Photonic Gated-Diode Method for Extracting the Energy-Dependent and Spatial Distributions of Interface States in MOSFETs

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Abstract

In this paper, a new photonic gated-diode method is proposed to extract the energy-dependent and spatial distributions of interface states in MOSFETs. For the photonic current–voltage (I–V) characterization of MOSFETs, an optical source with a photon energy less than the silicon bandgap ($h\nu$=0.95eV<E_g=1.12eV) is employed for the characterization of interface states (E_{it}) distributed in the photo-responsive energy band (E_C-0.95≤E_{it}≤E_C) in MOS systems with a polysilicon gate. The proposed novel method is simple and feasible for accurate extraction of interface traps MOSFETs.

I. Introduction

As the scaling of MOSFETs devices continues toward sub-0.1nm gate lengths, SiO_2 thickness values of 1.5nm and below are required.[2] These gate dielectrics are subjected to very high electric field during circuit operation. So, It is well known that the interface trap is one of the most important parameters for the reliability of MOS devices.[1] For low voltage, high-speed applications, implying low threshold voltages, accurate values of the subthreshold slope is particularly important in modeling leakage current and standby power-dissipation.[3]

The charge-pumping method (CPM) is known to be a powerful tool for quantitatively characterization of the energy-dependent [6] and lateral distributions of interface-states and the oxide-trapped charges in MOS systems [7,8,9]. However, in many cases the critical neutralization step required for the technique cannot always be performed in a satisfactory way, which could result in significant errors in the profiles and the geometry effect. The CPM is also time-consuming, there is no way to ensure that the injected carriers would not leak away during CPM and difficult to extract midgap. In order to overcome this limitation, we have reported the photonic capacitance-voltage (C-V) characteristics and new extraction method for the interface traps in MOS structures by photonic C-V characteristics [4].

In this work, a novel technique, namely photonic gated-diode method (PGDM)**,** is introduced for the extraction of interface traps MOSFETs. This nondestructive PGDM uses the photonic I-V characteristics with the photon energy less than the silicon band-gap energy. Based on the PGDM combining the interface state-induced-current (I_{it}) in MOSFETs under optical illumination, energy-dependent and spatial distribution with respect to the gated diode current, in optical illumination and dark condition. The reverse diode currents of the gated diodes (in accumulation, depletion, and inversion both under optical illumination and under dark condition) were measured and the energy-dependent and spatial distribution of the interface state density are characterized.

II. A New Interface State Profiling Technique

In the experimental characterization, HP 4145B parameter analyzer and ILX Light-wave 7200 are used to monitor the optically induced current in MOSFETs under applied optical illumination. N-MOSFETs is used as a test structure for this work. Physical process involved in this technique is shown in Fig.1. We measured gated diode current [6] under dark and optically-induced-drain-leakage current (I_{it}) described as following.

We assume that only optically responsive-electrons in interface traps contribute to the surface generation current. The interface-induced current under optical illumination is shown Figs.2 and 4. Trap-induced current I_{it} can be described as

$$I_{it} \equiv I_{Op} - I_{Dk} = A_g \sum_{\Delta E} J_{it} \tag{1}$$

where I_{Op} is the current under the optical illumination and I_{DK} is the dark current. J_{it} can be written as

$$J_{it} = qn_i s_o = qn_i \left(\frac{\sigma_s \upsilon_{th} N_{it}}{2} \right) \tag{2}$$

where n_i is the intrinsic carrier concentration in silicon, A_g is the gate area, s_o is the surface recombination velocity, σ_s is the effective capture cross section, υ_{th} is the thermal velocity, and N_{it} is the interface state density.

2.1. Energy-Dependent Interface States

Modulating the surface potential with applied gate voltage, we obtain the trap-induced leakage current density from

$$I_{it} = A_g \Delta J_{it} = qn_i \left(\frac{\sigma_s \upsilon_{th} \Delta N_{it}}{2} \right), \tag{3}$$

and, as shown Fig. 3, the energy-dependent interface state density D_{it} ($cm^{-2}eV^{-1}$) can be obtained from

$$D_{it} = \frac{\partial \Delta N_{it}}{\partial V_G} \frac{\partial V_G}{\partial \phi_S} = \frac{2}{A_g q n_i \sigma_s \upsilon_{th}} \frac{\partial \Delta I_{it}}{\partial V_G} \frac{\partial V_G}{\partial \phi_S} . \tag{4}$$

2.2. Spatial Distributions of Interface States

A reverse voltage V_R is applied across the drain-substrate junction in MOSFETs and the current is measured as a function of the reverse voltage. With the gate voltage fixed at the flat band voltage (V_{FB}), the distribution of traps in the channel near the drain can be obtained from the optically induced leakage currents a help of the energy band diagram as a function of the reverse bias. All of the interface states can't be filled with electrons without channel depleted by the reverse voltage. With increasing the reverse voltage, interface states in the depletion region are filled with electrons. In this condition, optical energy is illuminated on the DUT to emit electrons to the conduction band, and finally contribute to the surface generation current. And the interface state-induced-current, I_{it}, can be obtained. From the difference of the two curves (photonic-illuminated and dark current-voltage curve), interface states N_{it} can be obtained from the interface-induced-current as

$$I_{it} \equiv I_{Op} - I_{Dk} = WL_{Dep}J_{it} = WL_{Dep}qn_i\left(\frac{\sigma_s \upsilon_{th} N_{it}}{2}\right). \quad (5)$$

We note that the difference in the reverse currents depends on the depletion width of the drain junction. The relation between the trapped electrons in the interface states and a variation in the probed current can be described as

$$\Delta I_{it}\left(L_{Dep}\right) = qn_i W \int_0^{L_{Dep}} \Delta N_{it} dx \quad (6)$$

$$N_{it} \cdot \left(L_{Dep0} + \Delta L\right) - N_{it}\left(L_{Dep0}\right) = \frac{2}{Wqn_i\sigma_s\upsilon_{th}} \cdot f\left(L_{Dep}\right). \quad (7)$$

Therefore, spatial distributions of interface states in the channel near the drain is shown in Fig. 5, and it can be written as

$$N_{it} = \frac{2}{Wqn_i\sigma_s\upsilon_{th}} \cdot \frac{\partial I_{it}}{\partial V_D} \cdot \frac{\partial V_D}{\partial L_{Dep}} \quad (8)$$

where

$$L_{Dep} = \sqrt{\frac{2\varepsilon_s\left(V_{bi} + V_{Drain}\right)}{qN_{Sub}}} \quad (9)$$

$$f\left(L_{Dep}\right) = I_{it}\left(L_{Dep0} + \Delta L\right) - I_{it}\left(L_{Dep0}\right). \quad (10)$$

III. Summary and Conclusion

In summary, based on the new PGDM method for MOSFETs under optical illumination, the interface states density at a Si/SiO_2 interface was characterized. An optical source with a photon energy less than the silicon bandgap ($h\nu$=0.95eV<E_g=1.12eV) was employed for the photonic characterization of interface states (E_{it}) distributed in the photo-responsive energy band (E_C-0.95≤E_{it}≤E_C) in MOS systems. A U-shaped distribution of D_{it} has been obtained over the energy band (E_C-0.95≤E_{it}≤E_C) for N-MOSFETs. Spatial distribution of interface sates near the drain has also been characterized using the proposed PGDM technique and we expect that this new characterization technique is believed to be simple and accurate.

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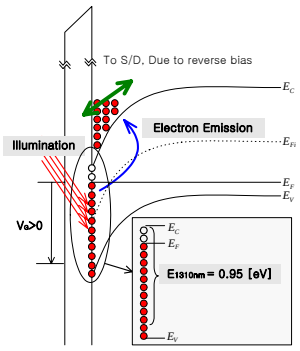

Figure 1. Schematic energy band diagram for a specific gate bias and generation of excess electrons from the interface states in N-MOS under optical input with E_{ph}<E_g.

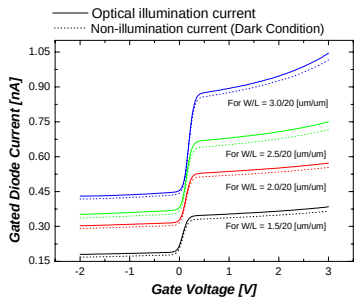

Figure 2. Measured reversed gated-diode current versus gate voltage from the photonic gated diode I-V characteristics of N-MOSFETs.

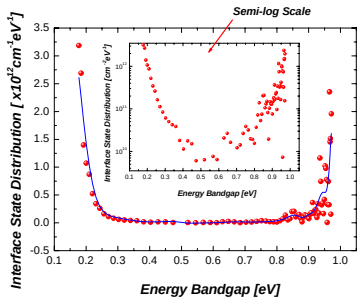

Figure 3. Interface trap distribution (Dit) at Si/SiO_2 heterojunction obtained from the photonic gated- diode I-V characteristics.

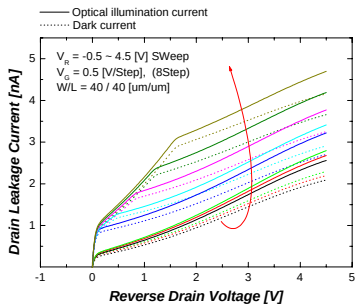

Figure 4. Measured reverse gated-diode current versus drain voltage.

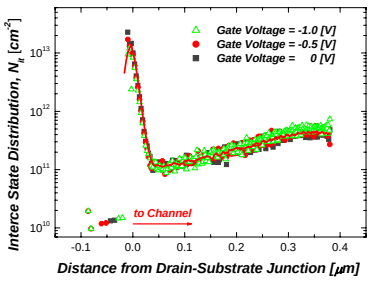

Figure 5. Spatial distribution of interface trap density (N_{it}).