Extended Abstracts of the 2016 International Conference on Solid State Devices and Materials, Tsukuba, 2016, pp561-562

N-2-01(Invited)

GaN-based Polarized Semiconductor Devices for Future Power Switching Systems

Hidetoshi Ishida, Ryo Kajitani, Yusuke Kinoshita, Hidekazu Umeda, Shinji Ujita,
Masahiro Ogawa, Kenichiro Tanaka, Satoshi Tamura, Masahiro Ishida and Tetsuzo Ueda

Panasonic Corporation.
3-1-1 Yagumo-Nakamachi Moriguchi, Osaka 570-8501, Japan
Phone: +81-6906-0485 E-mail: ishida.hi@jp.panasonic.com

Abstract

GaN-based Gate Injection Transistors (GITs) with p-type gate on AlGaN/GaN hetero structure are promising power devices with lower on-state resistance and smaller capacitance for power switching applications. In this paper, the current status of the GITs with normally-off operation is reviewed, after the basic technologies to realize GaN-based GITs are summarized. In addition, the methodology to increase switching frequency is described. The effects of improvement of electrical power conversion systems such as DC/DC converters by using GITs with short gate length are also examined.

1. Introduction

GaN-based materials are very promising semiconductors for power switching devices taking advantages of the superior material properties such as higher breakdown field and higher sheet carrier density of two dimensional electron gas (2DEG) at hetero interface between AlGaN/GaN. Although higher sheet carrier density of 2DEG is attractive to decrease channel resistance of GaN-based transistors, normally-off operation of the transistors is difficult. Thus much effort has been devoted to achieve GaN-based transistors with normally-off operation together with decreasing channel resistance and increasing breakdown voltage. GaN-based Gate Injection Transistor (GIT) with p-type gate on AlGaN/GaN hetero structure is a solution to overcome them.

In this paper, the current status of the GITs is reviewed after describing material aspects of GaN-based semiconductors to achieve higher sheet carrier density of 2DEG and higher breakdown voltage. The demonstrated performances of the GITs with the breakdown voltage of 600V are superior to those of Si-based power devices such as IGBTs and MOSFETs. Moreover, GITs with shorter gate length to reduce RonQg are also described to extend the application field of GITs. These GITs can be used to reduce the system size with keeping high conversion efficiency of electrical power conversion systems such as DC/DC converters.

2. GaN-based Gate Injection Transistor on Si substrate

Thick GaN layer can be grown on Si substrate with buffer layer in which the mismatch of lattice constant and thermal expansion coefficient between GaN and Si are relaxed [1]. Fig.1 shows a photograph of epitaxial wafer of GaN on Si substrate and the structure of buffer layer. The wafer size is 6 inch and can be increased up to 8 inch.

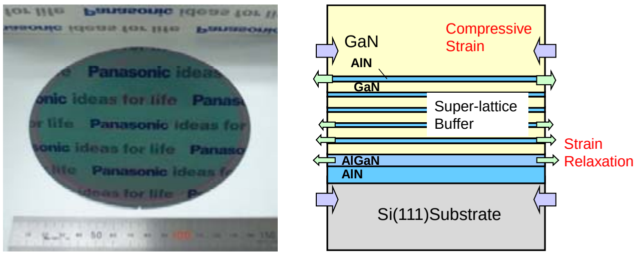

Fig. 1 Photograph of epitaxally grown AlGaN/GaN hetero structure on Si substrate and schematic structure of buffer layer.

A unique feature of the nitride semiconductor is a large amount of 2DEG induced at heterojunction such as AlGaN/GaN without any intentional doping. Although InAlN/GaN-based HFETs have been researched in which higher sheet carrier density of 2DEG owing to larger spontaneous polarization can be realized [2], more sheet carrier can be induced by introducing piezoelectric polarization additionally as shown in Fig.2. The hetero structure of InAlGaN/GaN has been applied to access region of GIT to decrease on-state resistance [3].

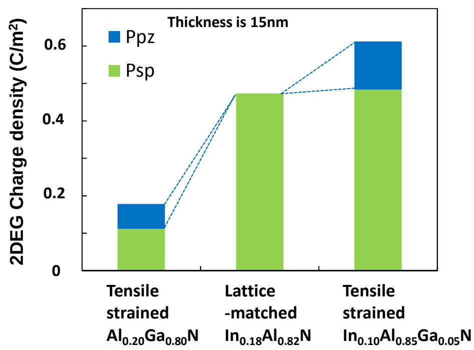

Fig. 2 Comparison of induced charge density of 2DEG for AlGaN/GaN, InAlN/GaN and InAlGaN/GaN.

Breakdown mechanism of GaN-based devices has been researched because it seems to be different from that of Si-based devices. The breakdown voltage can be increased by increasing electrode distance as shown in Fig.3. This characteristic is partially explained by the model that depleted single GaN layer acts as superjunction because the polarization charge density on front side of GaN layer is the same as that on back side [4]. In the actual devices, vertical breakdown as well as lateral breakdown is appropriately designed.

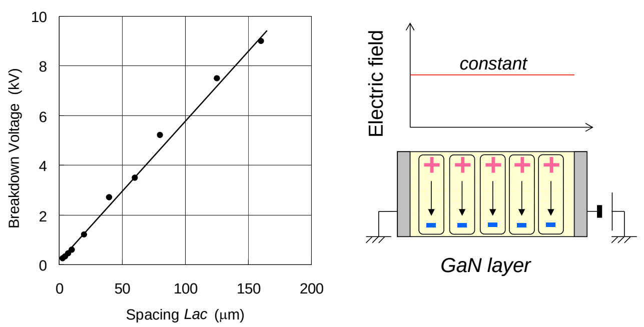

Fig. 3 The model of a single layer of GaN in which the polarization charges on front and back side are canceled.

A schematic cross section of GIT and its band diagram are shown in Fig.4 [5]. The p-type gate effectively depletes a large amount of sheet charges of 2DEG at the interface of AlGaN/GaN. Channel resistance can be reduced by applying gate voltage due to hole injection from the gate electrode, which is confirmed by Electro Luminescence (EL) characteristics [6]. The fabricated GIT with the breakdown voltage of 600 V shows 10 times less on-state resistance and several times less RonQg, which is attractive performance as compared to those of Si-based power devices.

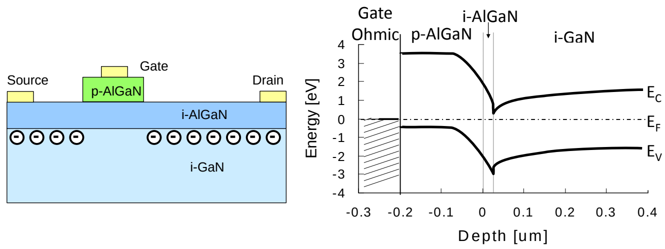

Fig. 4 A schematic cross section and operating principle of GIT.

3. Application to power switching systems

Reducing RonQg of GIT for higher power switching is important to extend the application field of GITs. The gate length of GIT has been reduced down to 0.5 μm as shown in Fig.5. The access distances of Lgd and Lgs are also decreased. The obtained RonQg is as low as 19 mΩnC. In addition, drain current can be increased by shortening the gate length. The breakdown voltage is around 30 V [7].

The fabricated GITs with short gate length have been applied to DC/DC converter module. Fig.6 shows frequency dependence of conversion efficiency of the module as a function of operation current. The module shows the conversion efficiency of 90 % at 2 MHz. The operation current can be increased up to 50A.

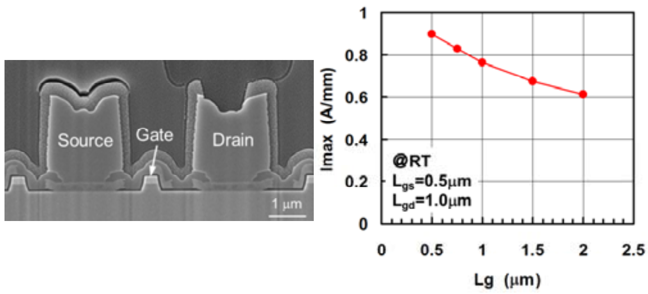

Fig. 5 SEM cross section of GIT with gate length (Lg) of 0.5 μm and Ids dependence on Lg.

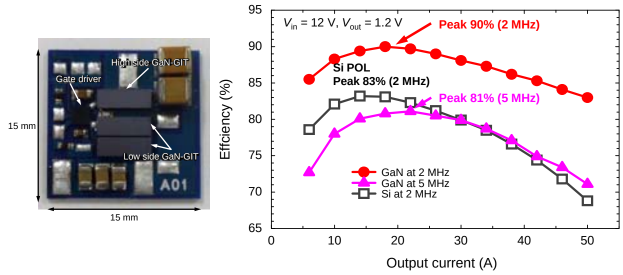

Fig.6 Photograph of DC/DC converter module and the frequency dependence of measured efficiency as a function of operation current.

4. Conclusions

Normally-off GITs on Si substrates together with the basic technologies supporting them are described. Shortening gate length is effective to reduce RonQg down to 19 mΩnC which serves switching operation at higher frequency for shrinking system size. These GITs are very promising for future power switching systems.

Acknowledgements

The authors would like to gratefully acknowledge Managing Director Eiji Fujii, Director Minoru Kume and General Manager Tsuguyasu Hatsuda, Panasonic, for their sincere encouragement. They express sincere gratitude to Prof. Daisuke Ueda of Kyoto Institute of Technology for his valuable discussions. This work was partially supported by the New Energy and Industrial Technology Development Organization (NEDO), Japan, under the Strategic Development of Energy Saving Innovative Technology Development Project.

References

[1] D.Ueda *et al.*, *IEEE IEDM2005*, 377.
[2] J.Kuzmic *et al.*, IEEE Electron Device Letters, **22**(2001), 510.
[3] R.Kajitani *et al.*, Jpn. J. Appl. Phys. **54** (2015) 04DF09.
[4] H.Ishida *et al.*, IEEE Electron Device Letters, **29**(2008), 1087.
[5] Y.Uemoto *et al.*, IEEE Trans. Electron Device, **54**(2007),3393.
[6] M.Menighini *et. al.*, Appl. Phys. Lett. **97**(2010), 033506.
[7] H.Umeda *et.al.*, *PCIM Europe 2014*, 45.