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Compressively Strained-$In_xAl_{1-x}N/Al_{0.22}Ga_{0.78}N/GaN$ (x = 0.245 – 0.325) Heterostrucures FETs with a Regrown AlGaN Contact Layer

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1. Introduction

InAlN is attractive as a barrier layer in the GaN-based FETs [1]. Lattice-matched (LM) $In_{0.18}Al_{0.82}N/GaN$ heterostructures can induce a large density of 2DEG (N_S) of over 2 x 10^{13} cm^{-2} because of the large spontaneous-polarization charge. Recently, we fabricated LM InAlN/AlGaN/GaN heterostructures [2] and found that the insertion of the AlGaN layer boosts the electron mobility and flattens the surface.

A compressively strained $In_xAl_{1-x}N$ (x > 0.18) barrier is also interesting. With the barrier, the piezoelectric polarization is antiparallel to the spontaneous one. Therefore, the N_S decreases with the increasing the In content. It has been predicted that N_S would be eliminated for $In_xAl_{1-x}N/GaN$ (x = ~0.3) barrier [3], which can be used to build enhancement-mode FETs.

In this study, we fabricated compressively strained $In_xAl_{1-x}N/Al_{0.22}Ga_{0.78}N/GaN$ heterostructures with regrown AlGaN layers and found that the threshold voltage varied from -3.2 to -0.2 V in the region of In content from 0.245 to 0.325.

2. Experimental

$In_xAl_{1-x}N/Al_{0.22}Ga_{0.78}N/GaN$ (x = 0.245-0.325) heterostructures were grown by MOVPE. The thickness of the InAlN, AlGaN, and GaN layers are about 15, 3, and 2000 nm, respectively. Figure 1 shows the schematic view of the InAlN/AlGaN/GaN heterostructures FET. With the gate region masked with the 2-μm stripe SiO_2, 10 nm dry etching and AlGaN selective regrowth on the window region and removement of SiO_2 mask were performed. This was followed by mesa formation and Ti/Al/Ni/Au Ohmic contact deposition and metallization. Finally, and Ni/Au was deposited. The gate length and width are 4 and 20 μm, respectively. The source-drain spacing is 8 μm.

3. Results and discussion

First, we estimated the electrical properties of the InAlN/AlGaN/GaN heterostructures by non-destructive eddy current measurement. Figure 2 shows the N_S and electron mobility as a function of the In content of the InAlN barrier layer. N_S decreased from 6.5 x 10^{12} to 1.3 x 10^{12} cm^{-2} as the In content decreased from 0.245 to 0.325, resulting from the decrease of the sum of the piezoelectric and spontaneous polarization. It is considered that these values are higher than those of InAlN/GaN because of the polarization charge of the inserted AlGaN layer. However, the inserted layer is effective for achieving high electron mobility [2], which is very low in the InAlN/GaN heterostructures due to the large alloly-disorder scattering rate [4, 5]. High mobility of 1570 cm^2/Vs was achieved for the $In_{0.245}Al_{0.755}N/Al_{0.22}Ga_{0.78}N/GaN$. It decreased to 416 cm^2/Vs with increasing In content. Because N_S is extremely low, the screening effect on Coulomb scattering centers, such as ionized impurities, becomes weak.

The 2DEG should be eliminated at the heterointerface for enhancement operation; however, this would insulate the access region and suppress device performance. In this work, we regrew the AlGaN contact layer in order to induce N_S in the access region. Figure 3 shows the TLM on the regrown area for $In_{0.325}Al_{0.675}N/Al_{0.22}Ga_{0.78}N/GaN$ with high sheet resistance of over 10000 Ω/sq. Contact and sheet resistance wete estimated to be 1.0 Ωmm and 584 Ω/sq, respectively. The inducement of N_S was confirmed at the heterointerface under the regrown area.

Figure 4 shows I-V and transfer characteristics of an $In_{0.325}Al_{0.675}N/Al_{0.22}Ga_{0.78}N/GaN$ heterostructure FET. The threshold voltage is about -0.2 V, *i.e.*, operation close to enhancement mode was observed. The maxim tranceconductance was 62 mS/mm, and the drain current was 0.11 A/mm. These low values are attributed to the large gate leakage current at the high gate voltage as seen in Fig. 4. The use of MIS structure would be one of the way to reduce the leakage current, though further investigation is needed. Figure 5 shows the correlation between the threshold voltage and In content. The threshold voltage became varied from -3.2 to -0.2 V as the In content increased from 0.245 to 0.325, indicating that the threshold voltage can be controlled by the adjusting the In content in the heterostructures. Enhancement operation should be possible by using a thinner barrier or by increasing the In content for the InAlN/AlGaN/GaN heterostructures.

4. Conclusions

Compressively strained $In_xAl_{1-x}N/Al_{0.22}Ga_{0.78}N/GaN$ (x = 0.245-0.325) heterostructures FETs were fabricated. The NS widely varied from 6.5 x10^{12} to 1.3 x 10^{12} cm^{-2} in the In content region. With the insertion of the AlGaN layer, electron mobility as high as 1570 cm^2/Vs was achieved at the In content of 0.245. The regrown AlGaN contact layer is effective for reducing the sheet resistance from 10000 to 511 Ω/sq. at the access layer for $In_{0.325}Al_{0.675}N/Al_{0.22}Ga_{0.78}N$ /GaN. The threshold voltage can be varied from -3.2 to -0.2 V by increasing the In content. These results indicate that the InAlN/AlGaN/GaN heterostructures FETs can control the threshold voltage in a wide range and can be applied for

enhancement operation.

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References

[1] J. Kuzumik, IEEE Electron Device Lett. **22** (2001) 510.

[2] M. Hiroki, N. Maeda, and T. Kobayashi, Appl. Phys. Express **1** (2008) 111102.

[3] O. Ambacher, R. Dimitrov, M. Stutzmann, B. E. Foutz , M. J. Murphy, J. A. Smart, J. R. Shealy, N. G. Weimann, K. Chu, M. Chumbes, B. Green, A. J. Sierakowski, W. J. Schaff, and L. F. Eastman, Phys. Stat. Sol. (b) **216** (1999) 381.

[4] V. W. L. Chin, B. Zhou, T. L. Tansley, and X. Lin, J.Appl. Phys. **77** (1995) 6064.

[5] M. Gonshorek, J. F. Carlin, E. Feltin, M. A. Py, and N. Grandjean, Appl. Phys. Lett. **89** (2006) 062106.

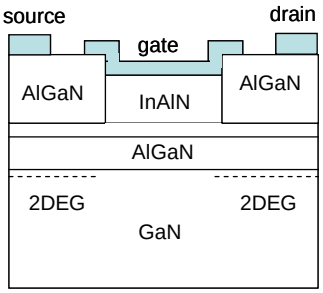

Fig. 1 Cross-sectional schematic view of the InAlN/AlGaN/GaN heterostructures FET.

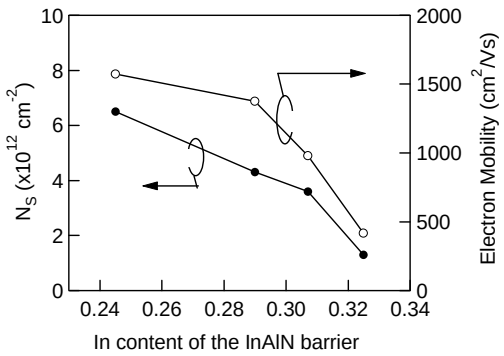

Fig. 2 N_S and electron mobility as a function of In content of the InAlN barrier layer.

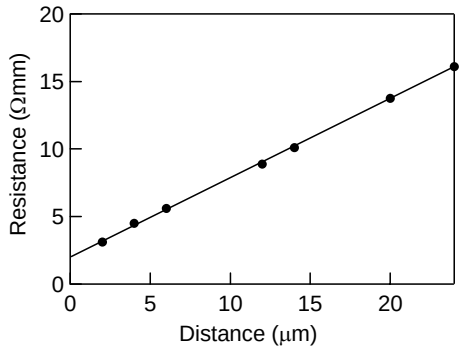

Fig. 3 Transmission line method of ohmic contact in the AlGaN regrowth area.

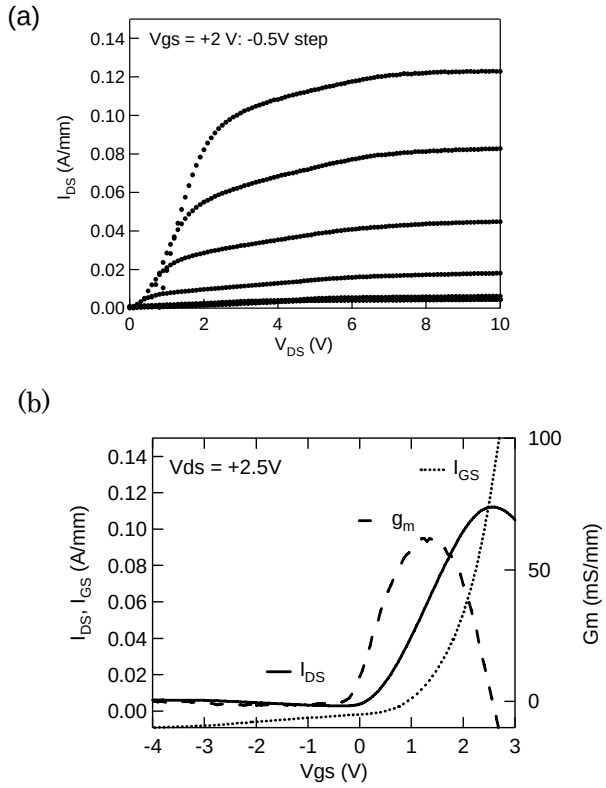

Fig. 4 (a) I-V and (b) transfer characteristics of InAlN/AlGaN/GaN heterostructures FETs.

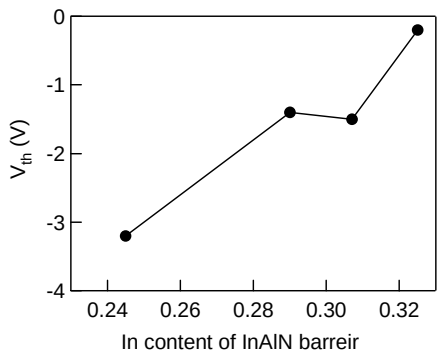

Fig. 5 Threshold voltage as a function of In content.