W-band Penta-Composite Channel InAlAs/InGaAs Metamorphic HEMT for High Power Application and Comparison with Pseudomorphic HEMT

Partha Mukhopadhyay¹ (Member, IEEE), Sudip Kundu¹ (Member, IEEE), Palash Das¹ (Member, IEEE), Saptarshi Pathak¹ (Member, IEEE), Edward Y. Chang² (Senior Member, IEEE) and Dhrubes Biswas¹ (Senior Member, IEEE)

¹Department of Electronics and Electrical Communication Engineering, Indian Institute of Technology – Kharagpur, India
²Department of Material Science and Engineering, National Chiao Tung University, Hsinchu, Taiwan

partha@ece.iitkgp.ernet.in, Ph: +91-9434502268

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Abstract

Advance device design of novel penta-composite channel of 0.25 μm InAlAs/InGaAs MHEMT has been reported for the first time in composite channel HEMT. Highest Indium mole fraction of 0.78 in channel and total channel thickness of 140 Å was found to be an optimized structure. It has both higher \( I_D \) of 1029 mA/mm and flatter gm of 648 mS/mm at \( V_{DS} \) of 1.3 V. AC analysis results \( f_t \) of 125 GHz and \( f_{max} \) of 250 GHz, which makes the device useful for W-band Power amplifier applications. Comparison between MHEMT and PHEMT has also been emphasized with respect to transconductance (gm) and drain current (\( I_D \)).

INTRODUCTION

Superior carrier transport and other favorable electronic properties of InAlAs/InGaAs High Electron Mobility Transistor (HEMT) have the capability to achieve high power at very high frequency with high linearity. The prime motivation behind the increasing Indium mole fraction in channel is to increase conduction band discontinuity by reducing the bandgap of the channel. It increases the quantum well depth, confining more carriers in the channel, leading to rise in the possibility of forming multiple sub-band energy levels in quantum well below the equilibrium Fermi level, hence almost complete removal of three-dimensional carrier movement effects. Higher Indium percent in the material also has lower electron effective mass which enhances the mobility. However, higher Indium in channel results in phase in-homogeneities due to the onset of kink effect while second next channel layer (x ~ 0.65) helps to introduce further Indium content in the middle channel and middle In\(_x\)Ga\(_{1-x}\)As (x ~ 0.78) channel layer improves the electron mobility under low electric field.

Fig 1: In\(_{0.78}\)Ga\(_{0.22}\)As penta-composite channel structure MHEMT
RESULT AND DISCUSSIONS

We have designed the optimized penta-composite channel InAlAs/InGaAs structure, keeping in view the Matthews and Blakeslee model [4]. This aggressive channel design has been implemented, with Indium mole fraction as in Fig 1 with varying total channel thicknesses between 120Å to 250 Å. 140 Å has been found to be optimum with average Indium mole fraction of 0.7; resulting in high ΔEc i.e. further confinement of free carriers in quantum well (QW). The transfer characteristics of 0.25 μm MHEMT is shown in Fig 2, where gm is 648 mS/mm at VDS of 1.3 V. The output characteristic is shown in Fig 3 with output saturation current (Ids) of 1029 mA/mm. At saturation the value of drain resistance, RdS = dVd/dIds ≈ 10kΩ and increases to 74 kΩ at VD of 5 V.

By varying channel thickness we have studied the same structure, with respect to gm and output saturation current for two different values of delta doping (9 × 10 18 / 3 × 10 18 cm-3 and 8 × 10 18 / 2 × 10 18 cm -3 top/bottom respectively). The comparative results are shown in Fig 4, from where it can be said that 140 Å channel structure is the optimized one among others. Though 120 Å has greater gm but it has much lower current which can be due to the scattering effect in narrow channel width. On the other hand in QW, 3D effect may arise in case of wider channels and result in lower current and gm.

The cut-off frequency fT is estimated at 125 GHz and the expected maximum frequency of oscillation fmax is 250 GHz as shown in Fig 5.

Table 1 shows the summary of the comparative results of the all optimized structure created in our design environment. It helps to determine the optimized structure and get the optimized values of both Id and gm for each structure.
Table 1: Comparative study among the optimized structures

<table>
<thead>
<tr>
<th>Material Scheme</th>
<th>Diff. Channel Structure scheme</th>
<th>Optimized structure</th>
<th>$I_D$</th>
<th>$g_m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>AlGaAs/InGaAs/AlGaAs PHEMT (varying from 100 Å to 250 Å)</td>
<td>Single (In% - 22) &amp; Three channel (In% - 22/35/22 top/mid/bottom)</td>
<td>120 Å tri-composite channel</td>
<td>525 mA/mm</td>
<td>440 mS/mm</td>
</tr>
<tr>
<td>InAlAs/InGaAs/InAlAs Metamorphic HEMT (varying from 100 Å to 250 Å)</td>
<td>Single (In% - 53) and Three channel (In% - 53/67/53 top/mid/bottom)</td>
<td>100 Å tri-composite channel</td>
<td>760 mA/mm</td>
<td>640 mS/mm</td>
</tr>
<tr>
<td>InAlAs/InGaAs Penta-Composite channel Structure</td>
<td>Penta-Composite channel</td>
<td>140 Å penta-composite channel</td>
<td>1029 mA/mm</td>
<td>648 mS/mm</td>
</tr>
</tbody>
</table>

Ratio of third-order sideband power to fundamental power (IP3) is proportional to $(g_{m''}/g_m)$. Reduction of this ratio (close to zero) presents improvement in linearity of the devices [7]. The comparative study of $g_m$ and IP3 curve among these three optimized structures, as defined in Table 1, is shown in Fig 6 and 7 respectively. The results show that in both cases, 140 Å penta-composite channel MHEMT is better than conventional PHEMT as well as three-channel MHEMT.

Since we are involved in optimization of design of multi-channel FETs for delivering superior Power, frequency and linearity performance in one structure, it is rather important for our model to be sensitive to the several alloy compositions of the alternate barrier and channels for both lattice matched and mismatched structure.

**CONCLUSION**

We have designed InAlAs/InGaAs metamorphic HEMT with multi-layer channel structure to achieve high current of 1029 mA/mm and high $g_m$ of 648 mS/mm while operating at high frequency, $f_T$ of 125 GHz and $f_{max}$ of 250 GHz. This structure shows high drain resistance i.e. less fluctuation at high voltage and high linearity than conventional PHEMTs and MHEMTs. Our structure has gate length, $L_g$ of 0.25 μm, which is much higher than current technology, while achieving very high $f_T$, which is remarkable. It can be attributed to the efficient device structure and choice of materials. This higher gate length leads to lower process costs with high performance devices which can be valuable for low cost wireless / space communications.

**REFERENCES**


