Extended Abstracts of the 21st Conference on Solid State Devices and Materials, Tokyo, 1989, pp. 281-284

D-3-2

Planar-Doped AlInAs/GaInAs HIFET

H. Shibata, H. Ishikawa and M. Kamada

SONY Corporation Research Center
Fujitsuka, Hodogaya, Yokohama 240

Planar-doped AlInAs/GaInAs heterostructures were grown by atmospheric-pressure MOCVD. The planar-doping method produces thinner AlInAs layers and more uniform doping concentrations than the conventional doping. A 1µm gate length HIFET (hetero-interface FET) showed a transconductance as high as 780mS/mm at room temperature. It was demonstrated that the distribution of threshold voltages for planar-doped HIFETs was better than that for the conventional HIFETs.

1. Introduction

We previously reported the first MOCVD growth of selectively-doped n-AlInAs/GaInAs heterostructures (SDHs)[1]. HIFETs using these heterostructures showed superior FET characteristics[2,3], however, better performance and uniform distribution of threshold voltages (*Vths*) are desirable for application to ICs. In this paper, we report the planar doping of AlInAs layers in HIFETs and a uniform *Vth* distribution, in addition to very high transconductance.

By introducing planar doping, we can make the AlInAs barrier layer thinner, resulting in a higher transconductance. Another advantage of planar doping is that uniform carrier concentration in the wafer is easily obtained. In the conventional HIFET using conventional SDHs, the distribution of *Vth* is determined by two factors: the thickness distribution and the doping density distribution of the n-AlInAs layer. In our case[3], however, the distribution of the doping density mainly contribute to the distribution of *Vth*. Uniform doping can be obtained and this improves the distribution of *Vths*.

2. Planar doping to AlInAs/GaInAs heterostructures

AlInAs and GaInAs layers lattice-matched to InP were grown by atmospheric-pressure MOCVD on 2-inch diameter Fe-doped semi-insulatating (100) InP substrates. The substrates were rotated during the growth to obtain good uniformity of the epitaxial layers. Si_2H_6 (5ppm/H_2) was used for n-type doping to AlInAs layers. Figure 1 shows the relationship between the sheet-carrier concentration and Si_2H_6 supply, which equals the flow rate times the doping period. Two planar-doped layers sandwiched between undoped AlInAs layers are shown in the cross-sectional view in Fig. 1. The sheet-carrier concentrations (n_s) increased linearly as Si_2H_6 increased and saturated at over 500scc. We also observed the difference in the distribution of the doping concentrations between the linear region and the saturation region. In the saturation region, the sheet-carrier concentration was almost uniform. The ratio of n_s at the center to n_s at the edge was 0.95. In the linear region, on the other hand, the ratio was 0.65, which was nearly the same in our case of conventional doping.

The saturation region was used for planar doping to AlInAs layers in SDHs.

Figure 2 shows the cross-sectional view of the planar-doped SDH. The undoped GaInAs channel layer was 1000Å thick and the spacer layer thickness ranged from 10Å to 100Å. The top undoped AlInAs layer was 150Å thick.

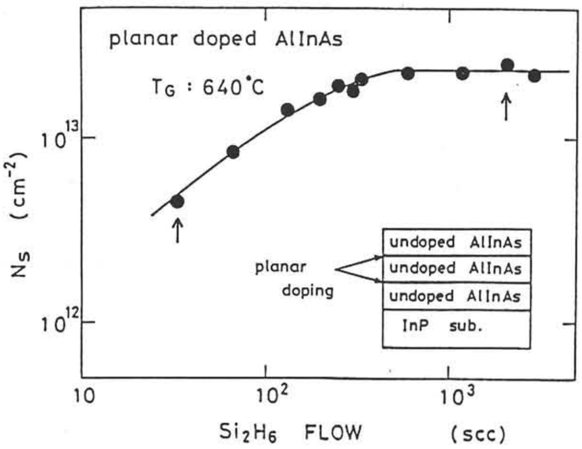

Fig. 1 Relationship between the sheet-carrier concentration and Si_2H_6 flow supply.

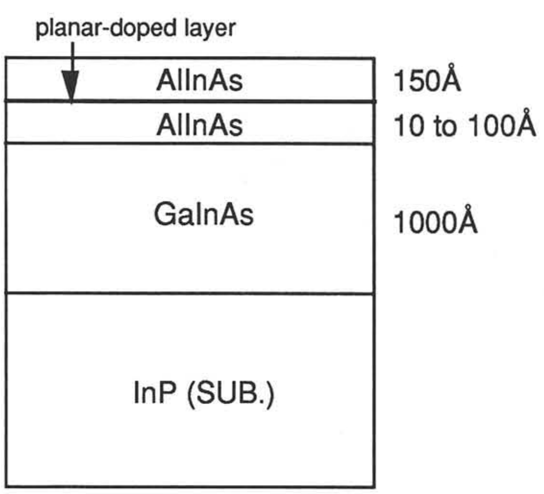

Fig. 2 Cross-sectional view of the planar-doped AlInAs/GaInAs SDH.

To compare the mobility of the two-dimensional electron gas in the planar-doped SDHs with different spacer-layer thicknesses, we etched the top AlInAs layers of each SDH by chemical etching to obtain SDHs with the same sheet carrier concentration of 2.3 X $10^{12}cm^{-2}$. Figure 3 shows the relation between the electron mobility at room temperature and the spacer thickness at the sheet-carrier concentration of 2.3 X $10^{12}cm^{-2}$. The highest electron mobility was 11500 $cm^2/V\cdot s$ when the spacer layer was 100Å thick. We observed a significant decrease in electron mobility when the thickness of the spacer was reduced. The mobility in the planar-doped SDH with 10Å thick spacer layer was only 3300 $cm^2/V\cdot s$.

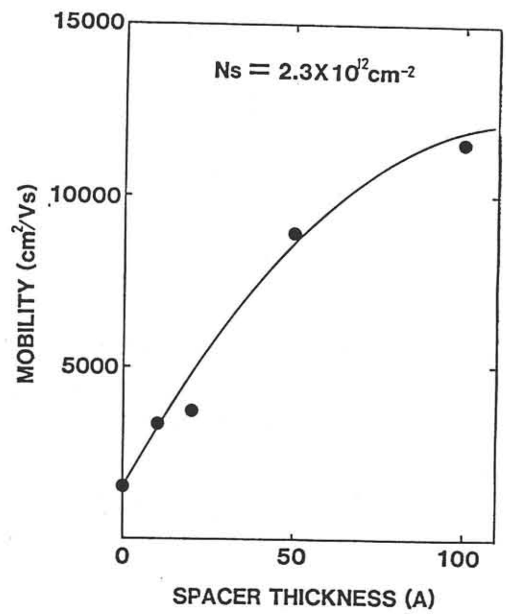

Fig. 3 Relation between electron mobility and spacer thickness at the sheet-carrier concentration of 2.3 X $10^{12}cm^{-2}$.

3. Planar-doped HIFETs

The fabrication of the HIFET started with mesa etching for device isolation. Source-drain ohmic contacts were formed by depositing AuGe/Au, followed by sintering in an H_2/N_2 atmosphere (H_2 4%) at 340 °C. Ti/Pt/Au gate metals were evaporated and lifted off using conventional lithography.

Figure 4 shows the typical FET characteristics of a 1.0μm-gate HIFET operated at room temperature. The HIFET shows good pinch-off characteristics. The maximum transconductance (*gm max.*), maximum K value (*K max.*) and threshold voltage (*Vth*) are summarized in Table I for HIFETs with different spacer layer thicknesses. All the HIFETs showed transconductance above 700mS/mm with a weak dependence on spacer layer thickness. The HIFET with the thinnest spacer layer shows a little higher *gm max.* This contrasted with the fact that the electron mobility drastically decreased as the spacer thickness decreased, as is seen in Fig.3, and implies that the saturation velocity does not seriously decrease as the spacer layer thickness decreases. The increase of the gate capacitance as the spacer layer thickness decreases may be the origin of the high *gm max.* in HIFETs with a thin spacer layer.

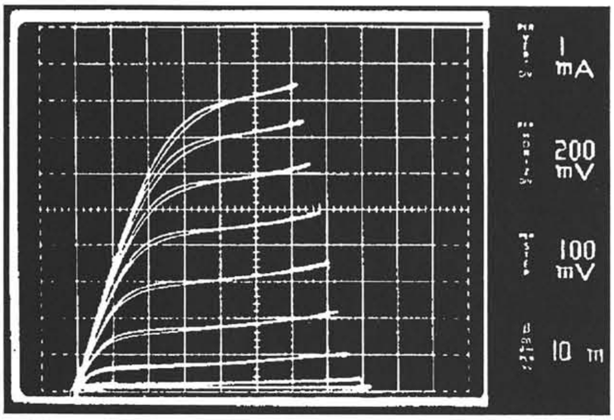

Fig. 4 FET characteristics of a HIFET operated at room-temperature. Lg=1μm, Wg=20μm; maximum gate votage was 0V.

Table. I FET characteristics of HIFETs operated at room-temperature.

Spacer thickness	100Å	50Å	10Å
max.gm(mS/mm)	720	750	780
max.K(mS/Vmm)	1150	1025	900
Vth(V)	-0.60	-1.0	-0.8

4. Distribution of the threshold voltages

Figure 5 shows the mapping of *Vth* of the planar-doped HIFETs and the conventional HIFETs. The average *Vth* and its standard deviation of the planar-doped HIFET were -0. 98V and 0.11V, respectively, and the average *Vth* and its standard deviation of the coventional HIFETs were -2.07V and 0.49V, respectively. Both maps showed point symmetrical patterns, representing rotation effect of the substrates during the growth. The *Vth* for the planar-doped HIFET decreased along the radial direction, but the *Vth* for the conventional HIFET increased. In the conventional HIFETs, the distribution of *Vth* is determined by two factors: the thickness of the n-AlInAs layer (*d*) and the doping concentration of the layer (*Nd*). *Vth* becomes higher with decreasing *d* and becomes lower with increasing *Nd*. We have observed that *d* in the center of the wafer is thicker than that on the edge and that *Nd* in the center is smaller than that on the edge[3]. Figure 5 shows that *Vth* in the center was higher than at the edge. This result shows that the distribution of *Nd* mainly contributes to the distribution of *Vth* in the conventional HIFETs. In the planar-doped HIFETs, on the other hand, the doping concentration was very uniform because of the use of the saturation region shown in Fig.1. We expected that the distribution of *d* would mainly contribute to the distribution of *Vths*. In fact, Fig.5 shows that *Vth* in the center was lower than that at the edge, confirming our expectation. In this way, planar doping can eliminate the influence of doping fluctuations on the distribution of *Vth*.

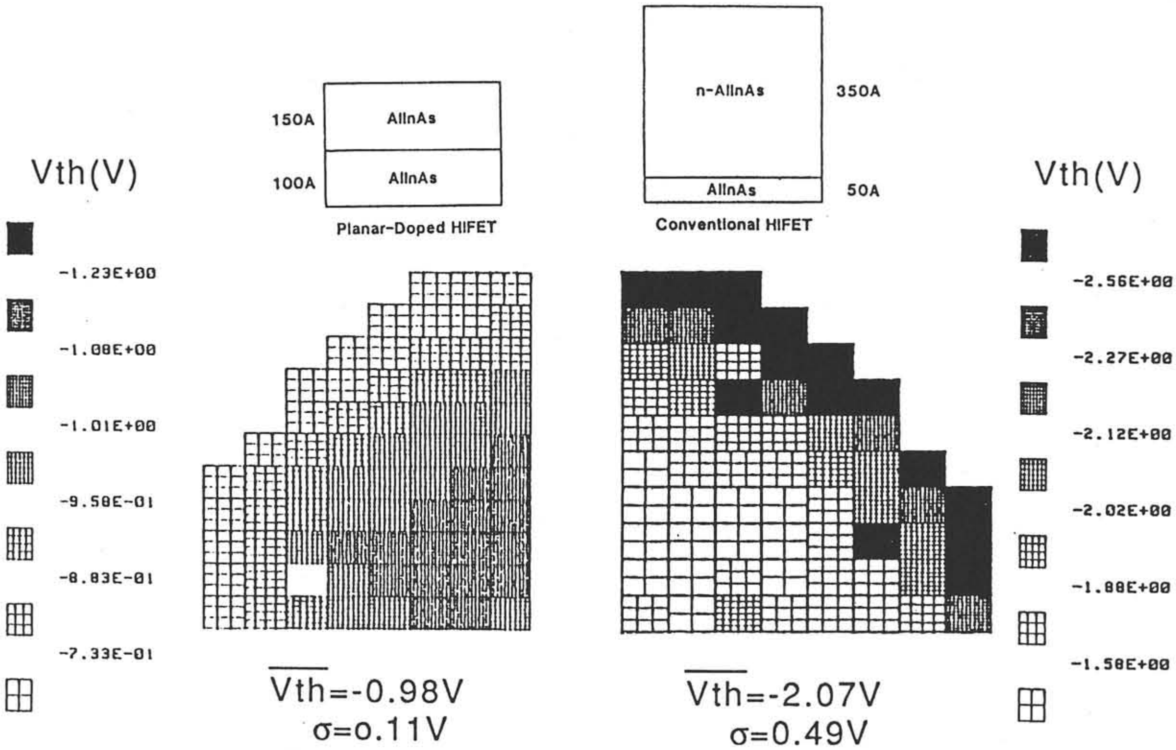

Fig. 5 Distribution maps of the *Vth* on the quater of 2-inch wafer of the planar-doped HIFETs and the conventional HIFETs.

5. Conclusion

Planar-doped AlInAs/GaInAs heterostructures were grown by atmospheric-pressure MOCVD. Electron mobility as high as 11500cm/Vs at room temperature with a sheet carrier concentration of 2.3×10^{12} cm^{-2} was obtained. The doping concentration in the planar-doped layers saturated as the doping gas supply was increases, and very uniform doping was realized by using the saturation effect. The introduction of planar-doping to SDHs improved the distribution of *Vth*. We fabricated 1μm-gate length HIFETs using the planar-doped SDHs, and they showed good pinch-off characteristics. A maximum transconductance of 780 mS/mm was obtained for a HIFET with 10Å spacer thickness. The electron mobility drastically decreased as the spacer layer thickness was reduced, but there was little change in the maximum transcondactance of the HIFETs with different spacer layer thicknesses. We conclude that the saturation velocity does not seriously change as spacer layer thickness is reduced.

6. References

1) M. Kamada, H. Ishikawa, M. Ikeda, Y. Mori and C. Kojima, : Proc. 13th Intern. Symp. on GaAs amd Related Compounds, Las Vegas, NV, 1986, Inst. Phys. Conf. Ser.
2) M. Kamada, T. Kobayashi, H. Ishikawa, Y. Mori, K. Kaneko and C. Kojima, Electron. Letters 23 (1987) 297.
3) Y. Mori and M. Kamada, J. Crystal Growth 93 (1988) 892.