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Observation of Thermal Reliability of BCB Passivated InAlAs/InGaAs HEMTs

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1. Introduction

InP-based HEMTs have emerged as promising candidates for ultra-high speed applications [1]. For practical system applications, the question of reliability and degradation is imperative. Extensive works have been done on the reliability of GaAs- and InP-based HEMTs. [2-3]. Recently, the performance improvement of benzocyclobutene (BCB) passivated GaAs pHEMT has been reported, demonstrating the advantages of its low dielectric permittivity and a low loss tangent of BCB [4]. But, up to date, there has been no report on the reliability study on BCB passivated InP-based HEMTs to our knowledge. In this work, the photosensitive-BCB layer was applied to InAlAs/InGaAs HEMTs for passivation and their thermal reliability under thermal stress was investigated and compared with the SiN_x- and polyimide-passivated devices by DC, RF and power characterization for the first time.

2. Device Structure and Fabrication

The designed HEMT layer structure, lattice matched to InP substrate, is as follows from the substrate; 80Å/20Å i-InAlAs/i-InGaAs super-lattice layers (×10), a 2500Å i-InAlAs buffer layer, a 250Å i-InGaAs channel layer, a 30Å i-InAlAs spacer layer, a δ-doped (4×10^{12} cm^{-2}) layer, a 200Å i-InAlAs barrier layer, a 100Å n^+ (5×10^{18} cm^{-3})-InGaAs cap layer. For device fabrication, the mesa was defined by wet chemical etching. For ohmic contacts, AuGe/Ni/Au were evaporated and alloyed by rapid thermal annealing giving a contact resistance of 0.085Ω·mm. The thickness of Ni layer was optimized to minimize the resistance variation during thermal stress. The conventional succinic acid:H_2O_2 solution was used for mesa-sidewall and gate recess etching. The Schottky gate was formed by evaporation of Ti/Au metal. The fabricated unpassivated-HEMTs with a 1.2µm gate-length showed good pinch-off characteristics with V_p of -0.6V and a maximum DC-transconductance g_m of 398 mS/mm as shown in Fig. 1. The peak f_T and f_{max} measured at V_{ds}=2.5V, estimated from -20dB/decade extrapolation, were 25.7GHz and 53.1GHz, respectively. For fair comparison, the devices having I_d and g_m variations within 5% were chosen and passivated by SiN_x (SiN-HEMT), polyimide (PI-HEMT) and BCB (BCB-HEMT). A 90nm SiN_x was deposited with SiH_4/NH_3/He gas mixtures using an RPCVD for the SiN-HEMT. For the PI- and BCB-HEMT, the polyimide and photosensitive-BCB were spin coated and cured at 200°C during 30 min in nitrogen atmosphere, respectively.

3. Reliability Test and Discussion

The devices were first characterized prior to thermal stressing, and during thermal stressing at 200°C for a period of 100 hrs. The devices were not biased and were exposed to air in a closed oven during thermal stress. As shown in Fig. 1, g_m was reduced by 5.6% in the BCB-HEMT and that of PI-HEMT was reduced by 4.5% after passivation. Compared to the PI- and BCB-HEMT, the significant g_m degradation in the SiN-HEMT (25%) at a high V_{gs} was observed due to the surface property modification by the inherent CVD RF damage [5]. In all cases, some degradation of I_{ds} and g_m were observed after passivation due to the increase of access resistance as shown in Fig. 3. The g_m variation during thermal stress is shown in Fig. 2. The g_m degradation of the SiN-HEMT was recovered by stabilization bake as reported in Ref. [2], whereas the PI-HEMT showed most severe degradation. The BCB-HEMT showed most stable DC characteristics during thermal stress. In order to investigate the effect on thermal stability, parameter extraction was performed and analyzed based on the measured S-parameters. As shown in Fig. 3, the variation of increased ohmic resistance in the BCB-HEMT is minimal due to the low moisture uptake- and low barrier oxidation-characteristics of BCB. The gate-to-source capacitance (C_{gs}) has opposite characteristics to that of access resistance. The C_{gs} of the BCB-, SiN- and PI-HEMT decreased by 10%, 48% and 22% after 100 hrs' thermal stress, respectively. Relatively large variation of C_{gs} in the SiN-HEMT was observed after long-term test. The variation of C_{gs} related to the high frequency performance is minimal in the BCB-HEMT, due to the minimal variation of access resistance. Cutoff frequencies of the devices were also characterized to determine the impact on the microwave performance as shown in Fig. 4. The f_T of devices showed a similar behavior to that of g_m during thermal stress according to its relation to g_m. The f_{max} of the PI-HEMT is dramatically degraded after thermal stress, so polyimide is thought to be inadequate for

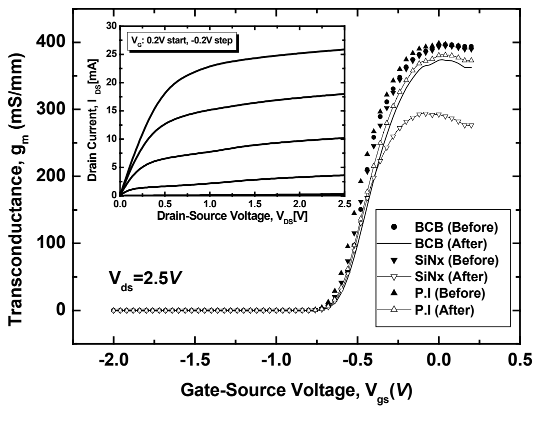

Fig. 1. Variation of DC-transconductance (g_m) before and after passivation. The inset shows the *I-V* characteristics of unpassivated-HEMT.

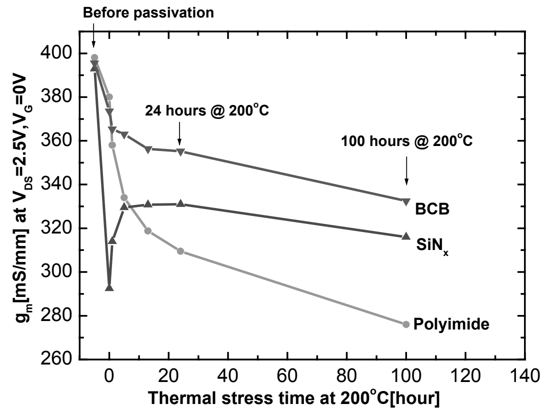

Fig. 2. g_m variation during thermal stress.

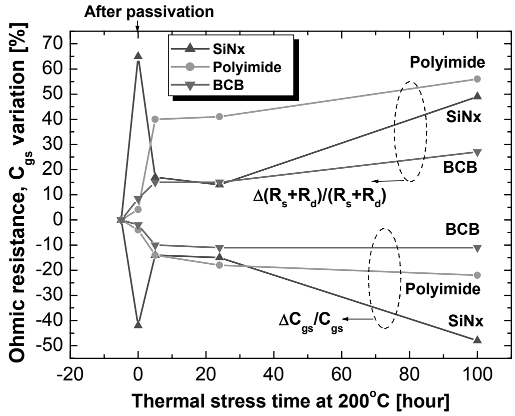

Fig. 3. Variation of access resistance and gate-to-source capacitance (C_{gs}).

passivation of InAlAs/InGaAs HEMT. In early test period, the BCB- and SiN-HEMT, having suppressed leakage path, showed enhanced f_{max} values resulting from the increased output resistance of r_{ds} by 33% and 43% for 24 hrs' test, respectively. After thermal stress of 100 hrs, degradation of f_{max} was observed for both devices and it was affected by g_m rather than r_{ds}. The microwave power characteristics were measured at 1.8 GHz with a drain bias of 2V, and devices were biased at a class A (V_{gs}= –0.2V). Fig. 5 shows the output power and power gain (P_{gain}) versus the input power after passivation and after 100 hrs' thermal stress. After passivation, the power performance of the SiN-HEMT was more degraded than that of unpassivated-device due to the significant g_m degradation associated with the surface damages. The 1dB gain compression point (G_{1dB}) of 9.4 dB for the BCB-HEMT was almost the same as that of the PI-HEMT after passivation. The G_{1dB} of the BCB- and PI-HEMT were reduced to 5.3 dB and 4.2 dB after 100 hrs' thermal stress, respectively. With a minimum variation of power performance, the BCB-HEMT showed higher P_{gain} and power-added-efficiency (PAE) than the SiN- and PI-HEMT after 100 hrs' reliability test.

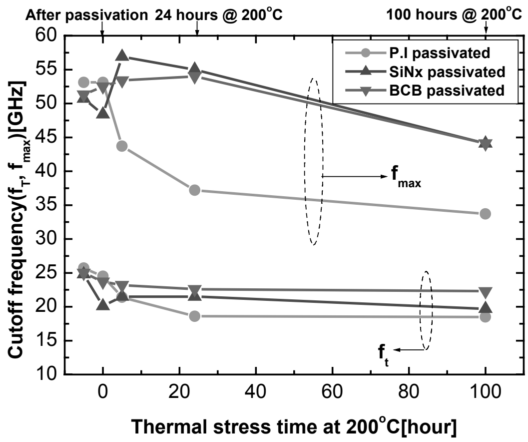

Fig. 4. Cutoff-frequency variation during thermal stress.

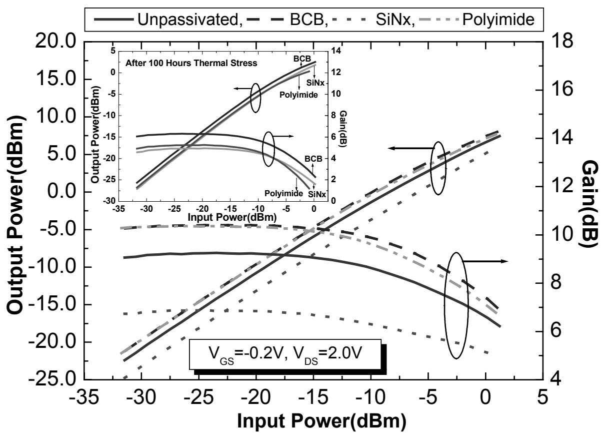

Fig. 5. Power characteristics of the fabricated HEMTs. The inset shows the power performance after 100 hrs' thermal test.

4. Conclusions

In conclusion, InAlAs/InGaAs HEMTs passivated by different dielectric layers were fabricated and their performances were investigated prior to thermal stress and during thermal stress through DC, RF and large-signal power measurements. The BCB-passivated HEMTs show good device characteristics during the reliability test. The BCB-passivated HEMTs, also, have distinct advantages of much simpler fabrication process and reduced surface damages together with good thermal stability, sufficient for attractive alternative to the conventional SiN_x passivation technique.

Acknowledgements

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