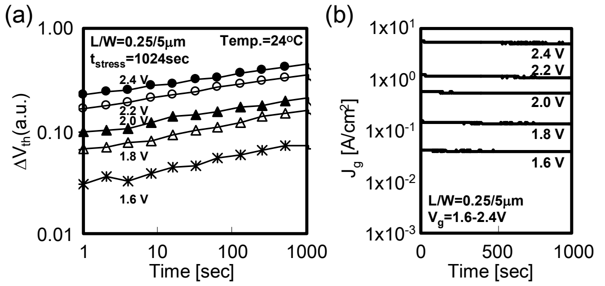

Fig.5 (a) Threshold voltage shift (ΔV_{th}) and (b) Gate current density (J_g) under PBT stress with different gate bias voltage (V_g=1.6-2.4V) at 24 °C. L/W=0.25/5µm.

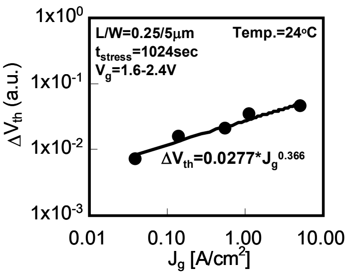

Fig.6 J_g dependence of ΔV_{th} after 1024sec PBT stress at 24°C. L/W=0.25/5µm.

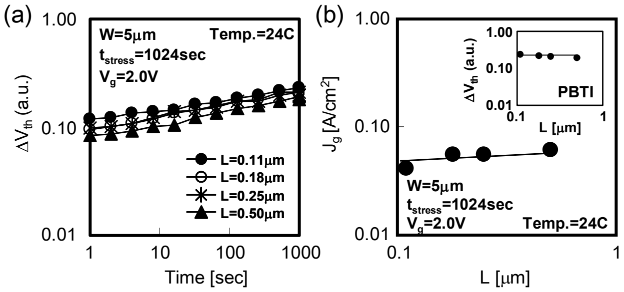

Fig.7 Channel length dependence of PBTI at 24°C (L/W=0.11-0.5/5µm). (a) Threshold voltage shift (ΔV_{th}). (b) Gate current density (J_g) under PBT stress. Inset shows the channel length dependence of ΔV_{th} after 1024sec PBT stress at V_g=2V.

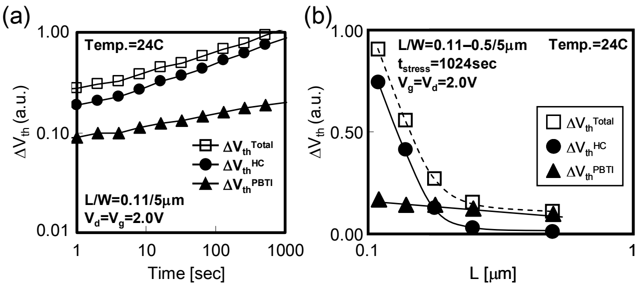

Fig.8 (a) HC degradation (ΔV_{th}^{Total}) and its PBTI and HC components (ΔV_{th}^{PBTI}, ΔV_{th}^{HC}) decoupled by our method. HC stress condition is at $V_g=V_d$=2V and T=24°C. (b) Channel length dependence of threshold voltage shift after 1024sec HC stress (ΔV_{th}^{Total}) and its PBTI and HC components (ΔV_{th}^{PBTI}, ΔV_{th}^{HC}). HC stress condition is at $V_g=V_d$=2V and T=24°C.

Decoupling of NBTI/HC components from HC degradation

We performed HC stress on different channel length pFETs (L/W=0.11-0.50/5µm) and decoupled the degradation in the same way (Fig.9). The HC and NBTI components are also decoupled from HC degradation. Fig.10(a) shows the temperature dependence of NBTI and Fig.10(b) shows that of NBTI and HC components during HC degradation. The activation energy of NBTI component is almost the same with that of NBTI (~0.1eV). And similar values were reported [7,8]. The channel length dependence of decoupled HC and BTI components and the activation energy of NBTI component indicate the validity of this decoupling method.

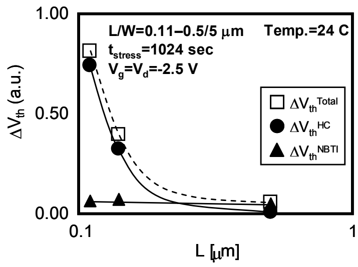

Fig.9 Channel length dependence of threshold voltage shift after 1024sec HC stress (ΔV_{th}^{Total}) and its NBTI and HC components (ΔV_{th}^{NBTI}, ΔV_{th}^{HC}). HC stress condition is at $V_g=V_d$=-2.5V and T=24°C. L/W=0.11-0.5/5µm.

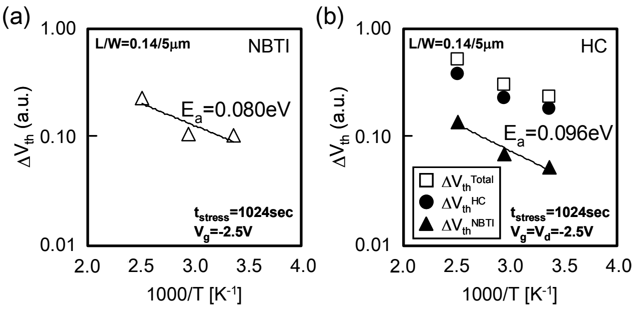

Fig.10 (a) Temperature dependence of threshold voltage shift after 1024sec NBT stress. Stress condition is at V_g= -2.5V. L/W=0.14/5µm. (b) Temperature dependence of threshold voltage shift after 1024sec HC stress (ΔV_{th}^{Total}) and its NBTI and HC components (ΔV_{th}^{NBTI}, ΔV_{th}^{HC}). HC stress condition is at $V_g=V_d$=-2.5V. L/W=0.14/5µm.

4. Conclusion

A convenient decoupling method of HC degradation was proposed. Using ΔV_{th}-J_g relation, the HC and BTI components were decoupled from the degradation during $V_g=V_d$ stress condition. The reasonable channel length dependence of each component was obtained for both n and pFETs. The similar activation energy of NBTI and decoupled NBTI component from HC degradation indicates the validity of our method.

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