Photoresponse of InAlAs/InGaAs Metamorphic HEMT on GaAs substrate with Composite Channel

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***Abstract**: We report photoresponse characteristics of InAlAs/InGaAs/GaAs metamorphic HEMT on GaAs substrate with composite channel for the first time. The HEMT with the high photoresponsivity which cannot be obtained in conventional photodiode is expected to be utilized for monolithic integrated 1.55μm optical receivers.*

I. Introduction

The photodetection characteristics of indium phosphide based HEMTs (InP HEMTs) have been extensively studied for the development of high-speed 1.55μm optical receivers [1]. However, low photoresponse of InP HEMTs under 1.55 μm optical illumination severely limits the sensitivity of the devices, thereby makes it difficult to utilize these devices as a 1.55 μm photodetector. Moreover, low breakdown characteristics of InP HEMTs and difficulties in fabrication on the fragile InP substrate remain as severe obstacles for the integration with the other micro/millimeter-wave circuits.

In this work, we fabricated the metamorphic InAlAs/InGaAs HEMT on GaAs substrate with composite channel [2] and measured 1.55 μm optical characteristics for the first time. It is shown that the metamorphic HEMT with the $In_{0.53}GaAs/In_{0.35}GaAs$ composite channel has very large photoresponsivity at low optical incident power, which cannot be obtained in conventional photodiode.

II. Experimental Setup

The metamorphic InAlAs/InGaAs HEMT was fabricated with the heterostructure epitaxial layers grown on semi-insulating GaAs substrate by using molecular beam epitaxy (MBE), as shown in Fig. 1. The fabricated metamorphic HEMT have the $In_{0.53}GaAs/In_{0.35}GaAs$ composite channel in order to improve carrier transport characteristics without sacrificing breakdown voltages for high power gain.

The photoresponse of the metamorphic HEMT was measured by utilizing the semiconductor parameter analyzer and 1.55μm DFB laser diode. It should be noted that the $In_{0.35}Al_{0.65}As$ barrier is transparent to 1.55μm lightwave, thus the absorption occurs at only 10nm $In_{0.53}GaAs$ channel.

III. Results and Discussion

The measured I_D-V_D characteristics for the metamorphic HEMT with and without the 1.55 μm illumination are shown in Fig. 2. The metamorphic HEMT exhibits the significant increase in drain-current (I_D) under 1.55μm optical illumination. The origin for the increase in drain-current is considered to be due to the photovoltaic effect caused by the increase of photo-generated holes beneath the source area [2].

In order to verify the photodetection mechanism, the photovoltaic effect, we measured the threshold voltage shift under different incident optical powers. It should be noted that the actually absorbed optical power in the HEMT is less than 10% of the incident power because of the reflection at the T-shaped gate metal and the passivation layer. Threshold voltage was extracted by extrapolating the linear region of I_D-V_G characteristics into the V_G axis and defined as the interception voltage at V_G axis.

As explained in [2], the optically induced voltage shift is regarded as the major origin in the increase of drain current. The optically induced photovoltage can be simply expressed as following equation.

$$V_{ph} = \frac{nkT}{q}\ln(1+\frac{\eta q P_{opt}}{I_{dark,hole} h\nu}) \qquad (1)$$

where,

η	quantum efficiency;
$I_{dark,hole}$	dark current for holes
P_{opt}	incident optical power
n	fitting parameter

In Fig.3, threshold voltage shift (-□-) under various optical powers is plotted. The points are measured data and the line is fitted to the equation (1). We clearly observe that V_T shift is logarithmic in the optical power. If optically induced threshold voltage shift is the major origin for the increase of driving current in the HEMT under 1.55μm optical illumination, photocurrent (ΔI_D) caused by the change of threshold voltage is given by

$$\Delta I_D = G_m \Delta V_{TH} \qquad (2)$$

where G_m is intrinsic transconductance.

The symbol (-●-) indicates the measured photocurrent (I_D(illuminated)-I_D(dark)) of the HEMT. Otherwise, the symbol (-○-) is predicted by the equation 2 incorporating with the measured threshold voltage shift and intrinsic transconductance of 39.7mS. From the result that the measured photocurrent coincides with the calculated photocurrent, we conclude that major photodetection mechanism in the HEMT is the optically induced threshold voltage shift caused by the optically generated holes which diminish the potential barrier between the source and the gate.

The optical responsivity as a function of optical power is shown in Fig.4. In these results, it is noted that the responsivity of the metamorphic HEMT with composite channel is much larger than that of any other reported works in InP HEMTs in spite of high insertion loss at the illumination. This is believed to arise from the optical absorption in thin (100Å) double heterojuntion composite channel which effectively confines the photogenerated carriers in active channel.

V. Conclusion

The 1.55μm photoresponse characteristics of the metamorphic HEMT with the composite channel were investigated. The physical mechanism for photocurrent was experimentally verified. The high optical responsivity of the HEMT was obtained, particularly at low optical power. The metamorphic HEMT which have the high photoresponsivity as well as the structural inherent advantages including high breakdown characteristics and the availability of low cost 2- to 4-in GaAs substrate is regarded as the promising high optical gain phototransistor for 1.55μm optical receivers.

References

[1] Y. Takanashi et al., IEEE TED, pp.2271, 1999

[2] M. Chertouk et al., IEEE EDL, pp.273, 1996

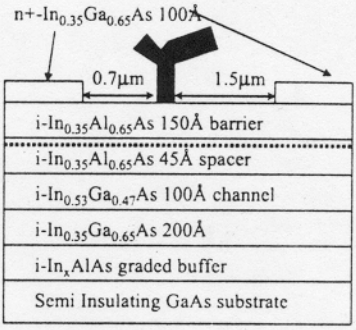

Fig.1. Epitaxial structure of the metamorphic HEMT

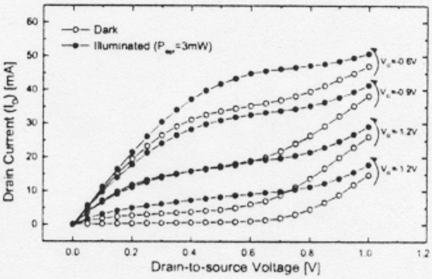

Fig.2. I_D-V_D characteristics of the HEMT under optical illumination and dark

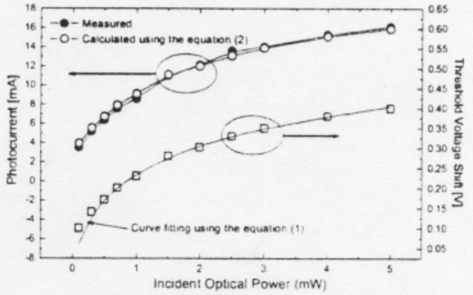

Fig.3. Measured, calculated photocurrent and threshold voltage shift as a function of incident optical power.

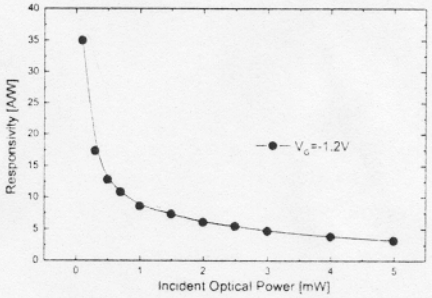

Fig.4. Photoresponsivity of the metamorphic HEMT as a function of incident optical power