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HBTs and HEMT Based on InGaP/GaAs Heterostructures

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1. Introduction

InGaP-based devices such as FETs and HBTs have superior performance compared with AlGaAs-based devices. Controlling InGaP/GaAs heterointerface grown by MOVPE is important for obtaining higher performance. In this paper, we show the reproducibility of low H-concentration in C-GaAs of InGaP/GaAs HBTs. In addition, we report that electron depletion occurred at the interface from ordered n-InGaP to n-GaAs and electron accumulation occurred at the interface from n-GaAs to ordered n-InGaP [1,2,3]. We also studied the method to improve the electrical characteristics using highly ordered-InGaP using Sb doping [4,5]. We could obtain good electrical characteristics and device performance at interface without changing growth temperature.

2. Experimental Conditions

We used a reduced pressure horizontal MOVPE reactor capable of growing a 4-inch wafer per run. TEGa, TMGa, TMIn, TMSb, CBr_4, AsH_3, PH_3, and Si_2H_6 are used. We grew Sb-doped InGaP at the same growth temperature to grow highly ordered InGaP around 640-740℃. V/III ratios of InGaP and GaAs were 400 and 5. Growth pressure was 100hPa.

3. Experimental Results and Discussions

1)C-doping into GaAs in InGaP/GaAs HBT

Figure 1 shows the reproducibility of H-concentration in C-doped GaAs during 300 runs with same growth conditions for $3x10^{19}$ cm^{-3}. TEGa, TMGa, CBr_4 and AsH_3 were used at a high growth temperature such as 650℃ to reduce H-concentration. We could maintain H/C ratio as low as 3% for a long time.

2) Interface from GaAs to ordered-InGaP

Ordered InGaP was grown at 650℃ is to obtain strong PL emission. Figure 2 shows carrier profile at the heterointerface from GaAs to InGaP. When InGaP was ordered, electrons accumulated, resulting in high 2DEG concentration. In this case, 2DEG mobility is quite low such as 2000 $cm^2V^{-1}s^{-1}$ for InGaP/(In)GaAs P-HEMT [3]. Inserting Ga-rich InGaP at InGaP/InGaAs effectively improved mobility (Fig.3). P-diffusion into InGaAs-channel is reduced by Ga-rich InGaP.

3) Interface from ordered-InGaP to GaAs

When GaAs was grown on ordered-InGaP, electrons were depleted (Fig.4a)). InGaAsP formation at heterointerface never affected this electron depletion. This is maybe due to piezoelectric effect [6].

4) Effect of Sb doping

We investigated Sb-doping into ordered InGaP. Sb/V ratio is $2.35x10^{-3}$. Sb is incorporated into InGaP with an order of $1x10^{19}$ -$1x10^{20}$ cm^{-3}. PL peak wavelength is still the same as that of ordered-InGaP, indicating that InGaPSb is also ordered. This is different from other report [7]. This is maybe due to precursor difference.

Figure 2b) shows carrier profile of InGaPSb/GaAs heterointerface. We observed normal valley and peak profile of electron concentration which corresponds to electron depletion and accumulation due to ΔEc at InGaPSb/GaAs interface. This suggests that the interface between ordered-InGaP and GaAs is improved only by Sb-doping.

Figure 4b) shows carrier profile at the heterointerface from InGaPSb to GaAs. Although InGaPSb is still ordered, we also observed normal peak and valley profile.

5) Device structures (FETs and HEMTs)

We introduced InGaPSb to device structure. We investigated InGaPSb-channel MESFET structure and InGaPSb-channel double-hetero-HEMT structure. (Fig.5) InGaP-channel MESFETs have extremely high breakdown voltage over 40V [8]. It is promising for base-station application for mobile communication. However, threshold voltage was negatively high, i.e. –8V, due to electron accumulation at ordered-InGaP/AlGaAs buffer. When we used InGaPSb channel MESFETs, we could suppress electron accumulation and obtain a low threshold voltage such as -4V (Fig.6). Using InGaPSb channel DH-HEMTs, lower threshold voltage with lower sheet resistance can be obtained.

6) Device structures (HBTs)

We also investigated n-InGaPSb ($n=4x10^{17}$ cm^{-3}) /C-doped GaAs ($p=4x10^{19}$ cm^{-3}) HBT structures. By simple process without any passivation, we obtained hfe of 65 for large size HBT (Fig.7).

4. Conclusions

In summary, we obtained low H-concentration at InGaP/GaAs HBTs and excellent electrical characteristics at ordered-InGaP/GaAs devices using Sb-doping.

References

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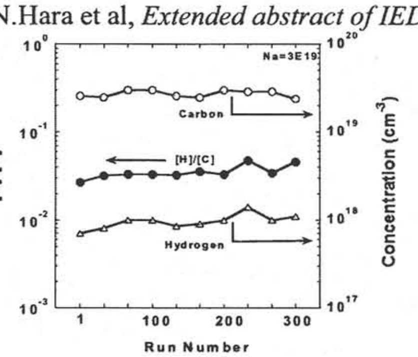

Fig. 1 Trend of C and H concentration during 300 runs.

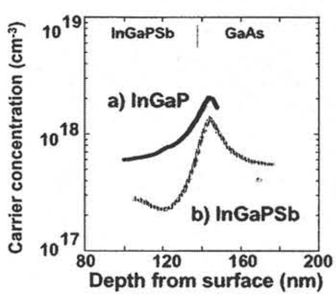

Fig. 2 Carrier profile of a) ordered-InGaP/GaAs and b) ordered-InGaPSb/ GaAs heterointerface.

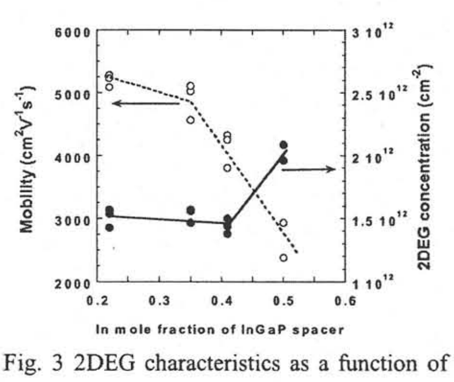

Fig. 3 2DEG characteristics as a function of In Content of InGaP spacer layer in InGaP/InGaAs pseudomorphic HEMT structures.

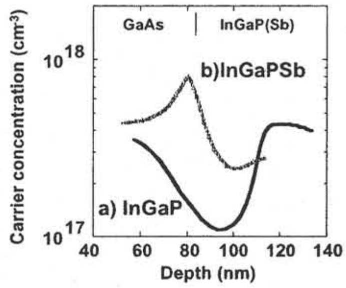

Fig. 4 Carrier profile of a) GaAs/ordered-InGaP and b) GaAs/ordered-InGaPSb heterointerface

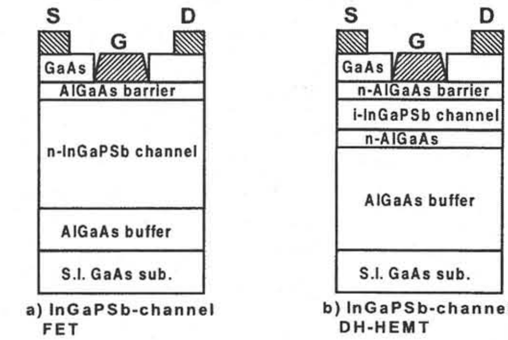

Fig. 5 Schematic drawing of a) InGaPSb channel FET and b) InGaPSb channel DH-HEMT structure.

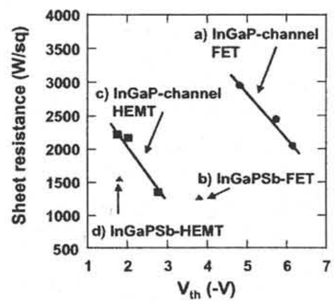

Fig.6 Relationship between Threshold voltage and sheet resistance of a) conventional InGaP-channel FET, b) InGaPSb-channel FET, c) InGaP-channel DH-HEMT, and d) InGaPSb-channel DH-HEMT.

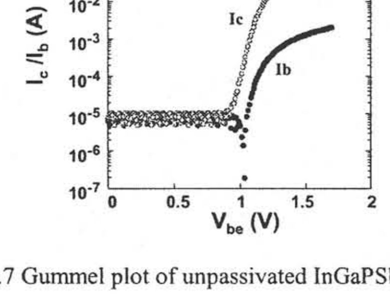

Fig.7 Gummel plot of unpassivated InGaPSb-HBT.