Potential and pitfalls of the diode characterization technique for ULSI devices analysis

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Scaling microelectronic devices into the deep sub-micron range is associated with the introduction of advanced processing modules, which often are employing alternative or new materials. The use of these steps can lower the yield and performance, which need to be optimized. Junction diodes have been proposed as a valuable test vehicle to study the front-end-yield because their processing contains most of the critical steps of modern complementary metal-oxide-semiconductor (CMOS) technology [1]. Important physical parameters of a diode are the generation (τ_g) and recombination (τ_r) lifetime, the surface generation velocity (S_g) and the activation energy (E_T) of the trapping levels involved. Theoretically, τ_r could be calculated from the area diffusion current density (J_{dA}), while τ_g and S_g are derived from the area bulk generation (J_{gbA}) and surface generation (J_{gsP}) current density, respectively [1,2]. A first step in such an extraction usually consists of the separation of the different geometrical components, by combining the characteristics of different geometry diodes. The physical current contributions in the area component such as J_{dA} and J_{gbA}, and in the peripheral component such as J_{gsP} are further split by combining the current voltage (*I-V*) and capacitance-voltage (*C-V*) characteristics.

Unfortunately, this all breaks down when the junction becomes too shallow, as is the case for state-of-the-art highly doped source and drain junctions. There, the diffusion current is no longer dominated by the substrate (or well) contribution, but suffers from the contribution of the highly doped region as well. This is called here "the shallow junction effect", preventing the standard analysis for minority carrier lifetime extraction. A further complication arises for silicided shallow junctions, which may suffer from the local penetration of silicide through the junction into the depletion region (also called the Schottky effect). This enhances drastically the leakage current. Therefore, a new procedure adopted for silicided shallow junctions has been developed and will be outlined here.

The basic procedure consists of measuring the *I-V* and *C-V* characteristics of different geometry diodes. It is advisable to measure the *I-V* characteristics from reverse to forward bias by using an appropriate waiting time (i.e. 120 s) and medium to long integration time to avoid transient effects. It is also essential to measure the *I-V* and *C-V* characteristics as a function of temperature. First, one should check for the Schottky effect (i.e. due to local penetration) in case of silicided junctions. This could be derived from the Arrhenius plot of the forward current. When the Schottky effect is present, the slope of that plot is less than the silicon bandgap energy (1.12 eV), expected for the ideal part of the forward *I-V*. Local penetration leads in principle also to a higher than expected leakage current – which can be used as another finger print of the effect – although there is a gradual transition from 'good' junctions, with negligible local penetration to leaky ones, with severe local penetration. If the Schottky effect is present, it will be demonstrated that no reliable τ_r and τ_g can be extracted from the diode *I-V* characteristics. Instead, one can still derive the Schottky contact area from the forward current and the local electric field from the reverse current, using the proposed methods. If there is no (or negligible) Schottky effect, it will be proposed to determine τ_r and τ_g simultaneously from the forward recombination current of yielding (i.e. low leakage) junctions. Alternatively, τ_g can be derived from the generation current (Fig. 1). However, for junctions in a highly doped well, one should deal with the electric field enhancement of the carrier generation. An empirical approach was developed to derive the electric field enhancement factor (Γ) and the area generation width (W_{gA}). Overall, for the different cases studied a good agreement between the τ_g derived from the forward recombination current and the reverse generation current was observed. Accurate values for the activation energy of the reverse generation current can be obtained from the Arrhenius plot *I* vs *1/kT* by taking different proposed corrections into account. It will be shown that for the studied devices the strongest effect stems from the temperature dependence of τ_r. It will also be shown that E_T derived from this correction procedure is in good agreement with the one calculated from the lifetime ratio τ_g/τ_r. One should remark, however, that in the latter case an effective activation energy is derived, which not necessarily corresponds to a real defect level in the bandgap.

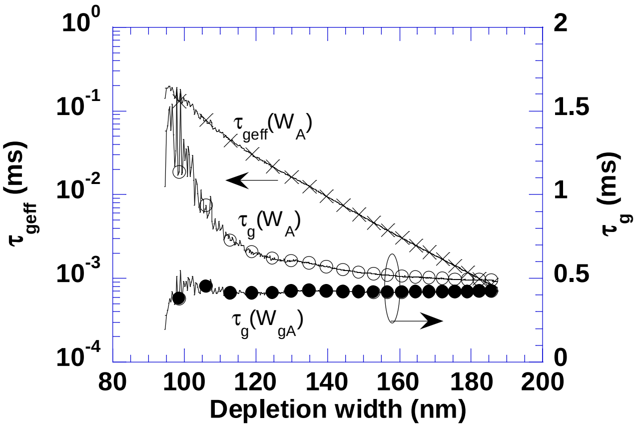

Fig. 1 Effective generation lifetime [$\tau_{geff}(W_A)$] and generation lifetime [$\tau_g(W_A)$] which is calculated from the depletion width, and generation lifetime which is calculated from the generation width [$\tau_g(W_{gA})$], versus the depletion width for a n^+- p-well diode surrounded by STI.

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