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Investigation of Illuminated High-Frequency Capacitance-Voltage Response in Deep Depletion of HfO_2 and SiO_2 MOS Capacitors with Ultra-thin Gate Oxides

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1. Introduction

Deep depletion in MOS structure is so far of use for the characterization of the interface properties [1-2]. Recently, we have demonstrated the edge enhanced deep depletion MOS photodiode by high-*k* material [3]. The photonic application of deep depletion is of interest. Based on the concept of local depletion capacitance (LDC), deep depletion reveals that localized area formed by injection carriers from substrate can be observed clearly in magnified *C-V* curves [4]. However, the correlation between photonic *C-V* curves and deep depletion in high-*k* stack is lack of discussion.

In this work, we examine illuminated *C-V* curves via LDC model. The smaller initiation voltage of deep depletion in HfO_2 is observed from magnified *C-V* curves. The non-uniform area ratio increases in HfO_2 and SiO_2 device after the illumination was also investigated.

2. Experimental

For SiO_2, ultra-thin oxides were grown through the tilted anodization process with applied DC voltage of 12.5V. Post-oxidation annealing was carried out in 100 torr, N_2, at 850 ^oC for 15 secs. For HfO_2, after initial SiO_2 layer was grown by RTP at 950^oC for 15s with 15 torr O_2 ambient, the sample was sputtered with Hf metal at 400V,0.15A (60W) for 2 mins. The Hf layer was oxidized in 50% HNO_3 for 6 mins to form HfO_2 then annealed by N_2 ambient at 380 ^oC for 12 mins. After each oxidation process, pure Al was thermally evaporated as gate electrode. The gate area of $2.25x10^{-4}$ cm^2 was defined. Finally, Al was thermally evaporated on backside as back contact. The overall process flows of MOS capacitors with SiO_2 and HfO_2 are shown in Fig. 1 (a) and (b), respectively. *C–V* characteristics were measured by an HP4284 LCR meter, and illuminated *C-V* curves are also derived by using 13W Circular Fluorescent Microscope Illuminator (Coherent's Model 9, CFMI). From correction model proposed by Hu [5], EOTs of gate dielectric was extracted by fitting the corrected *C–V* curves based on 1 MHz and 100 KHz with the consideration of quantum mechanical effect.

3. Simulation Result and Discussion

Fig.2 and 3 show the *C-V* curves of SiO_2 and HfO_2 with illumination and dark measurement, respectively. The inset of the Fig. 2 and 3 manifests the *C-V* curves and show the different initiation voltages of deep depletion in corresponding devices. Clearly, the initiation voltage of deep depletion in HfO_2 is smaller than the SiO_2 in both illuminated and dark *C-V* curves under large bias. We then subtract the capacitance of dark from illuminated *C-V* curves as shown in Fig.4. The peak of the diagram indicated the initiation voltages of SiO_2 and HfO_2 are 1.6V and 0.12V, respectively. Previous research shows the saturated inversion current occurs earlier in HfO_2 than in SiO_2 under the same condition (EOT, bias) [6], which are consistent with the result found in this work. Fig. 5 and 6 show the fitting *C-V* curves via LDC model [2, 4]. Both of them were perfectly fitted and the fitting curves are shown in solid lines. Interestingly, the uniform area ratio (K) decreases after illumination in both SiO_2 (from K=0.97 to 0.75) and HfO_2 device (from K=0.75 to 0.66). In the deep depletion mode without illumination, the variation of the capacitance is mainly caused by the depleted acceptor charges. Due to the built-up of photoexcited excess electrons at SiO_2/Si hetero interface (the photovoltaic effect), the reduced surface potential result in the shrinkage of depletion width with increasing of the capacitance as illustrated in schematic diagram in Fig.7. Furthermore, in our latest research [3], the charge collection phenomena at edge in MOS device indicated the inversion tunneling current was dominated by the geometrical perimeter of the device, i.e., the tunneling induced deep depletion expansion-shrinkage has been enhanced by the edge field of abrupt junction in the hetero structure during the illumination. It is believed that the lateral non-uniformity effect (non-uniform area ratio) has been manifested on the illuminated *C-V* curves.

4. Conclusions

The correlation between illuminated *C-V* response and deep depletion of SiO_2 and HfO_2 was demonstrated. The HfO_2 shows the earlier occurrence of deep depletion than SiO_2 device at the same EOT. The electrical characterization of deep depletion (LDC model) in dielectric stack indicated the non-uniform effect in MOS structure was manifested during the illumination.

Acknowledgements

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References

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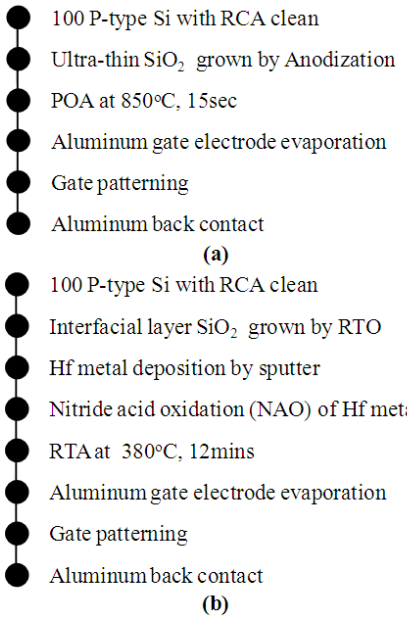

Fig. 1 Fabrication flow of MOS capacitors with SiO_2 and HfO_2 dielectrics

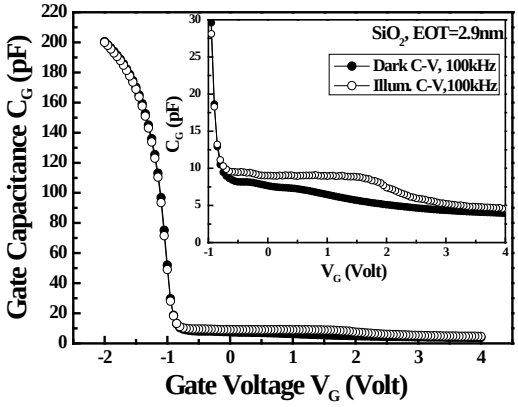

Fig.2 Illuminated *C-V* curves of SiO_2 (EOT=2.9nm) under 100kHz measurement. *C-V* curves in the deep depletion region is enlarged in the inset.

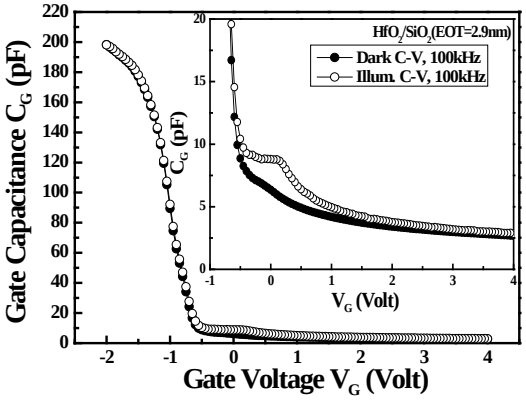

Fig.3 Illuminated *C-V* curves of HfO_2 (EOT=2.9nm) under 100kHz measurement. *C-V* curves in the deep depletion region are enlarged in the inset.

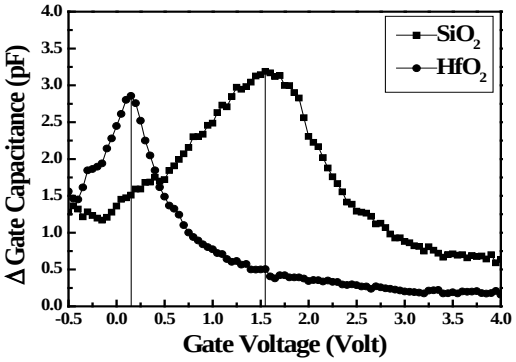

Fig.4 Variation of gate capacitance from *C-V* curves before and after illumination. The initiation voltages of deep depletion in HfO_2 and SiO_2 are 0.12V and 1.6V, respectively.

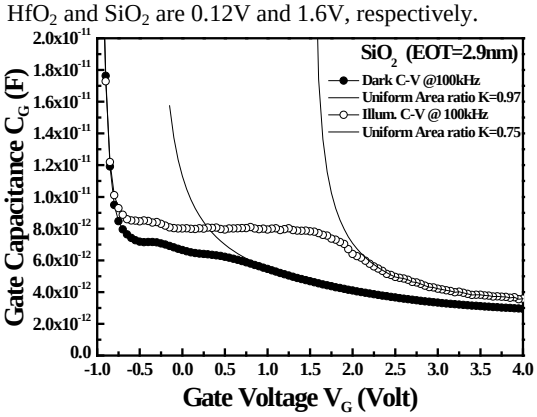

Fig.5 *C-V* curves of SiO_2 in the deep depletion. The solid lines show the calculated *C-V* curves by LDC model. K=0.97 and 0.75 for dark and illuminated *C-V* curves, respectively.

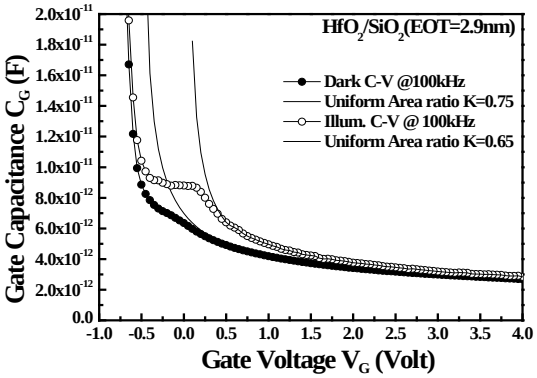

Fig.6 *C-V* curves of HfO_2 in the deep depletion. The solid lines show the calculated *C-V* curves by LDC model. K=0.75 and 0.65 for dark and illuminated *C-V* curves, respectively.

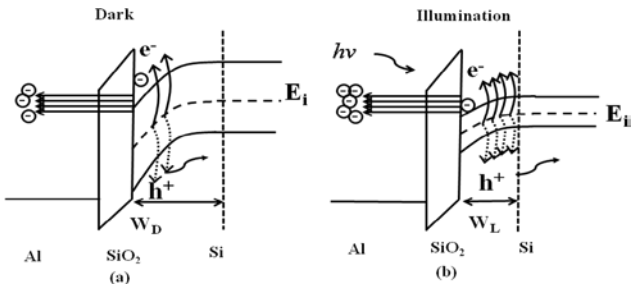

Fig.7 Schematic energy band diagrams for Al-SiO_2-Si structure in deep depletion under (a) darkness and (b) illumination.