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288 V-10 V DC- DC Converter Application using AlGaN/GaN HFETs

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Abstract. We report on the 288 V-10 V DC- DC converter circuit using AlGaN/GaN HFETs for the first time. The AlGaN/GaN HFET with a large current and a high breakdown voltage operation was fabricated. That is, the maximum drain current was over 50 A, and the minimum on-resistance was 70 mohm. The breakdown voltage was over 600 V. A DC-DC down-converter from input DC 288 V to output DC 10 V was fabricated using these HFETs. It was confirmed that the switching speed of the AlGaN/GaN HFET was faster than that of Si MOSFET. The DC-DC down-converter was fabricated using these HFETs. This converter was composed of a full bridge circuit using four n-channel AlGaN/GaN HFETs. In the case of AlGaN/GaN HFET, a gate switching wave (Vgs) and source-drain wave (Vds) were abrupt compared with those of using Si MOSFETs. In both cases, a stable and constant output DC 10V was also obtained and the conversion efficiency of the converters with AlGaN/GaN HFETs was 84%.

Introduction

III-V nitrides such as GaN and related materials are very promising for high-power, high-efficiency, and high-temperature conditions compared with SiC and Si [1-3]. A high speed operation of power devices is important for a low-loss power switching application. We have already demonstrated AlGaN/GaN heterojunction field effect transistors (HFETs) with a large current, a high breakdown voltage, and a high switching speed [4-10]. Switching devices such as inverters or converters are required to reduce a power loss and their size are also required to become smaller and smaller. Using AlGaN/GaN HFETs with a low on-state resistance and a high switching speed, low loss power switching applications such as inverters or converters can be realized. There is no report concerning the DC-DC down-converter using AlGaN/GaN HFETs.

In this paper, we report on the DC-DC down-converter from input DC 288 V to output DC 10 V using AlGaN/GaN HFETs for the first time. The DC-DC converter is composed of a full brigde circuit using four AlGaN/GaN HFETs. Using the same DC-DC converter circuit, the performances of the converter were compared by replacing the AlGaN/GaN HFETs and the Si MOSFETs.

Experimental

An $Al_{0.22}Ga_{0.78}N$ (30 nm) /GaN (3000 nm) hetero-structure was grown on the sapphire (0001) c substrate using metal organic chemical vapor deposition (MOCVD) method. A large current operation AlGaN/GaN HFET with a multi-finger structure was fabricated using this hetero-structure. The distance of a gate and drain and the distance of a source and gate of the HFET were 15 micrometers and 3 micrometers, respectively. The gate length was 2 micrometers. The gate width was 240 mm. Ti/AlSi/Mo was used for the ohmic electrode [11, 12]. Ni/Au was used for the gate electrode. The chip size of this HFET was 5x6 mm^2 including electrode pads for the bonding. After the fabrication of the HFET, the electrical properties such as I-V and switching properties were measured. Using AlGaN/GaN HFETs, the DC-DC down-converter was designed. The output conversion efficiencies of the DC-DC down-converter with using AlGaN/GaN HFETs and that with Si MOSFETs were compared.

Results and discussion

We first measured the electrical properties of the AlGaN/GaN HFET. As a result, the maximum drain current (Ids) was over 50 A, and the on-resistance (Ron) was about 70 mohm. The breakdown voltage was over 600 V. The switching time was about 10 ns, shorter than that of Si MOSFET.

We next measured the gate charge (Qg) of the AlGaN/GaN HFET. Figure 1 shows the comparison of the gate charge (Qg), which is one of switching parameters in the cases of a Si MOSFET (SPW20N60C3, Cool MOSFET) and the AlGaN/GaN HFET. The gate charges (Qg) of the AlGaN/GaN HFET was smaller than that of Si MOSFET. Table 1 shows the comparison of Qg, Ron, and RonQg in the case of using several Si MOSFETs (2SK3683, SPW20N60C3, and 2SK2370) and an AlGaN/GaN HFET. The RonQg, which shows a figure of merit of a switching speed of an AlGaN/GaN HFET is smaller than that of Si MOSFETs. That is, it was confirmed that the switching speed of the AlGaN/GaN HFET was faster than those of Si MOSFETs.

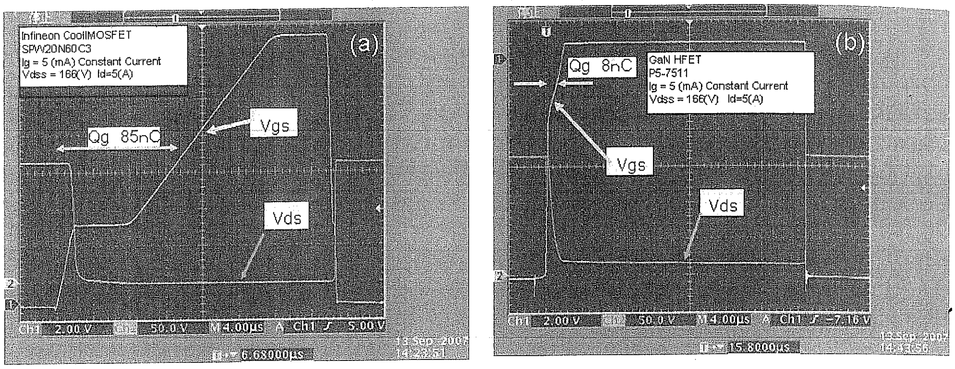

Fig. 1 Comparison of switching properties showing the gate charge (Qg) in the cases of using a Si MOSFET (a) and using an AlGaN/GaN HFET (b).

Table 1 Comparison of Qg, Ron, and RonQg in the case of using several Si MOSFETs and an AlGaN/GaN HFET.

	Qg(nC) @Vds=330V	Ron (ohm)	RonQg (ohmnC)
GaN HFET	12.5	0.07	0.875
2SK3683	34	0.29	13.92
SPW20N60C3	85	0.20	17.5
2SK2370	65	0.30	19.5

Using these HFETs, a DC-DC down-converter from input DC 288 V to output DC 10 V was designed and fabricated. Figure 2 shows a block diagram of the converter circuit. This DC-DC converter is composed of a full-bridge circuit using four n-channel FETs. In this circuit, the input voltage can be changed in the range from DC 350 V to DC 250 V and the output voltage can be converted in the range from DC 30 V to DC 10 V. The operation of this down-converter was first confirmed using Si MOSFETs. As a result, the input DC voltage in the range from DC 350 V to DC 200 V was successfully converted in the range from DC 30 V to DC 10 V. In the case of using AlGaN/GaN HFETs, it was also confirmed that an input voltage of 288 V was converted to DC 10

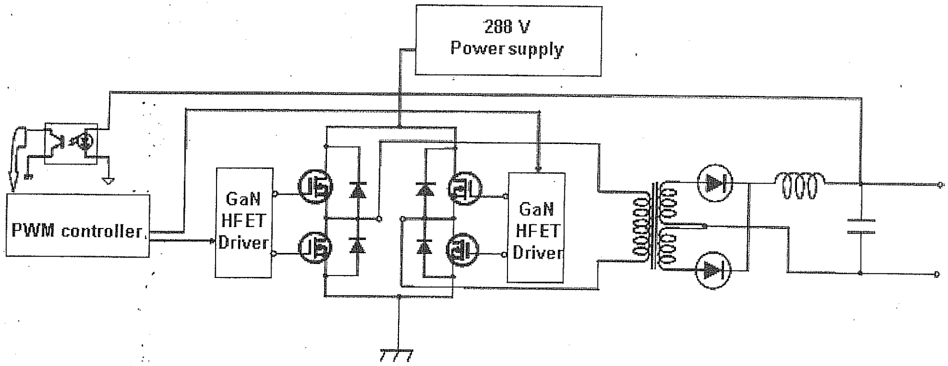

Fig. 2 Block diagram of 288 V-10 V DC- DC converter using AlGaN/GaN HFETs.

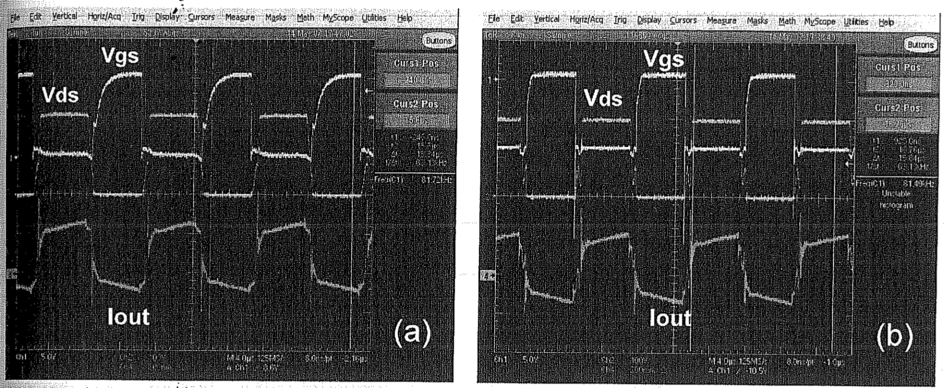

Fig. 3 Comparison of switching waves at the full bridge circuit using Si power MOSFETs and GaN HFETs.

V. However, the output conversion efficiency was lowered, since the current collapse of the HFET became large. Therefore, below the condition of the input DC 250V which the current collapse is negligible; the DC-DC converter properties of AlGaN/GaN HFETs were compared with those of using Si MOSFETs. That is, using the same circuit, the properties such as input waves of voltage and current, and output conversion efficiency in the case of using AlGaN/GaN HFETs and Si super-junction MOSFETs (2SK2370) were compared.

Figure 3 shows the input waves of a pulsed current and voltage before passing the transformer as shown in the block diagram of Fig. 2. The rising form of gate-source voltage (Vgs) in the case of using AlGaN/GaN/HFETs was sharper than that of using Si MOSFETs. Input waves of current are noisy at 80 KHz in both cases. After conversion to DC 10 V, this output was stable and constant.

Figure 4 shows the comparison of the output conversion efficiencies in the case of using the Si super-junction MOSFETs (a) and using the AlGaN/GaN HFETs (b). The output conversion efficiency was about 84% above 60 W. This value was a slightly lower value compared with that (86%) of using the Si super-junction MOSFETs. In this time, the current collapse of the AlGaN/GaN HFET slightly occurred. The maximum conversion efficiency of this circuit was also estimated to be about 90% on a simulation. In order to realize a high efficiency, the current collapse of HFET has to be moreover suppressed.

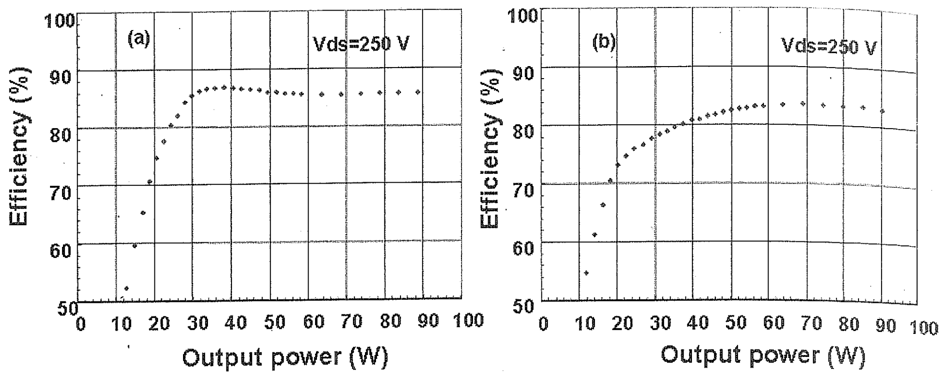

Fig. 4 Comparison of the output conversion efficiencies in the case of using Si super-junction MOSFETs(a) and using AlGaN/GaN HFETs (b)

Summary

A DC- DC down-converter circuit using AlGaN/GaN HFETs was demonstrated for the first time. The AlGaN/GaN HFET with a large current and a high breakdown voltage operation was fabricated. That is, the maximum drain current was over 50 A, and the minimum on-resistance was 70 mohm. The breakdown voltage was over 600 V. It was confirmed that the switching speed of the AlGaN/GaN HFET was faster than that of Si MOSFET. The DC-DC down-converter for input DC 288 V to output DC 10 V was fabricated using these HFETs. This converter was composed of a full bridge circuit using four n-channel AlGaN/GaN HFETs. In the case of AlGaN/GaN HFET, a gate switching wave (Vgs) and source-drain wave (Vds) were abrupt compared with those of using Si MOSFETs. In both cases, a stable and constant DC 10V was also obtained. The efficiency was 84% or so above the output power of 60 W. The efficiency of the converter using AlGaN/GaN HFET can be furthermore improved by suppressing the current collapse.

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