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Direct evaluation of an interfacial layer in high-*k* gate dielectrics by 1/f noise measurements

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1. Introduction

Interfacial layer of high-*k* gate stack for advanced CMOS is essential to ensure the high mobility [1-3]. However, the characterization of the interfacial layer has been insufficient, because the conventional evaluation methods, such as quasi-static *C-V* or charge pumping, need the extremely low leakage current. It is difficult even for high-*k* gate stack to satisfy the requirement.

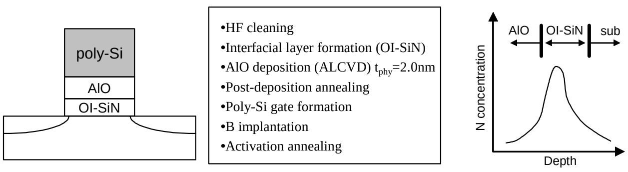
In this paper, we show that the 1/f noise measurements are valid to evaluate the interface state density (D_{it}), while the conventional methods are not applicable. With this method, the interfacial characteristics of OI-SiN (SiN dielectric with an oxygen-enriched interface)/AlO [3] are reported.

2. Samples

Table 1 summarizes the samples. The various thickness of OI-SiN under the AlO layer is prepared (Fig. 1). We also measured pure SiO as a reference.

Table 1: Measurement device parameter

Sample No.	#1	#2	#3	#4 (ref.)
AlO thickness (physical) [nm]	2.0	2.0	2.0	
Interfacial-layer OI-SiN thickness (physical) [nm]	1.4	1.7	2.1	
Total equivalent oxide thickness (EOT) [nm]	1.6	1.9	2.2	3.0 (pure SiO)



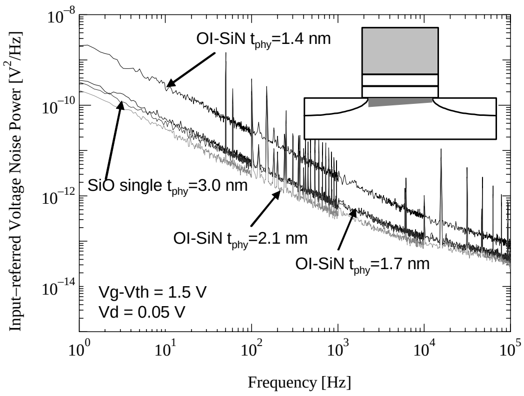
(a) Gate structure (b) Process flow for the gate stack (c) N profile

Fig. 1: AlO/OI-SiN stacked gate device and process flow

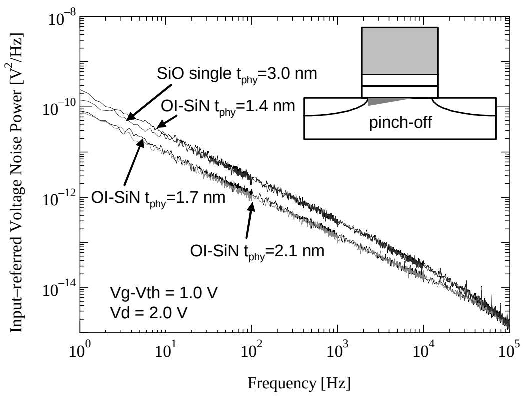
3. 1/f noise measurement

Figure 3 shows the 1/f noise spectrums for various interfacial OI-SiN film thicknesses. Pure SiO_2 is also plotted for comparison. The 'input-referred voltage noise power spectrum (S_{vg})' was used to compare the noise characteristics of different samples. To consider the difference of gate-dielectric thicknesses, S_{vg} is obtained from the drain-current noise spectrum (S_{id}) data with g_m.

In the linear-region measurements [Fig. 2(a)], the inversion-layer appears in the whole channel area and band bending is almost constant along the channel. Consequently, it is suitable for analysis of the interface to measure the 1/f noise in the linear-region. Clear dependence of the interfacial thickness on the 1/f noise spectrum is observed in the Fig. 2(a). However the difference is small for the saturation region (Fig. 2 (b)). Therefore, the difference is not severe for practical operation.



(a) Linear region



(b) Saturation region

Fig. 2: 1/f noise spectrums of n-MISFETs (L/W=3/10 μm) in (a) saturation region and (b) linear region with various devices (AlO/OI-SiN t_{phy}=1.4, 1.7, 2.1 nm/sub-Si)

4. Discussion

For the MISFET structure, the 1/f noise spectrum of the drain current fluctuation is dominated by the trap/detrap due to D_{it}, as shown in Fig. 3. It has been reported that there is the relation between noise amplitude and D_{it} [5]-[7]. In the low drain voltage region, the relation expresses as the following:

$$S_{V_g}(f) \propto D_{it} \cdot$$

Figure 4 shows the dependence of D_{it} (OI-SiN physical thickness of 2.1-nm) on energy measured by the 1/f noise and quasi-static methods. 1/f noise was measured in linear region at 10 Hz.

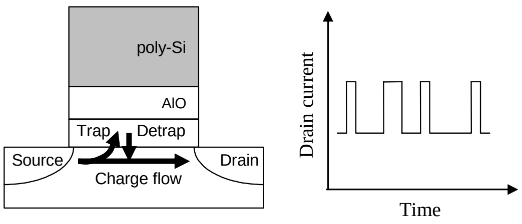


Fig. 3: The mechanism of 1/f noise

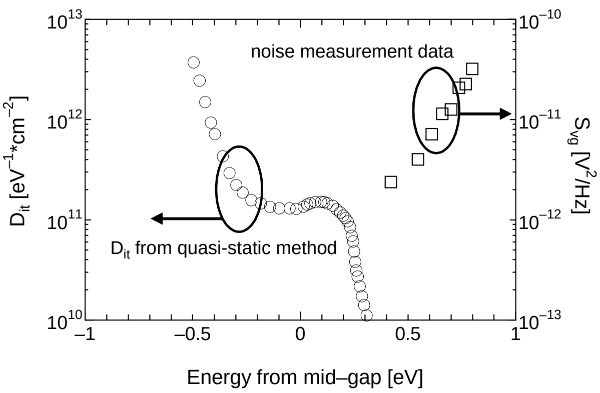


Fig. 4: The dispersion of the interface-state density (D_{it}) with interfacial OI-SiN 2.1-nm thick extracted by quasi-static method

Quasi-static *C-V* cannot be used above 0.2 eV from the mid-gap, because of the large leakage current in the inversion. On the other hand, 1/f noise measurement shows that D_{it} increases approaching to the conduction band edge.

To confirm the correlation between 1/f noise measurement and D_{it}, we compared 1/f noise measurement with charge-pumping method (Fig. 5). The charge-pumping methods show that D_{it} increases with decreasing the thick of OI-SiN. This implies that the peak position of N profile is located closer to the interface for the thinner OI-SiN, which is consistent with the XPS measurement [4].

The similar tendency is also observed by the 1/f noise measurement. The noise level of the device with interfacial OI-SiN 2.1-nm thick is smaller than that of pure 3.0-nm SiO_2. This suggests that stacked AlO layer dose not degrade the quality of the interfacial OI-SiN.

Thus, it can be concluded that 1/f noise measurement is a good probing method for investigating the interface state.

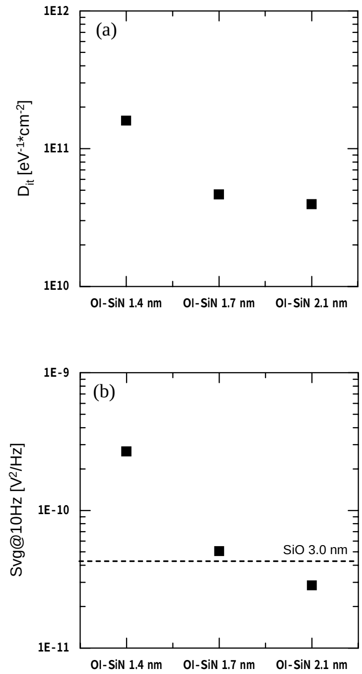


Fig. 5: (a) The interface-state density (*D_{it}*) at mid-gap extracted by charge-pumping method and (b) 1/f noise amplitude at 10 Hz taken from the Fig. 3(a). The dotted line represents the noise level of the device with 3.0-nm SiO gate dielectric.

5. Conclusions

Using 1/f noise measurement, we evaluated the interfacial characteristics of high-*k* gate stacks. We showd that this method is valid to extract D_{it} in the region, where quasi-static *C-V* measurement cannot be applicable. We found that D_{it} correlated with the thickness of interfacial OI-SiN, and the noise level of OI-SiN/AlO is comparable to the pure SiO_2. Since 1/f noise measurement is not affected by the leakage current, it is useful to extract D_{it} for the characterization of future scaled MOSFET.

References

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