A 140-GHz Monolithic Low Noise Amplifier

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Abstract—**This paper presents the development of a 140-GHz monolithic low noise amplifier (LNA) using 0.1-μm pseudomorphic InAlAs/InGaAs/InP low noise HEMT technology. A two-stage single-ended 140-GHz monolithic LNA has been designed, fabricated and tested. It exhibits a measured small signal gain of 9 dB at 142 GHz, and more than 5-dB gain from 138–145 GHz. This is the highest frequency monolithic amplifier ever reported using three terminal devices.**

I. Introduction

MILLIMETER-WAVE (MMW) low noise amplifier (LNA) is a very important component for smart munitions, passive imaging and radiometer applications. The pseudomorphic (PM) HEMT devices using both GaAs and InP materials have demonstrated the high gain and low noise capability at W-band (75-110 GHz) and D-band (110-170 GHz) frequencies for hybrid integrated circuits [1]-[3]. Since MMIC is advantageous over hybrid circuit in high reliability, light-weight, small size and low cost for high volume insertion into real systems, there is a need to pursue the development of MMW monolithic LNA for future low cost system applications. The high gain low noise MMIC LNA's have been successfully developed up to 120 GHz [4], [5]. However, radar and radiometric imaging in the propagation window around 140 GHz benefit higher resolution and smaller size antenna aperture due to the shorter wavelength. In addition, passive imaging benefits from brighter images due to stronger black body radiation, limited in range only by higher atmospheric attenuation. For the frequency around 140 GHz, InP-based HEMT's are advantageous over GaAs-based HEMT's as amplification devices due to the higher electron peak drift velocity and higher mobility of the InGaAs channel in the former devices. The motivation of this work is pushing forward higher frequency performance of a monolithic LNA to 140 GHz using the developed InP-based HEMT MMIC technology [5] to enable new applications.

This paper presents the recent development of a 140-GHz monolithictwo-stage amplifier using the 0.1-μm InAlAs/InGaAs/InP pseudomorphic HEMT technology. This 140-GHz MMIC amplifier has been designed, fabricated and tested. A measured small signal gain of 9 dB is achieved at 142 GHz. To our knowledge, this is the highest frequency monolithic amplifier ever reported using three terminal devices. The gain performance rivals the previously reported hybrid amplifier [2]. The success of this development not only demonstrates state-of-the-art high frequency performance MMIC amplifier using InP-based HEMT technology, but also enables new system configuration of 140-GHz radiometer systems.

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II. Device Fabrication and Characteristics

The MMIC chip was fabricated on a 2" Fe-doped InP substrate grown by molecular beam epitaxy and employed 0.1-μm T-gate PM HEMT devices. The InAlAs/InGaAs/InP HEMT ($In_{0.6}Ga_{0.4}As$ channel) structure is same as the one reported in [2]. The typical room temperature and 77 K mobilities of this device are 10500 and 35000 cm^2/V-sec, respectively, with a sheet carrier concentration typically between 3.0×10^{12} and 3.5×10^{12} cm^{-2}. Silicon planar doping is employed in the InAlAs layer to simultaneously achieve a high channel aspect ratio for a 0.1-μm gate length device and high electron transfer efficiency. Doping levels and layer thicknesses are optimized to achieve sharp pinch-off characteristics, high transconductance levels and good Schottky characteristics. The device structure and layout are also carefully designed to yield minimum parasitic capacitances and resistances. All of these parameters have been found to impact the minimum noise figure of the device. This InP-based PM HEMT's have achieved state-of-the-art performance with a dc transconductance of 1400 mS/mm, a unit current gain frequency (f_T) of 240 GHz, and a maximum oscillation frequency (f_{max}) of 400 GHz. A measured noise figure of 1.3 dB at 95 GHz with an associated gain of 8.2 dB, and a measured gain of 7.3 dB at 140 GHz were obtained for single stage hybrid amplifiers using InP HEMT devices [2]. The same device also achieved state-of-the-art performance for a Q-band hybrid cryogenically cooled amplifier which demonstrated a noise temperature of 13 K at 41 GHz [6].

The InP HEMT MMIC fabrication process was adopted from the baselineMMIC fabrication process used for GaAs-based HEMT MMIC's [4]. The differences in the fabrication process steps include the device isolation process, the ohmic metallization, alloying conditions and the through substrate via hole etch. The MMIC LNA's fabricated using this process have also achieved state-of-the-art high gain and low noise figure performance at lower frequencies, which include a Q-band (44 GHz) two-stage LNA exhibiting 2.2-dB noise figure with 23-dB associated gain [7], a V-band three-stage LNA demonstrating less than 3-dB noise figure with 22-dB gain at 60 GHz [8], a W-band one-stage LNA showing 2.6-dB noise figure with 7-dB gain at 96 GHz [9], and a W-band four-stage

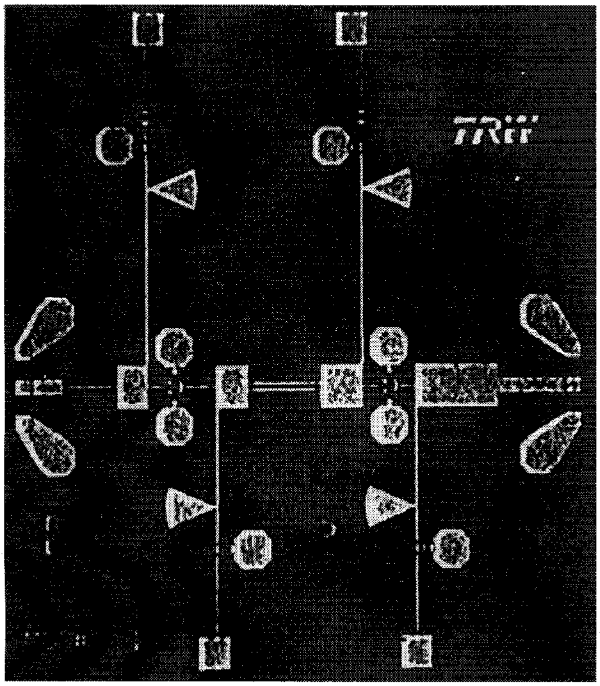

Fig. 1. The photograph of the 140-GHz InP-based HEMT monolithic two-stage low noise amplifier.

balanced amplifier with small signal gain of 23±3 dB from 75 to 110 GHz [10].

III. Circuit Design and Measurement

The linear small signal model for a 0.1-μm gate length four finger, 40-μm gate width PM InP HEMT, used in this 140-GHz LNA design is obtained from curve fitting of the measured small signal S-parameters up to 50 GHz. The resulting parameters are consistent with the estimated values based on device physical dimensions and parameters. The equivalent circuit and parameters of the small signal model can be found in [5].

Fig. 1 shows the the chip photograph of this monolithic amplifier. The size of this chip is 1.8×2.0 mm^2. The 140-GHz amplifier is a two-stage single-ended design and each stage uses a 40-μm PM InP HEMT. The input, output, and interstage matching networks are all constructed by cascading high-low impedance microstrip lines on a 70-μm-thick InP substrate. Edge coupled lines are used for dc blocking and radial stubs are employed for RF bypass. Shunt n^+ bulk resistors are included in the bias networks for amplifier stability. A wet chemical etching process is used to fabricate back side via holes for grounding. The design/analysis procedures of this the monolithic chip design, which include accurate active device modeling and full-wave electromagnetic (EM) analysis of passive structures, is documented in [11].

The chip was tested in a D-band (110–170 GHz) fixture. Microstrip line to waveguide finline transitions fabricated on 3-mil quartz substrates were used to couple the MMIC chip to the measurement system. The measured insertion loss for a pair of back-to-back transitions was 2 dB with a return loss better than 15 dB. Fig. 2 plots the gain and input/output return losses performance from 130–150 GHz. A peak gain of 9 dB

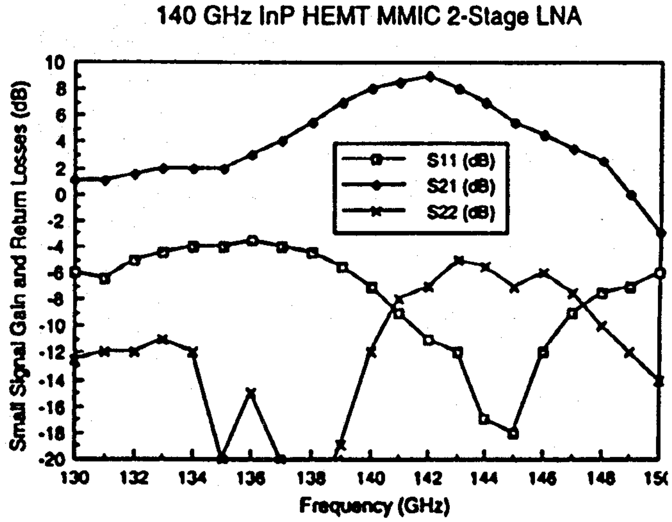

Fig. 2. The measured small signal gain and input/output return lossesfrom 130 to 150 GHz of the 140-GHz monolithic amplifier.

occurs at 142 GHz. It demonstrates more than 5-dB gain from 138–145 GHz with input return loss better than 10 dB and output return loss better than 5 dB. The gain results have been corrected by 2 dB finline transition loss factor. The noise figure will be measured and reported later. To our knowledge, this is the first results published for a monolithic amplifier in this frequency range using three terminal devices. For each stage, the drain current is 20 mA under 1 V drain bias. Since there is a shunt resistor of 100 Ω in each drain bias network, the actual power consumption for each HEMT device is about 10 mW.

IV. Summary

We have presented the development of 140-GHz monolithic low noiseamplifier (LNA) using 0.1-μm pseudomorphic AlInAs/InGaAs/InP low noise HEMT technology. The two-stage single-ended 140-GHz monolithic LNA exhibits a small signal gain of 9 dB at 142 GHz, and more than 5-dB gain from 138–145 GHz. This is the highest frequency monolithic amplifier ever reported using three terminal devices.

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