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AlGaN/GaN MOS-HEMT Single-Chip DC/DC Boost Converter Using High-k Gd_2O_3 Insulator

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Introduction

In recent years, energy problem has been taken seriously. Therefore, the power semiconductor device is showing increasing important in power electronics. To break through the material limits of silicon to realize the drastic performance improvement, GaN-based high electron mobility transistors (HEMTs) have been proven to be outstanding candidates for future microwave power applications [1]. GaN HEMTs have several special properties: fine thermal stability, high breakdown voltage, high electron velocity, and high current density [2] [3]. For the development of GaN-based integrated power converters that require both HEMT switches and rectifiers, it is desirable to integrate high-performance power transistors and rectifiers on the same epitaxial wafer with the same fabrication process. However, according the report in [4][5], about 60% of the total loss comes from the ON-state resistances of HEMT and Schottky barrier diode (SBD). The key to increase the efficiency is decreasing the ON-state resistances, suppressing the leakage and improving the turn-on voltage. In this work, we fabricated a low turn-on voltage and high breakdown voltage circular rectifier to replace the traditional muti-finger SBDs, and a MOS-HEMT with Gd_2O_3 high-k film replaced HEMT. The detail DC characteristics are reported

Device Structure and Fabrication

The schematic cross-section of the integrated circular rectifier and a MOS-HEMT transistor was shown in Fig. 1. The design of circular rectifier was based on AlGaN/GaN HEMT epitaxial wafer grown with GaN-on-Si. The cathode electrode (C) of the circular rectifier was made of an electrode in Ohmic contact with the 2DEG, while the anode electrode (A) is made of Schottky contact with Ni/Au. The sample used in this work was a commercial AlGaN/GaN HEMT wafer grown by MOCVD on (111) silicon substrate. The epitaxial structure includes an GaN buffer, a 1μm AlGaN electrical blocking layer, a 50 nm GaN channel layer, a 30 nm AlGaN barrier layer and a 1 nm GaN cap. The wafer demonstrated a sheet resistance of 446 ohm/square, a sheet charge density of 9.80×10^{12} cm^{-2} together with a Hall mobility of 1431 cm^2/V-s at 300K.

Devices were processed by conventional optical lithography and lift-off process. Ohmic contacts were realized by using Ti/Al/Ni/Au followed by a 850°C, 30 sec RTA annealing in N_2 ambient. To define an active region, high density coupled plasma was used for 250nm depth mesa etching. Then a Gd_2O_3/Ni/Au and Ni/Au was deposited by electron-beam evaporator for gate electrode and anode electrode, respectively. A 300nm Au was deposited for interconnection and probe pads. Finally, a 300nm SiO_2 was deposited using plasma enhance chemical vapor deposition (PECVD) chamber at 200°C for 20 seconds for device passivation layer. Finally, the wafer was subjected into 200 °C N_2-rich oven for 4 hours to walk-out and stress the transistors and better device uniformity can hence be obtained [6]

Experimental Results

A Boost converter, a major component for switch mode power supply, was demonstrated using the integrated MOS-HEMT/circuit rectifier pair as shown in Fig. 2. In this demonstration, a MOS-HEMT (gate length (L_G) = 2 μm, gate-to-source distances (L_{GS}) = 3 μm gate-to-drain distances (L_{GD}) = 16 μm and gate width (W) = 2 mm) and a circuit rectifier (diameter of anode electrode = 400 μm, and the drift length (L_D) = 20 μm) are integrated on AlGaN/GaN heterostructure using the same process. Off-chip components including a capacitor of 47 nF, an inductor of 330 μH and a load resistor of 5 kΩ, were used in this demonstration.

The 2μm length gate Gd_2O_3/Ni/Au was characterized on-wafer for DC performance. The Schottky characteristic of MOS-HEMT was shown in Fig. 3(a). Due to Gd_2O_3 high-k film, the MOS-HEMT exhibited a significant improvement in the gate leakage current with a gate breakdown voltage of 463 V at 1 mA of gate leakage. Fig 3(b) showed the breakdown characteristic of circuit rectifier. The circular rectifier presents a very low turn-on voltage of 0.48 V, low R_{ON} of 4 $\Omega\cdot cm^2$ and a high breakdown voltage (BV) of 418 V. The circular rectifier exhibits significantly lower turn-on voltage and low turn-on resistance than the muti-finger SBDs. The transistor DC characteristic performances MOS-HEMT was shown in Fig. 4. Left side showed the I_{DS} verse the V_{DS}, and the right side was the transfer characteristics. The maximum transconductance ($g_{m,max}$) and maximum drain-to-source current ($I_{DS,max}$) was 50 mS and 283 mA, respectively. The on-resistance (R_{DS_ON}) was 35.2 Ω.

The measured waveforms operating at a switching frequency (f_{sw}) of 0.5 MHz, a duty cycle (D) of 55%, and an input voltage (V_{in}) of 50 V were shown in Fig. 5. An output voltage (V_{out}) of 102 V and a power efficiency of 79.7% were obtained. The contribution from each loss mechanism had been calculated based on the measurement results and was shown in Fig. 6. According to the result, about 54.7% of the total loss comes from the ON-state resistances of MOS-HEMT (R_{DS_ON}) and circuit rectifier (R_{ON}) devices.

Conclusion

In summary, AlGaN/GaN MOS-HEMT and circular rectifier are fabricated successful. The circular rectifier features low turn-on voltage and high reverse BV. The MOS-HEMT also displays high reverse BV, low leakage current and high switching speed. All of these can increase the efficiency of boost converter.

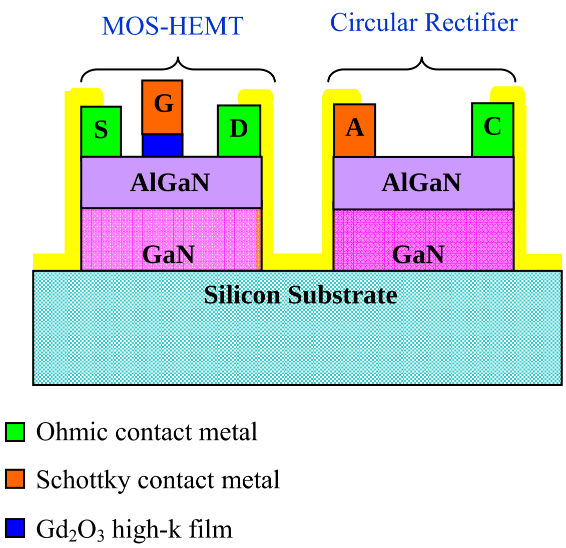

Fig. 1 Schematic cross section of integration of the circular rectifier with a MOS-HEMT for single-chip boost

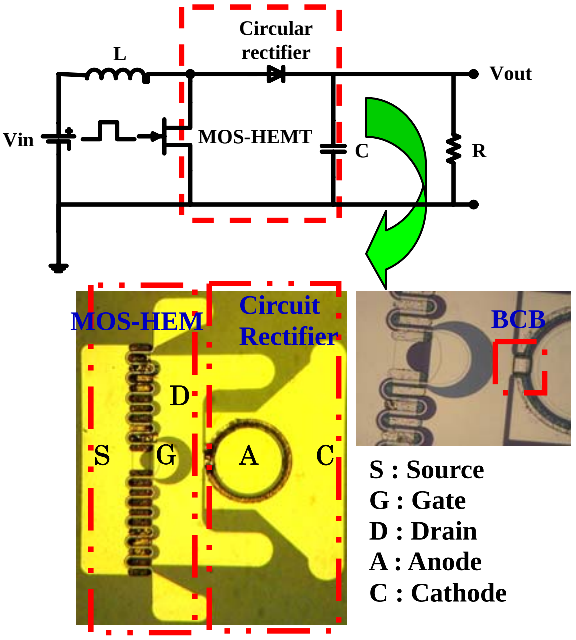

Fig. 2 Demonstrated single chip boost converter where the drain (D) of MOS- HEMT and the anode (A) of circuit Schottky diode sharing the same electrode.

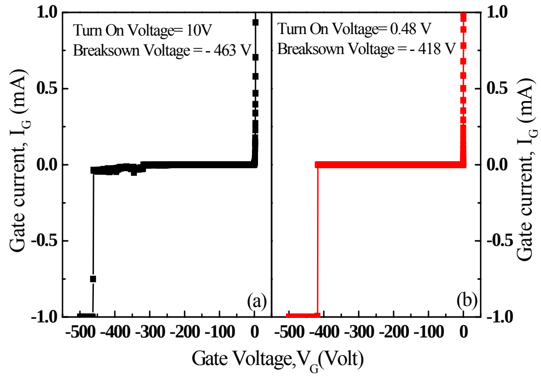

Fig. 3 (a) Schottky characteristics of the MOS-HEMT (b) Output characteristic of circular rectifier. Diameter of anode electrode is 400μm, and the drift length (L_D) is

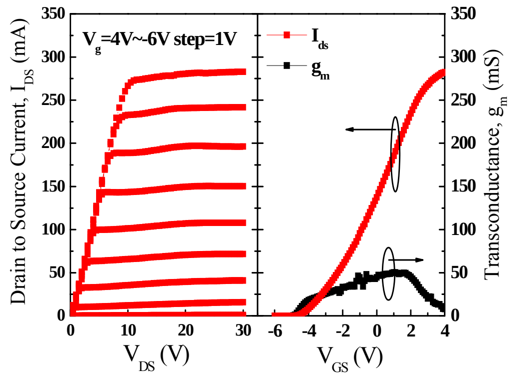

Fig. 4 DC characteristics of the MOS-HEMT with L_{GS} = 3μm, L_G = 2μm, and L_{GD} =16μm. On-state characteristics: (left) I_{DS} vs. V_{DS}, (right) transfer characteristics.

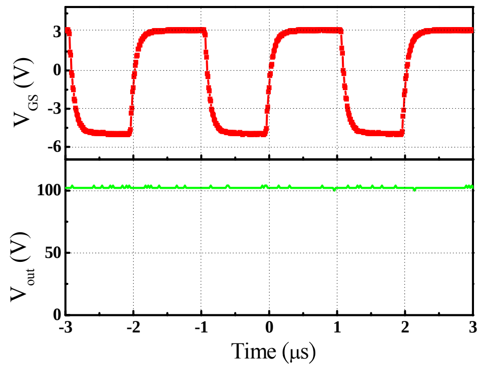

Fig. 5 Measured voltage waveforms of the GaN based Boost converter operating at the switching frequency (f_{sw}) of 0.5 MHz, duty cycle (D) of 55% and input voltage (V_{in}) of 50 V, where, the V_{GS} and V_{out} are gate-source voltage of MOS-HEMT and output voltage, respectively.

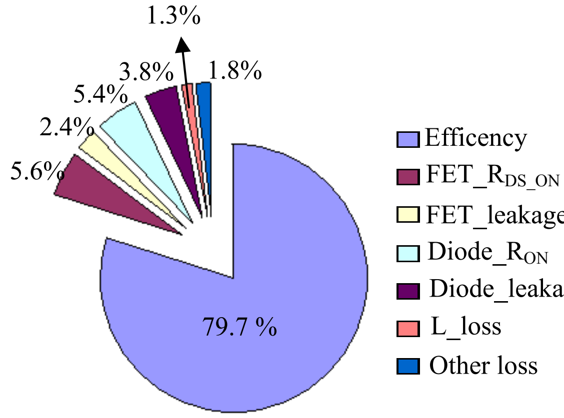

Fig. 6 Power loss analysis of the demonstration with f_{sw} of 0.5 MHz, V_{in} of 50 V, and D of 55%.

References

[1] W. Saito, Y. Takada, M. Kuraguchi, K. Tsuda, I. Omura, T. Ogura, and H. Ohashi, *IEEE Trans. Electron Devices* vol. 50, pp. 2528-2531, Dec., 2003.

[2] Y. Dora, A. Chakraborty, L. McCarthy, S. Keller, S. P. DenBaars, and U. K. Mishra, *IEEE Electron Device Lett.*, vol. 27, no. 9, pp. 713–715, Sep. 2006.

[3] N. Tipirneni, A. Koudymov, V. Adivarahan, J. Yang, G. Simin, and M. Asif Khan, *IEEE Electron Device Lett.*, vol. 27, no. 9, pp. 716–718, Sep. 2006.

[4] W. Chen, K. Y. Wong, and K J. Chen, *IEEE Electron Device Lett.*, vol. 30, no. 5, 2009

[5] W. Chen, K.-Y. Wong, and K. J. Chen, in *IEDM Tech. Dig.*, Dec. 15–17, 2008, pp. 141–144.