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# InGaP/InGaAs p-HEMTs Having Channel Layers Over the Critical Layer Thickness Grown on Patterned GaAs Substrates

Sung-June Jo, Jeong Hoon Kim, Sang-Soon Kim[1], and Jong-In Song

Department of Information and Communications, K-JIST, 1 Oryong-dong Buk-gu, Kwangju, Korea 500-712
Phone: +82-62-970-2208, Fax: +82-62-970-2224, E-mail: jisong@kjist.ac.kr
[1]R&D Group1, Mobile Communication Division, Samsung Electronics,
San #14, Nongseo-Ri, Kiheung-Eup, Yongin-City, Kyungki-Do, Korea 449-900

## 1. Introduction

The performance of GaAs-baed p-HEMTs can be improved by increasing the In composition (x) of $In_xGa_{1-x}As$ channel layer due to the improved confinement and mobility of two-dimensional electron gas in the channel layer. However, the In composition and the thickness of the $In_xGa_{1-x}As$ channel layer used for conventional GaAs-based p-HEMTs have been restricted below approximately 0.22 and 120 Å, respectively, due to the limitation of the critical layer thickness of the highly strained $In_xGa_{1-x}As$ layer. To exploit the improved transport property of the highly strained $In_xGa_{1-x}As$ channel layer, special techniques for the growth of high-quality InGaAs layers having a reduced dislocation density are required. A metamorphic buffer growth technique is one of the techniques used for the growth of the high-quality $In_xGa_{1-x}As$ layers having the In composition in excess of 0.33 [1]. A patterned substrate growth is another technique to grow high-quality and highly strained InGaAs layers. Using this technique, growth of thick (more than 10 times thicker than the critical layer thickness) $In_xGa_{1-x}As$ layers having a reduced misfit dislocation density was reported [2]. The technique was also successfully applied for devices requiring highly strained InGaAs layers, resulting in improved device performances [3]. In this paper, we compare the performances of the InGaP/$In_xGa_{1-x}As$ (x=0.22~0.40) p-HEMTs grown on patterned and non-patterned GaAs substrates.

## 2. Characterization of The InGaP/$In_xGa_{1-x}As$ p-HEMTs

The InGaP/$In_xGa_{1-x}As$ (x=0.22, 0.33, 0.40) p-HEMT structures, shown in Fig. 1, were grown by using a V80H-10K compound source molecular beam epitaxy at 500 °C. The thickness of the channel layers for x values of 0.33 and 0.40 are approximately 50% and 150% in excess of the critical layer thickness (the Matthews and Blakeslee limit), respectively. For the patterned substrate growth, approximately 2,500 Å high mesa patterns (area = 50x60 μm$^2$) used for the device active area were formed on the GaAs substrates before the epitaxial layer growth. Transistors having a 1.5x50 μm$^2$ gate were fabricated using a conventional optical lithography. DC characteristics (transconductance and drain saturation current) of the p-HEMTs grown on patterned and non-patterned substrates are shown in Fig. 2. The highly strained InGaP/$In_xGa_{1-x}As$ (x= 0.33, 0.40) p-HEMTs grown on non-patterned substrates showed degraded performances due to the increased dislocation density. The highly strained InGaP/$In_xGa_{1-x}As$ (x=0.33) p-HEMTs grown on patterned substrates showed the best performance. While the performance of the highly strained InGaP/$In_xGa_{1-x}As$ (x=0.40) p-HEMTs grown on patterned substrates degraded due to the increased dislocation density, it was still better than that of the InGaP/$In_xGa_{1-x}As$ (x=0.40) p-HEMTs grown on non-patterned substrates.

| | | | |
|---|---|---|---|
| GaAs | Cap | 500Å | n=8E18 |
| $In_{0.5}Ga_{0.5}P$ | Schottky | 200Å | n=5E17 |
| $In_{0.5}Ga_{0.5}P$ | Doping | 50Å | n=1E19 |
| $Al_{0.24}Ga_{0.76}As$ | Spacer | 60Å | undoped |
| $In_xGa_{1-x}As$<br>(x=0.22, 0.33, 0.4) | Channel | 100Å | undoped |
| GaAs | Buffer | 4,000Å | undoped |
| Semi-insulating <100> GaAs Substrate | | | |

Fig. 1. Epitaxial layer structures of the InGaP/$In_xGa_{1-x}As$ p-HEMTs.

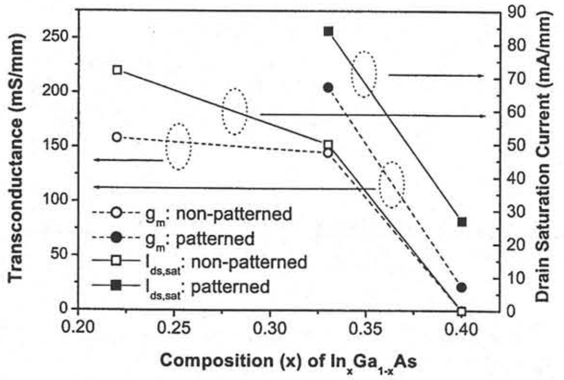

Fig. 2. Normalized transconductances and drain saturation currents (at $V_{gs}$=0V) of the InGaP/$In_xGa_{1-x}As$ p-HEMTs.

Microwave performances ($f_T$ and $f_{max}$) of the highly strained InGaP/$In_{0.33}Ga_{0.67}As$ p-HEMTs grown on patterned substrates and the conventional InGaP/$In_{0.22}Ga_{0.78}As$ p-HEMTs grown on non-patterned substrates are compared in Fig. 3. Low-frequency noise performances of the InGaP/$In_xGa_{1-x}As$ p-HEMTs were characterized for the temperature range of 150 K - 440 K and for the frequency range of 1 Hz - 53 kHz. Figure 4 shows the room temperature low-frequency input noise spectral density ($S_{iv}$) of the p-HEMTs as a function of the frequency measured at $V_{gs}$ = 0 V and $V_{ds}$ = 2 V. The noise level and the Hooge parameter of the InGaP/$In_{0.33}Ga_{0.67}As$ p-HEMT grown on patterned substrate were approximately an order of magnitude smaller than those of the InGaP/$In_{0.22}Ga_{0.78}As$ p-HEMT grown on non-patterned substrates. The low-frequency noise spectra showed pure *1/f* noise behavior for most of the temperature and the frequency ranges investigated.

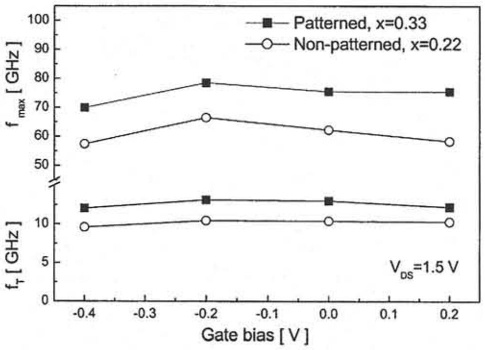

Fig. 3. Dependence of $f_T$ and $f_{max}$ of the InGaP/$In_xGa_{1-x}As$ p-HEMTs on the gate-source bias voltage.

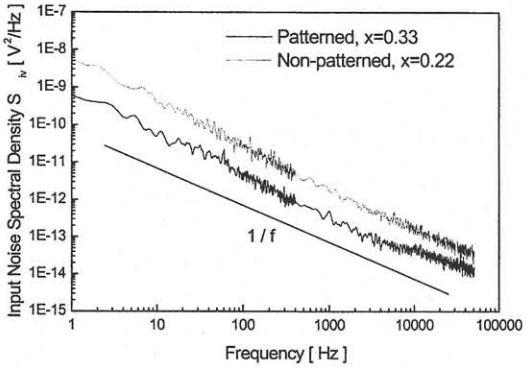

Fig. 4. Room-temperature low-frequency input noise spectra of the InGaP/$In_xGa_{1-x}As$ p-HEMTs.

Microwave noise performance of the p-HEMTs were measured for the frequency range of 1-3 GHz. Figure 5 shows the minimum noise figure ($NF_{min}$) and the associated gain ($G_a$) of the p-HEMTs as a function of frequency measured at $I_{ds}$ = 1.5 mA and $V_{ds}$ = 1 V. Figure 6 shows the drain current dependence of the minimum noise figure and the associated gain of the p-HEMTs measured at 2 GHz and $V_{ds}$ = 1 V. The minimum noise figure of the InGaP/$In_{0.33}Ga_{0.67}As$ p-HEMT grown on patterned substrates was lower than that of the InGaP/$In_{0.22}Ga_{0.78}As$ p-HEMT grown on non-patterned substrates by more than 1 dB for most of the bias conditions.

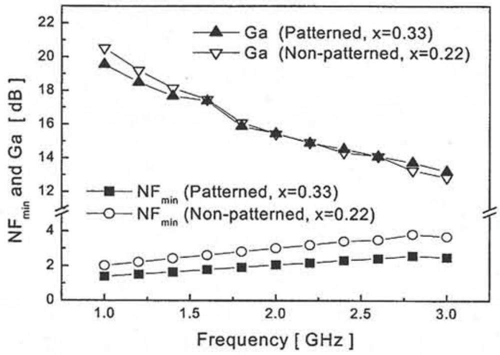

Fig. 5. Frequency dependence of minimum noise figure and associated gain of the InGaP/$In_xGa_{1-x}As$ p-HEMTs ($I_{ds}$ = 1.5mA and $V_{ds}$ = 1V).

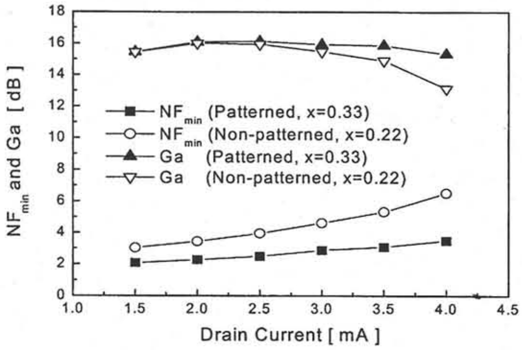

Fig. 6. Minimum noise figure and associated gain of the InGaP/$In_xGa_{1-x}As$ p-HEMTs as a function of the drain current ($f$ = 2GHz and $V_{ds}$ = 1V).

## 4. Conclusions

Substantial improvements in device performances including DC ($g_m$ and $I_{ds,sat}$), microwave ($f_T$ and $f_{max}$), and noise characteristics of the InGaP/$In_{0.33}Ga_{0.67}As$ p-HEMTs having a highly strained InGaAs channel layer (50% in excess of the critical layer thickness) are reported. The results indicate the potential of highly strained p-HEMTs grown on patterned substrates for use in high-performance device applications. Further studies on the dependence of the dislocation density on layer structure, growth temperature, and area of patterns are required to achieve high-quality $In_xGa_{1-x}As$ layers having a higher strain.

## References

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