Extended Abstracts of the 2004 International Conference on Solid State Devices and Materials, Tokyo, 2004, pp. 546-547

P6-3

Performance of AlGaN/GaN Heterostrucrure FETs Over Temperatures

Chien-Chi Lee, Cheng-Feng Shih, Chien-Ping Lee, Ru-Chin Tu[1], Chang-Cheng Chuo[1] and Jim Chi[1]
Department of Electronics Engineering, National Chiao Tung University
1001 Ta-Hsueh Road, Hsinchu, Taiwan, 30050, R.O.C
Phone: +886-3-571-2121, ext 54240 Fax: +886-3-572-4361 E-mail:chienchilee.ee88g@nctu.edu.tw
[1]Opto-Electronics & Systems Laboratories, Industrial Technology Research Institute
195 Sec. 4, Chung Hsing Road, Hsinchu, 310, Taiwan, R.O.C.

I. Introduction

GaN-based heterostructure field effect transistors (HFETs) are promising candidates for high temperature and high power device applications at high frequencies due to their superior material properties [1]. For such operations, the stability of devices over temperature is extremely important. In addition to the commonly known problem in the thermal conductivity of substrates [2], the device structure plays a crucial role in realizing GaN-based HFETs for high temperature application. So far various device structures, such as the undoped structure [3], the modulation-doped structure [4] and the channel-doped structure [5], have been used to realize high performance GaN-based HFETs. Apparently devices with different structures may exhibit different electrical behaviors at high temperature due to their different transport properties. It is therefore desirable to understand which structure has better device performance at high temperature. In this work, a comparison on the high temperature performance of the undoped and modulation-doped AlGaN/GaN HFETs is reported. The results obtained indicate that device structure has a significant influence on the device high temperature performance. The modulation-doped devices, with a higher electron concentration, comparable mobility and lower parasitic source resistance at high temperatures, exhibited better dc and RF performance than the undoped devices over temperatures.

II. Experiment

Two structures, one undoped structure and one modulation-doped structure, were grown by metalorganic chemical vapor deposition (MOCVD) on c-plane sapphire substrates. The undoped structure consists of a 3 μm undoped GaN buffer layer and a 28 nm undoped AlGaN layer. The modulation-doped structure consists of a 3 μm undoped GaN buffer layer, a 3 nm undoped AlGaN spacer, a 20 nm Si-doped AlGaN with a doping concentration of 5×10^{18} cm^{-3} and a 5 nm undoped AlGaN cap layer. The Al composition is 0.3 for all AlGaN layers. After layer growth, mesa patterns for device active regions were defined by photolithography. Excellent ohmic contacts using contact metal, Ti/Al/Ti/Au (200/1500/450/550 Å) were obtained after the samples were annealed at 750°C for 30 s in N_2 gas ambient. Contact resistances of 0.59 ohm-mm for the undoped devices and of 0.38 ohm-mm for the modulation doped devices were obtained. The source-drain spacing is 2 μm for all samples. T-shaped gates using Ni/Au (20/300 nm) were then formed to complete the FET fabrication.

At room temperature, the Hall measurement results showed that the undoped structure had an electron concentration of 1×10^{13} cm^{-2} and a mobility of 1100 cm^2/Vs. The modulation-doped structure had an electron concentration of 1.23×10^{13} cm^{-2} and a mobility of 953 cm^2/Vs. The sheet electron concentration for the undoped structure was independent of temperature even when the temperature was raised to 500K. For the modulation doped structure, however, the sheet carrier density increased to 1.33×10^{13} cm^{-2} at 500K. The electron mobility decreased at high temperatures. At 500K the values were 537 cm^2/Vs and 529 cm^2/Vs for the undoped structure and the modulation doped structure, respectively.

III. Result and discussion

Devices with a gate dimension of 0.15 μm (gate length) by 75 μm (width) were used for this study. Both devices showed good dc performance over the whole measured temperature range. The threshold voltages at room temperature were around –7 V and –9 V for the undoped and the modulation doped devices. Figure 1 shows the comparison of the temperature dependence of the maximum drain current at a gate bias V_{gs}= 2 V. The undoped device showed the maximum drain current of 700 mA/mm at room temperature. At 200°C it reduced to 567 mA/mm. The modulation-doped device exhibited a larger maximum drain current. At room temperature, it was of 1040 mA/mm and at 200°C it became 678 mA/mm. The larger change in the maximum drain current for the modulation-doped device can be attributed to the temperature dependent sheet carrier density.

Figure 2 shows the comparison of the maximum extrinsic transconductances measured at a drain bias V_{ds}= 5 V for both devices over temperature. In general, the modulation-doped devices had a higher transconductance than the undoped devices. But the undoped device had a smaller change in transconductance over temperature. For the modulation doped structure, the transconductance changed from 198 mS/mm at room temperature to 125 mS/mm at 200°C. For the undoped device, the transconductances ranged from 113 mS/mm to 86 mS/mm over the temperatures. The lower transconductance is due to the large source resistance, which was 3.4 ohm-mm, of the undoped channel in the undoped device. For the modulation-doped device it was 2.67 ohm-mm.

Figure 3 shows the comparison of the temperature dependence of the current gain cut-off frequency (f_T) for both devices. The undoped device was operated at V_{ds}= 6 V and V_{gs}= -3.5 V. The modulation-doped device was operated at V_{ds}= 6 V and V_{gs}= -6 V. For the undoped device,

the cut-off frequency was 32 GHz at room temperature, but degraded to 22 GHz at 200°C. The modulation-doped device had a room temperature f_T of 75 GHz and did not show obvious degradation until 100°C. Above 100°C, the cut-off frequency became lower and dropped to 52 GHz at 200°C. As a whole, both devices did not show obvious degradation for temperatures below 100°C. Similar results were also observed in the doped channel AlGaN/GaN HFETs [5]. The main reason is the weak temperature dependence of electron transport property [6-7]. The lower cut-off frequency for the undoped device is mainly attributed to the larger parasitic source and drain resistances.

Based on the Hall measurement results, the undoped device had a constant two-dimensional electron gas (2DEG) concentration in the channel over a wide temperature range. The modulation-doped device had a higher electron concentration but it increased with temperature, due to the thermal activation of Si donors in the AlGaN layer [8]. Although lower electron mobility was observed in the modulation doped devices due to the additional ionized impurity scattering associated with the Si donors, the electron mobilities for both devices are similar at high temperatures where phonon scattering is the dominant scattering process [9]. Because of the additional doping, the modulation-doped devices has lower parasitic source and drain resistances than the undoped devices over temperatures. Putting all these factors together, we may conclude that the modulation-doped devices are superior to the undoped devices over the temperatures studied. The stability (the temperature dependence of device performance), however, is not as good as the undoped devices.

IV. Conclusion

We have compared the performance of the undoped and modulation-doped AlGaN/GaN HFETs over temperatures. The results obtained indicate that the device structure has a great influence on the device performance. The modulation-doped devices are superior to the undoped devices over the temperatures studied. The stability (the temperature dependence of device performance), however, is not as good as the undoped devices.

Acknowledgements

This work was supported by the National Science Council under contract No. 91-2215-E-009-017.

References

[1] L. F. Eastman *et al.*, IEEE spectrum, **May**, 28, 2002.
[2] R. Gaska *et al.*, IEDM Tech. Dig. 1997, 565
[3] L. F. Eastman *et al.*, IEEE Trans. Electron Devices, **48**, 479, 2001.
[4] M. Akita *et al.*, IEEE Electron Device Lett., **22**, 376, 2001.
[5] Q. Chen *et al.*, Electron Lett., **33**, 637, 1997.
[6] N. S. Mansour *et al.*, J. Appl. Phys., **77**, 2834, 1995.
[7] U. V. Bhapkar *et al.*, J. Appl. Phys., **82**, 1649, 1997.
[8] C. C. Lee *et al.*, to be published in Jpn. J. Appl. Phys.
[9] N. Maeda *et al.*, Appl. Phys. Lett., **79**, 1634, 2000.

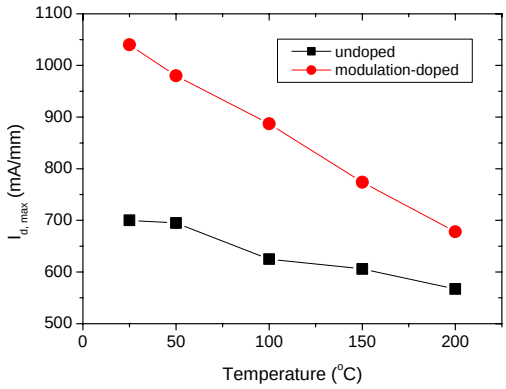

Fig. 1 Temperature dependence of the maximum drain current of the undoped and modulation-doped devices.

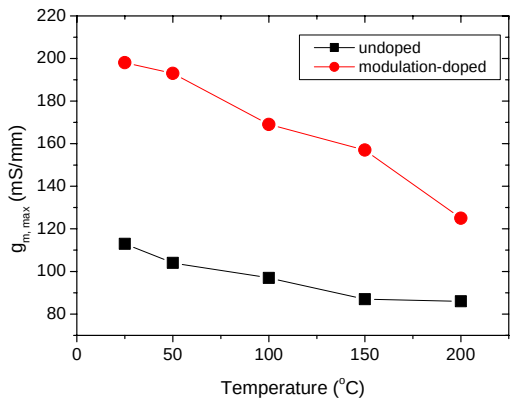

Fig. 2 Temperature dependence of the maximum extrinsic transconductance of the undoped and modulation-doped devices.

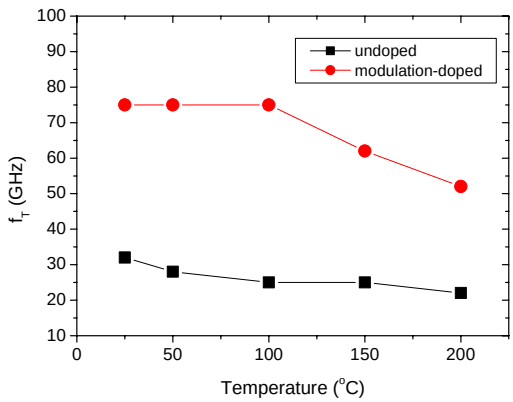

Fig. 3 Temperature dependence of current gain cut-off frequency of the undoped and modulation-doped devices.