W-Band and D-Band Low Noise Amplifiers Using 0.1 Micron Pseudomorphic InAlAs/InGaAs/InP HEMTs

P.D. Chow, K. Tan, D. Streit, D. Garske, P. Liu, and R. Lai

TRW Electronic Systems Group,
Redondo Beach, CA 90278

ABSTRACT

We report the W-band and D-band performance of 0.1 micron T-gate pseudomorphic $In_{0.53}Al_{0.47}As/In_{0.60}Ga_{0.40}As/InP$ High Electron Mobility Transistors (HEMTs). The device achieved 1.3 dB noise figure and 8.2 dB associated gain when biased and tuned for minimum noise figure at 95 GHz. It achieved 7.3 dB gain when biased and tuned for gain at 141.5 GHz. This is the highest gain ever reported for a three-terminal semiconductor device in this frequency range. The two-stage hybrid LNA fabricated with these devices demonstrated a minimum noise figure of 2.6 dB and 14.2 dB associated gain at waveguide interface at 92 GHz. This is the lowest reported noise figure for a two-stage LNA at this frequency.

INTRODUCTION

W-band and D-band frequencies have been of great interest for imaging and radar sensor applications where they offer higher resolution and smaller size. These frequencies are also attractive for satellite cross-link and deep space communication applications where they have the advantages of higher gain and narrower beamwidth at a given antenna size as well as wider bandwidth. Recently significant progress has been made in the W-band receiver technology due to the rapid advances in both GaAs-based and InP-based three terminal devices [1-5]. While latticed-matched InAlAs/InGaAs/InP HEMTs have shown the lowest noise and highest gain at W-band [1-5], no comparable D-band device data have been reported.

The use of strained pseudomorphic InGaAs channels grown on InP substrate [6,7] have shown improved device properties over lattice-matched channels due to reduced carrier scattering as a result of better confinement (larger conduction band discontinuity) and increased two-dimension electron gas (2-DEG) sheet charge density. However, there was little noise figure and gain performance reported for the pseudomorphic InP HEMTs. This paper reports the fabrication and measured W-band and D-band performance of 0.1 micron T-gate pseudomorphic InAlAs/InGaAs/InP HEMT devices. The performance of a two-stage W-band hybrid LNA fabricated using these devices is also presented.

DEVICE FABRICATION AND CHARACTERISTICS

The InP HEMT devices used in this work were grown on Fe-doped semi-insulating InP substrates by molecular beam epitaxy. The device cross-section is shown in Figure 1. The buffered layer consist of an $In_{0.53}Al_{0.47}As/In_{0.52}Ga_{0.48}As$ (80 A/20 A) superlattice and an undoped InAlAs layer. The strained pseudomorphic channel is an undoped 250 A $In_{0.60}Ga_{0.40}As$ layer followed by a 30 A spacer layer. The silicon planar doping in the otherwise undoped 200 A $In_{0.53}Al_{0.47}As$ layer was adjusted to give a 2-DEG sheet charge density of 2.5 to 3.0 x 10^{12} cm^{-2}. Hall mobilities obtained on the calibration wafer doped with similar 2-DEG sheet charge density showed 10,400 cm^2/V-s and 35,700 cm^2/V-s at 300 K and 77 K, respectively. The 200 A $In_{0.60}Ga_{0.40}As$ N+ cap layer was doped to 6.0 x 10^{18} cm^{-3} to minimize the source resistance. The N+ cap layer

X

doping is a tradeoff between device noise figure and breakdown voltage. Since low noise devices typically operate at low drain voltage and maximum gain is desired for D-band operation, it is doped high concentration in this work. The 0.1 micron T-shaped gate were written using a Philips EBPG-3 electron-beam lithography system.

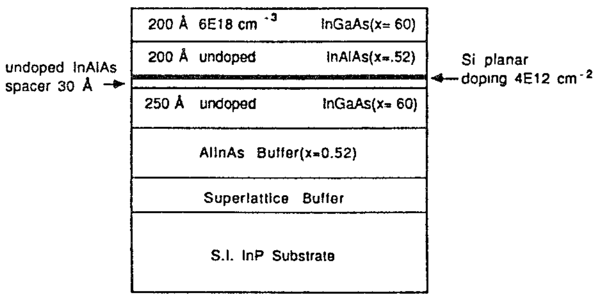


Figure 1. Device cross-section of pseudomorphic $In_{0.52}Al_{0.48}As/In_{0.60}Ga_{0.40}As/InP$ HEMT.

Figure 2 shows the I-V curves of a 40 micron device. The devices typically exhibited peak extrinsic transconductance of between 1000 and 1200 mS/mm. The gate-to-drain breakdown voltage was typically between 2-3 V. S-parameters of 40 micron gate width devices were measured using on-wafer Cascade probes to 40 GHz. The extrapolated unity current gain, f_T was as high as 200 GHz. Figure 3 shows a small signal model of the 40 micron device.

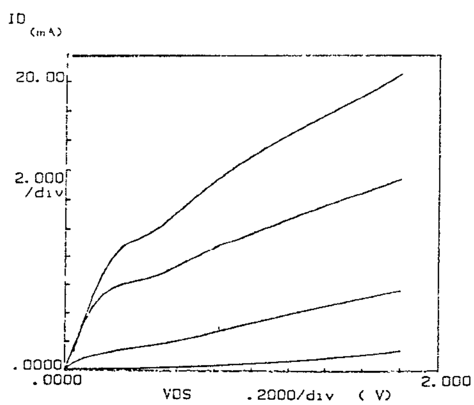
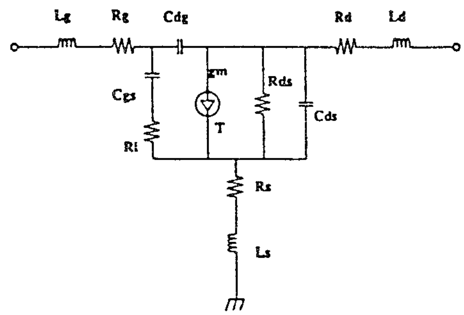


Figure 2. I-V Characteristics of 0.1 μm x 40 μm HEMT. (VGs=0.3V, 0.2V per step).



Cdg	Cgs	Cds	Gm	Rds	Ri	Rg	Rs	Rd	Lg	Ls	Ld	Tau
(fF)	(fF)	(fF)	(mS)	(Ω)	(Ω)	(Ω)	(Ω)	(Ω)	(pH)	(pH)	(pH)	(ps)
8 1	26.2	16.7	43.1	205	0 98	0.92	2.69	2.95	12.1	1.93	2 1	0.1

Figure 3. Small signal equivalent circuit model of 40 μm Hemt.

W-BAND MEASUREMENT RESULTS

Figure 4 shows the measured InP HEMT device noise figure and associated gain from 91 to 95 GHz when tuned and biased for minimum noise figure. The device achieved a minimum noise figure of 1.3 dB and 8.2 dB associated gain at 95 GHz. The bias condition used was V_{ds} = 0.9 V and I_{ds} = 5.0 mA. This data does not contain the test fixture loss of a pair of W-band waveguide-to-microstrip transitions which typically have 1.4 dB end-to-end insertion loss, and greater than 15 dB return loss. The correction factor used for fixture loss was 0.7 dB per transition.

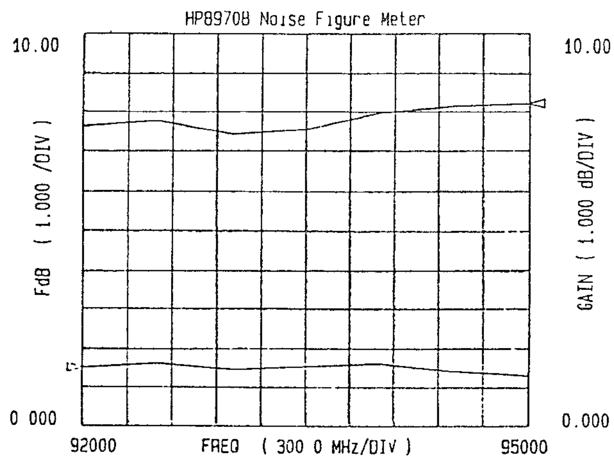


Figure 4. W-Band noise and gain performance of 0.1 μm x 40 μm HEMT.

W-band two-stage MIC low noise amplifiers were constructed using 40x0.1 micron pseudomophic InP HEMT devices. The detailed description of this amplifier design has been presented in an earlier paper [5]. A photo is included here for convenience (Figure 5). Figure 6 shows the measured result of this amplifier at the waveguide interfaces, with both devices tuned and biased for best noise figure. An extremely low noise figure of 2.6 dB and an associated gain of 14.2 dB was achieved at 92 GHz. The amplifier showed less than 3.1 dB noise figure across the frequency range of 91 to 95 GHz with an average gain about 13 dB. After correction of 1.2 dB loss associated with the input and output waveguide-to-microstrip transitions, this two-stage amplifier showed 2.0 dB noise figure and 15.4 dB gain at the 50 ohm microstrip interface at 92 GHz. To our knowledge, this is the lowest noise figure ever reported for a two-stage W-band LNA.

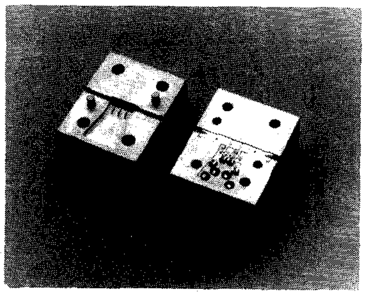


Figure 5. W-Band hybrid two-stage InP HEMT low noise amplifier,

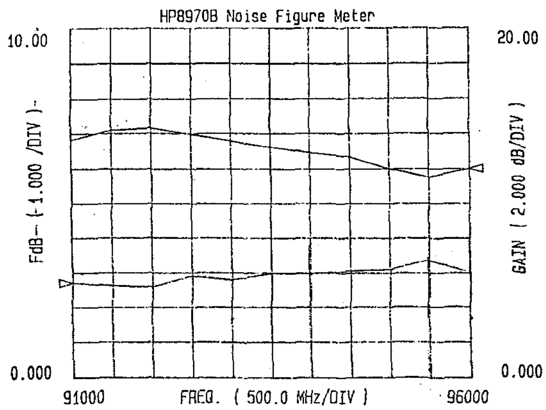


Figure 6. Measured performance of W-band 2-stage LNA using 0.1 μm pseudomorphic InGaAs/InP Hemts

D-BAND MEASUREMENT RESULTS

The devices were also tested in D-band single-stage amplifier fixtures (Figure 7). The finline waveguide-to-microstrip transition and the bias circuits were fabricated on 3 mil fused-silica substrates. Typical measured insertion loss of a pair of back-to-back D-band transition is 2 dB with 14 dB return loss. Both 40 micron and 30 micron gate width devices were tested at D-band. The 30 micron devices consistently showed higher gain. Figure 8 shows the measured device gain from 138.5 to 141.5 GHz for a 30x0.1 micron pseudomorphic InP HEMT when tuned and biased for best gain. The device achieved a gain of 7.3 dB at 141.5 GHz with a bias condition of V_{ds} = 1.5 V and I_{ds} = 11 mA. The correction factors used for the device gain was 1.0 dB per transition/matching circuit. No noise measurement was made at this frequency due to the lack of appropriate test equipment. A D-band two-stage MIC amplifier circuit and housing similar to the one shown in Figure 5 are being designed. The test results will be presented.

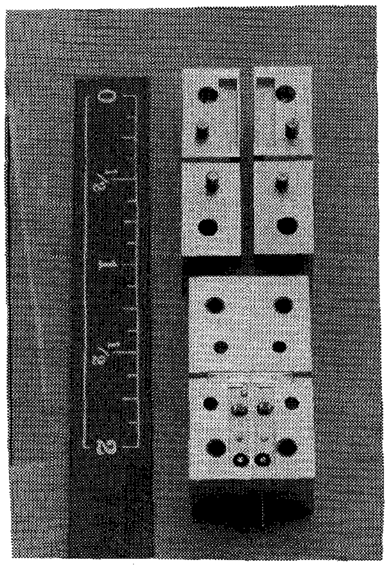


Figure 7. D-Band single-stage amplifier test fixture.

CONCLUSION

We have reported state-of-the-art performance from 0.1 micron pseudomorphic InP HEMT devices. The device achieved a gain of 7.3 dB at 141.5 GHz. At 95 GHz, we have achieved a noise figure of 1.3 dB and 8.2 dB associated gain. The gain at both of these frequencies are the highest ever reported for InP HEMT devices. A W-band two-stage hybrid LNA fabricated using these devices showed 2.6 dB noise figure and 14.2 dB associated gain at the waveguide interfaces at 92 GHz. This represents the lowest reported noise figure for a two-stage LNA at this frequency. We attribute these excellent device performances to careful optimization of source resistance, ultra-short gate length (0.1 micron T-gate), and the pseudomorphic InGaAs Channel (60% Indium). Our results demonstrate the feasibility of this device technology to operate at frequencies to 140 GHz.

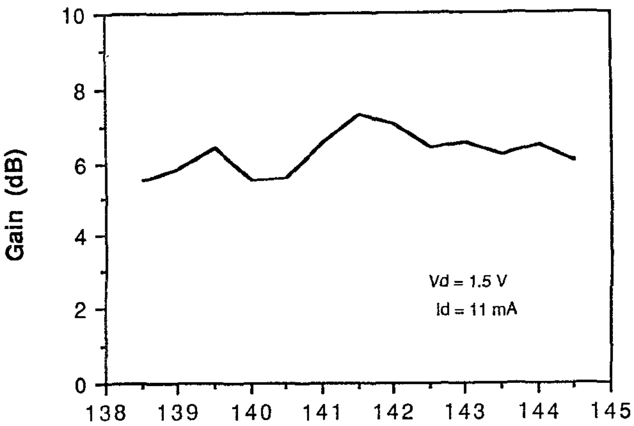


Figure 8. Measured D-Band performance of 0.1 μm pseudomorphic InP HEMT.

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REFERENCES

1. U.K. Mishra, A.S. Brown, and S.E. Rosenbaum, "DC and RF Performance of 0.1 Micron Gate Length $In_{0.52}Al_{0.48}As$-$In_{0.62}Ga_{0.38}As/InP$ " IEDM Technical Digest, pp 180-183, 1988.

2. K.H.G. Duh, P.C. Chao, P. Ho, A. Tessmer, S.M.J. Liu, M.Y. Kao, P.M. Smith, and J.M. Ballingall, "W-band InGaAs HEMT Low Noise Amplifiers," IEEE MTT-S Symposium Digest, p. 595, 1990.

3. P.C. Chao, A.J. Tessmer, K.H.G. Duh, P. Ho, M.Y. Kao, P.M. Smith, J.M. Ballingall, S.M.J. Liu, and A.A. Jaba, "W-band Low Noise InAlAs/InGaAs Lattice-Matched HEMT's," IEEE Electron Device Lett., vol. 11, no. 1, p. 59, 1990.

4. Kin Tan, et al, " 94 GHz 0.1 Micron T-Gate Low Noise Pseudomorphic InGaAs HEMTs", IEEE Electron Device Letters, pp. 5850587, 1990.

5. P.D. Chow et al, " Ultra Low Noise High Gain W-Band InP-Based HEMT Downconverter", 1991 MTT-s Digest, pp. 1041-1044.

6. J.M. Kuo, B. Lalevic, and T.Y. Chang, " New Pseudomorphic MODFET's utilizing $Ga_{0.0.47-u}In_{0.53+u}As/Al_{0.48+u}In_{0.52-u}As/InP$ heterostructures", IEDM Digest, 1986, pp. 460-463.

7. G.I. Ng, W.P. Hong, D. Pavlidis, M. Tutt, and P.K. Bhattacharya, " Characteristics of Stained $In_{0.65}Ga_{0.35}As/In_{0.52}Al_{0.48}As/InP$ HEMT with *optimized transport parameters,"* *IEEE Electron* Device Letters, pp. 439-441, 1988.