

New Measurement Technique of Sub-Bandgap Impact Ionization Current by Transient Characteristics of Partially Depleted SOI MOSFETs

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1. Introduction

Recently, the impact ionization has been observed in short channel MOSFETs at the drain voltage less than 1.1 V which corresponds to the bandgap energy of silicon [1,2]. This sub-bandgap impact ionization would affect the device reliability of very scaled MOSFET operating at very low voltage. Therefore, it is essential to elucidate the mechanisms of the sub-bandgap impact ionization phenomena. Some simulation results have been reported on its mechanism [3]. However, the sub-bandgap impact ionization current is generally too small and no experimental results have been reported on the mechanisms.

In this paper, we report the novel, sensitive measurement technique of the sub-bandgap impact ionization current using the transient characteristics of partially depleted (PD) SOI MOSFETs. The derived impact ionization current is in good agreement with the direct measurement of the impact ionization current. The sensitivity is less than 50 fA which is better than that of the direct measurements.

2. Sub-bandgap Impact Ionization

The device used is a 0.13 μm PD SOI MOSFET with a body contact [2]. Figure 1 shows a schematic view of the device. Figure 2 shows the body current measured directly. The well-known bell shaped current curves indicate that the body current is caused by the impact ionization. It should be noted that the sub-bandgap ionization current is clearly observed at the drain voltage below 1.1 V. The current cannot be measured below 0.9 V due to the limit of the direct current measurements.

3. New Measurement Technique

In the PD MOSFETs, the impact ionization current charges the body potential which cause the transient increase of the drain current. The new measurement technique makes use of this relationship among the impact ionization current, body potential, and drain current. Figure 3 shows the transient drain current at various drain voltages after the step voltage (1.1 V) is applied to the gate. From the transient increase of the

drain current in Fig. 3, the transient change of the body potential is plotted in Fig. 4. Then, the impact ionization current should be derived using the slope of the body potential (dV_{body}/dt),

$$I_{\text{body}} = C \frac{dV_{\text{body}}}{dt}$$

where C is the capacitance connected to the body.

4. Results and Discussions

Figure 5 compares dV_{body}/dt extracted from Fig. 4 and body current (impact ionization current) measured directly (squares). It should be noted that they are in very close correlation and the slope is unity. This indicates that the impact ionization current is accurately derived from the transient measurements and this technique is very reliable and precise. From Fig. 5, the capacitance C is estimated to be 4.6 pF, which corresponds to the sum of the body capacitance and the pad capacitance.

The sensitivity is better than the direct measurements and is less than 50 fA. A triangle in Fig. 5 indicates the derived impact ionization current at drain voltage of 0.8 V which is less than the sensitivity of the direct measurements. Figure 6 compares the impact ionization current measured by this technique (triangles) and directly (solid lines). They are in good agreement. This sensitive measurement technique will be very effective to investigate the mechanisms of the sub-bandgap impact ionization.

5. Conclusions

We have developed a novel, sensitive measurement technique of sub-bandgap impact ionization current of scaled MOSFET. The impact ionization current is derived from the transient measurement of PD SOI MOSFET and is in good agreement with the direct current measurement. The sensitivity is less than 50 fA which is better than that of the direct measurements.

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[2] T. Saraya, M. Takamiya, T.N. Duyet, T. Tanaka, H. Ishikuro, T. Hiramoto, and T. Ikoma, IEEE International SOI Conf. p.70, 1996.

[3] M.V. Fischetti and S.E. Laux, IEDM Tech. Dig., p.305, 1995.

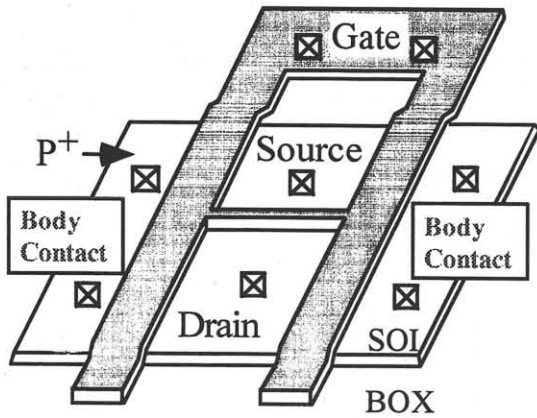


Fig.1 A schematic view of the partially depleted (PD) SOI MOSFET with single drain structure. The device fabricated on SIMOX substrates has body contacts on both sides. The thicknesses of the gate oxide, SOI layer, and buried oxide are 5.0nm, 100nm, and 100nm, respectively.

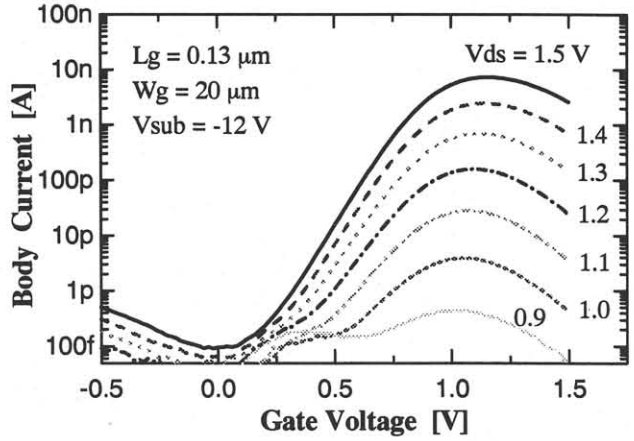


Fig.2 The body current as a function of gate voltage at different voltages in the PD SOI MOSFET. The body current corresponds the impact ionization current as well known bell shaped current. The sub-bandgap impact ionization is clearly observed at the drain voltage below 1.1V

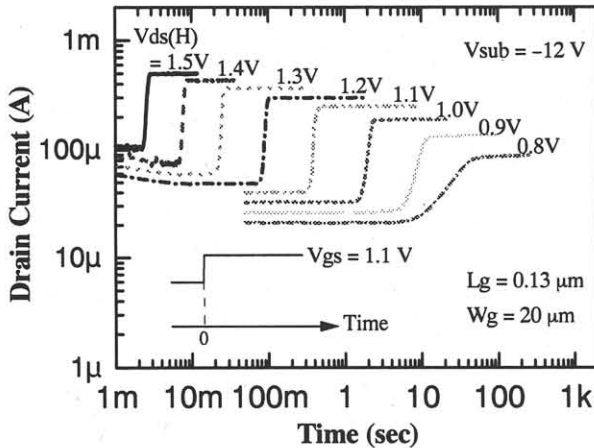


Fig.3 The transient drain current at various drain voltages after the step voltage (1.1 V) is applied to the gate. As the drain voltage decreases, the time constant of transient current increases exponentially.

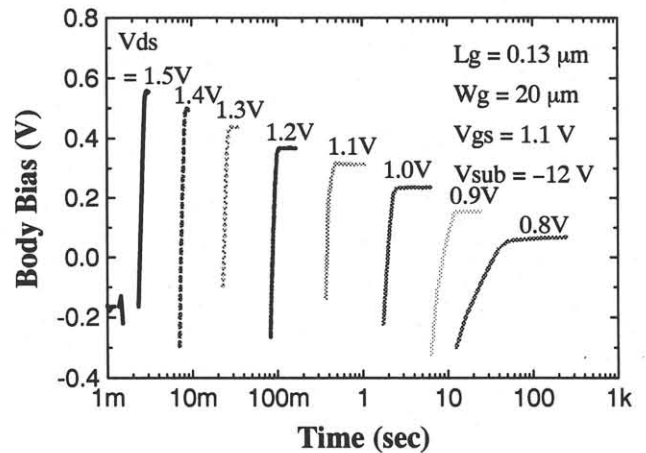


Fig.4 The transient change of the body potential is plotted from the transient increase of the drain current in Fig. 3. The body potential dependence of drain current was measured in advance.

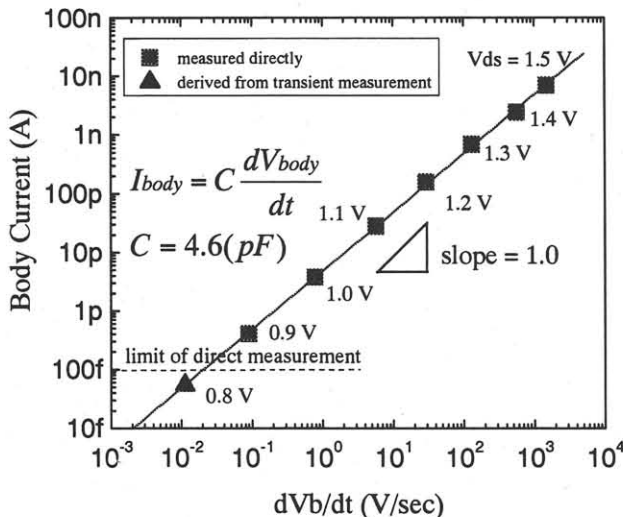


Fig.5 The relation between dV_{body}/dt and body current (impact ionization current). They are in very close correlation and the slope is unity. A triangle indicates the derived impact ionization current which is less than the sensitivity of the direct measurements.

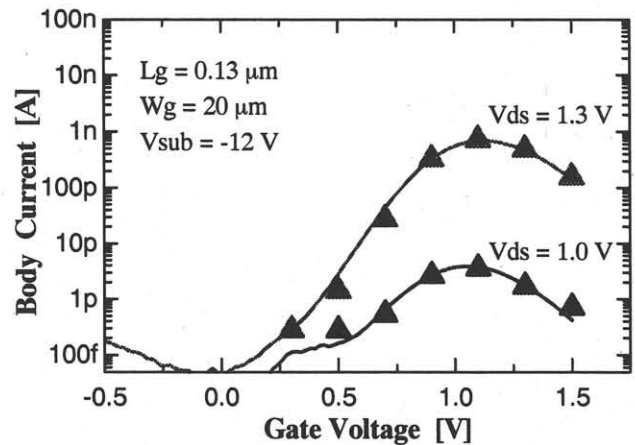


Figure 6 The impact ionization currents measured by this technique (triangles) and directly (solid lines) are compared. These measurements are in good agreement on both below and above the bandgap energy of silicon.