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Characterization of DC, analog/RF, and low frequency noise in silicon-on-insulator nMOSFETs with different body-contact structures

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ABSTRACT

This paper fabricated SOI nMOSFETs with floating body and different body-contact structures, including H-gate (HG), body-tied-to-source (BTS), and low-barrier-body-contact (LBBC), on the same SOI substrate. Through direct comparison of DC, analog, RF, and noise behaviors among these devices, the LBBC device has been found to show the best capability to suppress floating-body effects, superior output resistance, and low frequency noise characteristics. Although peak values of transconductance and cutoff frequency in the LBBC device are not so high as those in the HG or BTS device, weaker dependency on gate bias in the LBBC device makes choosing of work point more easy and flexible. Among these structures, the LBBC body contact structure could be a good candidate suitable to SOI nMOSFETs for analog/RF applications.

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1. Introduction

Silicon-on-insulator (SOI) has emerged as an alternative to bulk CMOS technology due not only to performance requirements for sub-100 nm devices, but also to unique integration potentials of combining CMOS circuits with new functional blocks, including MEMS, bioelectronics, and photonics, etc., to form system level chips. However, for partially depleted (PD) SOI technologies that are widely used in IC products and commonly applied to those new functional blocks, floating-body effects (FBE) and related issues still remain technology barriers to device engineers and circuit designers, especially for analog and RF applications [1–3]. Although a few body contact (BC) structures have been constantly studied and already recognized as effective ways to suppress floating-body effects, there still lacks straightforward and comprehensive evaluation among different BC structures, especially for DC, analog/RF, and noise characteristics that are important to device and circuit designs. By fabricating and characterizing PD SOI nMOSFETs with three mainstream body-contact structures, in comparison with floating-body (FB) devices, this paper completely evaluates their capabilities to suppress floating-body effects and positive/negative impacts on device performance.

2. Device structures and fabrication

Fig. 1 shows the schematics of SOI floating-body nMOSFET (Fig. 1a) and devices with different BC structures. The H-shape gate (H-gate) in Fig. 1b is the one most commonly used in practical products, which provides a lateral body contact on both sides along the channel width direction, at a cost of consuming additional chip areas; another familiar structure, the body-tied-to-source (BTS) shown in Fig. 1c, eliminates consumption of extra chip areas, however, it partially sacrifices effective channel width; Fig. 1d illustrates an alternative structure, the so-called low-barrier-body-contact (LBBC) [4], which features a deep p^+ diffusion layer between the shallow source junction and the buried oxide layer. The p-type layer under the n^+ source is created by an intentional p^+ mask implantation step ($^{11}B^+$, 25 keV, 1×10^{14} cm^{-2}) on the source side after poly gate implant/etch and before source/drain implant. This approach introduces asymmetrical source and drain junctions, but it avoids sacrificing channel width as the BTS structure does.

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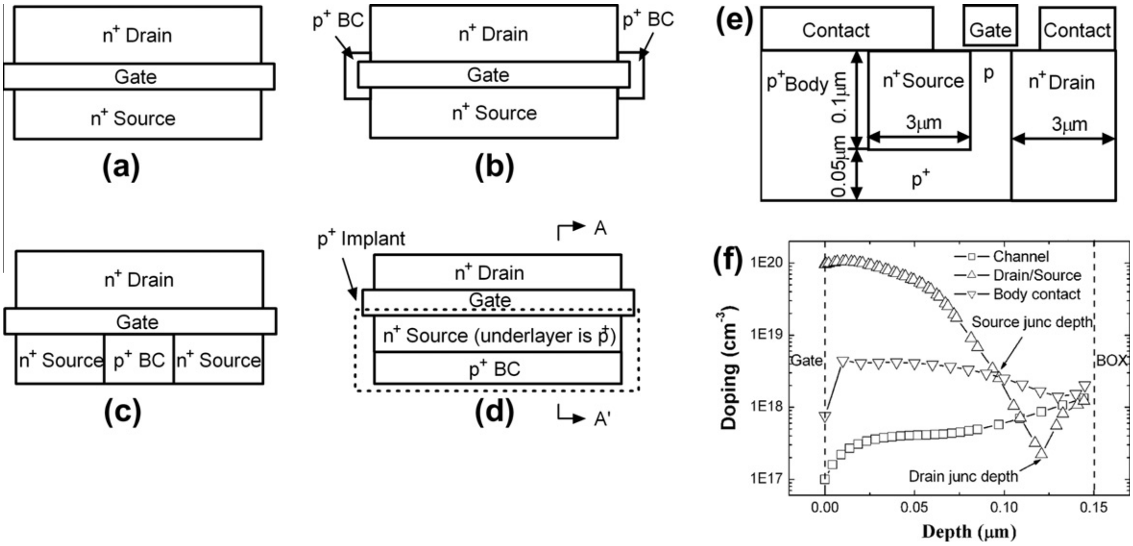

Fig. 1. Structures and doping profiles: schematic top view of SOI nMOSFETs with a (a) floating-body (FB) or body-contact structures of, (b) H-shape gate (HG), (c) body-tied-to-source (BTS), (d) low-barrier-body-contact (LBBC), (e) A–A$'$ cross-section of LBBC, and (f) doping depth profiles of LBBC.

The above body-contact devices are fully compatible with one another in structure formation, only requiring modification of p$^+$ body-contact implant mask compared with the floating-body device. Thus, all the devices were fabricated on the same SOI substrate featuring substrate resistivity of 10–20 ohm-cm, Si film thickness of 185 nm, and buried oxide thickness of 375 nm. Gate oxide (nitrided silicon dioxide SiO_xN_y) thickness is 6 nm and poly-silicon gate length is 250 nm. In layout design, gate width is 10 μm for each finger, and two parallel fingers are used for device characterization for call characterization except that, in practice, totally 30 fingers are used in RF *S*-parameter measurements to reduce gate resistance. The fabrication process flow and conditions could be found in earlier publication [5].

3. Results and discussion

Fig. 2 compares transfer characteristics I_{DS}–V_{GS} of these body-contact and floating-body devices. Among all structures, the LBBC device has excellent characteristics (refer to Table 1 in the last of Section 3) in terms of moderate threshold voltage 0.54 V (defined by constant current method 0.1 μA/μm), steep sub-threshold slope (79 mV/dec and 48 mV/dec for linear and saturation regions, respectively), slight DIBL (drain-induced-barrier-lowering) effect, and low off-state current 75 pA/μm. The 'anomalous' subthreshold slope is found to improve under the high drain bias, which is due to SOI floating-body effects in line with those reported in [1,2,6,7]. In comparison, the BTS has bad, and the HG has worse transfer characteristics, while the FB device is unable to shut off at all under the drain bias 3 V. Evidently, the LBBC is the only one enabling device operation at the drain bias 3 V.

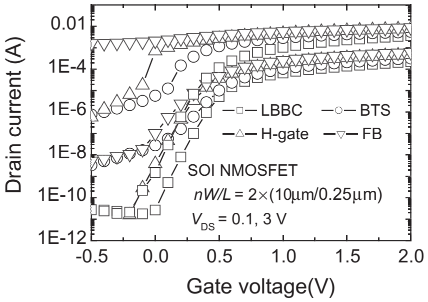

Fig. 2. Comparison of transfer characteristics of SOI nMOSFETs.

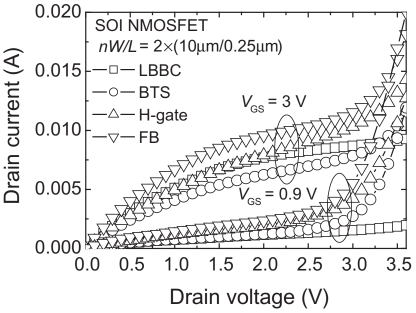

Fig. 3. Comparison of output characteristics of SOI nMOSFETs.

Output characteristics I_{DS}–V_{DS} curves at the gate biases 0.9 V and 3 V are shown in Fig. 3, respectively. Very flat saturation output curves, without visible kinks up to the drain bias 3 V, could be found for the LBBC device, indicating that floating-body effects are well suppressed; in contrast, the BTS device shows clear kinks in output curves, and lower drive current (due to loss of channel width) prior to the kink onset; the HG device has earlier and stronger kinks, behaving most close to the FB device in the worst case of all.

In Fig. 4, the LBBC device has around 2× higher off-state ($V_{GS} = 0$) drain breakdown voltage BV_{DS} (7.6 V), compared with any of its counterparts (BTS ~ 4.4 V, HG ~ 3.6 V, and FB ~ 3.0 V), where the breakdown voltage is defined as the drain voltage at which the drain current reaches 0.1 μA/μm under $V_{GS} = 0$. Besides, prior to the onset of breakdown, the LBBC device shows over two orders of magnitude lower junction leakage than any of other devices. Both high breakdown voltage and low pre-breakdown junction leakage are well recognized as indicators that parasitic bipolar-junction transistor effects are well restrained [1,2], suggesting floating-body effects are effectively suppressed.

From above *I*–*V* characterizations of Figs. 2–4, a conclusion could be drawn that the LBBC structure has the best capability to suppress floating-body effects, BTS the second, and HG the third.

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