1. Introduction

InP-based high electron mobility transistors (HEMTs) show excellent high-frequency performance because of their high electron mobilities, high electron velocities, and high sheet electron densities. In our previous works, we developed several fabrication techniques [1-4] and fabricated In_{0.52}Al_{0.48}As/In_{0.47}Ga_{0.53}As lattice-matched (L-M-, x=0.53) and pseudomorphic (P-, x=0.7) HEMTs with decanometer-scale gate length \( L_g \). In this paper, we review our recent results for InP-based HEMTs.

2. Fabrication Process and Device Performance

L-M- and P-HEMT epitaxial layers were grown on semi-insulating (100) InP substrates by metal organic chemical vapor deposition. The L-M-HEMT layers, from bottom to top, consist of a 300-nm InAlAs buffer, a 15-nm InGaAs channel, a 3-nm InAlAs spacer, a Si-δ-doped sheet (5 × 10^{12} \text{ cm}^{-2}) , a 10-nm InAlAs barrier, a 6-nm InP, and a 30-nm Si-doped InGaAs cap (1 × 10^{19} \text{ cm}^{-3}) layer. In the P-HEMT, the In_{0.7}Ga_{0.3}As channel layer is 12-nm thick and the In_{0.5}Ga_{0.47}As cap layer is 40-nm thick. The other layers are the same as those in the L-M-HEMTs. T-shaped Ti/Pt/Au Schottky gates with widths \( W_g \) of 50 × 2 \text{ μm} were fabricated using electron beam lithography and a standard lift-off technique within a source-drain spacing \( L_{sd} \) of 2 \text{ μm}. A two-step-recessed gate technique [5] was used to reduce the gate-channel distance \( d \) while maintaining a high electron sheet density in the side-etched region of the gate-recess.

S-parameters were measured at frequencies up to 50 GHz. Note that the parasitic capacitance due to the probing pads was subtracted from the measured S-parameters. Figure 1 shows the gate-channel distance \( d \) dependence of \( f_t \) for the 25-nm-gate L-M-HEMTs under a drain-source voltage \( V_{ds} \) of 0.8 V. As clearly seen in Fig. 1, the \( f_t \) increases with a decrease in \( d \). By decreasing the \( d \) from 15 to 4 nm, the \( f_t \) was increased from 377 to 500 GHz [3].

Figure 2 shows the gate-channel distance \( d \) dependence of transconductance \( g_m \) and gate capacitance \( C_g \) for the HEMT in Fig. 1. The \( g_m \) increased much more with a decrease in the \( d \) than the \( C_g \) did. Thus, reducing the gate-channel distance increases the \( f_t \), which results from an increase in the \( g_m \). Increasing the In content in the InGaAs channel layer (P-HEMT) is effective in increasing the \( f_t \), because the electron effective mass in the InGaAs layer becomes lighter by increasing the In content. We obtained an \( f_t \) of 562 GHz with a \( d \) of 4 nm for P-HEMTs [2].

An asymmetric gate-recess structure with a shorter source-side recess and a longer drain-side recess is effective for obtaining a higher maximum oscillation frequency \( f_{max} \). We developed a simple and high-precision fabrication technique for HEMTs that have an asymmetrically recessed T-shaped gate [4]. The technique uses a conventional triple-layer resist that has additional slit patterns beside a gate-foot pattern in the bottom layer. The gate metal is evaporated at a tilted angle to avoid evaporation through the slit patterns. The source-
drain-side recess length \((L_{rd}, L_{rg})\) can be precisely controlled by the etching time and by the size and position of the slits. We used P-HEMT with a 20-nm InGaAs cap layer for this process. Figure 3(a) shows a bird’s-eye view scanning electron microscopy (SEM) image of a triple-layer resist with additional small slit patterns after recess etching with an \(L_g\) of 60 nm. The recess etching was successfully done through such very small slits. The Ti/Pt/Au gate metal was evaporated at a tilted angle of 45°. Figure 3(b) shows a cross-sectional SEM image of a complete T-shaped gate with an \(L_g\) of 60 nm, an \(L_{rs}\) of 80 nm and an \(L_{rd}\) of 190 nm. Concerning the recess etching, we succeeded in increasing the \(f_{\text{max}}\) by using an asymmetrical gate-recess structure with a longer \(L_{rd}\). We will show the latest results at the conference.

3. Summary

In summary, we reviewed our recent results for InP-based HEMTs that have high \(f_2\) or high \(f_{\text{max}}\). The \(f_2\) increases with a decrease in the gate-channel distance \(d\) in L-M-HEMTs. We obtained an \(f_2\) of 500 GHz for the L-M-HEMT, and an \(f_2\) of 562 GHz for the P-HEMT. On the other hand, we succeeded in increasing the \(f_{\text{max}}\) by using an asymmetrical gate-recess structure with a longer \(L_{rd}\). We will show the latest results at the conference.

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References