AC Output Conductance of SOI MOSFET’s and Impact on Analog Applications

Dennis Sinitsky, Robert Tu, Chunlin Liang, Mansun Chan, Jeffrey Bokor, and Chenming Hu

Abstract—We report a frequency-dependent output conductance of partially depleted SOI MOSFET’s. For high-frequency analog applications, the output conductance is less than half and the dynamic range of $V_G$ is two times higher than the dc $I$–$V$ characteristics would indicate. A simple physical model for the phenomenon that involves a phenomenological body charging capacitance and can fit data within 10% is presented.

I. INTRODUCTION

RECENTLY, transient floating body effects in SOI MOSFET’s have gained a lot of attention. The importance of these effects on digital circuit performance was verified by both simulations [1] and experiment [2], [3]. In this paper we discuss the impact of transient body charging on analog device performance and give a model explaining the results. The experimental setup is shown in the insert of Fig. 1. It is essentially the same as in [4] and [8]. We measure the ac output conductance of the device at the drain while applying a dc gate bias.

II. DEVICE FABRICATION

The four-terminal n- and p-channel SOI MOSFET’s were fabricated on a single SIMOX wafer with a relatively thin buried oxide (850 Å) to minimize self-heating effect. We describe only NMOS process here. MESA isolation was created by etching a nitride/oxide/silicon stack, stopping at the buried oxide. A 1000 Å was grown on MESA sidewalls to prevent contact opening and metallization. The final Si film thickness of devices used was measured to be 1600 Å using nanospec.

III. RESULTS AND DISCUSSION

The $G_{out}$–$V_d$ curves measured with a floating body at different frequencies as well as dc are shown on Fig. 1. From the $V_G = 1.1$ V series of $G_{out}$ curves, one can see that the kink-related hump of output conductance is moving out as the frequency is increased: it occurs at about $V_d = 1.1$ V for dc case, 1.6 V for 11 kHz curve, 1.8 V for 110 kHz and 2.0 V for 1.1 MHz. The origin of the hump is the impact ionization current related body charging which gives a kink in a dc curve. The reason for the hump moving out with increasing frequency is that the impact ionization current change due to ac drain signal does not have time to charge the body, unless the drain dc bias is increased. After integrating the $G_{out}$ with respect to $V_d$, the dc $I$–$V$ characteristics are obtained [4] and shown in Fig. 2. The $I$–$V$ curves also show the same shift of kink position as the frequency is increased.

We used 10 mV and 20 mV for drain signal ac amplitude. The obtained $G_{out}$ curves agreed for both of them, so we assume “small signal” linear response of device currents to the ac signal.

Note that unlike [2], [3], the integrated $I_d$–$V_d$ curve is a result of the drain pulsing, so it is immune to the $V_g$ induced transient effects. This condition is related to many analog circuits where $V_g$ swing is small. The drain pulsing technique does not take gate-to-body coupling into account, which proved to be rather significant [6]. However, this condition is also relevant in the operation of a pass transistor.

All the transient response observed is due to impact ionization current taking time to charge the floating body. Note that drain-to-body coupling is independent of frequency. But we consider only the difference between measured output conductance $G_{out}$ and the high-frequency output conductance, so capacitive coupling is subtracted out. Actually, high-frequency output conductance agreed well with the grounded body contact dc output conductance, which means that drain-to-body coupling is negligible and all high-frequency $G_{out}$ is solely due to DIBL/channel length modulation.

The plot of $G_{out}$ versus frequency is shown on Fig. 3. Note that at low frequency the output conductance is rather high due to the response of body voltage or body charging to the $V_d$ signal. The ac output conductance can be modeled with a simple diode/capacitance model shown in Fig. 4. The $I_{di}$ current source is due to impact ionization, and the diode models the body-to-source junction current. Let us define $C_P(\equiv \frac{dQ_{B}}{dV_{B}})$—the small signal floating body capacitance to be charged. Here $Q_{B}$ is total charge in the body, and $V_{B}$ is body-to-source potential. It depends on device geometry.

Manuscript received May 7, 1996; revised October 18, 1996. This work was supported by SRC Contract SF-417, and the Air Force Office of Scientific Research Grants F49620-94-1-0464, and F49620-94-C-0038 (Joint Services Electronics Program).
D. Sinitsky, R. Tu, M. Chan, J. Bokor, and C. Hu are with the Department of Electrical Engineering and Computer Science, University of California, Berkeley, CA 94720-1772 USA.

C. Liang is with Intel Corp., Santa Clara, CA 95052 USA.

Publisher Item Identifier S 0741–3106(97)$010.00 \copyright$ 1997 IEEE.
and bias conditions. The differential resistance of the diode

\[ R_{\text{diode}} = \frac{\partial V_{\text{ds}}}{\partial I_{\text{ds}}} \approx \frac{kT}{qI_{\text{ds}}} \]

is fixed at each bias point. The dc bias point of \( V_{\text{ds}} \) is determined by

\[ I_{\text{ds}}(V_{\text{ds}}, V_{\text{gs}}) = I_{\text{diode}}(V_{\text{bs}}). \]

The ac \( V_{\text{bs}} \) is

\[ \frac{\Delta V_{\text{bs}}}{\Delta I_{\text{diode}}} = Z = \frac{R_{\text{diode}}}{\omega C_B R_{\text{diode}} + 1}. \] (1)

The expression for the output conductance can be written as

\[ G_{\text{out}} = G_{\text{diode}} + G_{\text{b}}, \]

and the output conductance due to body charging is

\[ G_{\text{b}} = \frac{\partial I_{\text{diode}}}{\partial V_{\text{bs}}} \frac{\partial V_{\text{bs}}}{\partial I_{\text{diode}}} \frac{\partial I_{\text{diode}}}{\partial V_{\text{bs}}} \frac{\partial V_{\text{bs}}}{\partial I_{\text{diode}}}. \] (2)

Hence, the frequency-dependent component of the output conductance is proportional to the derivative \( \frac{\partial V_{\text{bs}}}{\partial I_{\text{diode}}} = Z \). As can be seen from above, the \( Z \) dependence on \( \omega \) resembles the \( G_{\text{out}} \)-frequency plot of Fig. 3. The theoretical model was fitted to the experimental data on Fig. 3, which shows good agreement with data. Note in Fig. 3 the high-frequency

IV. CONCLUSION

The frequency dependence of output conductance of PD SOI MOSFET was studied. At high enough frequency which depends on the bias point, the ac output signal becomes insensitive to floating body kink. Hence, PD SOI technology offers better voltage gain and drain voltage dynamic range for analog design than dc characteristics would suggest. The LCR technique presented can also be used in parameter extraction of a PD SOI device without a fourth body contact, since the quantities measured in the experiment are directly related to

\( G_{\text{out}} \)'s agree well with the dc \( G_{\text{out}} \)'s measured with the body grounded.

Note that the values of \( C_B \) and \( R_{\text{diode}} \) cannot be directly extracted from Fig. 3. This is because a coefficient of proportionality between \( Z \) and \( G_{\text{b}} \) is related to current drive, body coefficient and impact ionization parameters, as can be seen from (2). One can directly see however the \(-3 \) dB frequency \( f_c \) of body charging process. It is strongly dependent on bias, especially on \( V_{\text{ds}} \), because \( I_{\text{diode}} \) is exponentially dependent on \( V_{\text{ds}} \). For the case of \( V_{\text{ds}} = 1.1 \) V we get \( f_c = 100 \) kHz \( (V_{\text{ds}} = 2.5 \) V), and 4 MHz \( (V_{\text{ds}} = 2 \) V).
source-body diode, body capacitance and the impact ionization current. Of course, a grounded body SOI MOSFET would be even more suitable for analog applications [7]; the additional body contact might also be used for SOI bipolar transistor.

ACKNOWLEDGMENT

The authors would like to acknowledge P.-K. Ko for suggestions regarding device fabrication, and Dr. C. Wann for help with the initial experimental setup. Devices were fabricated in Berkeley Microfabrication Laboratory, University of California, Berkeley.

REFERENCES