Large Diameter M-HEMT & InP-HEMT Epiwafers Grown in Multicharge MOVPE Reactors

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Abstract

Large diameter M-HEMT and InP-HEMT epitaxial wafers were fabricated in a lately installed Hitachi Cable's MOVPE reactor that was outfitted with mass production capability(8x4"or5x6").M-HEMTstructurewascombined with $In_{0.15}Ga_{0.85}P$ layer, which had the same lattice constant with $In_{0.36}Ga_{0.64}As$ channel and could be used for etch stop and/or surface passivation. Both of the M-HEMT and InP-HEMT wafers showed reasonable performance with abrupt etching selectivity, which will simplify device fabrication processed and realize high yield rates. Excellent uniformity overall the substrates was also achieved by optimizingatmospheresinsidethereactor.Thesewaferswill satisfactorymeetthedemandsinthenextgenerationlownoise and high power RF devices for wireless application and opto-electronic communication markets.

INTRODUCTION

The expansion of cellular phone market and upcoming demandsinmillimeter-waverangeoperationsinwireless-LAN, LMDS and ITS have stimulated the recent development of M(Metamorphic)-HEMT, which has the right characteristics for low noise and high power amplification at high frequency. Meanwhile, "wired" fiber-related components, in which 40Gbit/sec optic communication will be started in 2001, needs digital and analog integrated circuit with high maximum oscillation frequency. InP-HEMT and M-HEMT, which have high electron mobility and enough transport characteristics, are also indispensable devices for these high-speed ICs. Thus there is an impending need of large diameter epiwafers of M-HEMT and InP-HEMT, especially wafers grown by MOVPE (Metal Organic Vapor Phase Epitaxy), which has some advantages over the other epitaxial systems from the viewpoint of commercial application. At last year's MANTECH conference, we made the first report on the feasibility of M-HEMT wafers using MOVPE method [1]. Ourclient'srequestsmotivateustotransferthislaboratory level experimental technique into mass production technology. Inthisreport,wewillshowsuccessfuldevelopment inlargediameterM-HEMTwafergrowthusingHitachi-Cable's lately installed multi charge MOVPE reactor. The possibility of InGaP layer growth, which lattice matches to M-HEMT channel and will be used as etch stopper, is also explained. In addition, our capability of fabricating high uniformity InP-HEMT epiwafer, which is the precede alternative of M-HEMT, will be shown.

MANUFACTURING EQUIPMENT

We installed a new MOVPE system which had been designed to minimize the total epigrowth time and increase the number of holding wafers while maintaining clean surfaces, a contamination free epi/substrate interface, high doping efficiency, excellent uniformity and reproducibility reported before[2]. Theplanetaryconfigurationandthefacedownsystem were combined to improve throughput and realize these quality (Fig.1). The wafers, five 6" or eight 4", are loaded automatically from cassette to the reactor and set in a face down style. Gas then flows from the center of the bottom plate of the reactor. Both the susceptor (wafer holder) and the individual wafer rotate during the growth to achieve inside-wafer and wafer-to-wafer uniformity. The heating and cooling time are much reduced comparedtothatoftheconventionalhorizontal-flowtypereactor

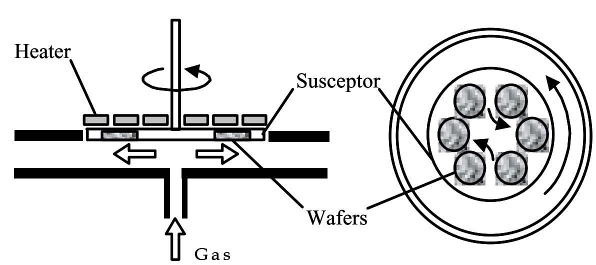

Fig. 1 System configuration of planetary and face-down MOVPE reactor used in this study. It was designed to rotate both the susceptor (wafer holder) and the individual wafer during the growth in order to improve uniformity.

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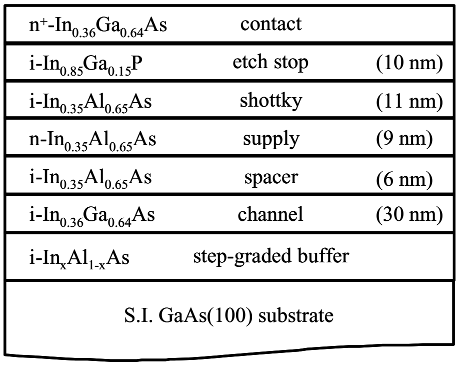

Fig. 2 Cross section of the structure of M-HEMT epiwafer used in this study.

due to the small thermal mass of the new reactor. These improvements in mass production reactors allow us to increase through put for mostof our products, including the M-HEMT wafers.

SAMPLE PREPARATION

All the samples were grown in MOVPE system mentioned above. Atmosphere in the reactor is low pressure (50 Torr) Hydrogen. Trimethylindium (TMI), trimethylaluminum (TMA) and trimethylgallium (TMG) were used as group III elements precursors, and both of arsine (AsH_3) and phosphine (PH_3) gases were chosen as group V sources. n-type doping is achieved by selenium, using H_2Se as a precursor. We need relatively high substrate temperature up to 700°C, in order to prevent impurity contamination into the InAlAs layer and accomplish superior morphology of the surfaces of epiwafers. Carriergasflowrateandsusceptorheaterbalancewereoptimized to achieve uniformity of indium composition in the epilayers. Figure 2 shows the cross sectional view of one of the M-HEMT epi structures grown on S.I. GaAs (100) substrate. The indium composition in each layer was determined by using 4-crystal XRD. Step-graded InAlAs buffer layers effectively decrease misfit dislocations and $In_{(x)}Ga_{(1-x)}As$ (indium mole fraction x=35-40%) channel layer will show high mobility, high sheet electron concentration and relatively high on-state breakdown voltages. In addition, an $In_{(y)}Ga_{(1-y)}P$ (indium mole fraction y=85-90%) etch-stop and passivation layer was inserted upon the InAlAs shottky layer. The phosphide layer has high etching selectivity, which can make device process more simple, improve Vp uniformity and realize high yield rates. It is also expected that phosphidesurface passivation layer leads to better noise figure and long-term reliability. In order to evaluate the ability to etch-stop, we grew an wafer with n-$In_{0.36}Ga_{0.64}As$(200nm)/ i-$In_{0.85}Ga_{0.15}P$(10nm)/ n-$In_{0.36}Ga_{0.64}As$(200nm) epistructure. This sample was etched by H_3PO_4:H_2O_2:DI water=1:1:10 solution and the change of sheet carrier concentration in this sample along with the etching time was plotted to calculated the etch rate and etching selectivity between the arsenide and phosphide layers. InP-HEMT, which also has InAlAs buffer/shottky and InGaAs channel layers, although the indium composition is higher (53%) than M-HEMT, was also grown on 4" semi-insulating M/A-COMInP(100) substrate, using the same growth condition with our M-HEMT. Electron mobility in both of M-HEMT and InP-HEMT were characterized by Van der Pauw measurement at room temperature.

RESULTS AND DISCUSSION

The dispersion of electron mobility in the 4-inch M-HEMT epiwafers are plotted in figure 3. The mobility in conventional P-HEMT was also added in the figure for comparison. M-HEMT wafer showed 8,000 cm^2/Vs mobility at $2.5x10^{12}cm^{-2}$ sheet carrier concentration, which was about 30% overtaking the mobility in P-HEMT epiwafer. The higher indium composition in InGaAs channel layer grown on step-graded InAlAs buffer layer in metamorphic epi structure realized this high electron transportation characteristic. Variation of the mobility in M-HEMT was 1.48%, meaning that high electron mobility was uniformly achieved overall 4-inch GaAs substrate. The mobility in InP-HEMT was also shown in figure 3. The value reached to 12,000 cm^2/Vs at room temperature and its diagonal uniformity was also sufficient.

Figure 4 shows the result of etch-stop characterization. $In_{0.36}Ga_{0.64}As$ layer was etch during the first 30 second at etch rate of 6.7 nm/sec, and then InGaP layer appeared to surface, where etch rate was reduced to 0.167nm/sec. It is understood that etch speed was abruptly changed at the InGaAs/InGaP interface and enough etching selectivity was obtained. The growth of phosphide layers with abrupt interfaces is one of our

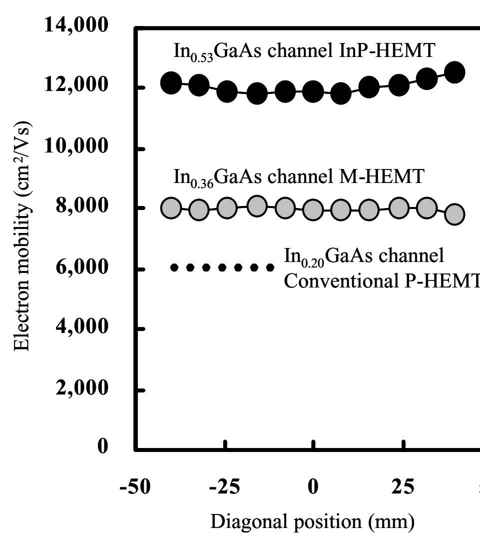

Fig. 3 Electron mobility in $In_{0.36}Ga_{0.64}As$ channle M-HEMT and $In_{0.53}Ga_{0.47}As$ channel InP-HEMT epiwafers grown by MOVPE. Both of them were grown on 4 inch substrates. Mobility in conventional P-HEMT was also shown for comparison.

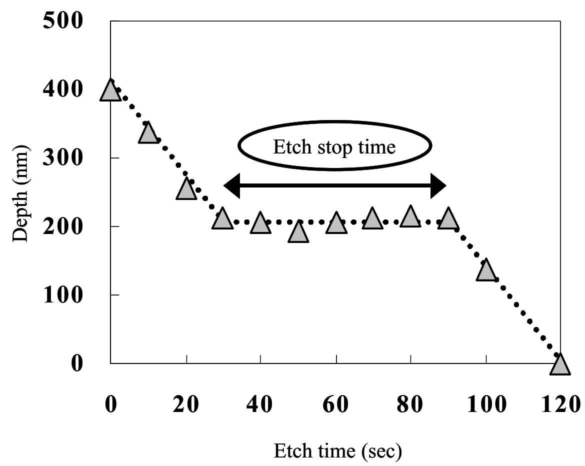

Fig. 4 Etching depth as a function of etch time. n-$In_{0.36}Ga_{0.64}As$(200nm)/ i-$In_{0.85}Ga_{0.15}P$ (10nm)/n-$In_{0.36}Ga_{0.64}As$ (200nm) etch-stop test structure grown on metamorphic buffer layer was etched by H_3PO_4:H_2O_2:H_2O = 1:1:10 solution to evaluate the etching selectivity between InGaAs and InGaP.

greatest assets with MOVPE, compared with solid source MBE that has difficulty in phosphide epi growth.

CONCLUSIONS

We are now ready to supply M-HEMT epiwafer with InGaP etch-stop & passivation layer and InP-HEMT epiwafer by using our new multicharge high throughput MOVPE reactor in mass production line. Both of 4 inch M-HEMT and InP-HEMT wafers showed reasonable electric characteristics and excellent uniformity. These waferes will satisfactory meet the demands in the next generation low noise and power RF devices for wireless application markets.

REFERENCES

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[2] Y. Otoki et. al., Digest of MANTECH 98, Seattle, (1998) p.137