25nm InP HEMT TMIC Process with 1 THz Amplifier Circuit Gain


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Abstract

We report a 25nm InP HEMT which achieves 4 dB maximum available gain at 1 THz and a gain of 9 dB at 1 THz for a 10 stage circuit. This achievement is based on a new state-of-art transistor which demonstrates a peak cutoff frequency \( f_C \) of 725 GHz and an estimated maximum frequency of oscillation \( f_{\text{MAX}} \) of 1.5 THz.

1. Introduction

Rapid progress has been made in the realization of high frequency transistors and circuits. [1-7] Terahertz Monolithic Integrated Circuit (TMIC) compatible processes with a cutoff frequency \( f_C \) > 600GHz [1] and a maximum frequency of oscillation \( f_{\text{MAX}} \) approaching or exceeding 1 THz have been reported [1-5].

Our recent work has focused on scaling our InP HEMT process to 25 nm, which has further increased transistor and integrated circuit frequencies. TMIC amplifiers using this process have been reported at 0.67 THz [6] and 0.85 THz [7]. In this letter, we report on \( f_C \) and \( f_{\text{MAX}} \) capabilities of this recently developed 25 nm InP HEMT process. We also report achieving measured on-wafer circuit gain at 1.0 THz.

2. 25nm InP HEMT Process

Our TMIC process starts with epitaxial layers grown using Molecular Beam Epitaxy (MBE) on 3-inch semi-insulating InP wafers. Room temperature mobility of 13000 cm\(^2\)/Vs and an Ns of 4.0e12 cm\(^-2\) are typically obtained by Hall measurements.

The transistor was processed with a Ti/Pt/Au-based non-alloyed metal stack as the Ohmic contact and a source to drain distance at 0.5µm, only 0.1µm wider than the gate top which is 0.4µm. A contact resistance (Rc) of 40mΩ.mm and a source resistance as low as 140 mΩ.mm is demonstrated with this process.

Electrical parameters are listed in Table 1. The device shows excellent pinch-off characteristics and controlled output conductance to Vds=1.0V. A peak transconductance \( g_{\text{m}} \) of 3.0 S/mm is measured. An on-

3. Transistor characterization

The dc Electrical parameters are listed in Table 1. The device shows excellent pinch-off characteristics and controlled output conductance to Vds=1.0V. A peak transconductance \( g_{\text{m}} \) of 3.0 S/mm is measured. An on-

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state breakdown voltage ($V_{\text{on, state}}$) of 2.2V and off-state breakdown voltage ($V_{\text{off, state}}$) of 3.0V is typical for this process.

Microwave measurements have been taken on a 1 to 110 GHz probe station on a two finger 30µm device biased at $V_d = 0.8V$ and $I_d = 600$ mA/mm. This gives an $f_T$ of 725GHz by extrapolating $|h_{21}|$ to unity with a -20dB/decade slope (Fig. 3). Shown in Fig. 4 is the MAG/MSG measured on a two finger 10µm device biased at $V_d = 1.2V$ and $I_d = 450$ mA/mm. The measurement was carried out for three different frequency bands, i.e. 20GHz-110GHz, 500GHz-700GHz and 750GHz-1.0THz, respectively. An $f_{\text{MAX}}=1.5$THz is estimated. 4 dB of maximum available gain is measured at 1.0 THz frequency, making this transistor capable of amplification at this frequency.

| $R_s$ | 0.04 Ω.mm |
| $R_e$ | 0.14 Ω.mm |
| $G_{m, p}$ ($V_d=1V$) | 3.0 S/mm |
| $V_c$ ($V_d=1V$) | -0.1V |
| $V_e$ (off-state) | 3.0V |
| $V_e$ (on-state) | 2.2V |
| $f_t$ | 0.725 THz |
| $f_{\text{MAX}}$ | 1.5 THz |

Table 1. Electrical parameters of a 25 nm transistor.

Fig. 3 The $h_{21}$ of a 2-finger 30µm device biased at $V_d=0.8V$ and $I_d=600$ mA/mm showing an $f_t=725$ GHz.

Fig. 4 The MAG/MSG of a 2-finger 10µm device biased at $V_d=1.2V$ and $I_d=400$ mA/mm.

4. TMIC amplifier Demonstration

A 10-stage amplifier circuit was designed with 8 µm transistors for each stage. The design is based on a grounded coplanar single-ended common source configuration. A picture of the completed circuit is provided in the inset of Fig. 5.

The TMIC was measured on-wafer using a test set which consists of WR1.0 frequency extenders covering 750-1100 GHz interfaced with a Rohde and Schwarz Vector Network Analyzer. The measurement results are shown in Fig. 5. 9 dB gain was measured at 1.0 THz, making this the first demonstration of transistor amplifier gain at and above the 1.0 THz mark.

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References

[1] D-H. Kim et al. “$f_T = 688$ GHz and $f_{\text{MAX}} = 800$ GHz in Lg = 40 nm In0.7Ga0.3As MHEMTs with $g_{\text{m, max}} > 2.7$ mS/µm”, Electron Devices Meeting (IEDM), 2011


