Multiple Independent Gate FET Ring Oscillators with Dynamic Frequency Tuning

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***Abstract*—Fully depleted SOI multiple independent gate FETs (MIGFETs) provide dynamic control of threshold voltage (Vt). This dynamic Vt capability is applied to ring oscillators for frequency tuning and compensation of voltage variation. The MIGFET ring oscillators were manufactured in an 180nm SOI process that supports both traditional double gate transistors and MIGFETs.**

Introduction

The semiconductor industry roadmaps have forecast the use of multiple gate FETs to resolve many transistor scaling problems, but implementation has been slowed by manufacturing challenges [1-2]. Multiple independent gate FETs (MIGFETs) allow for dynamic control of the transistor threshold voltage (Vt) [3]. This Vt tuning capability can be applied to many circuit applications including countering process variations and trading off power for performance. This paper presents experimental results from fully depleted SOI MIGFET ring oscillators manufactured in a production manufacturing process on 200mm wafers.

MIGFET Dynamic Vt Tuning

Fig. 1 shows measured data for a 180nm NMOS MIGFET. The second gate voltage (Vngate2) adjusts the threshold voltage (Vt) of the Id-Vngate1 curve. As the second gate voltage is increased, the threshold voltage of the NMOS transistor decreases. Other than the dramatic shift in Vt, the basic transistor operation is relatively unchanged by the adjustment of the second gate voltage. Fig. 2 provides the complementary set of curves for an 180nm PMOS MIGFET. Increasing the PMOS MIGFET second gate voltage (Vpgate2) decreases Vt.

MIGFET Inverter VTC Tuning

Fig. 3 is the schematic of a MIGFET inverter in which the second gates are available to adjust the voltage transfer characteristic (VTC). In Fig. 4, the inverter VTC is altered by stepping the NMOS second gate voltage (Vngate2) from +0.6V (low Vt) to -1.0V (high Vt) in -200mV steps. Changing Vngate2 results in a 190mV change in the inverter switching point (Vin = Vout). Similarly, Fig. 5 demonstrates a 280mV change in the inverter switching point as a result of stepping the PMOS second gate voltage (Vpgate2) from 2.9V (high Vt) to 1.3V (low Vt) in -200mV steps. Simultaneously changing the NMOS and PMOS second gate voltages supports a 430mV change in the inverter switching point.

MIGFET Ring Oscillator Frequency Tuning

101-stage MIGFET inverter ring oscillators were tested to evaluate the frequency tuning capabilities of the second gates. Fig. 6 illustrates frequency tuning of the MIGFET ring oscillator with nominal supply voltage of 1.8V. Changing the NMOS second gate voltage supports frequency variation of -11.8% to +7.6%. The PMOS second gate voltage has a greater effect on Vt and causes a frequency change of -34.7% to +18.2%. Changing both the NMOS and PMOS second gate voltages supports a frequency change from -42.9% to +28.2%.

Fig. 7 illustrates MIGFET Vt tuning to compensate for the ring oscillator frequency changes caused by supply voltage variation. Without compensation, the frequency variation ranges from -27.2% to +63.9% when the supply voltage varies from 1.5V to 2.5V. After compensation using the MIGFET second gates, the frequency variation is reduced to -1.8% to +0.6%. This is a nearly 40X reduction in supply induced variation.

In Fig. 8, the impact of substrate voltage on ring oscillator frequency is evaluated. Despite the relatively thin 1450Å buried oxide, this MIGFET SOI process is largely unaffected by the substrate voltage. A ±20V change in the substrate voltage had only a 0.6% effect on the ring oscillator frequency. At -40V, the frequency had changed by -8.8%. Using the MIGFET tuning capability allowed this variation to be reduced to only -1.2%.

Conclusion

Experimental data has demonstrated the Vt tuning capability of the 180nm Flexfet CMOS process to produce fully depleted SOI MIGFET circuits [4-5]. This capability was first applied to a single inverter to adjust the DC voltage transfer characteristic. Then, the Vt tuning capability was used to adjust the frequency of a 101-stage MIGFET inverter ring oscillator. The frequency tuning was demonstrated to allow successful compensation of variation caused by both supply voltage changes and substrate bias. Other potential applications of Flexfet Vt tuning include compensating for variations caused by process, temperature, and radiation damage.

References

[1] K. Endo, et al., EDL, pp. 1123-115, Dec. 2007.
[2] H-S. P. Wong, IBM J. of R&D, Mar/May 2002.
[3] Y.X. Liu, et al., IEDM, Dec. 2003, pp. 18.8.1-18.8.3.
[4] D Wilson, et al, IEEE SOI, Oct. 2007, pp. 147-148
[5] US Patents 6919657, 7015547, 7019342, and 7154135.

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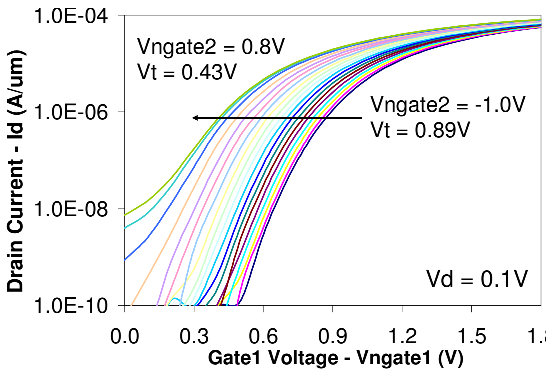

Fig 1. NMOS 180nm MIGFET Id-Vngate1 as a function of Vngate2

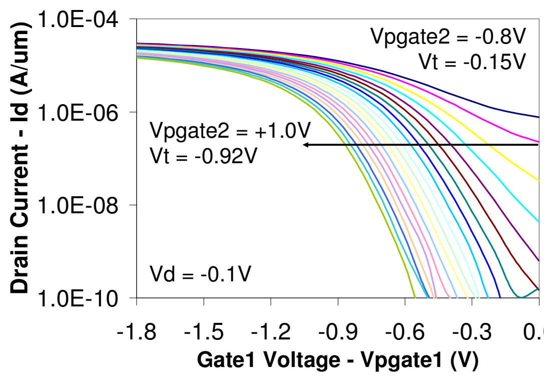

Fig 2. PMOS 180nm MIGFET Id-Vpgate1 as a function of Vpgate2

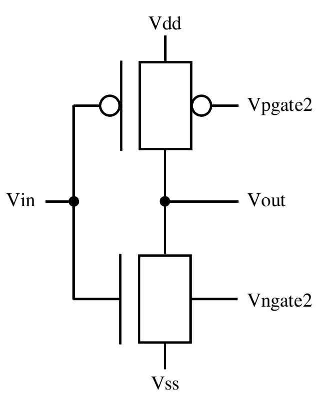

Fig 3. MIGFET inverter schematic

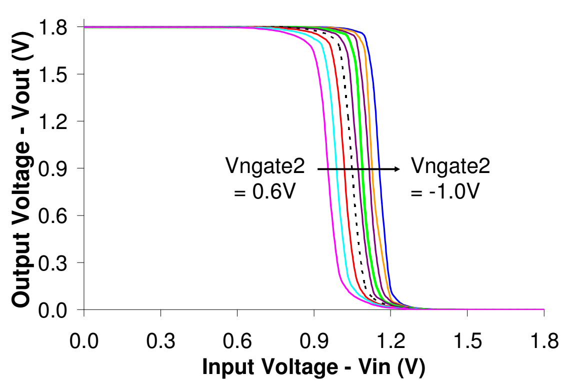

Fig 4. MIGFET inverter VTC tuning using the NMOS second gate

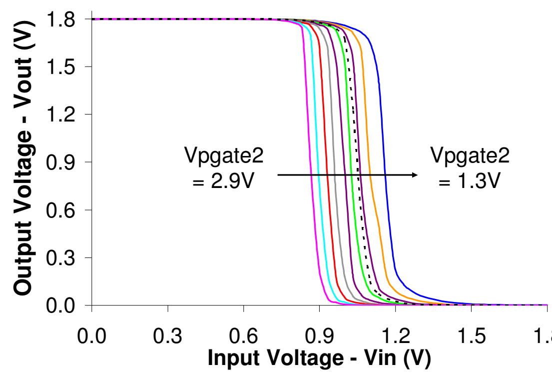

Fig 5. MIGFET inverter VTC tuning using the PMOS second gate

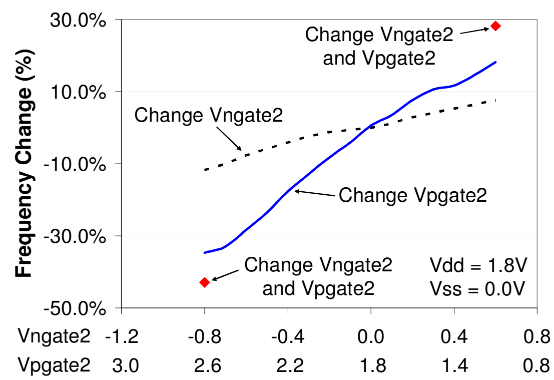

Fig 6. MIGFET tuning of inverter ring oscillator frequency

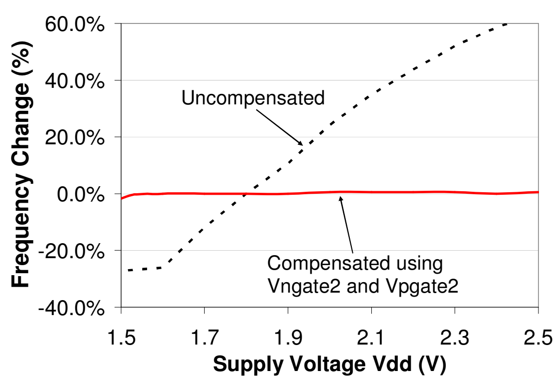

Fig 7. MIGFET compensation of Vdd induced frequency variation

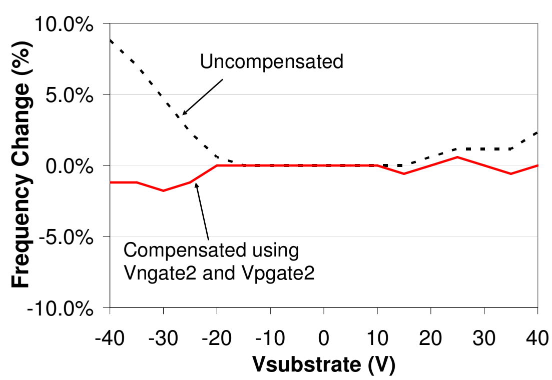

Fig 8. MIGFET compensation of substrate induced frequency variation