エネルギーハーベスティング向けの０Ｖオン電圧を有する高効率ｐ型GaNゲートAlGaN/GaN整流用ダイオード

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Novel p-GaN Gated AlGaN/GaN Diodes with 0 V Turn-on Voltage to Achieve High-efficiency Rectifications for Energy Harvesting Applications

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An AC-DC rectifier was demonstrated with extremely low turn-on voltage by using p-GaN gate AlGaN/GaN high electron mobility transistor in diode configuration. The p-GaN layer thickness is tuned to yield nearly-zero turn-on voltage for the p-GaN gated anode diode. In addition, ohmic p-GaN gate electrode was employed which enables high on-state current which sums the HEMT current and the p-GaN gate to 2DEG channel current. Full-wave rectification was achieved from 0.18V. Furthermore, a novel two-step p-GaN mesa is proposed to further enhance the on-state current without affecting the turn-on voltage.

1.　Research background

The next-generation power rectification circuits require rectifiers with low turn-on voltage, high on-state current, and high conversion efficiency. Up to present, none of the demonstrated semiconductor diodes are able to operate at 0 V turn-on with low power loss. In this report, we demonstrated an AC-DC rectifier with extremely low turn-on voltage by using p-GaN gate AlGaN/GaN high electron mobility transistor (HEMT) in diode configuration. The p-GaN layer thickness is tuned to yield nearly-zero turn-on voltage for the p-GaN gated anode diode. In addition, ohmic p-GaN gate electrode was employed which enables high on-state current which sums the HEMT current and the p-GaN gate to 2DEG channel current. Furthermore, a novel two-step p-GaN mesa is proposed to further enhance the on-state current without affecting the turn-on voltage.

2.　Experiments

Fig. 1 shows three types of the fabricated devices. Based on the 0V Vth p-GaN gate HEMT in our previous work [(1)], p-GaN gated anode diode with 35 nm p-GaN/16 nm $Al_{0.25}Ga_{0.75}N$ (Fig. 1 (a)) was fabricated. Furthermore, four identical p-GaN gated anode diodes were monolithically integrated to form a diode bridge for full-wave rectifications (Fig. 1 (b)). To further enhance the on-state current, a two-step p-mesa is embedded for the p-GaN gated anode diode with 60 nm p-GaN/21 nm $Al_{0.25}Ga_{0.75}N$ epitaxial structure on a SiC substrate (Fig. 1 (c)).

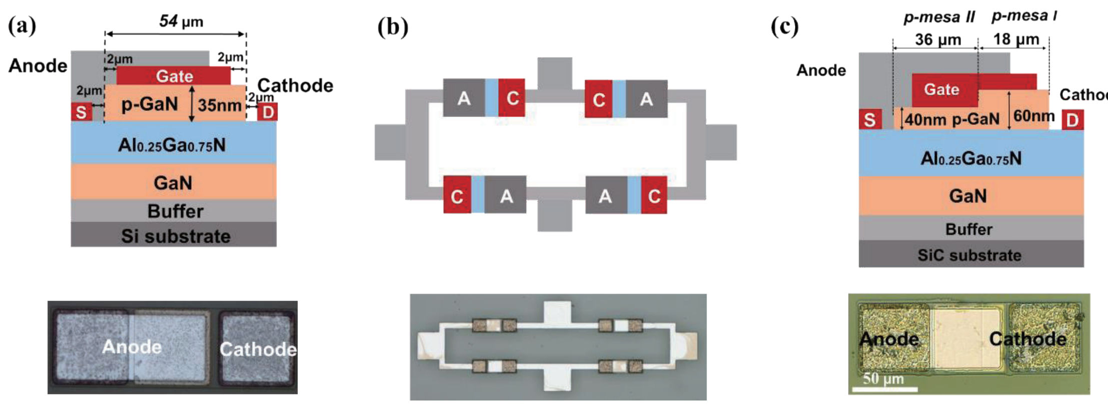

Fig. 1　Schematic device structures for p-GaN gate anode diode **(a)**, p-GaN gate anode diode bridge **(b)**, p-GaN gated anode diode with two-step p-mesa and their corresponding microscopy images.

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3. Results and discussions

Rectification characteristics of the gated anode of with 35 nm thick and 54 μm long p-GaN was demonstrated in Fig. 2. Half-wave rectification was achieved without any signal distortions at an AC input signal of 1.5 V. Thanks to the low turn-on voltage by our p-GaN designs, nearly zero-crossing is clearly observed for the gated anode diode (Fig. 2 (c)), i.e. even close to 0 V AC signal could be rectified which is able to reduce the power loss.

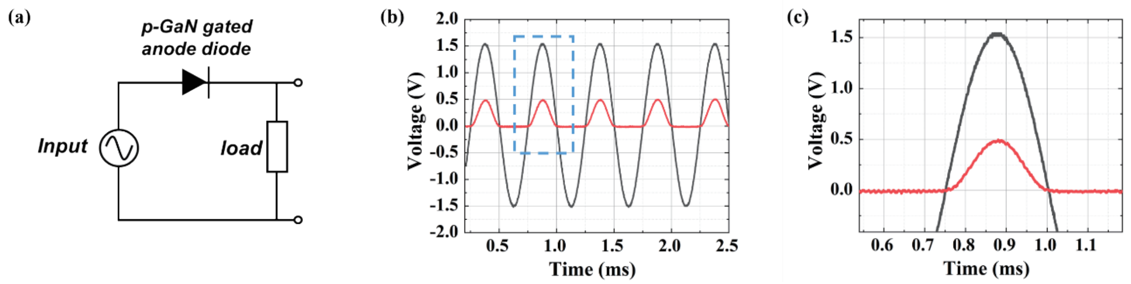

Fig. 2 Testing circuit schematic **(a)** and half-wave rectification operation with a 1.5 V AC input signal for p-GaN gated anode diodes with a Vth of 0.05 V **(b)**. The box in **(b)** is magnified which shows nearly 0 V crossing **(c)**.

Fig. 3 shows rectification characteristics of the diode bridge IC. Full-wave rectification was achieved at an input signal of 1.5 V without any distortion. In particular, the rectifier can operate properly at an input signal of 0.5 V as shown in Fig. 3 (c), which is impossible for the current Si diodes. Furthermore, an input signal as low as 0.18 V can be rectified (not shown here).

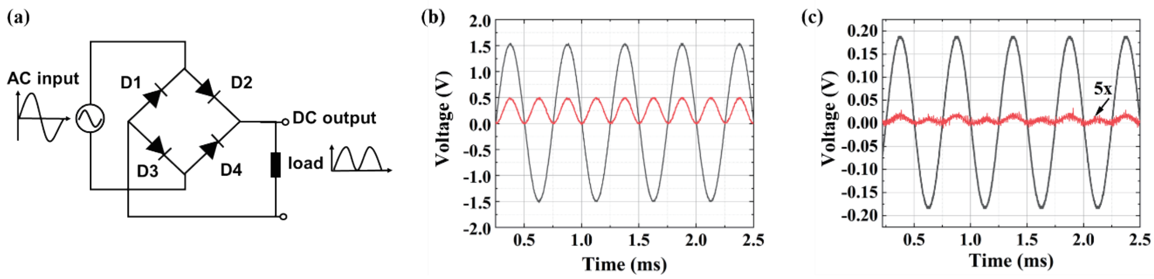

Fig. 3 Diode bridge testing circuit schematic **(a)** and 2 kHz full-wave rectification for the p-GaN gated anode diode bridge with an input signal of 1.5 V **(b)** and 0.18 V **(c)**. The output signal in **(c)** is magnified by 5 times of **(b)**.

Fig. 4 compares the I-V characteristics of the gated anode diodes with and without p-mesa II. The p-mesa II device turns on first due to the electron accumulation under p-mesa II region and a linear increase of current to 90 mA/mm at 3 V, which is significantly offsets the low-current drawback of the conventional long-gate HEMTs. This could result in an undistorted AC-DC rectification even with low input signal, opening up opportunities for future energy harvesting applications.

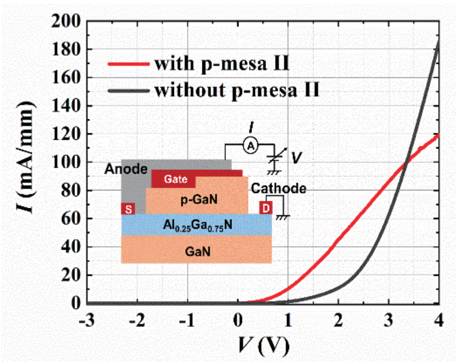

Fig. 4 I-V characteristics of p-GaN gated anode diodes with and without p-mesa II.

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REFERENCE

1) Y. Zhang and N. Iwata, ISPlasma 2021, online, 10aD06.