A Distributed Model for Near-Interface Traps in 4H-SiC MOS Capacitors

U. Tsukuba.[1], AIST[2] ○(D)Xufang Zhang[1], Dai Okamoto[1], Tetsuo Hatakeyama[2], Mitsuru Sometani[2], Shinsuke Harada[2], Ryoji Kosugi[2], Noriyuki Iwamuro[1], and Hiroshi Yano[1]
E-mail: s1536009@u.tsukuba.ac.jp

1. Introduction

Near-interface traps (NITs) are one of the most harmful oxide defects locating near the interface of SiO_2/4H-SiC, which leads to the poor properties of 4H-SiC MOSFETs. However, currently, there is no good approach to estimate the density and distribution of the NITs because it is hard to distinguish the NITs and fast interface states. In this work, we established a distributed model to investigate the NITs based on the tunneling mechanism in the strong accumulation region. It yields frequency-dependent capacitance and conductance in agreement with the experimental results of dry oxidation and NO-annealed samples. Based on the proposed model, we estimated the density distribution of the NITs against the tunneling depth.

2. Measurements and Distributed Model

Capacitance and conductance as a function of frequency were measured for three 4H-SiC MOS capacitors biased in strong accumulation (V_G = 20 V). The measured samples were oxidation without passivation (sample label: Dry), oxidation followed by nitidation for 10 min (NO 10) and 60 min (NO 60). We have observed the frequency-dependent characteristics [1], which cannot be explained by fast interface traps whose time constant in accumulation is too short in the frequency range. In this situation, the influence of NITs should be considered. We established an equivalent circuit with reference to the model for III-V MOS devices [2] by considering the series combination of series resistance R_s, shown in Fig. 1. The density of NITs per volume per energy at the depth x in SiO_2 from the interface is $N_{\mathrm{NIT}}(x)$ in unit of $\mathrm{cm}^{-3}\mathrm{eV}^{-1}$. Note that we assumed an exponentially decaying spatial distribution of $N_{\mathrm{NIT}}(x)$ [3], given by

$$N_{\mathrm{NIT}}(x) = N_{\mathrm{NIT0}}\exp(-\alpha x)$$

α is a decay constant considered as a fitting parameter. Based on the recursive nature of the circuit, a differential equation for $Y(x)$ can be obtained:

$$\frac{dY}{dx} = -\frac{Y^2}{j\omega C_{\mathrm{ox}}} + \frac{q^2 N_{\mathrm{NIT0}} e^{-\alpha x}\ln(1 + j\omega\tau_0\exp(2\kappa x))}{\tau_0\exp(2\,\kappa x)}$$

where, κ is the attenuation constant, depending on the band offset between 4H-SiC and SiO_2, and τ_0 is time constant at the interface. The admittance can be obtained numerically by integral from $x = 0$ to the oxide thickness t_{ox} and the initial value should be $Y(x = 0) = j\omega C_s$ obtained from the theoretical calculation. The total Y should be

$$Y(x = t_{\mathrm{ox}}) = G_{\mathrm{tot}} + j\omega C_{\mathrm{tot}}.$$

3. Results and Discussion

By choosing the fitting parameters of N_{NIT0} and α, good agreements were obtained between the model and experimental data in Fig. 2 (a) and (b) for the three samples. Figure 3 shows the exponential distribution of NITs over the depths from the interface for the 3 samples. It is worth pointed out that the influence of the NITs is significant only over a few nanometers (less than 5 nm) from the interface even though the integral is up to the oxide thickness (t_{ox} are 48.1nm, 51nm and 51nm for 3 samples, respectively). This could be explained by the following 2 reasons: first, the time constants of oxide traps locating farther from the interface are much longer so that they cannot respond to the ac signal and cannot induce frequency dispersion of capacitance and conductance; second, the NITs might only locate near the interface because the strain, one possible origin of NITs, is large near the interface due to the material difference and the NITs would gradually disappear with the growth of SiO_2. In addition, the decrease in N_{NIT0} and increase in α with the nitridation time indicates the NITs were effectively passivated by nitridation.

4. Conclusion

We developed a distributed model for 4H-SiC MOS capacitors based on electron tunneling into the NITs. The model reasonably explained the frequency-dependent characteristics of capacitance and conductance.

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References

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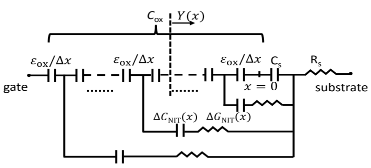

Fig.1. Equivalent circuit of MOS capacitors considering NITs.

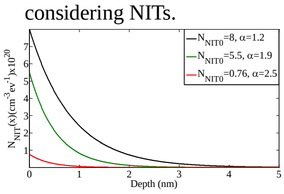

Fig.3. Density and distribution of NITs.

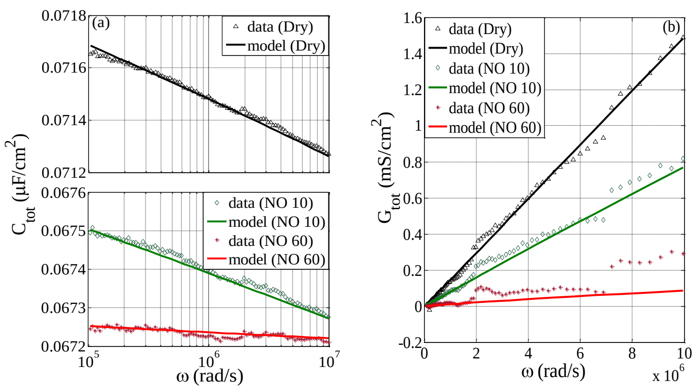

Fig.2. Experimental and model (a) capacitance and (b) conductance for 3 samples vs. ω.