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High-Temperature Performance of AlGaN/GaN HEMT-Compatible Lateral Field Effect Rectifier

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1. Introduction

There has been an increasing demand for power electronic systems to operate in high-temperature environment such as aviation and automotive vehicles. In addition, as power integrated circuits are continuously down-scaled, the power density also increases, imposing tremendous burdens upon thermal management. Therefore, power semiconductor devices capable of delivering satisfactory performance at high junction temperatures need to be developed, for operations at high temperature as well as for reducing the burden of thermal management. For silicon power devices, the maximum operation temperature is 200^{o}C. Above 200^{o}C, wide-bandgap III-nitride semiconductors such as GaN and SiC become imperative, as they inherently feature smaller intrinsic carrier concentrations than Si. Among GaN based power transistors, AlGaN/GaN high electron mobility transistors (HEMTs) are the most attractive because of their favorable devices properties including low on resistance, high breakdown voltage and high switching speed. High temperature operation of the depletion-mode and enhancement-mode (E-mode) AlGaN/GaN HEMTs have been reported [1, 2]. Meanwhile, two-terminal power rectifiers with high reverse breakdown voltage (*BV*), low forward turn-on voltage ($V_{F,ON}$) and low specific on-resistance (R_{ON},*sp*) are also essential components of power electronics circuits. Schottky barrier diodes (SBD) and p-i-n rectifiers on doped bulk GaN have been reported [3, 4]. However, these expitaxial structures are not compatible with that of the HEMT. Thus, a HEMT-compatible power lateral field effect rectifier (L-FER) [Fig. 1] with low turn-on voltage was proposed using the same fabrication process as that for normally-off AlGaN/GaN HEMTs [5]. In this paper, we report detailed DC characteristics of the proposed AlGaN/GaN L-FER at ambient temperatures ranging from room temperature to 250^{o}C.

2. AlGaN/GaN HEMT-Compatible Lateral Field-Effect Rectifier: Device Structure and Fabrication

The cross-section of the proposed lateral field-effect rectifier compatible with normally-off HEMT is shown in Fig. 1. The rectifier features a Schottky gate-controlled channel between the cathode (C) and anode (A). By tying up the Schottky gate and 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, our previously developed fluorine plasma treatment technique [6] is used. 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. The fabrication process flow is illustrated in Fig. 2. Before the Schottky contacts formation, these regions were treatment by CF_4 plasma at 130W for 150s. The negatively charged fluorine ions can effectively deplete the 2DEG channel and shifts the threshold voltage from the original -2.1 V to +0.2 V.

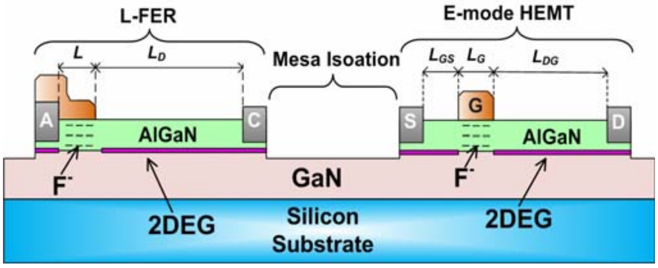

Fig. 1. Cross-section of the proposed power lateral field-effect rectifier integrated with an enhancement-mode HEMT.

3. Measurement Results and Discussion

In an L-FER featuring L=1.5μm and L_D =10μm, the turn-on knee voltages (V_k) at a 1mA/mm forward current is 0.2 V, and the forward current at a forward voltage (V_F) of 3V is 184mA/mm. For comparison, in an SBD with the same drift length, V_k is 1.3V and the forward current is 57.1mA/mm, as shown in Fig. 3(a). The L-FER and SBD with the same drift region length shows a nearly-identical reverse breakdown voltage of ~400 V at a current of 1mA/mm [Fig. 3(b)]. Temperature dependences of the forward turn-on voltage (@100A/cm^2) $V_{F,ON}$ and the specific on-resistance $R_{ON,sp}$ of L-FER with different drift lengths are shown in Fig. 4. Both $V_{F,ON}$ and $R_{ON,sp}$ exhibit monotonic increase as the ambient temperature increases. The longer is the drift length in an L-FER, the larger is the rate of the change for the $V_{F,ON}$ and $R_{ON,sp}$. The current densities and specific conductances as a function of forward voltage at different temperature for 10μm, 15μm 20μm drift lengths are plotted in Fig. 5. V_k exhibits very little temperature dependence as the temperature raised to 250^{o}C.

4. Conclusion

The AlGaN/GaN HEMT-compatible lateral field effect rectifiers have been shown to be capable of proper functions from room temperature up to 250^{o}C. The temperature dependences of the forward turn-on voltage and the specific on-resistance have been obtained.

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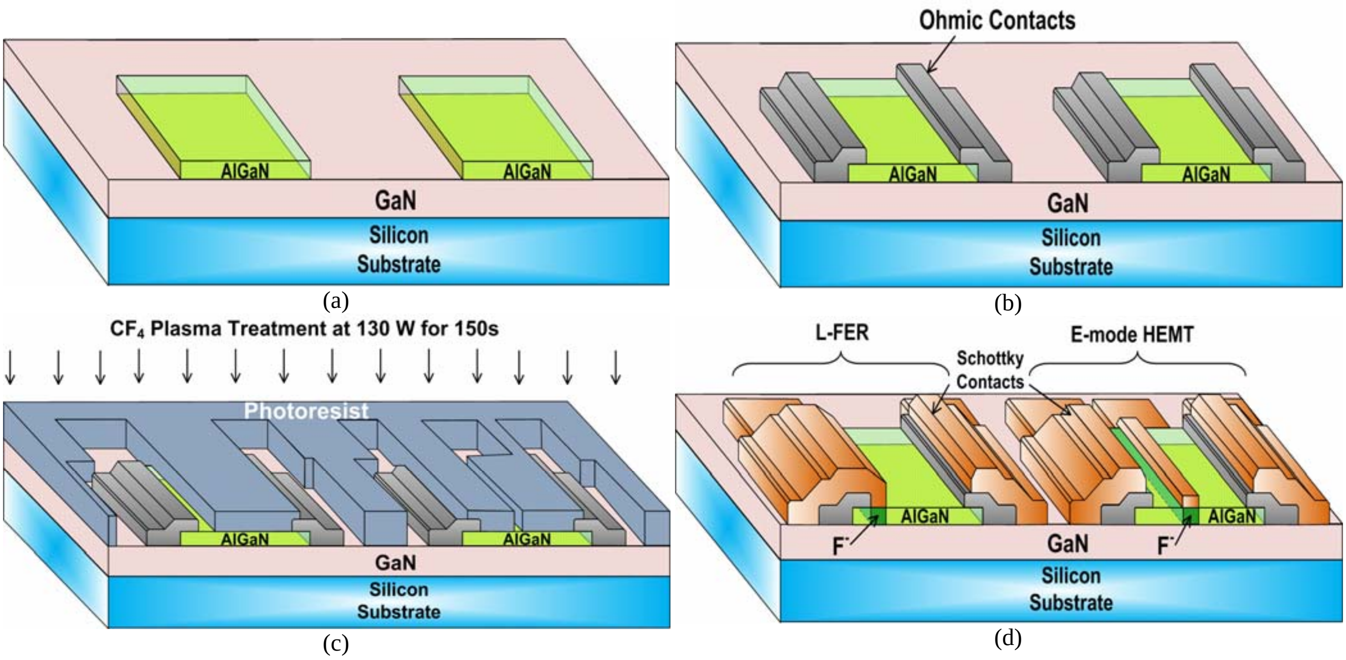

Fig. 2. Schematics showing the process flow of monolithic integration of lateral field-effect rectifier and E-mode HEMT: (a) Mesa etching; (b) Ohmic contacts; (c) Anode area of LFER and E-mode HEMT gate definition and CF_4 plasma treatment; (d) Schottky contacts for LFER and E-mode gate.

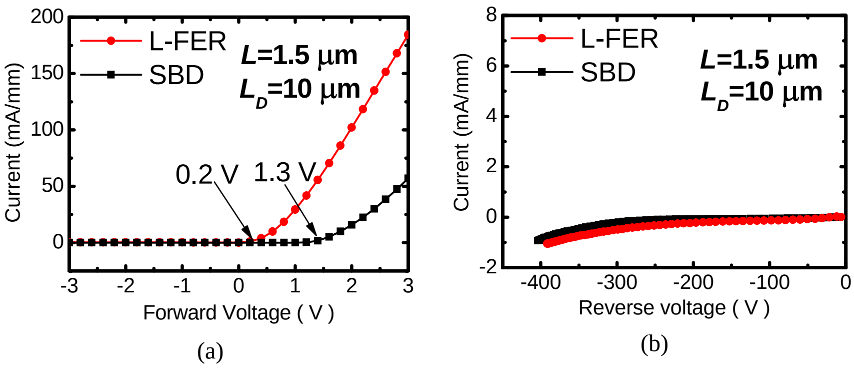

Fig. 3. Measured output characteristics of an L-FER and an SBD at (a) forward bias; and (b) reverse bias.

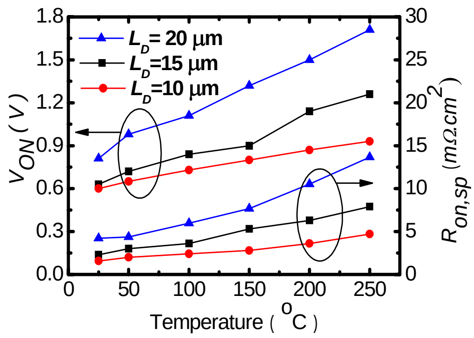

Fig. 4. Temperature dependences of forward turn-on voltage and specific on-resistance of L-FER with different drift lengths.

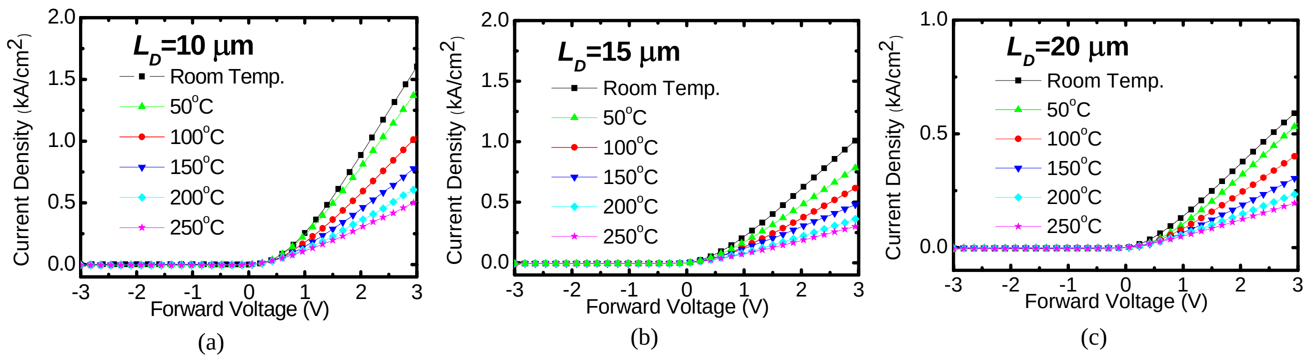

Fig. 5. Current densities as a function of the forward voltage at different temperatures in L-FER with a drift length of (a) 10μm, (b) 15μm and (c) 20μm.

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