494-GHz-f_T high-speed InP-based high-electron-mobility transistors with MOVPE-grown InAs/$In_{0.8}Ga_{0.2}As$ quantum-well

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【Introduction】InP-based high-electron-mobility transistors (HEMTs) with InAs quantum well exhibit record high-speed performances because of their high electron mobility and saturation velocity [1-2]. In this work, we report on an InP-based HEMT with an InAs/$In_{0.8}Ga_{0.2}As$ quantum well in the channel and a single Si δ-doping, which provide a high-speed operation for short-gate-length (L_G) HEMTs.

【 Device Structure & Results 】 Our MOVPE-grown HEMT structure is based on a 5-nm-thick InAs/$In_{0.8}Ga_{0.2}As$ quantum well in the channel, with only a single Si δ-doping placed above the channel. The measured room-temperature mobility (μ) and the two-dimensional electron gas density (N_S) were 14,800 cm^2/V.s and 3.20×10^{12} cm^{-2} respectively. A 5-nm-thick $In_{0.8}Ga_{0.2}As$ and 3-nm-thick InAs quantum well structures were also examined to show the impact of our proposed quantum well structure, and their μ was 13,000 and 13,700 cm^2/V.s respectively, with an equivalent N_S. This shows that the 2DEG confinement in the InAs/$In_{0.8}Ga_{0.2}As$ quantum well is better than that in the others. The measured f_T of 100-nm-L_G HEMT with the proposed quantum well was 257 GHz compared to 217 GHz and 205 GHz for that of HEMTs with 5-nm $In_{0.8}Ga_{0.2}As$ and 3-nm InAs quantum well structures respectively, which also confirms the good performance of the proposed quantum well. Using this high-speed quantum well, we fabricated a scaled-down HEMT with a L_G of 33 nm. A dry etching procedure was performed to obtain a 9-nm gate-channel distance (d_{GC}) for vertical scaling. Despite the low N_S due to the use of a single Si δ-doping, and the large d_{GC} compared with aggressively scaled HEMTs with double Si δ-doping exhibiting high RF performances [1-2], the I-V characteristics of 33-nm-L_G HEMT exhibited a high drain current density of 0.93 mA/μm, with a transconductance (g_m) of 1.8 S/mm at V_D = 0.6 V (Fig. 1), and the current gain cut-off frequency (f_T) was 494 GHz at V_D = 0.6 V and V_G = 0.1 V (Fig. 2). An electron transit time ($\tau_{transit}$) of 253 fs was calculated from the total delay time (τ) given by $1/(2\pi f_T)$, the parasitic delay time (τ_{par}) (~45 fs), and the channel-charging time (τ_{cc}) (~25 fs) [3-4]. The τ_{par}, accounting for 14% of the total delay time, is relatively large compared to the reported THz transistors, and its reduction will improve further τ and f_T.

【Summary】A HEMT structure with a 5-nm-thick InAs/$In_{0.8}Ga_{0.2}As$ quantum well was investigated. A fine 2DEG confinement in the InAs/$In_{0.8}Ga_{0.2}As$ quantum well provides high room-temperature mobility of 14,800 cm^2/V.s with high Ns. Thus, f_T of 494 GHz for 33-nm-L_G HEMT is achieved. Further scaling of d_{GC} and L_G with reducing the parasitic components possibly provides higher f_T values with the presented channel configuration.

This work was supported in part by the research and development program Multi-ten Gigabit Wireless Communications Technology at Sub-terahertz Frequencies of the Ministry of Internal Affairs and Communications, Japan.

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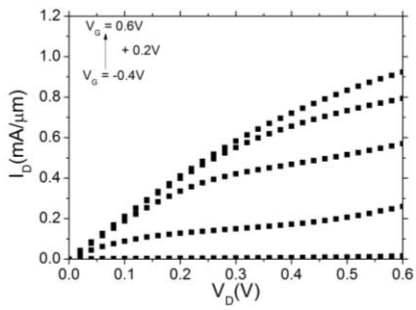

Fig. 1. I-V characteristics of a 33-nm-L_G HEMT

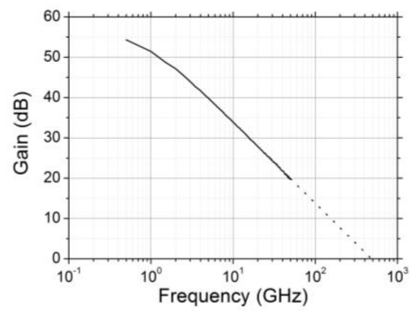

Fig. 2. De-embedded $|h_{21}|^2$ vs. the frequency for a 33-nm-L_G HEMT at V_D = 0.6 V and V_G = 0.1 V