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AN EXTENDED "Y FUNCTION" METHOD FOR SATURATION REGIME CHARACTERIZATION: APPLICATION TO BULK Si AND Ge TECHNOLOGIES

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Abstract

In this work, we extend the "Y function" method to the saturation regime of MOSFET operation. This allowed us for the first time to extract a low charge apparent mobility up to high drain voltage and consequently the saturation velocity without the need of source drain series resistance correction. The method has successfully been applied to silicon (Si) and germanium (Ge) bulk technologies and the non convergence of linear mobility and saturation velocity improvement is highlighted.

INTRODUCTION

MOS devices characterization is getting more and more problematic because of the scaling and alternative materials introduction. A lot of advanced characterization techniques have been implemented but most of them only focus on the linear operation region at low drain voltage. One of them is the so-called "Y function" method [1], which has the advantage to eliminate the influence of series resistance. Many improvements have been brought to this method for more accurate parameters extraction in the linear regime [2-3].

In this work, we investigate the device behavior in the saturation regime and focus on low charge apparent mobility and saturation velocity by extending the "Y function" method to high drain voltage (V_D) values for the first time. Apparent mobility values in the saturation regime are more reliably extracted and the deduced saturation velocities are in good agreement with those found from standard method (9). The saturation velocity is finally extracted with this method in bulk Si and Ge devices for application.

"Y FUNCTION" METHOD: FROM LINEAR TO SATURATION REGIME

In [1], the "Y function" was defined in the linear regime as in (1) where I_D is the drain current and g_m is the transconductance value (2). One can also link the total channel resistance (R_{tot}) with the dissipated power (P) as in (3) [4], and, by combining (1), (2) and (3), we can define an extended "Y function" versus gate voltage (V_G) for any drain voltage (V_D) values as in (4), eliminating access resistance influence. In such a case, as for ohmic regime [1], the low charge apparent mobility μ_{0sat} i.e. for V_G tending to V_{TH} (5), can still be extracted from the square of the slope of the linear variation of the $Y(V_G)$ function but considering the longitudinal field degradation of μ_{0sat} as in (6). So, from the straight line observed in the $Y(V_G)$ (fig. 1), we can extract for different drain voltages V_D, the threshold voltage V_{TH}, the transconductance gain β, and by turn, the low charge apparent mobility using (7). The drain current is written with parameters extracted as in (8) (fig. 2).

LOW CHARGE APPARENT MOBILITY VERSUS V_D EXTRACTION

The low charge apparent mobility μ_{0sat} can be calculated using β extracted from "Y function" slope and the effective gate length (L_{eff}), the effective width (W_{eff}) and the oxide capacitance (C_{ox}) using (7). Fig. 3 & 4 show μ_{0sat} versus V_D for both N & PMOS Si bulk technology [5]. One can notice that the apparent mobility degradation with gate length is less accentuated at high V_D.

SATURATION VELOCITY CALCULATION

One possible way of extracting the saturation velocity (v_{sat}) is given in (9) (fig. 5). However, the limitation of this method is the need of source drain resistance (R_{SD}) to correct the gate voltage. In this paper, we propose to calculate the saturation velocity using μ_{0sat} at high V_D without the need of R_{SD} correction using the inverse of (6). In fig. 6, the slope of the plot of μ_{0sat}^{-1} versus V_D gives v_{sat}. The v_{sat} of a Si bulk technology is extracted like in (6) and (9) and are plotted in the same graph in fig. 7. One can see that our method is in good agreement with the one given by standard (9) but it is easier to implement industrially because of the no need of R_{SD} correction.

TRANSPORT PARAMETERS EXTRACTION OF SIGE AND GE DEVICES IN THE SATURATION REGIME

Characterizing germanium (Ge) devices [6] transport in the saturation regime is a challenging subject because of Ge good transport properties. Higher Ge split CV mobility compared to silicon has been evidenced in our previous studies [7]. However, like it is shown in figs 8 & 9, mobility improvements differ from linear to saturation regime. Mobility in Ge materials is more improved in linear regime. Fig. 8 shows that the linear mobility is 160 % increased from silicon germanium device (30 % germanium content) to bulk germanium devices. The apparent saturation mobility is only 50 % enhanced (see fig. 9). This lower mobility improvement mainly explains the saturation velocity (v_{sat}) enhancement noticed in bulk Ge compared to $SiGe_{30\%}$ as v_{sat} is 58 % increased (Fig. 10). This raise doubts for ballisticity expectation in Ge devices despite its good transport properties. This confirms what we advocated in our previous studies [7]. For ballisticity transport observation in Ge devices, very short devices should be engineered.

CONCLUSION

In this paper, apparent saturation mobility has been extracted for the first time using an extended "Y function" method to high V_D. Consequently, the saturation velocity is extracted without the need of source drain resistance corrections. The method is successfully applied to Si and Ge bulk technology and can easily be implemented industrially.

The non convergence of linear mobility and saturation velocity improvement when we move from Si to Ge is cleared by the apparent saturation mobility calculation.

$Y=\dfrac{Id}{\sqrt{gm}}$ **(1)**	$gm=\dfrac{\partial Id}{\partial V_G}$ **(2)**	$P=R_{tot}.I_d{}^2$ **(3)**	$\dfrac{dR_{tot}}{dV_G}=\dfrac{V_D}{Y^2}$ **(4)**	$\mu_{eff} \xrightarrow[V_G\text{-->}V_{TH}]{} \mu_0$ **(5)**
$\mu_{0sat}=\dfrac{\mu_0}{1+\dfrac{V_D\mu_{00}}{L_{eff}v_{sat}}}$ **(6)**	$\beta=\dfrac{W_{eff}.C_{ox}.\mu_{0sat}}{L_{eff}.}$ **(7)**	$Id=\dfrac{\beta.V_D.(V_G-V_{TH})}{1+\theta_1.(V_G-V_{TH})}$ **(8)**	$v_{sat}=\dfrac{Idsat}{W_{eff}.C_{ox}.(V_G-V_{TH})}$ **(9)**	

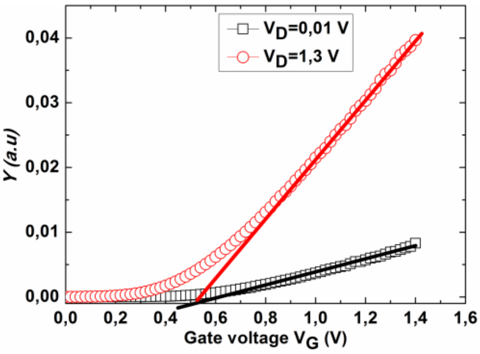

Fig. 1:"Y function" extraction in linear and saturation regime

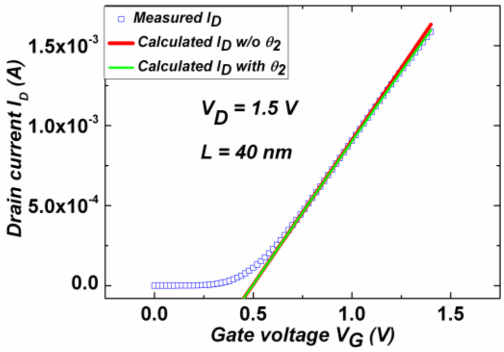

Fig. 2: I_D-V_G measured and recalculated with parameters

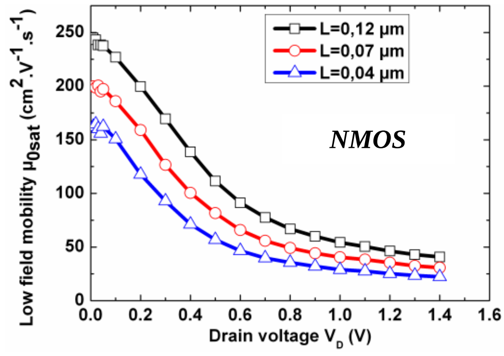

Fig. 3: low field mobility versus V_D, NMOS

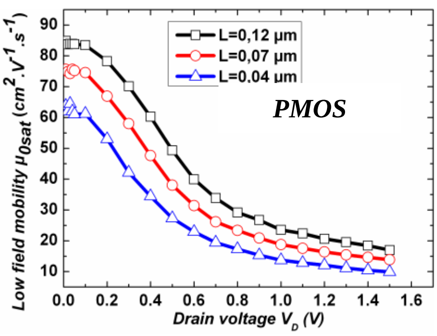

Fig. 4: low field mobility versus V_D, PMOS

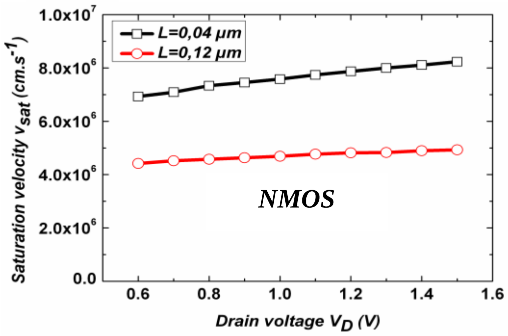

Fig. 5: v_{sat} extracted using (9)

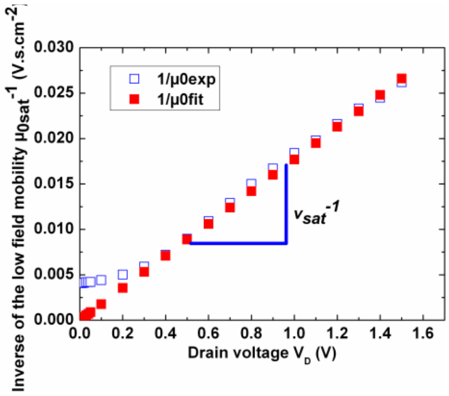

Fig. 6: v_{sat} extracted with the saturation mobility methodology using Eq. (6)

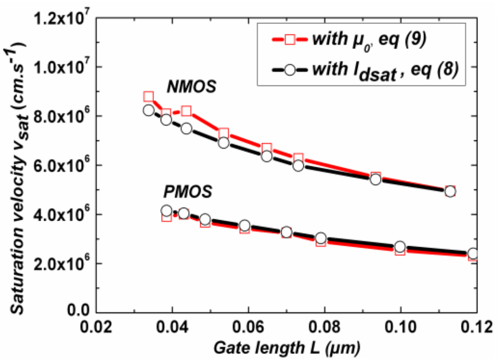

Fig. 7: v_{sat} extracted using Eq. (6) compared to v_{sat} using Eq. (9)

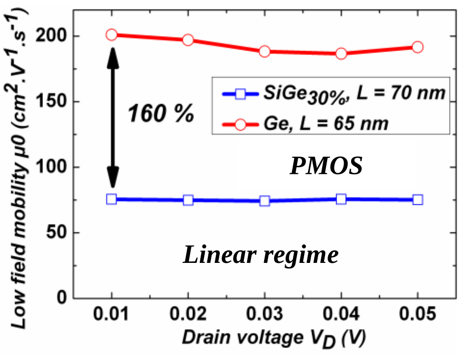

Fig. 8: Linear mobility of SiGe and Ge

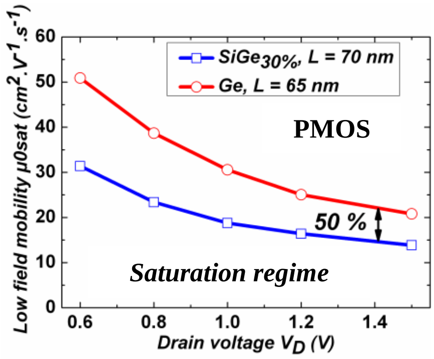

Fig. 9: Saturation mobility of SiGe and Ge

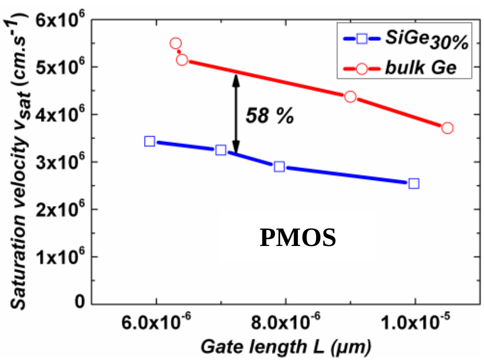

Fig. 10: Saturation velocity of SiGe and Ge

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