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Electrical characterization of advanced MOSFETs towards analog and RF applications

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***Abstract*— This *invited paper* reviews main approaches in the electrical characterization of advanced MOSFETs towards their target analog and RF applications. Advantages and necessity of those techniques will be demonstrated on different study cases of various advanced MOSFETs, such as FDSOI, FinFET, NW in a wide temperature range, based on our original research over the last years.**

Keywords—UTBB, FDSOI, FinFET, MOSFET, Self-heating, S-parameters, Analog and RF figures of merit

I. INTRODUCTION

Enormous progress of the semiconductor technology was mostly driven during the last decades by the continuous demand for the increase of the operation speed and integration density of complex digital circuits. Aggressive device downscaling has requested the introduction of both new channel and gate stack materials, as well as non-classical device architectures.

Two main contenders have emerged to satisfy IRDS requirements for device nodes towards 20 nm and beyond [1-10]:

(i) planar fully depleted (FD) Silicon-on-Insulator (SOI) with ultra-thin body (UTB) and ultra-thin buried oxide (BOX), so called UTBB MOSFETs;

(ii) multiple-gate (MuG) MOSFET (FinFETs and nanowire (NW) FETs).

While digital aspects of these new architectures are widely addressed, their perspectives for analog and RF applications received less attention. Device analog/RF performance is generally evaluated through their key figures such as transconductance, g_m, output conductance, g_d, intrinsic gain, A_v, ($A_v=g_m/g_d$), cut-off frequencies, f_T and f_{max}.

In this *invited talk* we will review the main characterization approaches enabling a fair assessment of novel device architectures for the future analog/RF applications.

II. REVIEW OF DC/RF MEASUREMENT TECHNIQUES

Firstly, we will discuss the DC characterization approaches that allow for a fair analog/RF comparison of different devices. A very useful methodological approach for analog performance assessment of different devices is calculating g_m/I_d as a function of normalized drain current. This is because such plot gives a complete picture of studied device, valid for different applications: from base-band, where high gain, high precision is needed, to high frequency where high current and g_m are requested. Furthermore, as g_m/I_d is inversely proportional to the subthreshold swing in weak inversion regime and proportional to $\mu \cdot C_{ox}/n$ (where μ is the mobility, C_{ox} the oxide capacitance and n the body factor) in strong inversion, such plot is independent of threshold voltage, of substrate/back gate (or body) bias and, to the first order, of length. This allows an assessment of the device performance that is purely related to physical parameters, thus providing a fair comparison of devices issued from different technologies, with different dimensions and operated under different conditions. Another useful tool for benchmarking different devices for their analog/RF perspectives is g_m-A_v plot. This plot was introduced as an "analog equivalent" (in terms of visuality) of the widely known I_{on}-I_{off} plot in a "digital world". Indeed, for analog/RF applications we look for a device with both highest g_m (and hence f_T) and highest A_v. We will also emphasize on the importance of physical and robust threshold voltage, V_{th}, extraction for comparison of various devices at the same bias conditions.

Secondly, we will establish the importance of the wide-frequency band assessment, as all above mentioned figures of merit (FoM) vary with frequency. Thus, one should consider that performance prediction based exclusively on DC data may be inaccurate. Only wide-frequency band characterization allows for a proper separation of various non-stationary effects (such as e.g. self-heating, substrate coupling, floating body) and their relative effects on analog/RF performance. Furthermore, this technique is a powerful tool for extraction of device parameters (such as e.g. μ and Vth) free from non-stationary effects, which is of high importance for modelling. We will also discuss the advantages of this approach for self-heating figures extraction in advanced devices. Non-linearities, cross-talk and noise figures will be briefly mentioned.

Thirdly, we will introduce S-parameters RF characterization for the extraction of a small-signal equivalent circuits. We will discuss the harmful effect of parasitic elements through the analysis of the impact of series resistance and extrinsic capacitances on the device performance. We will show that when device length is scaled down, the importance of parasitic components increases enormously (particularly in advanced device architectures, as 3D and thin films), and

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parasitic elements can even dominate the device performance. So, it becomes crucial in advanced nowadays technologies to be able to separately extract "intrinsic" and "extrinsic" elements for their further analysis and optimization.

Above characterization approaches will be illustrated by the results obtained on UTBB FDSOI MOSFETs, Si NWs and FinFETs. We will give some examples of application of these techniques not only at room temperature but also at cryogenic (down to 77 K) and high (upto 500 K) temperatures.

More details and original results used in this paper as well as related works can be found in [11-67].

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