# Improvement of RF performance by using double δ-doping in InP-based high-electron-mobility transistors with MOVPE-grown InAs/$In_{0.8}Ga_{0.2}As$ quantum-well

日本電信電話株式会社 NTT 先端集積デバイス研究所

○エルムタワキル アミン，星　拓也，杉山 弘樹，松崎 秀昭

NTT Device Technology Laboratories, ○Amine El Moutaouakil, Takuya Hoshi, Hiroki Sugiyama, Hideaki Matsuzaki

E-mail: elmoutaouakil.amine@lab.ntt.co.jp

【Introduction】InP-based high-electron-mobility transistors (HEMTs) with InAs quantum-well are known for their record high-speed performances, mainly due to their high electron mobility and saturation velocity [1-2]. Along with scaling, double δ-doping in HEMTs is used to boost the operation speed. However, there are no quantitative reports comparing structures with both single- and double-doping layers. In this work, we report on the performance of the double-δ-doped (DD) HEMT in comparison to the single-δ-doped (SD) HEMT.

【 Device Structure & Results 】 Our MOVPE-grown HEMT structure is based on a 6-nm-thick InAs/$In_{0.8}Ga_{0.2}As$ quantum well in the channel. The SD structure [3] has a single Si δ-doping placed above the channel with a doping density ($N_s$) of $3.2\times10^{12}$ $cm^{-2}$. The DD structure has δ-doping layers placed above and below the channel, with a bottom $N_s$ in the buffer layer of $1.2\times10^{12}$ $cm^{-2}$, and a top $N_s$ in the barrier of $2.8\times10^{12}$ $cm^{-2}$. The total doping density for DD structures ($4.0\times10^{12}$ $cm^{-2}$) was higher than the one for the SD structure, therefore, their measured room-temperature mobility (μ) (~13,600 $cm^2$/V.s) was lower than that for the SD structure (14,800 $cm^2$/V.s). Using these high-speed quantum well structures, scaled-down HEMTs with gate lengths ($L_G$) between 33 and 310 nm were fabricated. A dry etching procedure was performed to obtain a 9-nm gate-channel distance for vertical scaling. At $V_D$ = 0.6 V, the I-V characteristics of 33-nm-$L_G$ HEMTs exhibited a high drain current density of 1.2 mA/μm compared to 0.93 mA/μm for SD HEMT. The increase in the current density can be attributed to the higher $N_s$ in the DD structures. As for the drain conductance ($g_D$), its value in DD HEMTs was 0.8 S/mm, compared with 1.0 S/mm in SD HEMTs. The DD structure improves $g_D$.

Figure 2 shows the current gain cut-off frequency ($f_T$) for DD and SD HEMTs. $f_T$ shows a similar dependence on gate length for both structures, despite the differences in μ and $N_s$. The maximum-oscillation frequency ($f_{MAX}$) on the other hand, was higher in the DD HEMTs than in the SD HEMTs, especially in the short gate-length region, as shown in Fig. 3.

【 Summary 】 SD and DD HEMTs with a 6-nm-thick InAs/$In_{0.8}Ga_{0.2}As$ quantum well were investigated. For DD HEMT, equivalent $f_T$ values to those of SD HEMT were obtained even with lower μ, and $f_{MAX}$ shows higher value than that of SD HEMT. These results can be explained in part by the low $g_D$ in DD HEMTs.

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[2] E.-Y. Chang et al., Applied Physics Express (2013) 034001.
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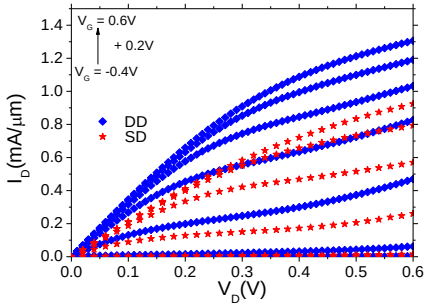


Fig. 1. I-V characteristics of a 33-nm-$L_G$ SD and DD HEMTs

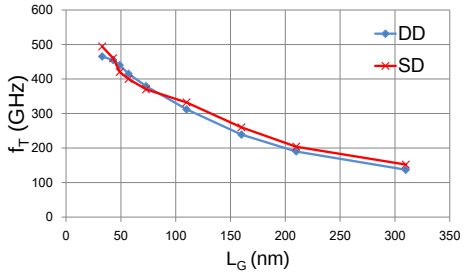


Fig. 2. Measured $f_T$ for SD and DD HEMTs

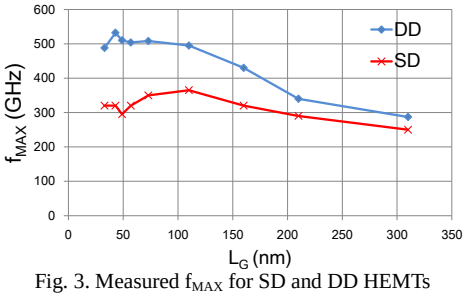


Fig. 3. Measured $f_{MAX}$ for SD and DD HEMTs