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Analog Circuit Design in PD-SOI CMOS Technology for High Temperatures up to 400°C using Reverse Body Biasing (RBB)

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This work focuses on analog integrated CMOS (Complementary Metal-Oxide-Semiconductor) circuit design in SOI (Silicon on Insulator) technology for the use in high temperature applications. It investigates the influence of reverse body biasing (RBB) on the analog characteristics of SOI-MOSFET (Metal-Oxide-Semiconductor-Field-Effect-Transistor) transistors. Additionally, the enhancement of the operation capability of fundamental analog circuits at high temperatures up to 400°C with the use of RBB is investigated. Analog and digital integrated circuits are used in a variety of applications, e.g. consumer electronics or industrial measurement equipment. These integrated circuits have to work properly in the temperature range predefined by the application. As an example, operating temperatures reaching from −50°C to 250°C are required for geothermal drilling applications. Currently in the automotive industry, electronics have to operate reliably up to 150°C and as control electronics are placed closer to the engine, a much higher operating temperature is required. High temperature electronics are also used in avionic- and space applications, e.g. for future Venus exploration missions, where they have to withstand operating temperatures of 300°C to 500°C. Active or passive cooling of electronic components requires additional space and weight that increases the cost of the overall system. Cooling can be avoided in case electronics are capable of operating in harsh environmental conditions, i.e. at high temperatures. SOI-MOSFET devices are theoretically capable of operation up to 400°C or even higher, depending on the doping concentration of the silicon film. Nearly all material and device properties of importance to electronics worsen with increasing temperature, which is why 300°C to 350°C is the currently stated experimental maximum operating temperature of SOI devices. Analog circuit design up to the theoretical temperature limit exhibits severe limitations as SOI-MOSFET device characteristics are degenerated. SOI-MOSFET devices are partially depleted (PD) or fully depleted (FD), depending on the temperature, doping concentration of the silicon film, silicon film thickness and also channel length. FD devices offer a much better analog performance compared to their partially depleted counterparts and are preferred for analog circuit design. In the considered SOI technology, SOI- MOSFET devices are FD at low temperatures and PD at high temperatures. The transition from FD to PD at high temperatures leads to increased device leakage currents and hence reduces the overall performance of the transistor devices. Thereby, the gm/Id factor as a major figure of merit is decreased dramatically at high temperatures. Especially the moderate inversion region, which offers high intrinsic gain and moderate intrinsic bandwidth, is strongly affected as device leakage currents exceed the range of device operating currents at high temperatures. Reverse body biasing (RBB) refers to the reverse biasing of the film-source PN-junction of a MOSFET transistor. In recent works, reverse body biasing has been applied to digital circuits in order to reduce the static current consumption. Reverse body biasing has also been investigated in the analog domain. Nevertheless, the importance of the technique to realize analog circuits capable of operating at the theoretical temperature limit of SOI technology has not been identified yet. SOI-MOSFET devices with an H-shaped gate are investigated in a 1.0 μm PD-SOI technology. These devices provide a body-contact, which is used to apply the reverse body bias. It is found that due to the use of RBB, these devices remain fully depleted in the considered temperature range up to 400°C. Due to the reduction of leakage currents, reverse biased SOI-MOSFET devices are capable of operating in the mid moderate inversion region, with an operating current of one fifth of the leakage current level which was measured without RBB. This results in an improved gm/Id factor and an increase of the intrinsic gain by approximately 14 dB. Besides the investigation of SOI-MOSFET device characteristics, reverse body biasing is also applied to fundamental analog building blocks, e.g. an analog switch, current mirrors, a twostage operational amplifier and a first order bandgap voltage reference. It is found that reverse body biasing significantly improves the high temperature operation of these circuits. In summary, the proposed technique of reverse body biasing offers the possibility to achieve FD device characteristics in a PD-SOI technology and thereby to improve the performance of analog circuits at high temperatures up to 400°C.