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The Characteristics of Light-Emitting HEMT with Single Quantum Well Inserted

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Abstract

In this study, a light-emitting HEMT (LE-HEMT) with a single quantum well inserted is fabricated and analyzed. The light-emitting occurs from the radiative recombination of electrons in the 2DEG and holes from the p-GaN layer confined in the quantum well. From the experiment, the light-emitting wavelength is shifted from 365 nm in the UV range to 550 nm in the visible range when the quantum well is inserted. LE-HEMT has potential applications such as optical integrated circuits, visible/invisible light communication, and other optoelectronic technologies.

1. Introduction

In the path decade, GaN-based material has been widely used for the light-emitting applications that benefit from the wide range of spectra from UV to visible. Quantum well structure consisted of InGaN/GaN layers is a well-known and mature approach to realize visible light emission. Furthermore, GaN-based devices like high-electron mobility transistors (HEMTs) are also used as switching devices in power and integrated circuits. In order to improve the reliability, switching speed, and reduce the power loss, the monolithic integration of LED-HEMT structure via selective area growth or selective epi removal have been proposed and demonstrated [1], [2]. Recently, we demonstrated the AlGaN/GaN HEMTs structure that has a built-in light emitter called light-emitting HEMT (LE-HEMT) by using radiative recombination of holes from p-GaN and electrons from 2DEG [3], [4]. The function of luminescence and switching can be combined in a single device. Furthermore, through the study of modifying the structure of the channel layer, we found that the major recombination location is under the AlGaN barrier layer [5]. Thus, in this study, a single quantum well consisting of GaN/InGaN/GaN layers inserted in a standard p-GaN/AlGaN/GaN HEMT epi structure is demonstrated and characterized. The electrical and optical characteristics are compared to the standard structure without quantum well.

2. Device Structure and Experiment Details

There are two different GaN-on-Si epi structures used in this study which were grown by MOCVD. One is the standard (STD) epi of p-GaN/AlGaN/GaN heterostructure. The other one has a single quantum well (QW) consisting of a 3 nm

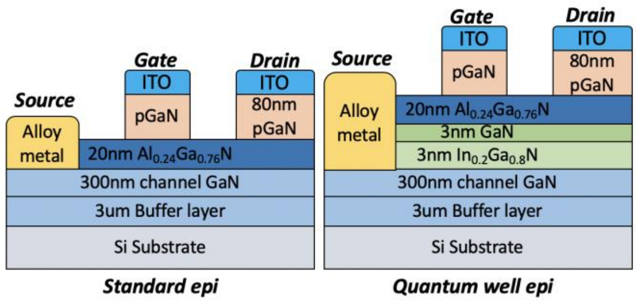

Fig. 1. Schematic cross-section view of LE-HEMTs fabricated on two different epi structures.

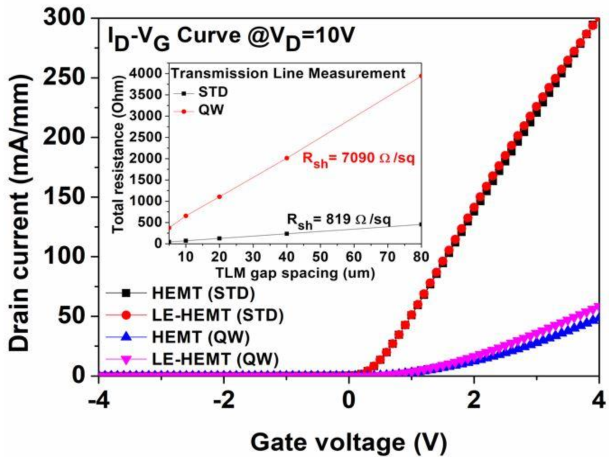

Fig. 2. The I_D–V_G curves of the HEMT/LE-HEMT fabricated on two different epi structures. The sheet resistances extracted via TLM measurement is shown in the inset.

$In_{0.2}Ga_{0.8}N$ layer inserted and underneath the AlGaN barrier layer in the standard epi structure. The same process was conducted on two epi structures.

After the solvent clean, the device isolation was done by the oxygen implantation. A 225-nm ITO was deposited on top of the p-GaN layer via the sputtering. After the gate and drain region defined via the lithography, the ITO was etched by the ITO etchant. Subsequently, selective etching was conducted via ICP-RIE to remove the p-GaN layer. Ti/Al/Ti/Au (25/125/45/55 nm) was used as the source ohmic contact, followed by rapid thermal annealing in nitrogen at 850°C for 30 seconds. Finally, a 30-nm Al_2O_3 was used as the passivation layer. The gate width and the gate length for the device used in this study were 50 μm and 3 μm, respectively, with $L_{gd} = L_{gs} = 5$ μm. Fig. 1 shows the schematic cross-section view of LE-HEMTs fabricated on these two different epi structures.

3. Results and Discussion

A typical p-GaN gate HEMT is created using the same process flow on the same chip, without retaining the p-GaN layer at the drain side is also fabricated and compared with the LE-HEMT. The I_D–V_G curves of HEMT/LE-HEMT fabricated on two epi structures are shown in Fig. 2. The sheet resistance of 2DEG can be extracted via a transmission-line-method structure shown in the inset. It can be shown that the sheet resistance of 2DEG of QW epi is much higher than the STD epi, thus, reducing the drain current. It may be due to non-optimized epi structure and growth. The characteristics of electrical and optical would be improved after improving the process of growth and the epi structure. Fig. 3 shows I_D–V_D characteristics of LE-HEMTs fabricated on two epi structures. The offset voltage around 3 V for both structures is attributed to the built-in voltage between p-GaN and 2DEG. Fig. 4 shows the image of the lighting of LE-HEMTs taken by an optical microscope camera. Under a CCD camera, the brightest spot is at the edge of the drain side for both epi structures. QW epi structure shows the non-uniform lighting pattern, which also indicated some issues of growth condition. Fig. 5 shows the EL intensity of the two epi structures measured by a micro-spectrometer with an optical fiber. The main wavelength peak of STD epi is located at 365 nm which in the UV range. On the other hand, the QW structure has a main wavelength peak of around 550 nm with a satellite peak of 365 nm.

4. Conclusions

In summary, a p-GaN gate HEMT with built-in light emitter were fabricated on two different epi structures. The light emitting occurs from the radiative recombination of electrons in the 2DEG and holes from the p-GaN layer. The brightest location is at the edge of the drain side for both epi structure. Furthermore, it is demonstrated that the wavelength peak can be shifted to visible via insertion of a single quantum well in a LE-HEMT.

Acknowledgements

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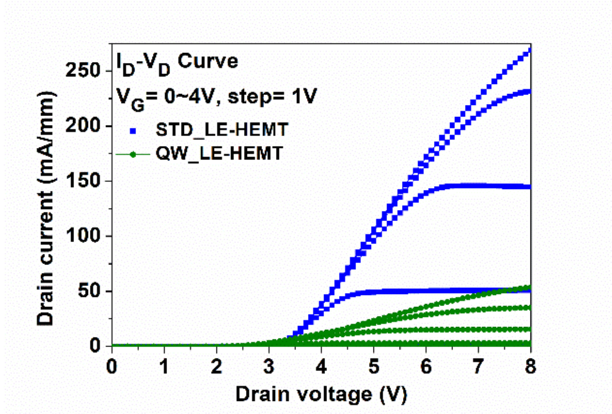

Fig. 3. The I_D–V_D curves of the LE-HEMT fabricated on two different epi structures.

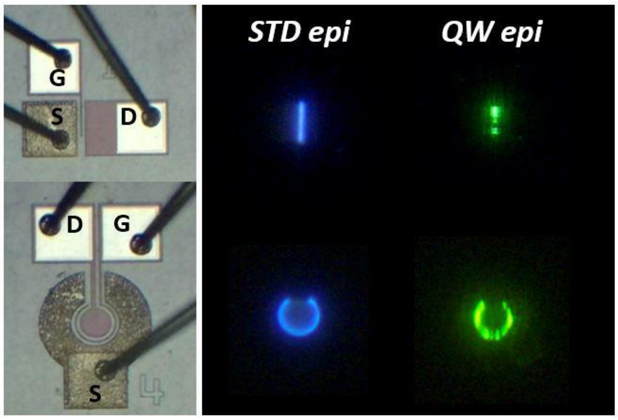

Fig. 4. Image of LE-HEMT in the off-state under illumination (left) and in the on-state emitting light in the dark (right).

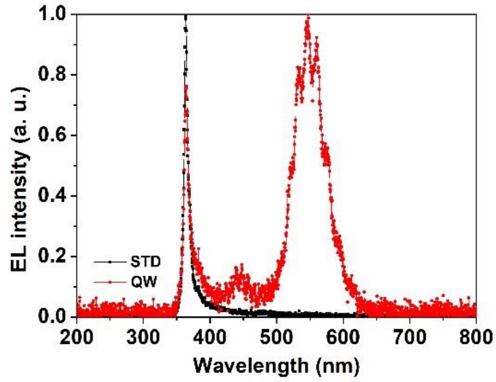

Fig. 5. Electroluminescence spectrum of LE-HEMT fabricated on two epi structures.

References

[1] Y. Cai, Y. Gong, J. Bai, X. Yu, C. Zhu, V. Esendag, K. B. Lee, and T. Wang, *IEEE Photonics Journal*, vol. 10, no. 5, 2018.

[2] Z. Li, J. Waldron, S. Chowdhury, L. Zhao, T. Detchprohm, C. Wetzel, R. F. Karlicek, and T. P. Chow, *Phys. Status Solidi A*, vol. 212, no. 5, pp. 1110–1115, 2015.

[3] C. –Y. Chang, Y. –C. Li, and C. –F. Huang, *in International Conference on Solid State Devices and Materials*, 2018.

[4] C. –Y. Chang, Y. –C. Li, K. Ren, Y. C. Liang, and C. –F. Huang, *IEEE J. Electron Devices Soc.*, vol. 8, pp. 346–349, 2020.

[5] C. –Y. Chang, J. –L. Wu, and C. –F. Huang, *in 9th Asia-Pacific Workshop on Widegap Semiconductors*, 2019.