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Integration of a HEMT and a MSM PD Using an InGaAsP(λ=1.3 ㎛) Buffer

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1. Introduction

Recently, the devices for the short distance optical communication have drawn much attention with the introduction of the Fiber To The Home (FTTH). The key issue for the FTTH is low cost device manufacturing for individual subscribers. A good method to reduce the cost is the device integration in a single step grown epitaxial layers. Up to now, many ideas are published and the results are categorized by 3 structures. The first is stacking of two different device structures in a single step growth [1] and the second is using two step growth of epitaxial layers [2]. The third one has some layers which are shared by different devices [3]. The first two methods seem to be costly, and the last method is attractive but mainly done with the HBT and p-i-n PD integration. So here, we suggest another integration of a High Electron Mobility Transistor (HEMT) and a Metal-Semiconductor-Metal Photo-Detector (MSM PD) using an InGaAsP(λ=1.3 ㎛) buffer layer, which is categorized as a third method.

The advantages of the integration of a HEMT and a MSM using InGaAsP buffer is that there is no need of additional layer for the MSM PD, just the buffer material is exchanged by InGaAsP, and no additional process steps are required, compared to a conventional HEMT technology. InGaAsP can absorb the 1.3 ㎛ light used in a short distance optical communication and the thickness of the buffer has minor effects on HEMT characteristics, so the thickness of epitaxial layers are controlled independently.

2. Experimental

Epitaxial layers structure

The device layers consist of a highly n-doped 300 Å thick InP contact layer, an 140 Å thick InAlAs barrier layer, a 60 Å n-doped InAlAs doping layer and a 30 Å thick InAlAs spacer layer, a 200 Å thick InGaAs channel layer, and a 3200 Å thick InGaAsP(λ=1.3 ㎛) buffer. All ternary and quaternary layers are lattice matched to InP.

Generally, most of the 2-Dimensional Electron Gases (2DEG) in an InGaAs Quantum Well (QW) of a HEMT are confined in first two energy states. If the band offset at the InGaAs channel and a buffer is larger than the second energy level of confined electrons, then the structure can confine almost all 2DEG and can perform the HEMT operation with little degradation of device performance.

When the InGaAsP (λ=1.3㎛) is used as a buffer, the band offset between the InGaAs channel and the buffer is 90 meV and the second energy state of electrons in the 200 Å thick InGaAs QW is located below 50 meV from the InGaAsP conduction band edge at the QW side.

In this study, InP is used for a contact layer. The doping concentration of the layer is $2x10^{19}$ cm^{-3} confirmed by Hall and SIMS measurements. Because InP and InAlAs are etched selectively by a H_3PO_4:HCl etching solution, we expect this structure will enhance the process reliability.

The doping concentration of the InAlAs doping layer is $2x10^{18}$ cm^{-3} and the concentration of the generated 2DEG is $2.5x10^{12}$ cm^{-2} and the mobility is 10575 ㎠/V·sec. In this Hall sample, we used InP as a buffer.

Device Fabrication

We have used the LP-MOCVD to grow the epitaxial layer structure. The InP, InGaAsP, and InGaAs layers were grown at 650℃ and the InAlAs layer was grown at 670℃. The reactor pressure was 20mbar.

For the HEMT fabrication, Ti(400 Å)/Pt(150 Å)/Au (1500 Å) were evaporated for an ohmic contact to the InP layer and then mesa etching for the device isolation was followed. In mesa etching, the H_3PO_4: HCl etching solution was used for the InP and the H_3PO_4:H_2O_2:H_2O etching solution was used for the InAlAs, InGaAs, and InGaAsP layers. The Pt(200 Å)/Ti(50 Å)/ Pt(200 Å)/Au(2000 Å) gate metal was evaporated after the InP ohmic layer had been removed.

For the MSM PD fabrication, first the InP ohmic layer was removed by H_3PO_4:HCl etching solution and a gate metal used for the HEMT technology was evaporated. No anti-reflection coating was done. The final integrated device structure is shown in the Fig. 1.

Measurements and Discussions

The Fig. 2 and Fig. 3 show DC characteristics of the fabricated HEMT. To investigate the effects of the buffer, the measurement results of an InP Buffer HEMT is included as a dashed line. The InP Buffer HEMT has same epitaxial layers as the InGaAsP Buffer HEMT except InGaAsP (λ=1.3 ㎛) is exchanged by InP for the buffer.

The InGaAsP Buffer HEMT shows almost same currents level near Vgs = 0.2 V where the DC g_m has maximum value and 6% decreased maximum g_m value compared to the InP Buffer HEMT. From these results, we confirm that the InGaAsP buffer does not degrade the HEMT performance so much and have comparable performance to the InP buffer.

The turn-off characteristics are not good in two devices. We have found the reason from the SIMS measurements. Si layer with a concentration of $1x10^{18}$ cm^{-3} is detected at the interface between the epitaxial layer and the substrate. As a result of this, a thin layer of highly conductive channel is formed and the energy band profile of the buffer is bended like a bow. Therefore, there would be a hill between the InGaAs channel and the conductive channel at that interface and the currents would flow in this conductive channel under high negative gate bias. This effect is severe for small band-gap materials because the height of the hill would be low. In this study, the InGaAsP buffer is affected more than the InP buffer.

The RF characteristics, f_T and f_{max}, of the InGaAsP Buffer HEMT are f_T = 9 GHz and f_{max} = 33 GHz (measured at Vgs=-0.15 V and Vds=3.5 V), and the InP Buffer HEMT has f_T = 11 GHz and f_{max} = 33GHz (measured at Vgs=0.0V and Vds=3.5V). These low RF characteristics are due to the non-optimized InAlAs barrier layer thickness. The 140Å thick InAlAs barrier layer is too thin, so the DC g_m peak values are in near Vgs=0.2 V and the reverse leakage currents are so large which is shown in the Fig. 4, the MSM PD characteristics.

The Fig. 4 shows the MSM PD photo-response characteristic. the active area is 120 ㎛ x 100 ㎛ (2.5㎛ wide finger and 20 ㎛ wide spacing). The large dark currents are due to the thin InAlAs barrier layer. The responsivity shows saturation characteristic as λ=1.3 ㎛ light power is increased. The maximum responsivity is 0.18 at 210 ㎼ light power with 5 V bias. But if the dark currents are reduced more by optimizing the InAlAs barrier layer thickness, the responsivity would be enhanced at lower light power.

3. Conclusions

In this paper, we propose new integration of a HEMT and a MSM PD using an InGaAsP buffer layer. The InGaAsP Buffer HEMT has comparable performance to the InP Buffer HEMT and the MSM PD works well. Although there are some problems on the InAlAs barrier layer thickness and the interface between the epitaxial layers and the substrate, these problems are irrespective to the epitaxial layer structure so we can expect this integration scheme would be another candidate for the device integration method for the short distance optical communication.

Acknowledgements

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References

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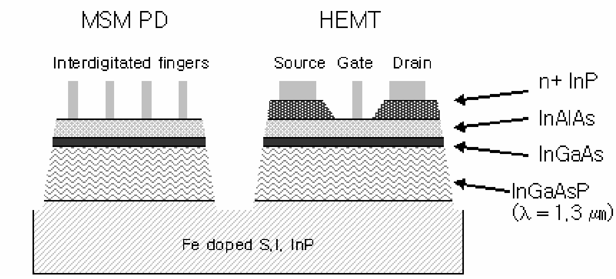

Fig. 1 A integration scheme for a HEMT and a MSM PD

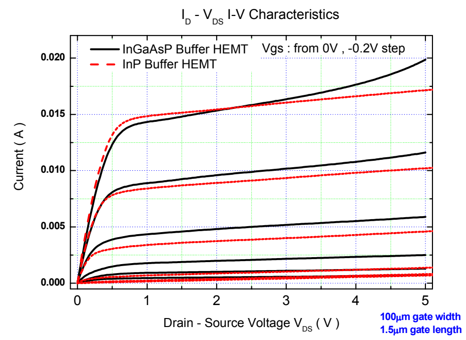

Fig. 2 The HEMT I_D-V_{DS} characteristic

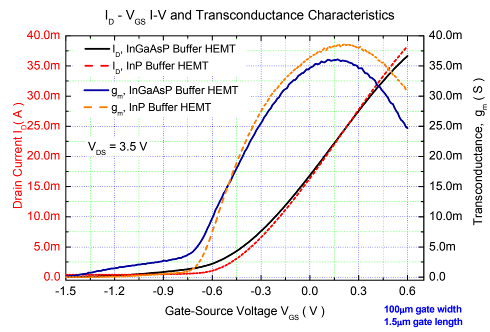

Fig. 3 The HEMT I_D-V_{GS} and g_m characteristic

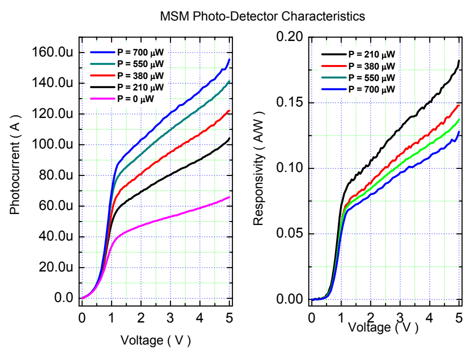

Fig.4 The MSM PD characteristics. The PD area is 120x100 $㎛^2$ and the finger width and spacing are 2.5 ㎛ and 20 ㎛ respectively. The light source was λ=1.3㎛ Fabry-Perot laser