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Development of AlGaN/GaN power HFET for the application of an inverter circuit

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GaN based power semiconductor devices are expected to have excellent performances as well as SiC compared with conventional Si devices. GaN based field effect transistor (FET) can operate under high-power, high-frequency, and high-temperature conditions, since GaN has excellent figure of merits for these purposes. Especially, the specific on-state resistance (Ron) of the FET can be lower than that of Si based FET. That is, using GaN based electronic devices a power loss of switching devices such as inverters or converters can be reduced compared with that of using conventional Si devices, resulting in the reduction of cooling system. It is also expected that a higher switching speed, a high frequency operation, and a high efficiency operation can be realized by using GaN based FET. In this paper, we report on the AlGaN/GaN HFET with a very lower on-state resistance and application of an inverter circuit using AlGaN/GaN HFETs.

A heterostructure of an undoped $Al_{0.2}Ga_{0.8}N$ (30nm) / GaN (2000nm) / GaN buffer (50nm) / sapphire substrate was grown using a gas-source molecular beam epitaxy [1-3]. The sheet carrier density was $1.0\times10^{13}cm^{-2}$ and the mobility of a two dimensional gas (2DEG) was about $1200cm^2/Vs$ at room temperature. The maximum sheet resistance of an undoped GaN was about $100M\Omega/cm^2$. The FET structure was formed using a dry-etching technique. A highly Si-doped GaN contact layers of the source and drain with a carrier concentration of $2\times10^{19}cm^{-3}$ was selectively grown in the window area of the mask in order to obtain a very low contact resistance. The contact resistivity of $1\times10^{-7}\Omega cm^2$ was reproducibly obtained. The gate width was 20cm and the gate length was 2μm. The distance of source and drain was 13μm. The electrode materials of the source and the drain were Al/Ti/Au and Schottky electrodes were Pt/Au. The chip size was $0.25cm^2$ and active layer area was $0.15cm^2$. We also confirmed that the breakdown voltage of Schottky property was about 600V and that the AlGaN/GaN HFET was operated at a current of over 10A [3] and the on-state resistance of an active area of the FET except for pads area was $5m\Omega cm^2$ at 370V as shown in Fig. 1. Figure 2 shows that the on-state resistance of the HFET is lower than that of a conventional Si-based FET. Recently, it is reported that the on-state resistance superjunction metal oxide semiconductor (SJ-MOS) FET was lower than that of a conventional MOSFET as shown in Fig. 2 [4,5].

Furthermore, a switching time of AlGaN/GaN HFET was investigated. As a result, a turn-on time was 10ns and turn-off time was 11ns.These values were lower than those of a conventional Si MOSFET. The maximum operation

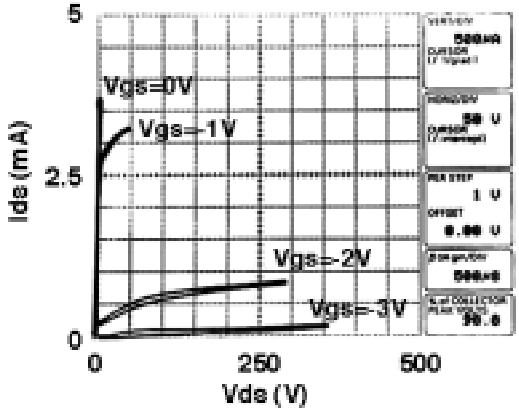

Fig. 1 Current-voltage property of an AlGaN/GaN HFET.

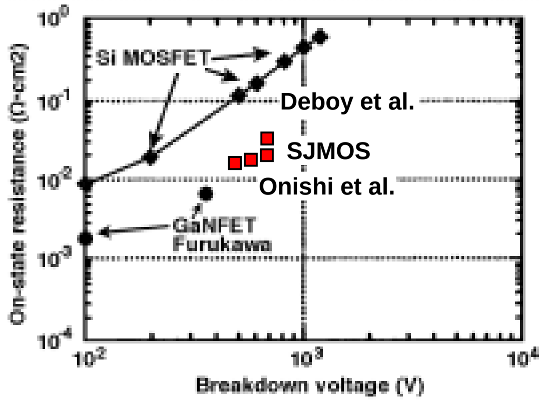

Fig. 2 Comparison of the on-state resistance between Si and GaN based FET.

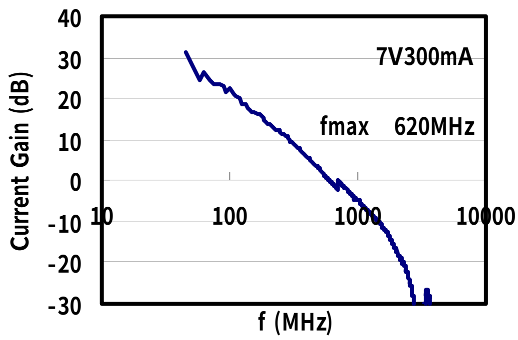

Fig. 3 Frequency property of a large current operation AlGaN/GaN HFET.

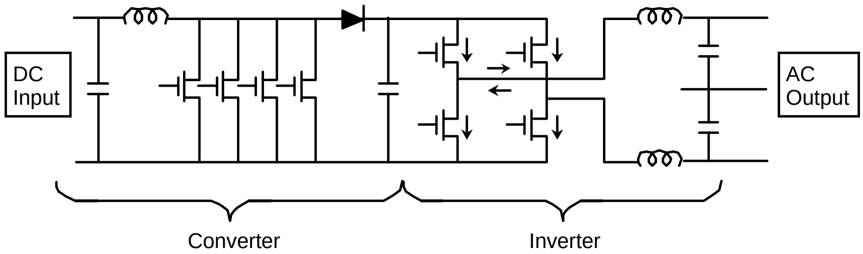

Fig. 4 Schematic inverter circuit using AlGaN/GaN HFETs.

frequency of an AlGaN/GaN HFET was 0.62GHz as shown in Fig. 3 and the threshold frequency was 0.50GHz. The gate-source capacitance was 120pF. Based on these results, it was confirmed that the AlGaN/GaN HFET could be operated at the conditions of a lower on-state resistance and a higher switching speed. We also investigated the application of an inverter circuit using AlGaN/GaN HFETs. The AlGaN/GaN HFET is a normally-on FET. The normally-off state of FET is necessary for switching operation. The normally-off state was realized by microcomputer control. This inverter was composed of DC converter and AC inverter using these HFETs, respectively as shown in Fig. 4. Figure 5 shows the photograph of an inverter circuit using AlGaN/GaN HFET. Using this inverter, DC 30V was converted to AC 100V. The output power was typically 50W and the maximum power was 200W. It was thus demonstrated that an inverter circuit using AlGaN/GaN HFETs was operated.

Finally, the possibility of a normally-off FET is discussed, since a normally-off FET is required for switching devices such as inverters or converters. We tried to fabricate the normally-off FET using an undoped $Al_{0.3}Ga_{0.7}N$ (25nm) / AlN (10nm) / p-GaN structure on Si substrate. Figure 6 shows the I-V characteristic of a normally-off FET. In this case, the n-type contact layers were not fabricated. When the gate-bias was 0V, Ids was almost 0mA. When the gate bias was increased, Ids was also increased. The breakdown voltage of the FET was about 80V. It was thus demonstrated for the first time that the normally-off FET was operated using a GaN based FET. Furthermore, by forming a contact layer of source and drain, the operation current of FET is expected to increase. This GaN based normally-off FET is very promising for a very low loss and a high efficiency switching devices.

In summary, we fabricated AlGaN/GaN HFETs for an inverter with a low power loss and a higher switching speed. The on-state resistance of AlGaN/GaN HFET was $5m\Omega cm^2$ at 370V and a switching time was about 10ns. AlGaN/GaN HFETs were applied for an inverter circuit and AC 100V was obtained. The maximum output power was 200W. The inverter performance will be moreover improved by improving the performance of GaN based FET.

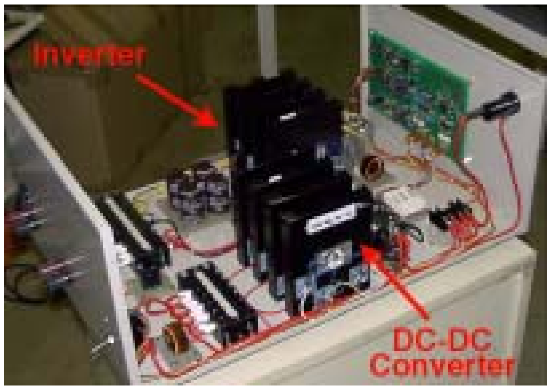

Fig. 5 Overview of an inverter circuit using AlGaN/GaN HFETs.

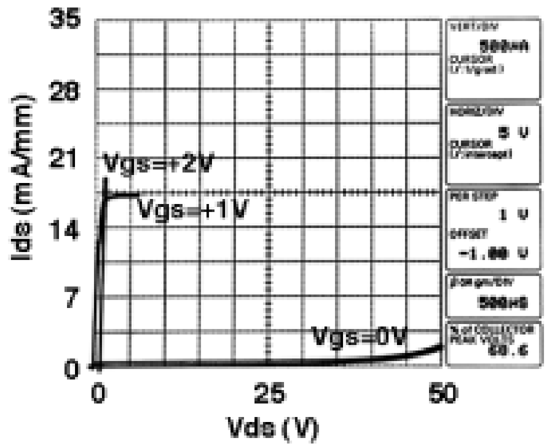

Fig. 6 I-V property of a GaN based normally-off FET.

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