AlInAs/GaInAs ON InP HEMT LOW NOISE MMIC AMPLIFIERS

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Abstract

We have developed AlInAs/GaInAs on InP HEMT single-stage low-noise MMIC amplifiers for operation at 12 GHz, 35 GHz, and 60 GHz. A noise figure of 0.78 dB with associated gain of 15 dB was achieved at 12 GHz. This is the lowest noise figure yet reported for a monolithic amplifier at 12 GHz. A noise figure of 1.2 dB with gain greater than 12 dB was obtained from 10 to 14 GHz. At 35.5 GHz, we have obtained 13 dB gain with 17 dB input return loss. At 55 GHz, we have obtained 8 dB gain with more than 12 dB input return loss.

Introduction

In recent years InP-based HEMTs have demonstrated record low-noise [1,2] and high frequency performance [3,4]. The integration of these transistors into monolithic microwave and millimeter-wave integrated circuits (MMICs) is important for savings in cost and size as well as for performance enhancements due to the lower losses of shorter line lengths, reduced parasitics, etc.

This paper describes a family of monolithic low-noise InP based single-stage HEMT amplifiers designed for operation at 12 GHz, 35 GHz, and 60 GHz, which demonstrate the feasibility of this technology for MMIC applications. The amplifiers employ off-chip biasing to ease testing at the wafer level.

Device Structure

A schematic cross-section of the device structure is shown in Figure 1. The AlInAs/GaInAs HEMT structure was grown on a Fe-doped semi-insulating (100) InP substrate. An undoped AlInAs buffer layer is used to separate the active channel from the epitaxial layer-substrate interface. It also provides a high-bandgap barrier to ensure a sharp device pinch-off. The active layer is an undoped 400 Å thick GaInAs layer. It is followed by a 15 Å thick undoped AlInAs spacer layer and an 80 Å thick heavily doped AlInAs donor layer ($n=5\times10^{18}cm^{-3}$). A 200 Å undoped AlInAs layer is then incorporated to enhance the Schottky barrier height of the gate. Finally, the structure is capped by a heavily doped GaInAs contact layer. The sheet-charge density and the mobility, measured at 300 K, are approximately $3\times10^{12}cm^{-2}$ and $10,000cm^2V^{-1}s^{-1}$, respectively.

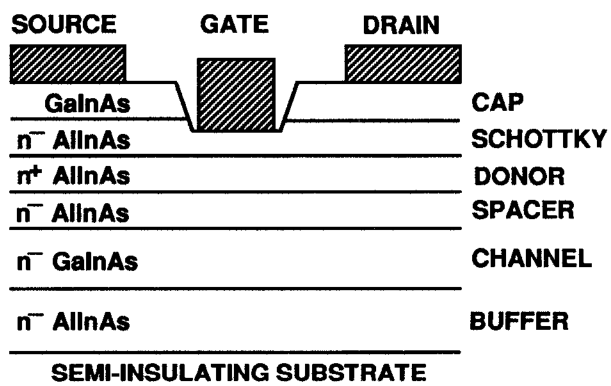

Figure 1: Cross-section of AlInAs/GaInAs on InP HEMT

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The gate is 0.15μm long and T-shaped for low series resistance. The gate is defined by a bi-layer electron-beam resist scheme. The gate recess was carried out by by an citric-acid-based wet etch. The gate contact was formed using Ti/Pt/Au metal. A wet-etched backside via process is employed for low inductance grounds.

Device Performance

Initial determination of device performance and design parameters was accomplished by a combination of S-parameter and noise parameter measurements. S-parameter measurements were measured from 0.045 to 26.5 GHz using a Hewlett-Packard 8510 Automatic Network Analyzer. Noise analysis was carried out by using an Automatic Testing and Networking (ATN) noise parameter measurement system from 2-18 GHz. All measurements were made "on-wafer" using Cascade Microtech microwave probes.

A plot of minimum noise figure and associated gain for a 300μm gate width device is shown in Figure 2. The minimum noise figure at 12 GHz is 0.38 dB with an associated gain of 14.5 dB. The equivalent noise resistance, R_N, which determines the variation of noise-figure due to changes in the source impedance, is 9.5Ω. The unity short circuit current gain frequency, f_T, for the devices is 124 GHz at the low-noise bias.

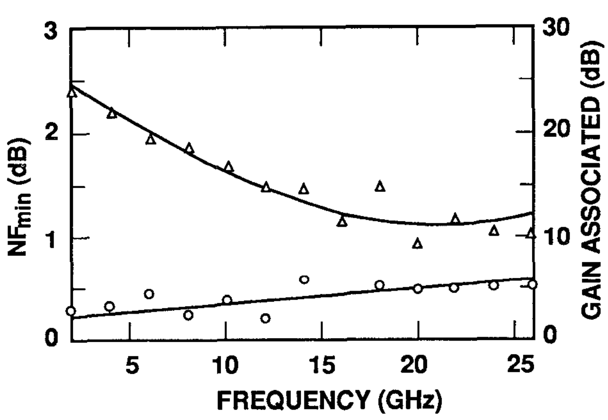

Figure 2: HEMT minimum noise figure and associated gain vs. frequency

Amplifier Design and Performance

The amplifiers were designed using a combination of S-parameter and noise parameter data. The 12 GHz amplifier was designed by synthesizing the optimum source impedance for minimum noise figure and optimum output match for maximum gain using single open-stub microstrip impedance transformers.

The predicted performance of the 12 GHz amplifier is shown in Figure 3 and the measured results are shown in Figure 4. The minimum noise figure is 0.78 dB at 11.8

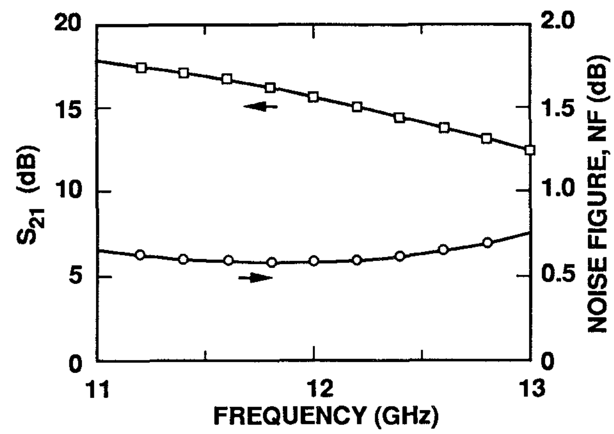

Figure 3: Predicted noise figure and gain of 12 GHz amplifier

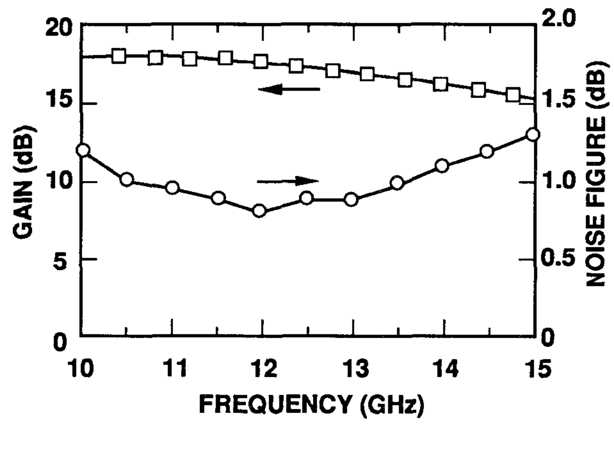

Figure 4: Measured noise figure and gain of 12 GHz amplifier

GHz and the noise-figure is less than 1.2 dB from 10 to 14 GHz. This is the lowest noise-figure reported for a monolithic amplifier at these frequencies. In addition, the associated gain is between 12 dB and 16 dB over the same frequency range. The 35 GHz and 60 GHz amplifiers were designed using an equivalent circuit model of the device, which was extracted from the measured S-parameters. Due to the difficulty in measuring noise parameters at these frequencies, the devices were impedance matched for maximum gain at the low-noise bias conditions, using open-stub microstrip networks. Since the value of equivalent noise resistance, R_N, is so low for these devices, the resulting degradation in noise performance was not expected to be severe.

A microphotograph of the resulting fabricated 35 GHz amplifier appears in Figure 5. The measured gain and input return loss appears in Figure 6. The peak gain

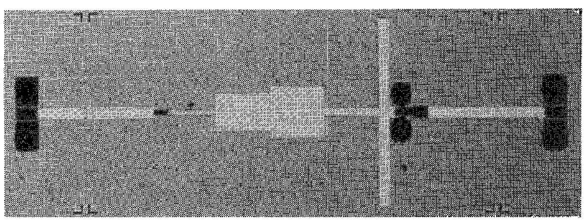

Figure 5: Microphotograph of 35 GHz amplifier

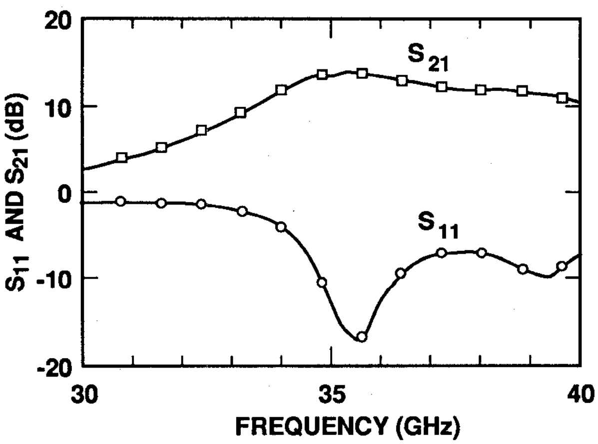

Figure 6: Measured gain and input return loss of 35 GHz amplifier

of the single-stage circuit is 14 dB at 35.5 GHz and the input return loss is -17 dB. Figure 7 shows the measured gain and input return loss of the fabricated 60 GHz amplifier. The peak gain is 8 dB at 55 GHz and the input return loss is more than 12 dB.

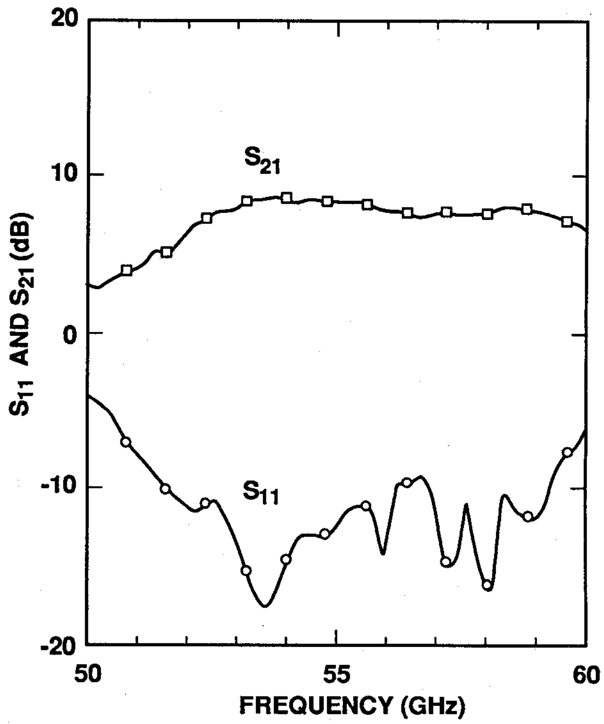

Figure 7: Measured gain and input return loss of 60 GHz amplifier

Summary

AlInAs/GaInAs on InP HEMT 12 GHz, 35 GHz, and 60 GHz single-stage monolithic low-noise amplifiers have been developed. These circuits are intended to demonstrate the potential of this technology for MMIC applications. At 12 GHz, we obtained a noise figure of 0.78 dB with an associated gain of 15 dB. The noise-figure was less than 1.2 dB from 10 GHz to 14 GHz. At 35 GHz, we obtained a gain of 14 dB with an input return loss of -17 dB. At 55 GHz, we obtained a gain of 8 dB with an input return loss of more than 12 dB.