Inversion-Layer Induced Body Current in SOI MOSFETs With Body Contacts

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***Abstract*—This letter investigates the body current of thin silicon-on-insulator MOSFETs with body contacts using H-gate and T-gate structures. Due to tunneling between the inversion layer and body contacts, the extra body current was measured and confirmed by the floating-source measurement technique. The drain current at saturation is increased due to the extra body current, which may result in smaller output resistance. A measurement example is also demonstrated.**

***Index Terms*—Body contact, body current, H-gate, inversion layer, output resistance, silicon-on-insulator (SOI) MOSFET, T-gate, tunneling.**

I. Introduction

DUE TO the fact that silicon-on-insulator (SOI) MOSFETs exhibit high current driveability [1], attenuated short-channel effects [2], and enhanced immunity to hot carrier degradation [3], many different types of SOI MOSFETs have been proposed and investigated. However, the floating body of an SOI MOSFET results in other problems, such as drain-current kink effect, low breakdown voltage [4], and latch effect due to the lateral parasitic bipolar junction transistor (BJT) [5]. Even though fully depleted SOI can reduce the kink effect, very thin Si film may lead to parasitic BJT effects.

Inclusion of the body contact in the device is one solution to improve the floating-body characteristics of SOI MOSFETs. The body contacts can also be applied to DTMOS [6], [7], in which the gate and the body are tied together for ultralow-voltage/low-power applications. Several body-fixed structures have been proposed. Here, we selected the same T-gate and H-gate structures proposed in [8] and [9]. By investigating body current, we found that extra current was generated by band-to-band tunneling near the P^+ body contact region below the gate edge, which may result in variation of output resistance.

II. Device Structure and Fabrication

Fig. 1 shows the top views of H-gate and T-gate SOI nMOSFETs. The channel width W and length L are labeled in the H-gate structure. Two extensions with width Wx and length Lx are also illustrated in the H-gate structure. The extensions are used to reduce junction capacitance in the source/drain (S/D) regions and simplify the process complexity.

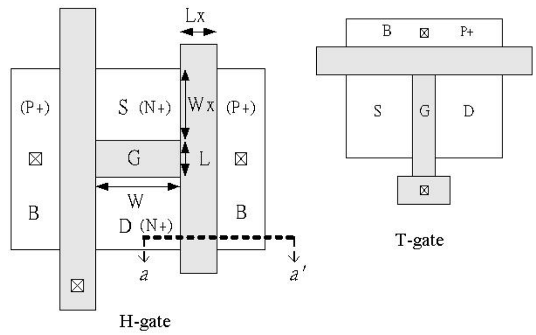

Fig. 1. Top views of H-gate and T-gate SOI MOSFETs.

The process conditions are the same as those reported in [8] and [9] and are briefly described below. N^+ poly-silicon-gate nMOSFETs were fabricated on boron-doped $\langle 100 \rangle$-oriented wafers, with buried oxide thickness of 400 nm and silicon film thickness of 190 nm. LOCOS was able to fully consume the active silicon layer in the isolation region. The channel implant was performed by BF_2 (50 keV, 6×10^{12}cm^{-2}), followed by 4-nm gate-oxide growth. After 200-nm poly-Si gates were generated, a shallow N^+ S/D extension implant with As (5 keV, 1×10^{15}cm^{-2}) was performed and TEOS spacers were formed. Then, As with 10 keV and 5×10^{15}cm^{-2} was used for N^+ S/D implant.

III. Measurement and Analysis

To avoid the complexity of short-channel and narrow-channel effects [8], [9], the H-gate and T-gate SOI MOSFET with $W = 100$ μm and $L = 20$ μm were used in the following analyses. The width Wx and the length Lx of the gate extension in Fig. 1 are 10 and 5 μm, respectively.

The extra body current can be observed in Fig. 2, which shows body current versus gate voltage of H-gate structure for $V_{ds} =$ 1–4 V and $V_{bs} = 0$. For each curve, the first hump is due to impact ionization. However, after the hump, unlike the conventional substrate current which diminishes as the gate voltage increases, the body current increases almost exponentially and then saturates. The right inset of Fig. 3 gives the normal I_d–V_d curves of the T-gate structure with the body tied to the source and $V_{gs} = 0.5, 1.5$, and 2.5 V. The threshold voltage is about 1.1 V and the kink effect is effectively inhibited. With the same bias conditions, Fig. 3 also shows the extra body current ramped at drain voltage around 1 V and then saturated at higher V_d.

Manuscript received December 2, 2002. This work was supported by the National Science Council of Taiwan, R.O.C., under Contract NSC 90-2215-E-005-001. The review of this letter was arranged by Editor B. Yu.

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Digital Object Identifier 10.1109/LED.2002.808168

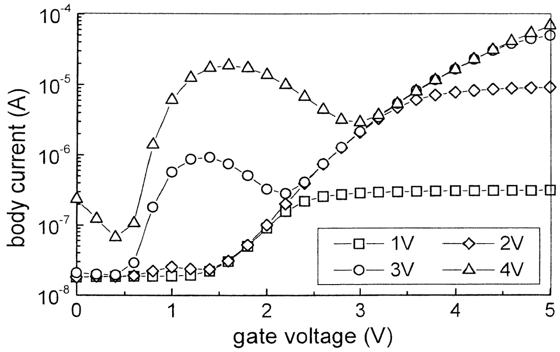

Fig. 2. Body current is plotted as a function of gate voltage using H-gate structures when the source and the body are grounded.

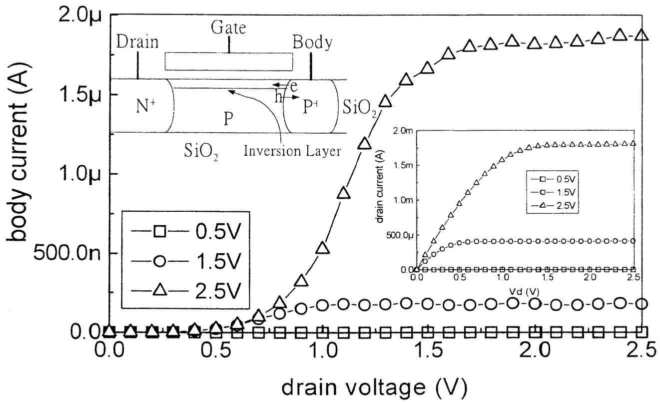

Fig. 3. Body current is plotted as a function of drain voltage using T-gate structures when the source and the body are grounded. The right inset shows the normal drain current at the same bias conditions. The left inset illustrates that the extra body current is caused by parasitic tunneling current between the inversion layer and the P^+ region.

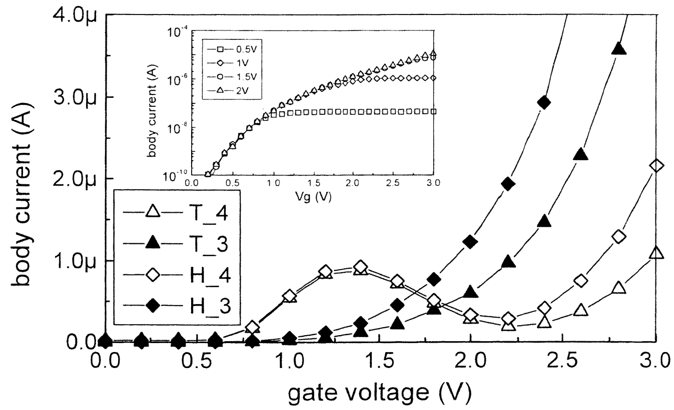

Fig. 4. Body current of H-gate is twice that of T-gate due the parasitic tunneling effect, while the body currents are identical because of impact ionization. The inset shows the body current is plotted as a function of gate voltage when the source is floating and the body is grounded.

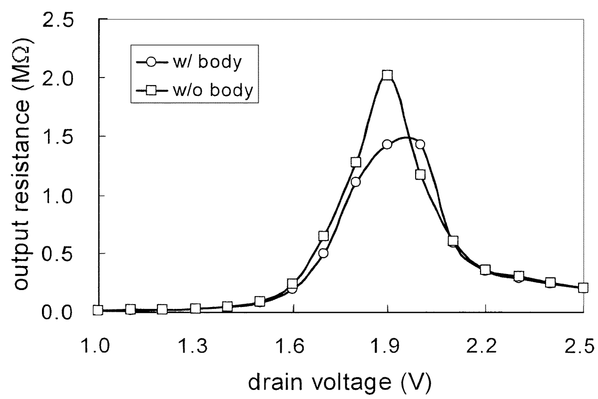

Fig. 5. Output resistance was obtained by taking the slope of I_d–V_d curves for T-gate structures at $V_g = 2.5$ V with and without deduction of body current from the drain current.

This phenomenon can be explained by cutting the H-gate device in Fig. 1 along a–a' and is shown in the left inset of Fig. 3. When the gate voltage is increased, the inversion layer is formed below the gate. Note that the gate extension near the body contact may be P^+-doped due to process variation. The influence is that slightly higher gate bias may be required to form the inversion layer. If the source is floating, the lateral electric field of the inversion layer near the body will be very strong. It provides the possibility of band-to-band tunneling between the P^+ body region and the inversion layer.

To confirm this phenomenon, we measured body current versus V_g of the H-gate structure for $V_d = 0.5$–2 V with the body tied to ground and the source node floating. The result is shown in the inset of Fig. 4. The similar trend in Fig. 2 for higher gate bias is also observed. The magnitude in the inset is about four to five times larger. The discrepancy may be due to the fact that the lateral electric field in the inversion layer near the source is much smaller, if the source node is grounded, which reduces the parasitic tunneling current shown in the left inset of Fig. 3. For further verification, Fig. 4 demonstrates body current versus gate bias at $V_d = 3$ V for the H-gate and T-gate using the bias methods of Fig. 2 (four electrodes) and the inset of Fig. 4 (three electrodes). For the four-electrode operations denoted by open marks, the humps of the body current of the H-gate and T-gate devices are very close, but the exponentially increased body current of the H-gate device is about twice that of the T-gate device due to one more gate extension of the H-gate device. The floating-source measurement using three electrodes, denoted by solid marks, also shows twice the body current in the H-gate device.

The extra body current makes the drain current slightly higher, which may influence the output resistance at saturation. Fig. 5 demonstrates the output resistance of the T-gate structure for $V_g = 2.5$ V if the channel width is scaled to 10 μm while the gate extension is kept the same. The square mark was calculated when the drain current was deducted by the body current, so the output resistance was generally higher.

IV. Conclusion

This letter investigated the inversion which induces body current of SOI MOSFETs with body contacts using H-gate and T-gate structures. The extra body current from the gate extensions due to tunneling was confirmed by floating-source measurement. It may result in smaller output resistance. It is suggested that reduction of extension width Wx may help reduce extra body current, but may complicate the processes, especially for short-channel devices.

ACKNOWLEDGMENT

The authors would like to thank Prof. T.-S. Chao from National Nano Device Laboratories of Taiwan for providing the SOI samples.

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