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The low-k BCB passivation layer on the GaN HEMTs

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1. Introduction

High performance AlGaN/GaN HEMTs on Sapphire or SiC substrates have been successfully applied to microwave power device applications. This is due to the excellent characteristics of GaN, namely a wide bandgap (3.4eV), a high breakdown filed (2×10^6 V/cm), and a high saturation velocity (2.2×10^7 cm/s). Additionally, the induced 2DEG in the interface of the AlGaN/GaN can reach about $1\text{x}10^{13}$ cm^{-2} sheet concentration, which is almost 5 times larger than the case in AlGaAs/GaAs HEMTs [1-2]. Because of the polarization effect, the passivation issue is very important for the GaN HEMTs [3]. In this study, we proposed and fabricated the low-k BCB as the passivation layer on GaN HEMTs, which demonstrate better rf performance, good pulse I-V and rf power characteristics of device performance.

2. Device fabrication, DC and pulse I-V performance

The MOCVD-grown AlGaN/GaN HEMTs consists of the sapphire substrate, a 3.3 µm undoped GaN buffer layer, a 30 nm undoped $Al_{0.25}Ga_{0.75}N$ Schottky layer, and a 5 nm GaN (5×10^{18} n-doped) cap layer. The electron sheet charge density and mobility of this structure were 9×10^{12} cm^{-2} and 1400 cm^2/Vs, respectively. Drain and Source ohmic contacts were formed by using the Ti/Al/Ni/Au and annealed at 850°C. The mesa etching was done by using the Ar/Cl_2 mixture plasma, and the gate recess etching was carried out by using the characterized $Ar/Cl_2/CH_4/O_2$ mixture plasma to own high etching selectivity and low surface damage advantages[4]. The 0.4 µm T-shaped gate with Ni/Au metals was deposited directly on the recessed area without any post-etching annealing. Finally, the device was spun by coating a 400 nm low-k BCB (ε_r = 2.7) as a passivation layer, for comparison the device with a PECVD Si_3N_4 film passivation was also fabricated.

The device I-V and transfer characteristics comparisons at drain-to-source voltage of 7 V are showed in the Fig.1(a) and (b). The maximum transconductance (g_m) and current density (I_{ds}) for these two kinds devices were 179 mS/mm and 838 mA/mm for the BCB passivated device and 176 mS/mm and 860 mA/mm for Si_3N_4 passivated device, respectively. Both of them demonstrate good pinch-off characteristics and the threshold voltages (V_{th}) was -4.6 V. In order to confirm the surface state of the GaN HEMTs has been stabilized by depositing the passivation layer, the pulse I-V measurement was carried out to observe whether the dispersion effect appearance or not [3]. The Fig.2 demonstrates the pulse I-V comparison of these two kinds devices with various pulse width of gate. These devices were biased at a V_{ds} of 20 V, and the high level and low level of the applied gate pulse voltage were 0V and -8V, respectively. After measuring the I_{ds} versus the gate pulse width, the I_{ds} of these two devices are decreased by increasing pulse width. This observation illustrates that the dispersion was not observed in these devices, which will result in the opposite current change versus the pulse width. It therefore indicates that both BCB and Si_3N_4 material are suitable for the passivation application on GaN HEMTs. Additionally, the self-heating effect of these devices can also be observed in the Fig.2, where this effect is more profound by increaseing the pulse width resulting in an I_{ds} reduction.

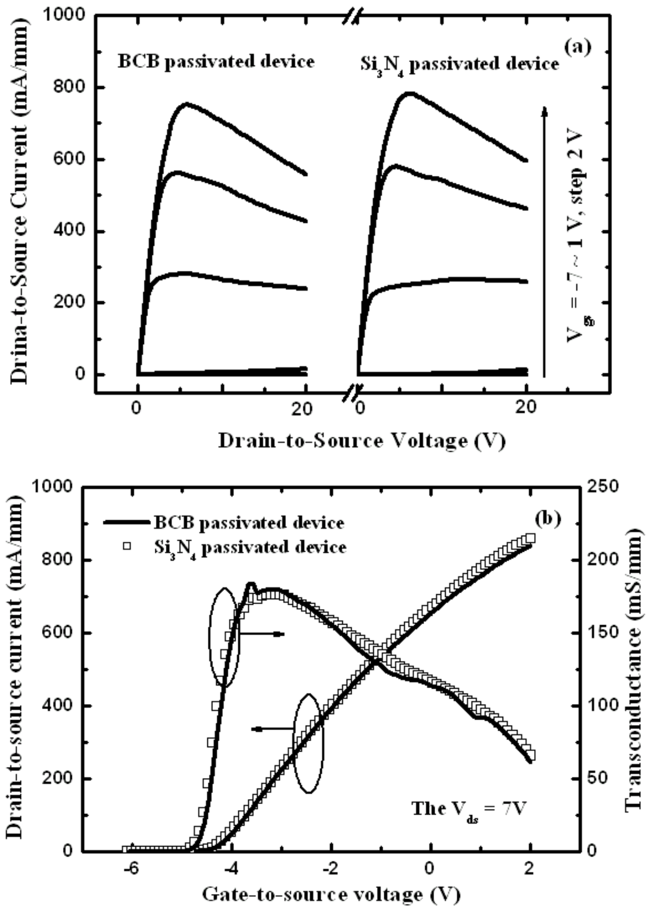

Fig. 1 The I-V characteristics of BCB and Si_3N_4 passivated devices (a), and the transconduction characteristics of BCB and Si_3N_4 passivated devices (b).

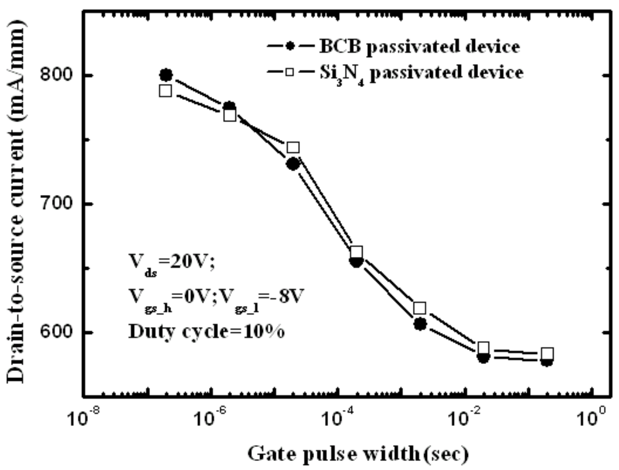

Fig. 2 The pulse I-V of BCB and Si_3N_4 passivated devices.

3. Device rf and power performance

The advantage of the BCB passivation layer is its low dielectric constant(2.6 F/m), and this parameter is very important for the high speed electronic device especially on the rf performance. After measuring the Yang-Long, Cold FET, and S-parameters of these two devices, the equivalent circuit models could be extracted by the matrix transformation[5]. The small-signal parameters comparisons of these two devices are summarized in the Table.1. Because of the low-k characteristics, the device passivated by BCB own lower parasitic capacitances. Therefore, the C_{gs}, C_{gd}, and C_{ds} of the BCB passivated device are lower than these in the Si_3N_4 passivated device, resulting that BCB passivated device achieves higher f_T and f_{max}. From the Fig.3, because of BCB passivated device presenting a higher f_{max}, the power gain and power added efficiency performance are better in the lower input power region. The maximum output power densities at 2.4 GHz of these two devices are 2.3 W/mm for the BCB passivated device and 2.5 W/mm for the Si_3N_4 passivated device, respectively.

4. Conclusions

A low-k material, BCB has been used as a passivation layer on GaN HEMTs successfully. The pulse-I-V measurement demonstrates that the surface state can be stabilized well by this approach. Moreover, this device shows better rf performance than the Si_3N_4 passivated device because of its lower dielectric constant.

Acknowledgements

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Table.1The small signal parameters of these two devices

Parameter	BCB passivation	Si_3N_4 passivation
C_{gs} (fF)	87.3	104
C_{gd} (fF)	22.4	27.8
C_{ds} (fF)	4.4	4.9
R_{ds} (Ω)	1029	1030
R_i (Ω)	36.5	34.7
g_m (mS)	20	19.5
τ (psec)	4.05	4.7
f_T (GHz)	32	28
f_{max} (GHz)	48	42

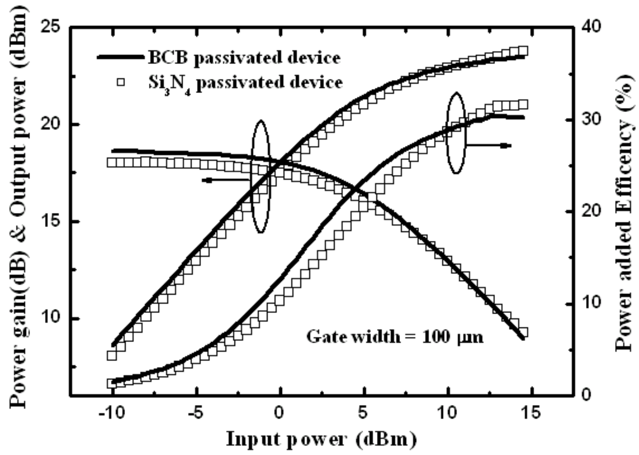

Fig. 3 The power performance comparison at 2.4 GHz of BCB and Si_3N_4 passivated devices.

References

[1] Y. F. Wu, D. Kapolnek, J. P. Ibbetson, P. Parikh, B. P. Keller, and U. K. Mishra, "Very-high power density AlGaN/GaN HEMTs", *IEEE Trans. Electron Devices*, vol. 48, pp. 586–590, Mar. 2001.

[2] S. T. Sheppard, K. Doverspike, W. L. Pribble, S. T. Allen, and J. W. Palmour, "High power microwave GaN/AlGaN HEMTs on silicon carbide", *IEEE Electron Device Lett.*, vol. 20, pp. 161–163, Apr. 1999.

[3] L. Shen, R. Coffie, D. Buttari, S. Heikman, A. Chakraborty, A. Chini, S. Keller, S. P. DenBaars, U. K. Mishra, "High-power polarization-engineered GaN/AlGaN/GaN HEMTs without surface passivetion", *IEEE Electronics Lett*, vol. 25, pp. 7-9, 2004.

[4] W. K Wang., Y. J Li., C. K. Lin, Y. J. Chan, G. T Chen., and J. I. Chyi "Low damage, Cl_2-based gate recess etching for 0.3μm gate-length AlGaN/GaN HEMT fabrication", *IEEE Electron Device Lett.*, vol. 25, pp. 52–54, 2004.

[5] G. Dambrine, A.Cappy, F. Heliodore, E. Playez, "A new method for determining the FET small-signal equivalent circuit", *IEEE Trans. Microwave Theory and Techniques*, vol. 36, pp. 1151-1159, 1988.