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Complementary Operation of Schottky Source/Drain SOI MOSFET with Shallow Doped Extension

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1. Introduction

SOI is of great interest for high-speed, low-power, and system-on-a-chip applications. MOSFETs fabricated on SOI of partially depleted type in particular, however, shows unstable operation due to the floating body effect(FBE), which give constraints on design of system integration on a chip. In order to suppress the FBE, we have proposed the use of the Schottky barrier contacts at the source/drain in SOI MOSFET.[1−2)]

The Schottky MOSFET has, however, the following three drawbacks. (1)The smaller current drive than the conventional pn-junction MOSFET. This is because of the presence of a potential barrier between the Schottky contact metal and the inverted channel. (2)Schottky MOSFET acts as an ambipolar device, which is unfavorable for CMOS applications. (3)CMOS process complexity increases. This is because two types of metal silicide whose workfunction are largely different must be employed and selectively formed.

In order to overcome these drawbacks while keeping the advantage of Schottky MOSFET, we propose a new SOI MOSFET whose source/drain is composed of Schottky contact and shallow doped extension shown in Fig. 1. In previous reports,[3−4)] we reported preliminary results on n-channel device. In this work, not only farther increase in current drive of n-channel SOI MOSFET but also successful operation of p-channel device are experimentally demonstrated. Moreover, the stability of CMOS operation with proposed devices under high supply voltage is demonstrated by comparing with conventional pn-junction MOSFET.

2. Experimental

SOI MOSFETs were fabricated using a self-aligned Co silicide process. The active layer of the SIMOX wafer was p-type, 200 nm in thickness, and 30 Ω·cm in resistivity. The channel doping of n-channel and p-channel devices was performed with BF_2^+-ions and P^+-ions.The gate oxide thickness was 12 nm. After gate patterning, extension implantation (Sb^+ at 25 keV to 2 $\times 10^{14}$ cm^{-2} for n-channel, BF_2^+ at 25 keV to 5×10^{13} cm^{-2} for p-channel) was carried out followed by annealing at 800°C for 15 min. The side wall spacer was formed and a 70 nm-thick Co film was deposited using vacuum evaporation in UHV. The wafer was then annealed in vacuum at 450°C for 30 min to form Co silicide. Unreacted Co on the side walls was removed with nitric acid.

3. Characteristics

Figure 2 shows subthreshold characteristics of Schottky SOI MOSFETs with and without extension. We can see that the current drive is increased for both n and p-channel MOSFETs by employing the shallow doped extension. The subthreshold slope is also improved by employing the extension. These are the results of reduction of the resistance between the Schottky contact metal and the inverted channel. The improvement in current drive and subthreshold slope is more pronounced in n-channel than in p-channel, since Co-silicide provides higher potential barrier for injection of electrons(0.7 eV) than for holes(0.42 eV). Moreover the leakage current is reduced by introducing the shallow doped extension. This is because that the electric field at the reverse-biased drain Schottky-contact is reduced by the presence of the shallow doped extension.

Figure 3 shows drain characteristics of Schottky SOI MOSFET with extension and conventional pn-junction SOI MOSFET. We can see that the kink in drain current is suppressed and the drain breakdown voltage increases in the Schottky MOSFET. These results indicate that the floating body effect is suppressed by using Schottky SOI MOSFET even when the shallow doped extension is employed. The current drive of the Schottky SOI MOSFET is still lower than, but it approaches to, that of the pn-junction SOI MOSFET.

In order to investigate the effect of Schottky contacts on the floating body effect in detail, lateral bipolar action of these devices have been examined by using devices with body contact tied. Figures 4 shows the output characteristics of the conventional pn-junction SOI MOSFET and the Schottky SOI MOSFET with extension when they are operated as a bipolar transistor using the body as the base. Although the pn-junction device shows bipolar action, the Schottky SOI MOSFET with extension does not operate as a bipolar transistor. In case of the proposed device, two junctions, extension /body(base) pn-junction and silicide/body(base) Schottky junction, are present in parallel. The Schottky junction offers a less energy barrier than the pn-junction for base-majority carriers to flow from the body to the source(emitter). Therefore since most of source(emitter)/body(base) current is carried by injection of carriers from the body to the source, the bipolar operation is hard to occur. These results indicate that the Schottky SOI MOSFET with extension structure is in fact formed and it is effective in suppressing the floating body effect.

4. CMOS operation

CMOS operation of these devices has been examined. Figures 5(a) and 5(b) show CMOS inverter characteristics of the pn-junction SOI MOSFETs and the Schottky SOI MOSFET with extension, respectively. The supply voltage was changed from 4 V to 9 V. In the case of the pn-junction SOI MOSFET, due to the early breakdown as a result of the floating body effect, the fracture in out-

put voltage(high output V_{OH} in particular) appears at the supply voltage higher than 7 V. On the contrary, the inverter composed of the Schottky SOI MOSFET with extension provides stable operation at least up to 9 V.

5. Conclusion

Incorporation of shallow extensions into Schottky source/drain SOI MOSFET can increase the current drive owing to reduction of the series resistance, and can decrease the leakage current owing to the reduced field at the drain Schottky contact, while keeping the effect of suppressing the floating body effect. CMOS can be fabricated with single metal silicide. Impact of the proposed device on CMOS operation has been verified. Although the present work was carried out by fabricating relatively large device relatively large devices, shrinkage of the device dimension is of straightforward. The proposed device will be useful particularly for constructing high voltage block in system on an SOI chip.

Acknowledgements

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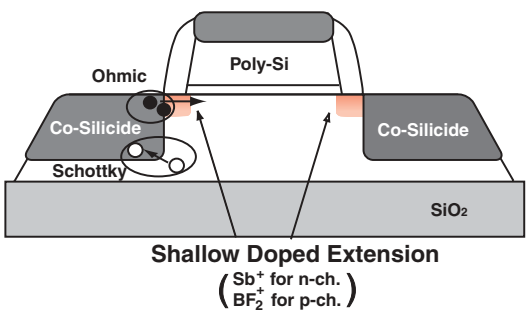


Fig. 1: Schematic cross-section of proposed Schottky SOI MOSFET with shallow doped extension.

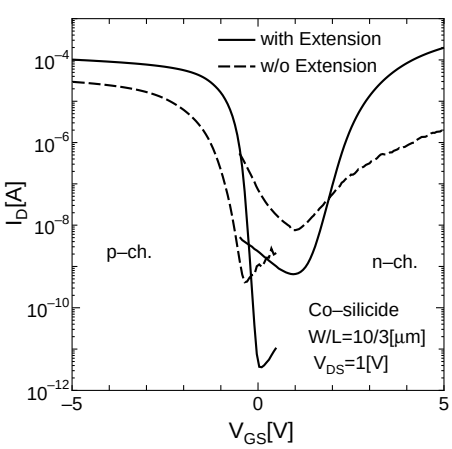


Fig. 2: Subthreshold characteristics of Co-silicide Schottky source/drain SOI MOSFETs with and without extension.

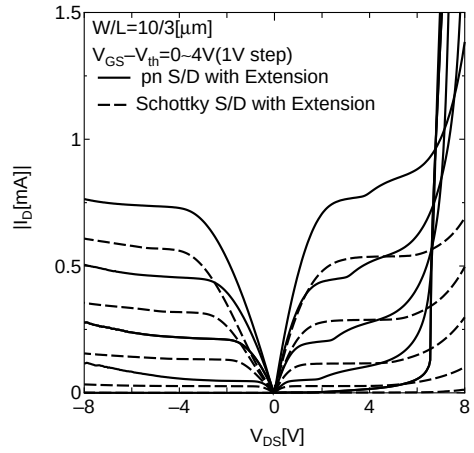
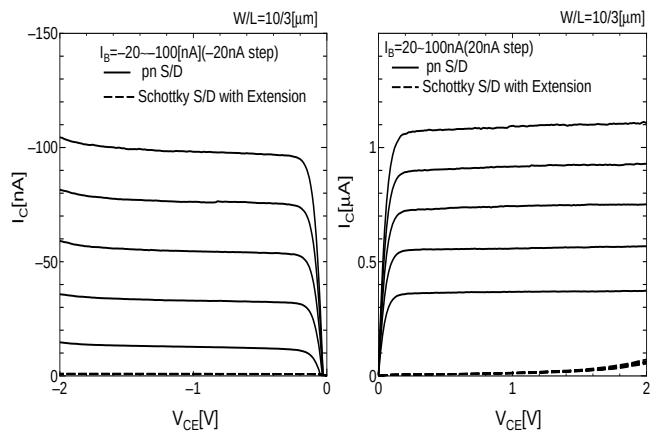
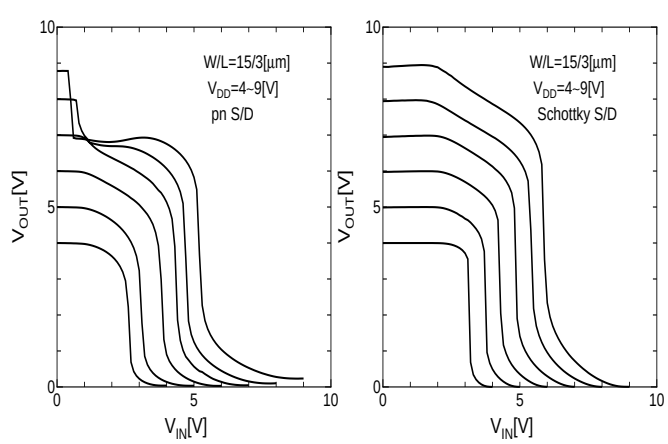


Fig. 3: Drain characteristics of Co-silicide Schottky SOI MOSFET with extension and conventional pn-junction SOI MOSFET.



(a) (b)

Fig. 4: Lateral bipolar-transistor characteristics of (a)p-channel SOI MOSFET and (b)n-channel SOI MOSFET.



(a) (b)

Fig. 5: CMOS inverter characteristics of (a)pn-junction SOI MOSFET and (b)Schottky SOI MOSFET.