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Device Technology for GaN Mixed-Signal Integrated Circuits

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1. Introduction

Gallium nitride and its related III-nitride materials are being established as the key materials for optoelectronic devices (e.g. light emitting diodes and lasers) and high-frequency power amplifiers, and recently have attracted great interest as candidates for the emerging high-voltage and high-temperature power electronics applications, owing to their high breakdown field (3 MV/cm), high electron saturation velocity (2.5×10^7 cm/s), and operating temperature. The AlGaN/GaN heterostructure system, enhanced by the spontaneous and piezoelectric polarization present in the heterostructure, yields two-dimensional electron gas (2DEG) with a high sheet charge concentration and high electron mobility. The impressive electronic properties of these materials have been exploited in the form of high electron mobility transistor (HEMT) that is capable of delivering high operating frequency and high breakdown voltage simultaneously, a desirable combination for high-performance mixed-signal integrated circuits that often require adequate supply voltage to achieve dynamic range.

In evaluating transistor technologies for RF, digital and high-speed mixed-signal applications, key performance parameters include cut-off frequencies, current drive capability and voltage drive capability (maximum output voltage swing). For many RF and analog electronic applications, small V_{BK} values greatly restrict the dynamic range of the circuit and represent a severe limitation. It is highly desirable in mixed signal electronics to have transistors capable of accommodating voltage swings of 10V or more. Thus, GaN mixed-signal technology is expected to provide benefits such as high speed, high breakdown voltage and high-temperature operation.

In this paper, a device technology platform for implementing GaN mixed-signal ICs is presented. High-performance GaN enhancement-/depletion-mode (E/D-mode) HEMTs are the key devices for implementing digital/analog functional blocks, while Schottky diodes and lateral field-effect rectifiers provide useful components for sensing circuits.

2. Technology platform for GaN mixed-signal ICs

Figure 1 Schematic platform for GaN mixed-signal ICs.

The schematic cross section of the proposed platform for GaN mixed-signal ICs is shown in Fig. 1. To achieve high integration density, a planar isolation process featuring fluorine ion implantation is used instead of mesa isolation [1]. Starting with a baseline AlGaN/GaN HEMT structure grown on (111) Si substrate, enhancement-mode (E-mode) HEMTs and the HEMT-compatible lateral field-effect rectifier [2] are fabricated using the fluorine plasma ion implantation technique. Schottky barrier diodes directly fabricated on the AlGaN/GaN heterojunction are also useful component for constructing analog circuits [3].

Using the GaN mixed-signal IC platform, we have demonstrated the monolithic integration of

enhancement-/depletion-mode AlGaIn/GaN HEMTs for direct-coupled FET logic (DCFL) circuits that operate properly up to 375 °C [4]. Low-power voltage reference generator [3] and comparator have also been demonstrated. The following section will further illustrate the implementation of a 2-bit quantizer circuit.

3. GaN mixed-signal functional blocks: a 2-bit quantizer circuit

A quantizer circuit is a key building block for quantization of input analog signals in flash analog-to-digital converters (ADC). A 2-level quantizer is designed with two bootstrapped comparators [5] in the upper and lower rails for high-/low-level detection of an analog signal, and a two-dimensional electron gas (2DEG) resistive ladder as a voltage divider to provide constant references V_1 and V_2 under a fixed reference voltage V_{ref} , as shown in Fig. 2.

The ac performance of the quantizer was measured with a V_{DD} of 15V, a V_{ref} of 5V, and $Bias_{1,2}$ of 2.4V. The input signal V_{in} was a 5 MHz triangular wave with a $5V_{p-p}$, and a dc offset of 2.5 V. As shown in Fig. 3, proper operations were obtained from room temperature to 250°C. The output waveforms (V_{out1} and V_{out2}) were measured with a high impedance probe and they exhibit a transition to logic high when V_{in} exceeds 2/3 (for the upper rail) or 1/3 (for the lower rail) of its amplitude.

3. Conclusions

A robust technology platform is demonstrated for the implementation of GaN mixed-signal integrated circuits. It can be envisioned that such a platform can also accommodate RF circuits and power converters, leading us to highly integrated system-on-chip solutions for many applications.

Acknowledgments

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Figure 2 DC characteristics of (a) E-mode HEMT, (b) D-mode HEMT, and (c) lateral field-effect rectifier.

Figure 3 (a) Microphotograph of a 2-level quantizer chip, and (b) the schematic circuit diagram.

Figure 4 Oscilloscope captures of a 5-MHz triangular wave signal at V_{in} , the output waveform V_{out1} at the upper rail, and the V_{out2} at the lower rail. The measurements were conducted at 25, 100, and 250°C respectively.