Screening and RC-limited Mobility in HK-FDSOI Devices

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Several mechanisms, such as Optical Soft phonons (SOph) and Remote Coulomb (RC), have been suspected to be at the origin of the observed mobility degradation in High-K MOSFETs devices. However, recent studies [1,2] have highlighted that, in devices with thick SiO_2 interfacial layer (T_{IL}>1nm), SOph scattering shows a smaller influence on carrier mobility than originally suspected. Several research groups have calculated the mobility degradation by RC scattering [1-5] and proved that a very large density of charges (or dipoles) at High-K/ Oxide interface would be required to match experimental data [1,2,4]. As mentioned in [2], this would significantly impact the electrostatics of the device. In this abstract, conventional approaches for RC-limited mobility are discussed. We present a Kubo-Greenwood-based model accounting for both RC-scattering and associated changes of the device electrostatic. The predictions of this model are compared to mobility measurements in HK NFDSOI and PFDSOI devices (shown in Fig. 1).

SCREENED COULOMB POTENTIAL

The elements of the scattering matrix write [3,4]:

$$M_{n,m}(k,k') = q\int dz V(Q,z)\xi_n^K(z)\xi_m^{K'}(z)$$

where $V(Q,z)$ is the screened potential produced by a *single* charge in the oxide layers. In general, the unscreened potential is obtained using an analytical expression for the Green function of the considered device (see e.g. [2,4] for HK devices). The screening parameter is a key variable for the evaluation of the dielectric function and the screened potential. It writes:

$$\beta_{n,m}(Q) = -\lim_{\varepsilon \to 0}\sum_{K'}\frac{f(E_K^n) - f(E_{K+Q}^m)}{E_K^n - E_{K+Q}^m + ih\varepsilon}$$

Various approximations, whose results are compared in Fig.2 to numerical results for the Δ_z valleys, exist in literature [3]. Their accuracy depends on the bandstructure model considered in the calculation. Fig. 2 compares $\beta_{n,m}(|Q|)$ obtained with the effective mass approximation model (EMA) and with a two-band k.p model (accurate approximations for $\beta_{n,m}$ for holes are in general more subtle due to the warping of the bandstructure). The screened potentials are obtained inverting the full tensorial dielectric response [3]. In Fig. 3 numerical results are compared to the simplified model of [5] that consideres only diagonal terms in the dielectric function and that approximate the electronic wave vectors by delta functions centred at the wave vector maxima. As clearly shown, this simplified model is accurate and can be efficiently used to evaluate the RC-limited mobility. It is worth mentioning nevertheless that using a scalar dielectric function can be much less accurate in double-gate FDSOI devices [6].

Alternatively, to evaluate the screened coulomb potential we have performed two self-consistent Poisson Schrodinger calculations, one with the oxide charges, and a second without. The electrostatic and the scattering potentials are shown in Fig. 4 and compared to the predictions of the previously mentioned model. The RC-limited mobility is shown as a function of the inversion charge in Fig. 5. For low oxide charge densities or at high channel inversion densities, the two approaches lead to very similar results. However, when the oxide charges significantly impacts the electrostatics of the device (as in Fig. 4 a)), the present model predicts a lower mobility. The mobility values, including phonon and surface roughness scatterings, are reported in Fig. 6 for NFDSOI and PFDSOI devices (L_{ch}=0.897μm).

DISCUSSION

As already mentioned, significant RC mobility degradation in High-K metal gate devices can be obtained with very high oxide charge density ($Q_{HK/IL}$>5e12). As a consequence, the electrostatics of the device is strongly impacted (even if dipoles are considered instead of fixed charges [2]). Thus the validity and the results of conventional approaches based on a perturbative treatment of the scattering potential remain questionable. Moreover, only fluctuation of this oxide charges density can cause mobility degradation. Considering these high density levels, lateral correlations between charges can further reduce the RC potential [4]. Other mechanisms such as neutral defects [7] or positive and negative charges randomly distributed at the HK/IL interface [2,8] could also explain the mobility degradation and its channel length dependency.

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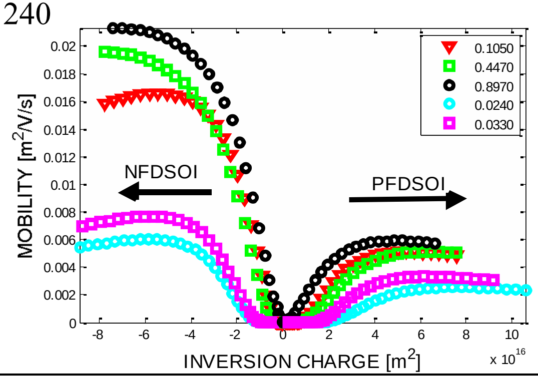

Fig. 1 Mobility extracted using split CV measurements in High-K metal gate NFDSOI and PFDSOI devices with various channel length (L_{ch} from 0.033µm to 0.89µm). As can be noted, the mobility depends on the device length.

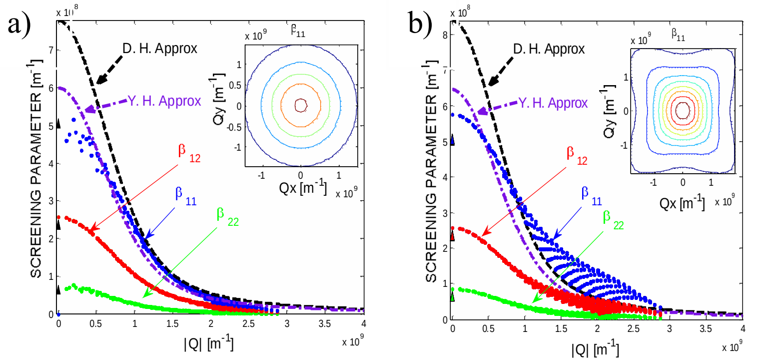

Fig. 2 Screening parameter calculated with a) EMA and, b) 2 band-k.p models for the Δ_z valleys as a function of the scattering vector ($\left|Q\right| = \left|K - K'\right|$). Approximations (Debye-Huckel and Yokoyama and Hess [3]) are also superimposed.

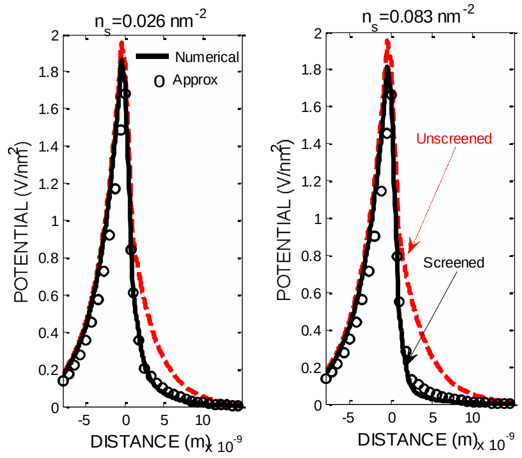

Fig. 3 Screened and unscreened potentials (Q=3.18e^8/m) calculated using the rigorous approach described in Ref. [3] and compared to the model of Ref. [5]. A device with a tick High-K layer on the top of a 1.1nm oxide layer is simulated for two channel inversion densities. The point charge is located 4.5A away from the High-K/IL interface. Only Δ_z electrons are considered.

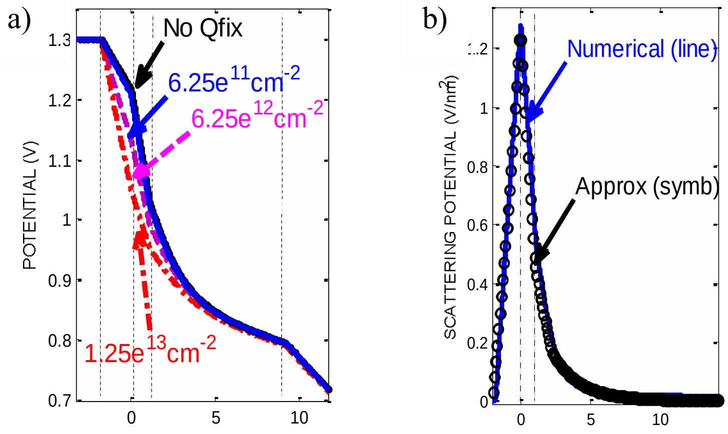

Fig. 4 The electrostatic potential a) for various interfacial charge densities (6.25e^{11}/cm^2 to 6.25e^{13}/cm^2). The scattering potential b) is compared to the simplified model of Ref. [5] for an arbitrary scattering vector Q=5.2e8/m.
Vertical dashed lines indicate the position of the layers (Metal Gate/ High-K material/ SiO$_2$ oxide/ Si channel/ SiO$_2$ BOX). As can be seen, the screening by the metal gate is also accounted for in the simplified model.

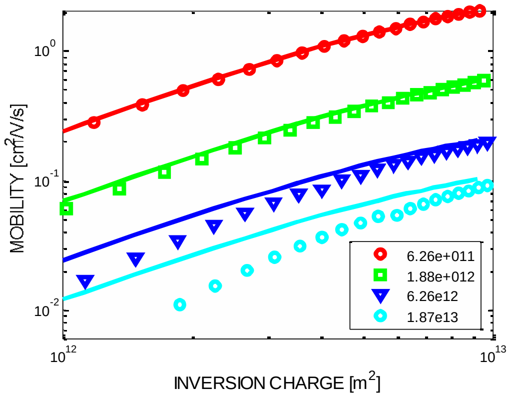

Fig. 5 RC-limited mobility as a function of the channel inversion charge density for various interfacial charge densities (From 6.25e^{11} to 1.87e^{13}). Lines correspond to the predictions of a RC mobility model based on Ref. [5] while symbols are obtained with the approach described in this abstract.

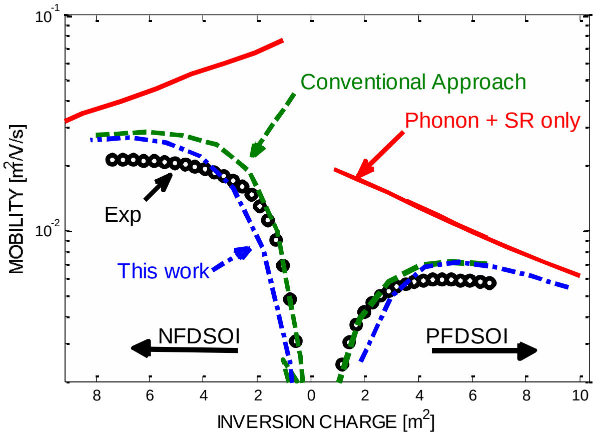

Fig. 6 'Best' fit to the experimental mobility in the long channel NFDSOI and PFDSOI devices. The concentration of charges, placed at the High-K/SiO$_2$ interface, has been found to be as high as 6.3e^{12} /cm^2 and 9.1e^{12} /cm^2, respectively.