Millimeter-Wave Monolithic Gain Block Amplifiers Using Pseudomorphic HEMT

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Abstract

Monolithic gain blocks for millimeter-wave amplifiers have been developed using 0.1 μ m-gate planar-doped pseudomorphic HEMTs and successfully applied to U- and W-band single-stage amplifiers. The gain block consists of the HEMT and input/output matching circuits integrated in a single chip.

The U-band amplifier exhibits a gain of 5.0± 0.7 dB and a noise figure of less than 2.8 dB over 45-55 GHz. The W-band amplifier shows a gain of 3.1 ± 0.3 dB and a noise figure of 4.5± 0.5 dB over 94-98 GHz.

I. Introduction

Since the advent of the high electron mobility transistor(HEMT), much efforts have been made toward developing high performance millimeter-wave amplifiers[1-3]. Developments of monolithically integrated HEMT amplifiers have also been carried out for millimeter-wave system applications[4-7]. Though fully integrated monolithic approach is attractive, overall circuit design is time consuming and costly except for large-scale production applications. At millimeter-waves, the hybrid-integrated-circuit approach using discrete HEMT chips suffers from lack of design accuracy due to the strict assembly tolerances required such as for bonding wire inductance. To fill the gap between these approaches, we have developed pseudomorphic HEMT chips with monolithically integrated RF matching circuits as a monolithic gain block for building millimeter-wave amplifiers.

This paper describes the design of the monolithic gain blocks for U- and W-bands and the performance of single stage U- and W-band amplifiers based on the gain blocks. The gain blocks consist of 0.1 μ m-gate planar-doped pseudomorphic HEMT and input/output matching circuits for operation in the frequency range of interest.

The U-band amplifier exhibits a gain of 5.0± 0.7 dB and a noise figure of less than 2.8 dB over 45-55 GHz. The W-band amplifier shows a gain of 3.1 ± 0.3 dB and a noise figure of 4.5± 0.5 dB from 94 to 98 GHz.

II. Planar-doped pseudomorphic HEMT

Figure 1 shows the schematic cross-section of the 0.1 μ m-gate planar-doped pseudomorphic HEMT [8] used in this work. For applications up to W-band, the gate width of the HEMT has been reduced to 50 μ m.

Figure 2 shows the top view of a HEMT chip designed to be used for device characterization. A coplanar structure is adopted for input and output terminals of the chip so as to perform on-wafer measurements. For the design of the amplifiers, the S-parameters of the HEMT were calculated up to 98 GHz using the equivalent circuit determined from S-parameters measured over 1-40 GHz.

This device typically shows a noise figure of 1.9 dB with an associated gain of 7.6 dB at 55 GHz.

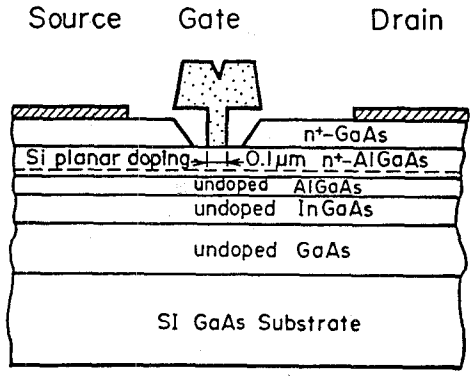

Fig.1 Schematic cross-section of 0.1 μ m-gate planar-doped pseudomorphic HEMT.

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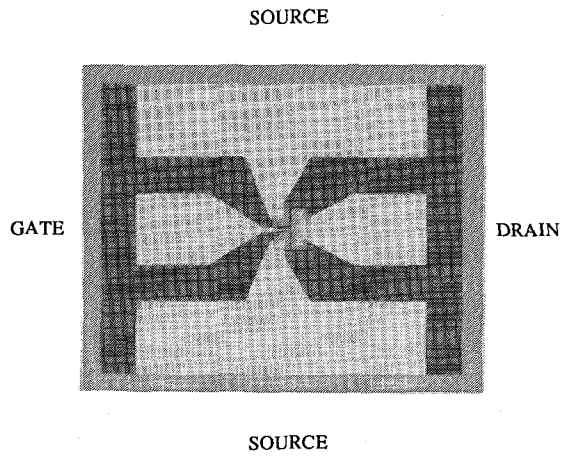


Fig.2 Photograph of TEG HEMT chip for S-parameter measurement.

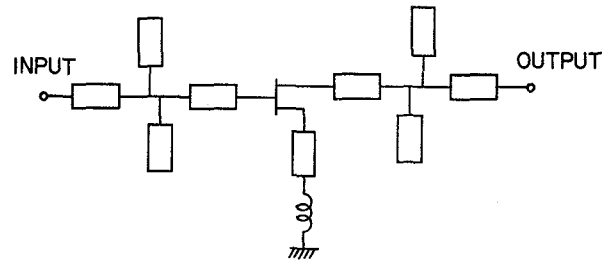
III. Monolithic gain block design

Figure 3 shows the schematic circuit configuration of the U-band and W-band monolithic gain blocks. The distributed elements consisting of open stubs and series high-impedance lines were designed to give a flat gain response as well as to satisfy input/output matching.

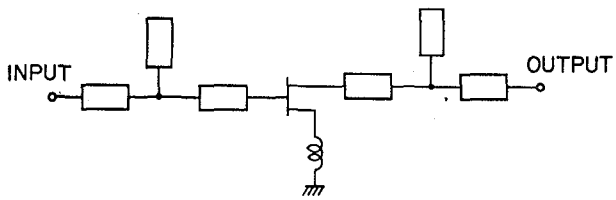
Predicted gain and input/output return loss characteristics of the monolithic gain blocks are shown in Fig.4. The calculated gains are 6.2-6.7 dB over 45-55 GHz for the U-band gain block and 2.2-3.9 dB over 94-98 GHz for the W-band gain block. Figure 5 shows the top view of the fabricated (a) U-band and (b) W-band gain blocks. The chip sizes are 550 μ m $\times$ 450 μ m and 550 μ m $\times$ 170 μ m for the U- and W-band gain blocks, respectively. The substrate thickness is 100 μ m.

IV. Amplifier performance

Each type of gain block was mounted on a carrier plate together with a pair of bias circuits consisting of DC-blocks, quarter-wavelength chokes and sheet resistors. The bias circuits are formed on a 0.25 mm thick alumina substrate for the U-band amplifier, and 0.1 mm thick fused silica substrate for the W-band amplifier. The carrier plate was then embedded in a test fixture with a pair of finline waveguide-to-microstrip transitions. In the following, measured gain and noise figure data are compensated for the test fixture loss and referred to the input and output terminals of the carrier plate unless mentioned otherwise.

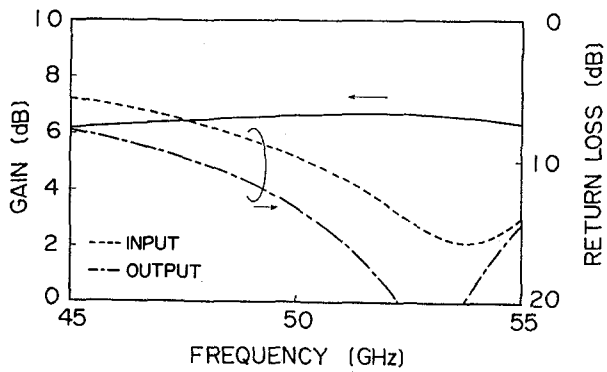


(a) U-band gain block

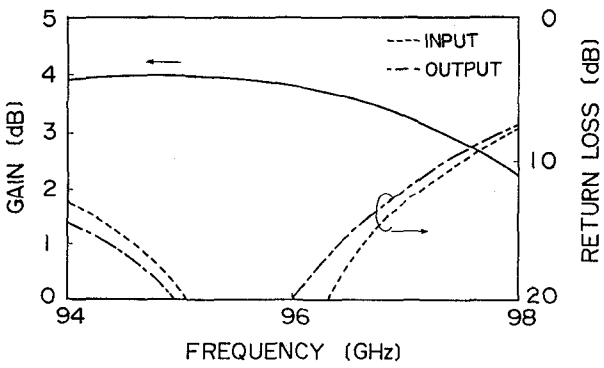


(b) W-band gain block

Fig.3 Equivalent circuits of millimter-wave Gain blocks

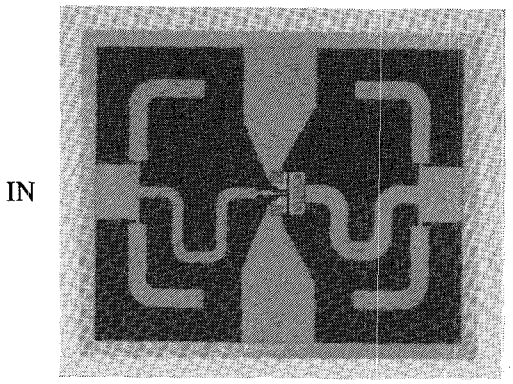


(a) U-band gain block

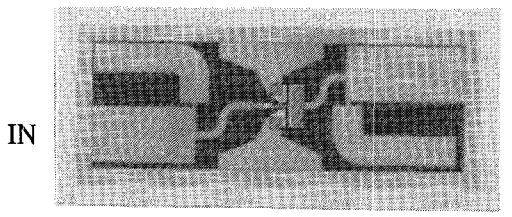


(b) W-band gain block

Fig.4 Calculated gain and return loss characteristics of gain blocks



(a) U-band gain block

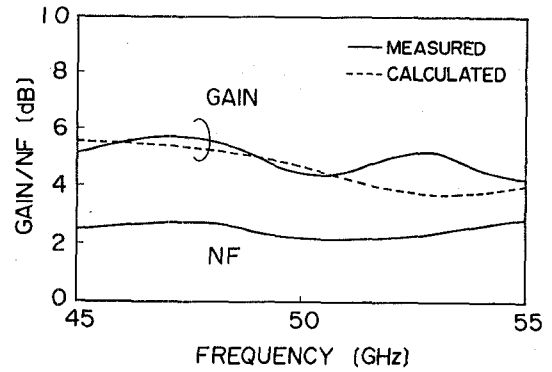


(b) W-band gain block

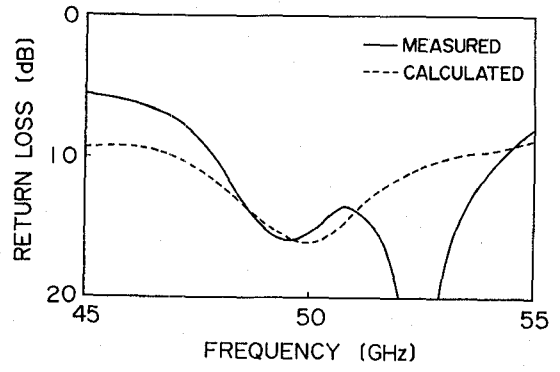
Fig. 5 Photographs of gain block chips

Figure 6 shows the measured (a) gain and noise figure, (b) input return loss, and (c) output return loss of the U-band amplifier. A gain of 5.0± 0.7 dB and a noise figure of less than 2.8 dB are obtained over 45-55 GHz. Input and output return losses are greater than 5.6 dB and 5.2 dB, respectively, over the same frequency range. Calculated responses of gain and return losses of the amplifier are also shown in Fig.6 for comparison. The calculated curves agree with the measured data much better than the curves in Fig.4 (a) calculated without the bias circuits. The minimum noise figure of 2.2 dB obtained at 50 GHz is comparable to that of the HEMT in a discrete chip form when the bias circuit loss is taken into account. This indicates that the matching conditions for gain and noise are simultaneously satisfied owing to the inductance of the source pads whose length is so chosen to realize such a match at 50 GHz (see Fig. 5(a)).

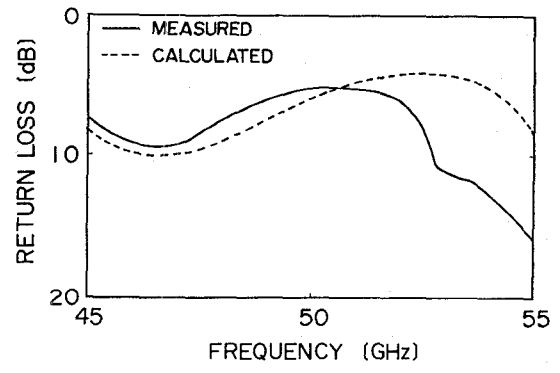
Figure 7 (a) shows the measured gain and noise figure characteristics of the W-band amplifier. This amplifier presents 3.1 ± 0.3 dB gain and 4.5 ± 0.5 dB noise figure from 94 to 98 GHz. The input and output return losses of the waveguide test fixture including the amplifier are greater than 10 dB in the same frequency range, as shown in Fig.7 (b)



(a) gain and noise figure



(b) input return loss



(c) output return loss

Fig.6 Performance of U-band amplifier

V. Conclusion

Single-stage U-band and W-band monolithic amplifiers have been successfully developed based on the monolithic gain block approach. After compensating for the waveguide test fixture loss, the U-band amplifier has exhibited a gain of 5.0± 0.7 dB and a noise figure of less than 2.8 dB from 45 to 55 GHz. The W-band amplifier has given a gain of 3.1± 0.3 dB and a noise figure of 4.5± 0.5 dB over 94-98 GHz. Monolithic integration of bias circuits in the gain block and multistage amplifier development are under consideration for the future work.

Acknowledgment

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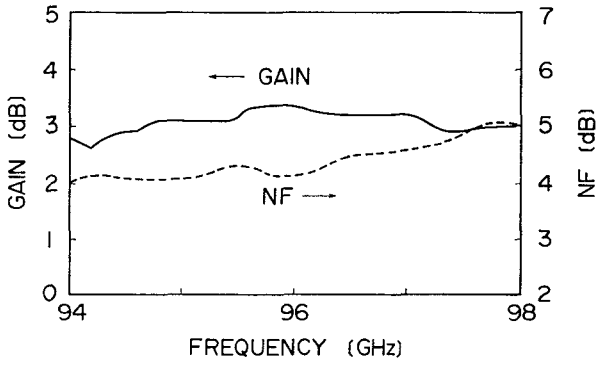
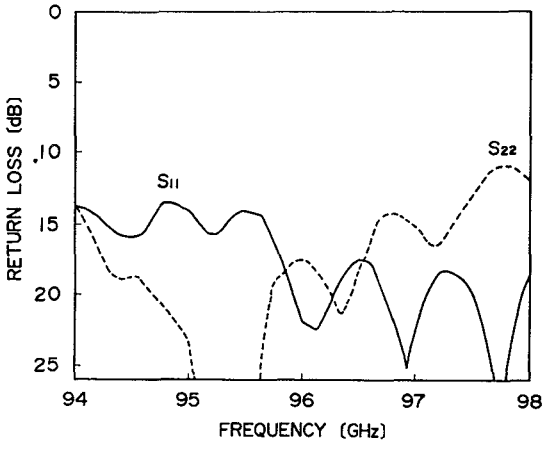


(a) gain and noise figure



(b) input/output return loss

Fig.7 Performance of W-band amplifier

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