Characterization of Interface States in MOS Systems by Using Photonic High-Frequency Capacitance-Voltage Responses


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II. INTERFACE STATE CHARACTERIZATION USING THE PHOTONIC HIGH FREQUENCY C-V CHARACTERISTICS OF MOS CAPACITORS

As shown in Fig. 1, the photonic HF-CV characteristics of MOS capacitors with \( t_{ox} = 23 \) nm and \( W \times L = 300 \times 300 \) \( \mu \)m\(^2\) were measured for a small signal frequency, \( f = 500 \) kHz, and at a slow DC sweep rate, 1 mV/s. Due to the limited contribution of photogenerated excess channel carriers only from the interface states at the Si/SiO\(_2\) interface under illumination with light having a wavelength of \( \lambda = 1314.5 \) nm, the gate capacitance in the inversion mode \(|V_G| > |V_T|\) increases little and shows a negligible variation with increasing optical power \( P_{opt}\). However, due to the abundant contribution of photogenerated excess carriers from the valence band to the conduction band under irradiation at a wavelength of \( \lambda = 850 \) nm, the gate capacitance in the inversion region is significantly increased, but its variation with increasing \( P_{opt}\) is negligible. Therefore, the slow sweep-rate HF-CV characteristics of a MOS capacitor under optical illumination is not suitable for the characterization when \( E_{ph} > E_g \) or \( E_{ph} < E_g \).

The photonic DD HF-CV characteristics were measured with the same small signal-frequency, \( f = 500 \) kHz, and fast DC sweep rate, 50 mV/s. The equivalent circuit model of a MOS capacitor under deep-depletion high-frequency conditions can be described by

\[
\frac{1}{C_G} = \frac{1}{C_{OX}} + \frac{1}{C_d} \tag{1}
\]

with an equivalent model as shown in Fig. 2 [6]. Without an optical input, we may assume \( C_{OI} = C_{OT} = 0 \). The

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Fig. 1. Photonic HF-CV characteristics of MOS capacitors under optical illumination ($\lambda = 1314.5$ nm, 850 nm): (a) NMOS capacitor and (b) PMOS capacitor.

![Photonic HF-CV Characteristics](image1)

$$\phi_s = \pm \frac{qN_e \varepsilon_s \varepsilon_0}{2} \left( \frac{C_{OX} - C_G}{C_{OX}C_G} \right)^2, \quad (2)$$

can be obtained from the measured DD HF-CV curve as a function of the gate bias. Extracted surface potentials for P- and N-MOS capacitors are shown in Fig. 3.

Photonic DD HF-CV curves for an optical input with $\lambda = 1314.5$ nm are shown in Fig. 4. Due to the photogeneration and to the contribution of excess carriers excited from the interface states at the Si/SiO$_2$ interface, the gate capacitance in the inversion region increases with increasing $P_{opt}$. Under a fast DC sweep rate (50 mV/s), which is fast enough that the ramping time is shorter than the minority-carrier response time, insufficient time exists for the photogenerated excess carriers.
under optical input, is given by the photogenerated carriers from the interface states and P-MOS capacitors. Using the above derivation, we can also obtain a distribution of the interface state density \( D_{it} \) which can be described by [2]

\[
D_{it} = \frac{C_{it}}{q}
\]

(6)

As shown in Figure 6, by using the photonic DD HF-CV method with \( E_{ph} < E_g \), we characterized MOS capacitors with \( E_{ph} (\lambda = 850 \text{ nm}) \) and \( E_g \) and we show the result in Fig. 7. Conversely to the C-V characteristics obtained for \( \lambda = 1314.5 \text{ nm} \) with the same measurement setup, DD HF-CV characteristics are predominantly controlled by the excess carriers from the band-to-band photogeneration in the bulk (\( E_{ph} > E_g \)). The photonic DD HF-CV response of the interface states under an optical input with \( \lambda = 850 \text{ nm} \) is fully screened by the abundant photogenerated excess inversion carriers. Therefore, photonic the DD HF-CV response and its physical mechanisms caused by the interface states are mainly governed by the photogenerated excess carriers from the interface states; therefore, the DD HF-CV response is effective for the characterization of \( D_{it} \) in MOS capacitors.

III. CONCLUSION

Fig. 6. Interface trap density in NMOS and PMOS capacitors.
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Fig. 7. Photonic DD HF-CV characteristics with $\lambda = 850$ nm: (a) NMOS capacitor and (b) PMOS capacitor.

Based on the photonic deep-depletion high-frequency C-V characteristics of MOS capacitors under an optical input with $\lambda = 1314.5$ nm, we obtained a U-shaped distribution for $D_{it}$ in the photo-responsive energy range. We believe that the photonic DD HF-CV method to be useful for characterizing the interface states in the Si/SiO$_2$ interface.

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REFERENCES