Ammonia (NH_3) Plasma Surface Passivation of InP/InGaAs Heterojunction Bipolar Transistors

Hong Wang*, Geok Ing Ng, Hong Yang and K. Radhakrishnan

Microelectronics Centre, School of Electrical and Electronics Engineering,
Nanyang Technological University, Singapore 639798, Republic of Singapore
*Corresponding author, Tel: (65)790 4234, Fax: (65)793318, e-mail: EWANGHONG@NTU.EDU.SG

InP/InGaAs heterojunction bipolar transistors (HBTs) have shown great potential for high frequency and high speed applications. Passivation and protection of the exposed junction surfaces is one of the most important issues for practical applications. Different dielectric materials such as SiN_X, SiO_2 and polyimide (PI) have been used for passivation. However, it has been found that, the covering of InP HBTs using these dielectrical layers normally cause the degradation of the device performance. Recently, Driad *et al.* [1] reported that InP/InGaAs HBTs could also be passivated by *ex situ* sulfur $(NH_4)_2S$ treatment which has been widely used for GaAs-based HBTs. In the past, electron cyclotron resonance hydrogen (H) and nitrogen (N) plasma treatments were demonstrated for the passivation of GaAs HBTs with a thermal stability up to 300°C [2]. In this study, we report on the first experimental results of ammonia (NH_3) plasma surface passivation of InP/InGaAs HBTs. The plasma treatment is found to reduce the surface recombination and improve the current gain. The passivation mechanism is believed to be similar to that of H and N plasma treatment for GaAs HBTs.

The InP HBTs used in this study were grown by gas-source molecular beam epitaxy (GSMBE) on semi-insulating (100) InP substrates. Si and Be were used as the n- and p-type dopants, respectively. Mesa-type devices were fabricated using optical lithography and selective wet etching [3]. The passivation study was carried out in a PLASMATHERM 790 PECVD processing chamber with a background pressure of 1×10^{-6} Torr. During the processes, the sample temperature was kept at 35°C,and the RF power was set at 40 W. The flow rates of NH_3 and N_2 were fixed at 20 and 600 sccm, respectively. The I-V characteristics of the HBTs were measured using a HP4156B semiconductor parameter analyzer.

Fig.1 compares the typical common-emitter I-V characteristics of an InP HBT before and after NH_3 plasma treatment. The base currents for the two measurements were the same, which was set at 10 μA/step. It can be seen from the figure that the collector currents were significantly increased with improved output conductance after 20 min treatment [1].

Fig.2 shows the variation of the current gain as a function of collector current density (J_C) for an HBT with a 5×20 μm^2 emitter before and after plasma treatments. A significant improvement of current gain can be observed. Notice that the improvement of current gain for the device is similar to that obtained by the sulfur treatment.

To study the effect of process time of NH_3 plasma surface passivation on the device electric characteristics, Gummel plots of an HBT (5×20 μm^2 emitter) for different process times are plotted in Fig.3. Comparing the Gummel plots, the collector currents are almost identical indicating that the I_C is not affected by the plasma process. The improvement of current gain is mainly due to the decrease of the base leakage current. The longer the plasma treatment time, the lower the base current at low collector current level. We believe that the improved base leakage current of the NH_3 plasma passivated HBT is attributed to the modification of the surface properties which leads to reduce the surface recombination. This is similar to that observed on the GaAs HBTs. The suppression of the surface recombination can also be supported by the reduction of the base ideality factor from ~1.7 for the as fabricated device to ~1.1 for the device after 20 min treatment.

Fig.4 demonstrates that the current gain of the HBTs after NH_3 plasma passivation show little dependence on the perimeter-to-area (P/A) ratio of the emitter junction. In contrast, the devices before NH_3 plasma treatment exhibit a significant dependence on the emitter size and layout.

It should be pointed out that the effectiveness of the NH_3 plasma passivation could be affected by the process temperature. A large increase in the base current and thus decrease in the current gain were observed when the process temperature was higher than 70°C. This could be due to the preferential etching of phosphorous. Moreover, it is found that the devices with long time plasma treatment normally exhibit higher base-emitter (B-E) and base-collector (B-C) junction leakage currents under the reverse bias. This is similar to the observations made on the devices after UV-ozone or oxygen plasma treatments [4]. This can be attributed to the plasma induced surface damages during the passivation process. Optimization of the NH_3 plasma passivation process to improve the current without inducing the additional junction reverse bias leakage is particularly important.

In summary, NH_3 plasma passivation of InP/InGaAs HBTs has been investigated. The reduced surface recombination and improved current gain are demonstrated. The passivation mechanism is believed to be similar to that of H and N plasma treatment for GaAs HBTs. Optimization of the NH_3 plasma passivation process to avoid plasma induced surface damages is particularly important to realize high performance devices.

References:

[1] R. Driad *et al.*, Appl. Phys. Lett., vol.73, pp.665-667, 1998.
[2] Q. Wang *et al*., IEEE Electron Device Lett., vol.13, pp.83-85, 1992.
[3] H. Wang *et al*., 11th International Conference on Indium Phosphide and Related Materials (IPRM99), pp. 447-450, Davos, Switzerland, May 1999
[4] R. Driad *et al.*, 12th International Conference on Indium Phosphide and Related Materials (IPRM00), pp.182-185, Williamsburg, Virginia, May 2000.

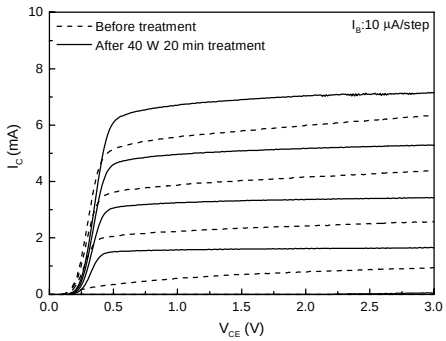

Fig.1 Typical common-emitter I-V characteristics of an InP HBT before and after NH_3 plasma treatment.

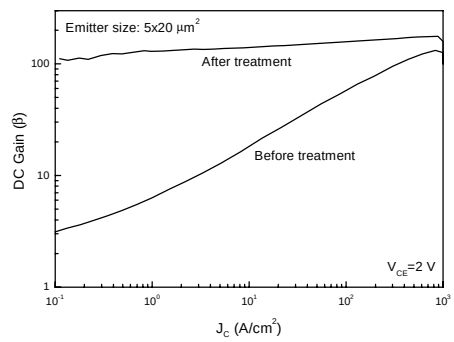

Fig.2 Current gain as a function of collector current density (J_C) for an HBT with a 5×20 μm^2 emitter before and after plasma treatments

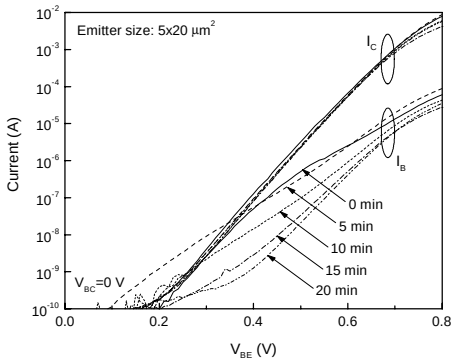

Fig.3 Gummel plots of an HBT (5×20 μm^2 emitter) with different process times.

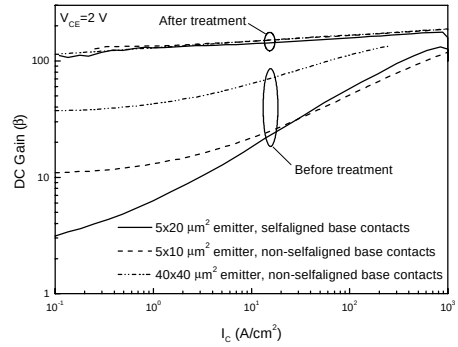

Fig.4 Current gain as a function of collector current density (J_C) for HBTs with different emitter sizes before and after plasma treatments