mm-Wave MIMIC Receiver Components

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ABSTRACT

Monolithic W-band amplifiers and a new W-band mixer fabricated using a pseudomorphic 0.1-μm MODFET technology are presented. Single-stage W-band amplifiers delivered 8.5-dB gain; four-stage units showed 23-dB maximum gain or 4.5-dB noise figure, 21.7-dB associated gain. Monolithic W-band mixers have shown 11.8 dB conversion loss.

1. Introduction

Pseudomorphic InGaAs Modulation-Doped Field-Effect Transistors (MODFET's) have recently demonstrated improved performance in the millimeter-wave operating range. Discrete devices or hybrid amplifiers have shown promising performance [1]-[2], but monolithic circuits are still in the early stages of development and integration [3]-[4].

Here we report the development of strictly monolithic receiver components. Three types of circuits -- monolithic single- and four-stage W-band amplifiers and balanced mixers -- are discussed. These circuits are the prototypes for circuits which will be combined to form a receiver module. W-band results of a working chip-to-chip interconnect technique are also discussed.

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2. Device Development

2.1. MODFET Design and Fabrication

The optimized epitaxial structure used to fabricate the devices is grown in-house using a Varian Gen II MBE system. Carrier densities of 1.7×10^{12} and 77 K Hall mobilities of 20,000 - 30,000 $cm^2/V{-}s$ are routinely obtained.

The mushroom gate consists of two 0.1-μm fingers defined by E-beam lithography using a trilevel resist technique. The total gate width is 50 μm.

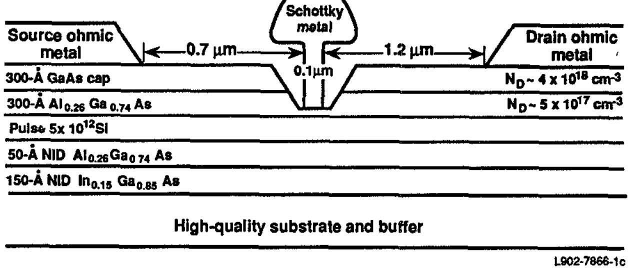

Figure 1 - *Cross-sectional profile of the active region showing typical contact spacings and doping concentrations.*

On-wafer DC and RF measurements to 40 GHz were used to develop the MODFET circuit model shown in Figure 3. A parameter extraction technique allowed the determination of the individual device parameters at each frequency. Parameter optimization and fitting was not used. Extrinsic transconductance values are typically in the range 600-700 mS/mm, corresponding to intrinsic transconductances from 800-1000 mS/mm.

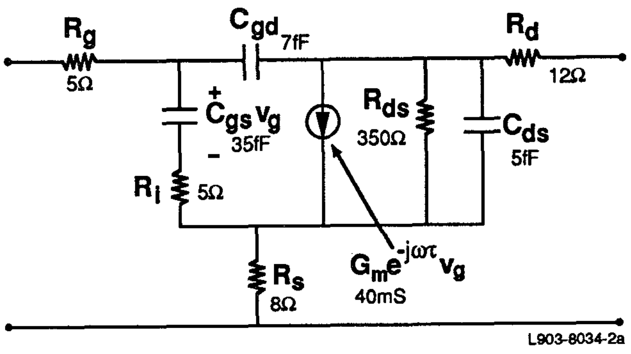

Figure 2 - *Equivalent circuit model of the pseudomorphic MODFET.*

2.2. Monolithic Diode Design and Fabrication

The monolithic diodes are fabricated directly on MODFET epitaxial material using our standard gate definition techniques and do not require any special or additional processing steps. This is the equivalent of using the gate-source junction of the MODFET as a diode. The junction region is shown in the photograph of Figure 2. In this case the gate periphery and number of fingers are optimized to achieve an RC cutoff of approximately 400 GHz. Although diodes on optimized (highly doped) epitaxial material can achieve better performance, they are not easily integrated with MODFET devices.

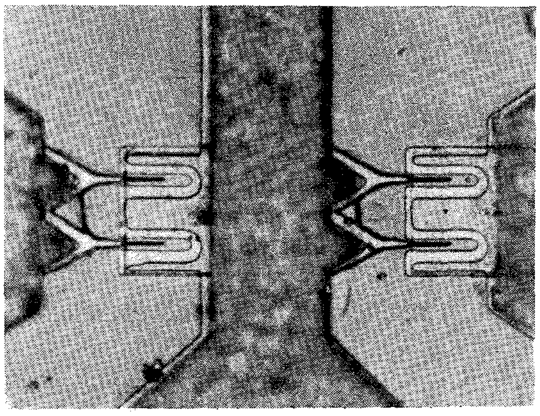

Figure 3 - *The E-beam-defined mm-wave diodes used in the monolithic balanced mixer.*

3. Circuit Design and Performance

3.1. Introduction

Figure 4 shows the three circuits of interest. All were designed using either microstrip or grounded coplanar waveguide (CPW) with a substrate thickness of 100 μm. The LNA circuits all have on-chip RC bypass networks to provide low-frequency device stabilization.

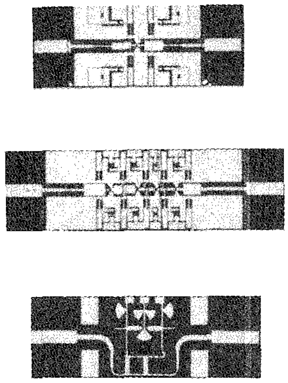

Figure 4 - *The three MIMIC circuits: a) single-stage W-band LNA, b) four-stage W-band LNA, and c) W-band balanced mixer.*

3.2. Integrated E-plane probe performance

Integrated waveguide-to-CPW transitions were included on all circuits. These transitions were developed and verified using low-frequency scale models. A back-to-back pair typically demonstrates greater than 15-dB return loss over a 10-GHz bandwidth with less than 1.5-dB insertion loss at W-band. Typical insertion loss at 94 GHz is 1.3 dB, of which 0.6 dB may be attributed to the 3-mm CPW line and 0.35 dB to each probe transition. The transitions are extremely repeatable and allow the circuits to be quickly mounted onto individual carriers for RF testing. Once mounted, only DC bond wire connections to the circuit are required and the circuits can be handled and tested easily. A mounted single-stage amplifier is shown in Figure 5. Other circuits are mounted similarly.

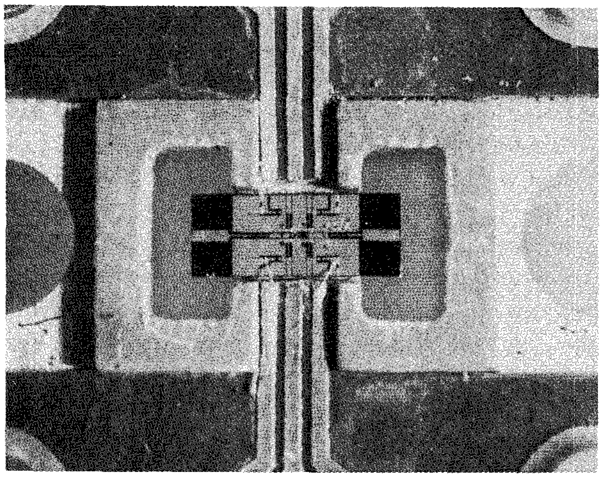

Figure 5 - *A mounted W-band single-stage MIMIC amplifier.*

3.3. Single-Stage W-Band Amplifier

Single-stage amplifiers tested at W-band showed 8.5-dB gain at 92 GHz with optimized bias (see Figure 6). This is the waveguide-to-waveguide gain and contains no corrections for transition loss or transmission-line attenuation. Correcting for these losses would yield a device gain of approximately 9.8 dB. Similar units with alternate tuning to provide the optimum generator impedance for low-noise operation showed a 3.8-dB noise figure with 4.8-dB associated gain when corrected for 0.35-dB transition loss. We believe these are the best reported results for monolithic single-stage amplifiers at this frequency.

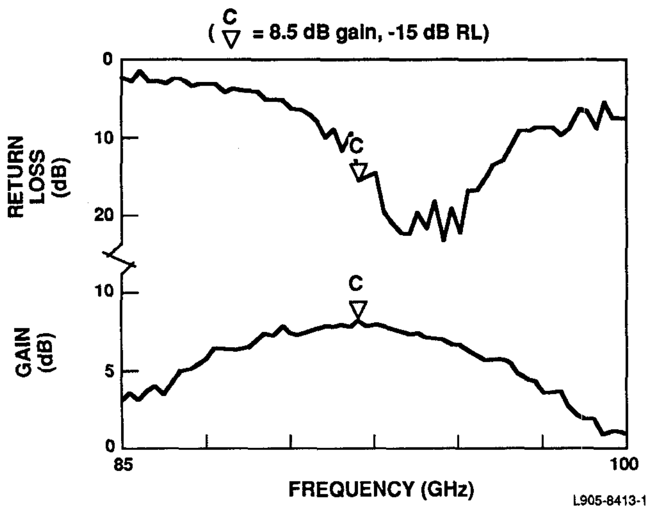

Figure 6 - *Gain and return loss of a single-stage W-band MIMIC amplifier.*

3.4. Four-Stage W-band Amplifier

Monolithic four-stage W-band amplifiers have also been designed and tested. Our standard waveguide-to-CPW transitions were incorporated onto each chip to provide RF input and output connections. On-chip transmission lines were fabricated using coplanar waveguide with a 200 μm ground plane spacing. Interstage tuning is accomplished with single element transmission line transformers. DC blocking is provided between stages and individual on-chip stabilization networks are incorporated for the gate and drain of each stage.

These first-iteration processing units showed a 4.5-dB noise figure at 80 GHz with 21.7-dB associated gain. The maximum gain observed was 23 dB, which we believe to be the highest reported from a monolithic W-band amplifier.

3.5. Balanced W-Band Mixer

The MODFET-compatible balanced mixers were designed using microstrip circuit elements. Here the E-plane probes serve as input coupling elements for the RF and LO signals. The individual diode bias connections and IF signal are coupled to the external circuitry by wire bonds. At 94 GHz the circuit showed a conversion loss of 11.8 dB and a DSB noise figure of 11.3 dB. Figure 7 shows the conversion loss versus diode current with LO drive applied.

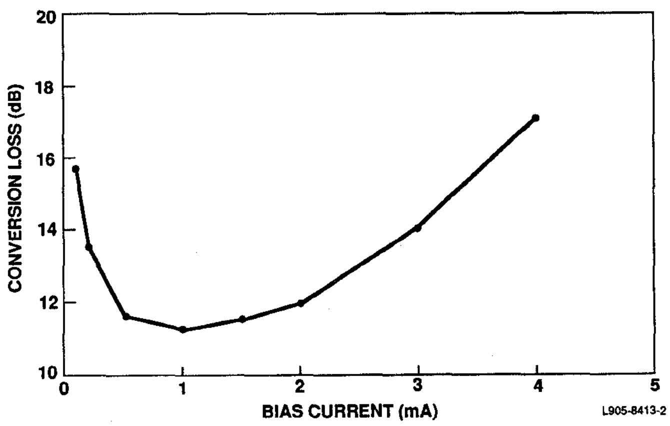

Figure 7 - *Conversion loss versus diode bias with LO signal applied.*

3.6. W-Band Chip Interconnections

Most mm-wave receiver systems require more than one type of circuit functioning at W-band. It is extremely desirable to be able to directly connect the various chips, although little is known about the performance of any type of chip-to-chip interconnect at these frequencies. To test the performance of a CPW-to-CPW interconnect, special half-chip through lines were fabricated. Each half-chip consisted of our standard E-plane transition and a CPW transmission line half normal length. The plated gold was set back 20 μm from the join line of the two chips. A pair of half-chips were mounted back to back in our standard fixture with one bond wire for the center conductor and three for each ground plane. Before bonding across the gaps the two-piece structure showed more than 15-dB insertion loss and a return loss of only 2 dB at 94 GHz. After bonding, W-band measurements indicate that this interconnect has only about 0.2 dB more insertion loss than the corresponding single-piece thru. The return loss of both through lines was 15 dB at 94 GHz. The measurement results are shown in Figure 8.

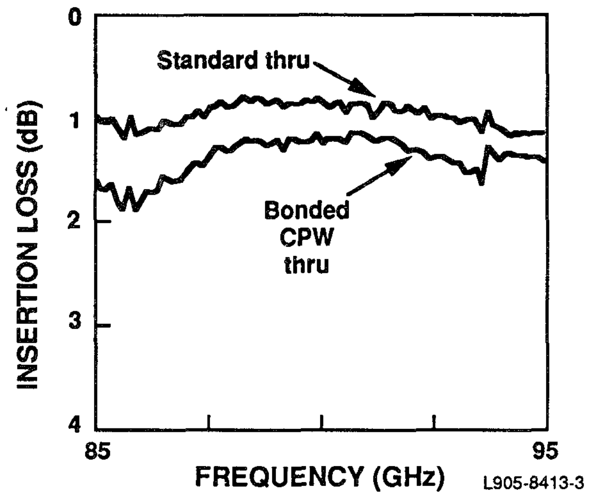

Figure 8 - *A CPW - CPW chip interconnection and a standard one-piece CPW thru.*

4. Summary

We have successfully designed, fabricated, and tested three monolithic receiver components which operate at mm-wave frequencies. Our single-stage W-band amplifiers have shown noise figures of 3.8 dB, which we believe to be the best reported values for a monolithic circuit. First-pass four-stage W-band amplifiers have shown promising results with gains as high as 23 dB. A new MODFET process-compatible balanced mixer, which will allow integration of amplification and mixing circuits onto a single chip, and a viable method to interconnect W-band circuits were demonstrated.

5. References

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