Accurate Extraction of MOSFET Interface State Spatial Distribution from Charge Pumping Measurements.

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The density of interface traps along the Si/SiO_2 interface of a "fresh" MOSFET considerably depends on the fabrication process and the device geometry. Necessity to consider a number of factors having different physical nature results in the absence of established model describing initial transistor defect profile even nowadays. Unfortunately, theoretical calculation of the defect concentration is very complicated problem and no known solution exists. One of the most widely used experimental methods to obtain this information is the charge pumping (CP) technique [1].

In papers devoted to extraction algorithms of the lateral interface state density $N_{it}(x)$ from CP currents different assumptions on the initial concentration $N_{it,0}(x)$ (of a fresh device) have been used. To our knowledge, only in a few papers a check of initial profile uniformity has been undertaken [2]. At the same time, in most techniques on $N_{it}(x)$ profile extraction from CP data it is commonly assumed that the initial $N_{it,0}(x)$ is homogeneous [3]. This assumption is just a simplification, which is not supported by physical reasoning. The presence of non-uniform $N_{it,0}$ profile is usually ignored while modeling the evolution of the $N_{it}(x)$ during hot-carrier degradation (HCD). In fact, HCD-induced N_{it} may easily reach $10^{12}cm^{-2}$, while $N_{it,0}$ has typical values of $\sim 10^{9}cm^{-2}$. However, the hot-carrier stress is usually performed at voltages higher than operating ones. Thus, at operation conditions and/or short stress times interface states density will be characterized with moderate values comparable with $N_{it,0}$. Therefore, for a proper description of HCD at operating conditions the information about the initial interface states concentration is of great importance.

We make an attempt of combining relevant approaches of $N_{it}(x)$ extraction from CP measurements [1-5] within a single framework, thereby obtaining an exhaustive technique. The suggested scheme takes a number of factors into account affecting the CP current behavior. As a starting point, careful calculation of local flatband and threshold voltage distributions (as crucial quantities controlling the matter) is performed. From the comparison (Fig.1) of the experimental CP current vs. the simulated one (employing Shockley-Read-Hall theory [2]), we have separated the contributions of interface states and charges trapped in the oxide bulk. In this context, special attention should be paid to devices with a varying (along the lateral coordinate x) oxide thickness $t_{ox}(x)$. In the presence of such variations, the effective oxide capacitance could not be described with the simple formula $C_{ox}(x)=\varepsilon_{ox}/t_{ox}(x)$, where ε_{ox} is the oxide permittivity. Instead, the $C_{ox}(x)$ distribution can be calculated (Fig.2, inset) according to the technique presented in [3]. Carefully integrating all these steps into a single approach, we have undertaken a thorough extraction of the initial density $N_{it,0}(x)$. Fig. 2 shows a pronounced difference between $N_{it}(x)$ profiles calculated with our HCD model [5] under assumption of a uniform initial profile and employing $N_{it,0}(x)$ extracted according to the proposed scheme. The lack of detail obtained from the uniform $N_{it,0}$ approach is apparent.

In this work we have extracted the interface stets density profile for a virgin transistor by carefully incorporating such details as the coordinate-dependent nature of the oxide capacitance and separating the contribution of bulk oxide traps. The information about $N_{it,0}(x)$ is of high importance in the context of HCD modeling to allow for a more detailed verification of the model.

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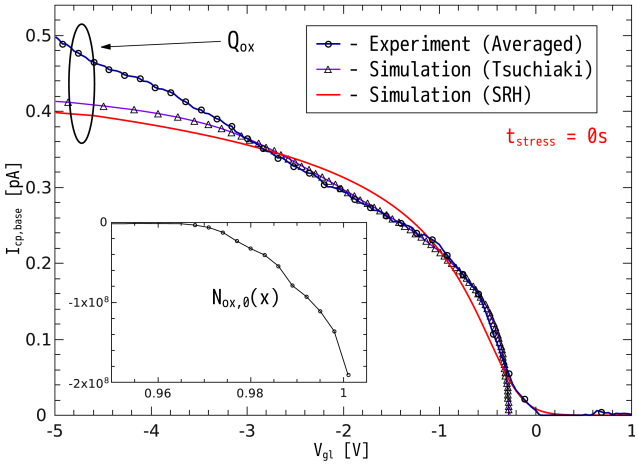

Fig. 1: Charge pumping current of an undamaged device shows a bulk oxide component. Inset: the trapped charge density where a negative value indicates electron trapping.

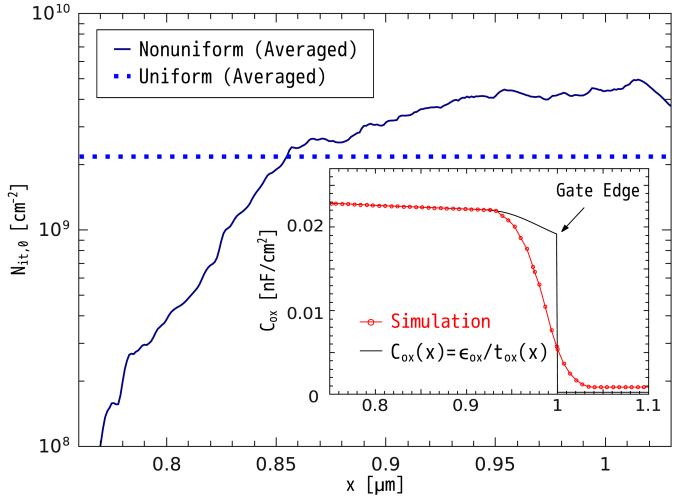

Fig. 2: The lateral interface state density with the origin placed at the source contact (device length – 1.5 μm) – comparison of uniform and nonuniform profiles. Represented averaged data from 12 measurement sets. Inset: lateral dependence of the effective oxide capacitance - simple formula vs. simulation.

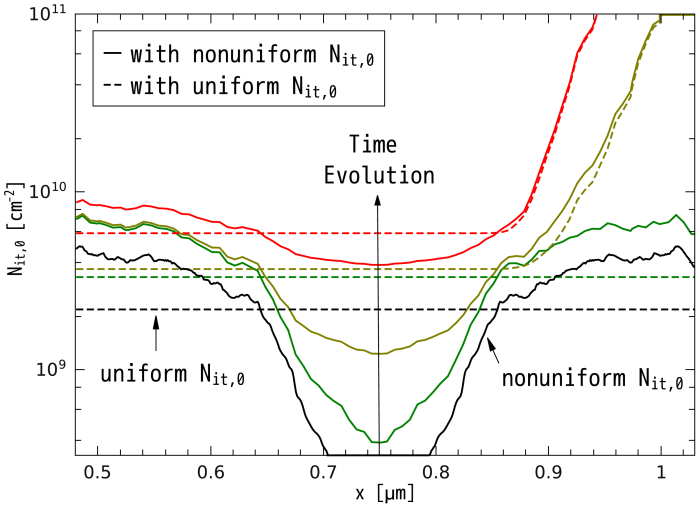

Fig. 3: $N_{it}(x)$ profiles calculated with our HCD model [5] under assumption of a uniform initial profile and employing $N_{it,0}(x)$ extracted according to the proposed scheme.

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