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GaN Zero-Bias RF Mixer Using a Lateral Field-Effect Rectifier

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1. Introduction

Owing to the wide energy bandgap of gallium nitride and related materials, AlGaN/GaN HEMTs are advantageous to the conventional silicon devices for high temperature applications because of the lower intrinsic carrier concentrations. GaN's strong chemical inertness makes GaN-based devices especially attractive for sensor systems operating in high-temperature environment. Thus, a GaN-based monolithic integration of sensing components with radio-frequency front-end functional blocks can potentially lead to compact system-on-chip (SOC) solutions for wireless sensor systems in high temperature electronics that are finding increasing demand in industrial control, automotives and oil well-logging. In order to avoid the use of battery or prolong the battery lifetime in the high-temperature environment, the electrical currents induced in the antenna by the incoming radio signals can be utilized to power up the integrated circuit and transmit the response signals. In such systems, key functional blocks with low or zero dc bias are desirable to obtain low power consumption.

As a critical part in RF transceiver, the mixer is considered as one of the most power consuming components. Various techniques such as dual-gate AlGaN/GaN HEMT and resistive HEMT mixers have been reported [1]-[2]. However, all of these techniques may not be suitable for ultra-low power applications due to the non-negligible DC power consumption of the HEMT. Although Schottky barrier diodes (SBDs) can be directly formed on AlGaN/GaN heterostructures to fabricate the diode mixers, the presence of AlGaN/GaN heterojunction in serious with the metal-AlGaN Schottky junction has resulted in relatively high forward-on voltage [3]. Therefore, the AlGaN/GaN SBD mixers also require non-zero DC-biasing. In this work, we proposed a zero-bias mixer based on the lateral field-effect diode (L-FED) [4]. The detailed characteristics of the proposed mixer are reported at ambient temperatures ranging from room temperature to 250°C.

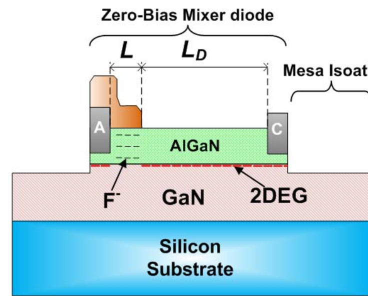

Fig. 1. Cross-section of the proposed zero-bias mixer diode.

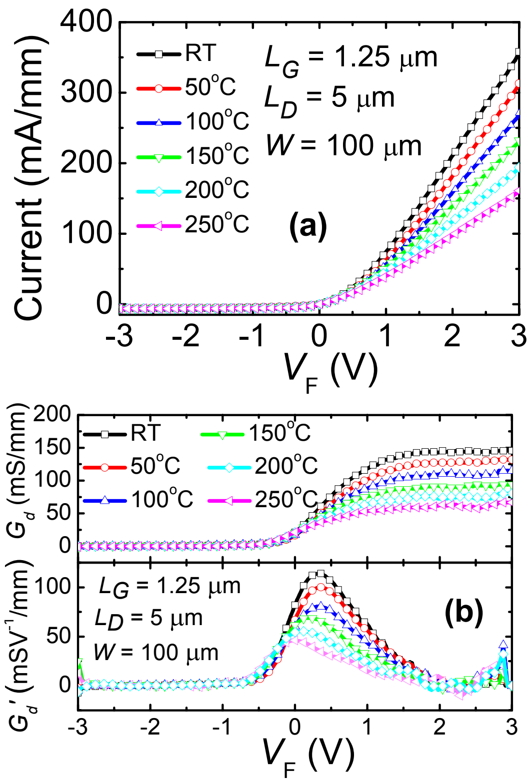

Fig. 2. Measured (a) current-voltage curve and (b) conductance and the derivative of the conductance of an L-FER at various temperatures.

2. Device Structure and Operating Principle

The cross-section of the proposed mixer diode is shown in Fig. 1. The diode features a Schottky gate-controlled channel between the cathode (C) and anode (A). By introducing a Schottky control contact to the conventional ohmic anode, the turn-on voltage is determined by the threshold voltage of the channel instead of the Schottky barrier. To achieve a low positive turn-on voltage and the strongest nonlinearity near zero bias, our previously developed fluorine plasma treatment technique [5] is used. Before the Schottky contacts formation, these regions were treatment by CF_4 plasma at 130W for 140s. Compared to the rectifier reported in our previous work [4], the plasma treatment time is reduced from 150 s to 140 s to achieve a higher non-linearity at zero bias. L and L_D represent the length of the Schottky contact region (with CF_4 plasma treatment) and the drift region of the L-FER, respectively. A commercial $Al_{0.25}Ga_{0.75}N$/GaN HEMT structure grown on 4-inch (111) silicon substrate by MOCVD was used in this work.

3. Measurement Results and Discussion

Fig. 2 shows the dc I-V characteristics. The turn-on knee voltages (V_k) at a 1 mA/mm forward current was 0.3 V at room temperature. V_k exhibited very little temperature dependence as the temperature is raised to 250 °C. At zero bias, the derivative of dynamic conductance (G_d'), the dominant factor in determining the diode mixer's conversion efficiency [6], maintains a value larger than 101 mS/V·mm at RT and features a peak at 250 °C, suggesting good conversion efficiency throughout wide temperature range.

Owing to the strong nonlinearity near zero bias, the diode is used to implement a zero-bias single-ended mixer with wide range operating temperature. The down-conversion mixing measurement was carried out with a local oscillator (LO) frequency (f_{LO}) of 2.4 GHz and radio frequency (RF) frequency (f_{RF}) of 2.5 GHz. The output frequency spectrum of the mixer operating without DC-bias at an LO power (P_{LO}) of 10 dBm and RF power (P_{RF}) with -4.7 dBm at 250 °C is shown in Fig. 3. The IF output signal was produced at 100 MHz with a power level of -22.1 dBm. The results show that the proposed diode fabricated by the CF_4 plasma treatment technique maintained an excellent mixer performance at temperature as high as 250 °C. The dependences of the conversion loss (CL) on the LO power level in the zero-bias condition at different temperatures are plotted in Fig. 4. The conversion loss increases with temperature due to the decreasing G_d'. The output IF power as a function of the input RF power at different temperature is depicted in Fig. 5. The compression of the conversion loss was only ~ 0.3 dBm, indicating a wide dynamic range for the mixer.

4. Conclusion

A zero-bias single-ended mixer using a lateral field-effect diode fabricated on standard GaN-on-Si AlGaN/GaN HEMT wafer has been demonstrated and characterized for high temperature operation up to 250 °C. The zero bias mixer implemented by the lateral field-effect diode exhibits zero dc power consumption, low conversion loss, excellent good linearity and high power handling capability.

Acknowledgment

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References

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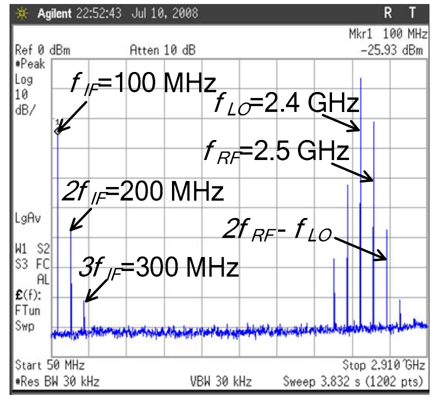

Fig. 3. Frequency spectrum of the mixer operating without DC-biasing at 250 °C.

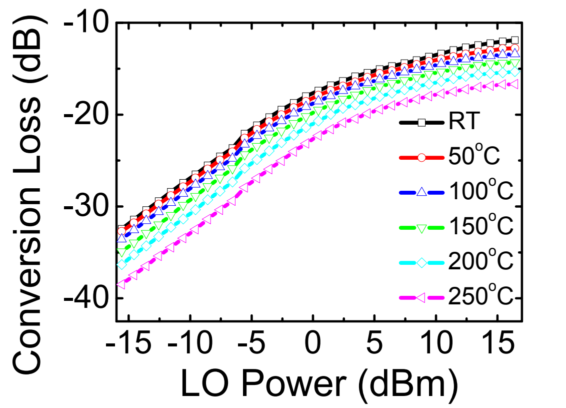

Fig. 4. Conversion loss vs. LO power at different temperatures (P_{RF} = -5 dBm).

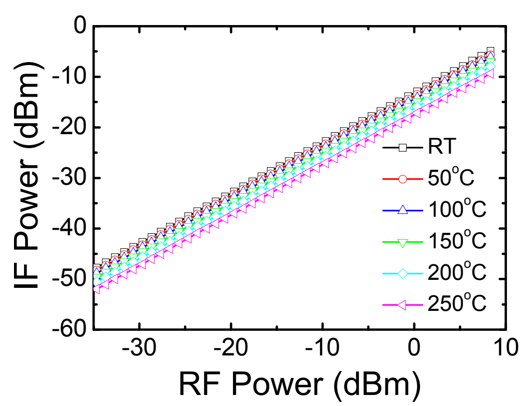

Fig. 5. IF power vs. RF power at different temperatures (P_{LO} = 10 dBm).