# Gas-source MBE growth of metamorphic $InP/In_{0.5}Al_{0.5}As/In_{0.5}Ga_{0.5}As/InAsP$ high-electron-mobility structures on GaAs substrates

K. Ouchi, T. Mishima M. Kudo, and H. Ohta*

Central Research Laboratories, Hitachi Ltd., Kokubunji, Tokyo 185-8601, Japan

*Process Engineering Development Dept., Hitachi ULSI Systems Co., Ltd., Kokubunji, Tokyo 185-8601, Japan

Phone: +81-423-23-1111, fax: +81-423-27-7821, e-mail: kiyoshi-crl.oouchi@c-net3.crl.hitachi.co.jp

Until now $In_{0.5}Al_{0.5}As/In_{0.5}Ga_{0.5}As$ metamorphic-HEMT structures have been grown exclusively by solid-source MBE. Their structures have not been equipped with a layer containing phosphorus, such as an InP capping layer to produce long-term reliability and highly selective etching. Accordingly, we have used a gas-source MBE to grow an improved M-HEMT structure that has not only an InP capping layer but also an $In_{0.5}Ga_{0.5}As/InAsP$ composite channel to improve breakdown voltage.

The M-HEMT, grown by solid-source MBE, has become one of the most promising devices for millimeter-wave applications because it yields very high maximum frequency of oscillations comparable to those obtained from an InAlAs/InGaAs HEMT lattice-matched to InP substrates. Besides, it overcomes some problems found in the lattice-matched HEMT, such as InP wafer's fragility, high cost, and small wafer size. However, two significant problems still remain. One is instability due to the easily oxidized InAlAs around the gate and the other is low breakdown voltage due to the small band-gap energy of the InGaAs channel. We have tried to solve the former problem by using an InP capping layer and the latter problem by using an InGaAs/InAsP composite channel, in which hot electrons can transfer from high-mobility InGaAs to high-saturation-velocity InAsP with a wider energy-gap, resulting in a higher breakdown voltage with a higher cut-off frequency. Gas-source MBE is a suitable method for fabricating such a complicated structure because it can be done under low temperature and can control the compositional ratio of As and P atoms precisely.

The layer structure from the top surface was as follows: $In_{0.5}Ga_{0.5}As$ (10 nm)/InP(7-10 nm)/$In_{0.5}Al_{0.5}As$(10 nm)/n-$In_{0.5}Al_{0.5}As$:Si(12 nm, $N_{Si}=5x10^{18}$ $cm^{-3}$)/ $In_{0.5}Al_{0.5}As$(2 nm)/$In_{0.5}Ga_{0.5}As$(20 nm)/InAsP(5 nm)/InP(5 nm)/ $In_{0.5}Al_{0.5}As$(200 nm)/InAlAs buffer layer (<500 nm)/SI-GaAs substrate. The As composition in the InAsP sub-channel was changed from 0.12 to 0.3. (Fig.1) And a simple channel structure was also fabricated by growing a 30-nm-thick InGaAs layer.

Figure 2 shows a transmission-electron micrograph of the M-HEMT. It is clear that successful epitaxial growth occurred, because the dislocation-density above the lattice-strain-relaxed InAlAs buffer layer is low. The maximum hall mobility of the simple InGaAs channel M-HEMT is as high as 9660 $cm^2/Vs$ at room temperature, which is the same as that of a previously reported M-HEMT grown by solid-source MBE. The mobility of the composite channel M-HEMT ranged from 8600 to 9300 $cm^2/Vs$ as shown in Fig. 3. These high mobilities were obtained at the growth temperature range of 350-400 C, which was the same as the results of the solid-source MBE, regardless of the difference in group-V sources. The sheet-electron concentrations of both HEMTs are around $3x10^{12}$ $cm^{-2}$. Damage-less selective wet etching was performed using citric acid to remove the surface n-InGaAs until the stable InP. Although the surface of the M-HEMTs is far from flat and cross-hatched, the selectivity of etching is much greater than 100, which is high enough for gate-recess processing. The advanced M-HEMT structures grown by gas-source MBE are thus very promising for ultra-high-frequency devices from the viewpoints of quality, stability, and mass-productivity. Detailed HEMT performances including on-state breakdown voltages will be presented at the conference.

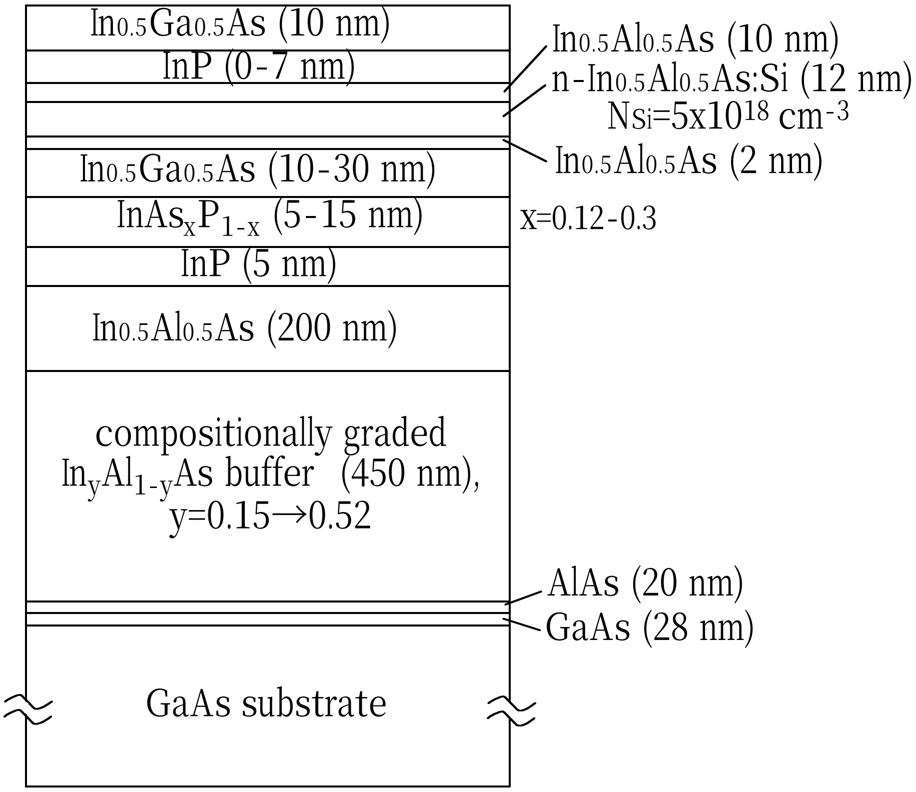


Fig. 1. M-HEMT structure for evaluation of crystalline quality.

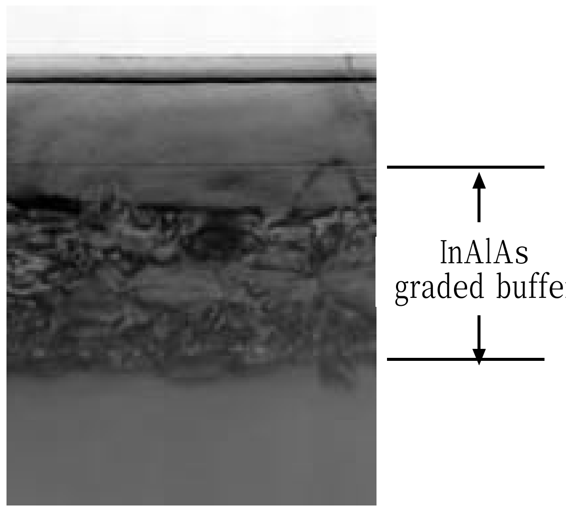


Fig. 2. Cross-sectional TEM micrograph of composite channel M-HEMT.

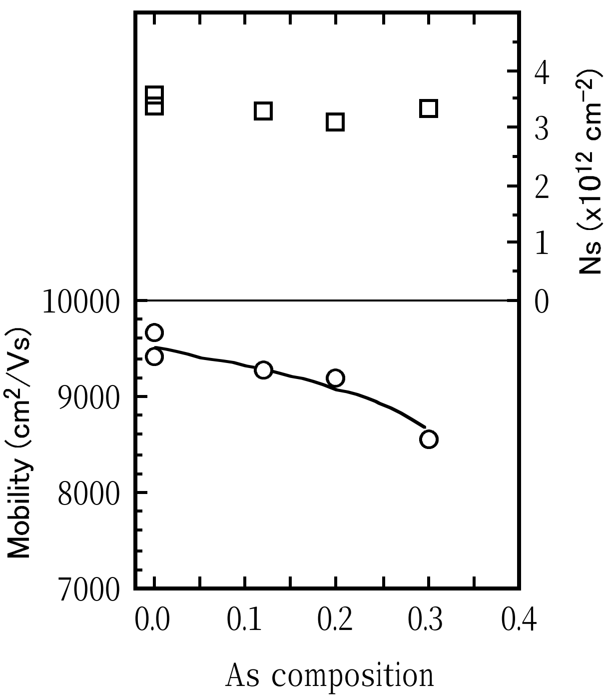


Fig. 3. Electric property variation against As composition in the InAsP sub-channel.