AMPLIFIER APPLICATIONS OF MILLIMETER WAVE InP GUNN DEVICES

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Abstract

Amplifier evaluations in the 30 to 45 GHz frequency range have yielded device noise figures below 9 dB with up to 5 dB associated gain. Other results and a device model in close agreement with measured impedances are presented.

Introduction

Increasing interest in millimeter-wave transferred electron amplifiers as a potential low noise TWT replacement has been generated by recent achievements in GaAs Gunn amplifier design. Wideband gains of 20 dB over 27 to 40 GHz have been demonstrated with noise figures in the 15.6-16.5 dB range [1]. Replacement of GaAs with InP is desireable to reduce device noise figure due to the lower ratio of electron diffusion to differential negative mobility in InP. It was the purpose of this effort to demonstrate the feasibility of designing and building wideband, low noise amplifiers from InP transferred electron devices.

In this paper, performance of InP transferred electron devices as reflection amplifiers in the 30 to 45 GHz range is presented. These devices were fabricated from vapor phase epitaxial grown InP. Active region carrier concentrations in the range of $4x10^{14}$ to $3x10^{15}$ cm^{-3} and lengths in the range of 3.5 to 6.5 μm were investigated. All devices evaluated as reflection amplifiers had n^+ buffer and contact layers and were contacted using an alloyed Au-Ge/Ni metallization. Typical operating voltages of 12 V and currents below 0.5 amp were used.

Experimentally determined noise measures for devices from several InP wafers are presented as a function of doping-length product in Figure 1. Minimum device noise measures between 9 and 17 dB were observed. Also shown on the same scale are theoretical noise measures for uniformly doped n^+-n-n^+ and uniform electric field device structures [2,3]. A strong dependence on nL product was observed in most cases as is predicted by theory. Theory also projects further noise figure reductions if lower nL products and/or uniform electric field structures are fabricated.

Devices were broadly grouped into two categories: low nL, low noise types and high gain, higher nL with somewhat higher noise contributions. Results from these two groups of devices will be independently discussed.

All devices were evaluated in a broadband amplifier circuit consisting of a 65 Ω coaxial line terminated on one end by the Gunn diode and on the other by a multisection low-pass filter for DC bias insertion. A portion of the outer conductor is removed to iris couple to a reduced height waveguide section. This type of circuit typically provides a broadband match to the InP device over a 20% bandwidth range [4].

High Gain, Higher Noise Wafers

Several wafers with carrier concentrations above $2x10^{15}$ cm^{-3} and lengths greater than 4.5 μm were evaluated. These devices exhibited high reflection gain levels, similar to those observed on comparable GaAs devices. The resulting device noise figures were in the 14 to 17 dB range, moderately high but still 5 to 7 dB less than noise figures measured on similar GaAs devices.

RF evaluation was performed on devices from several of these wafers in the 40 to 60 GHz frequency range at NELC's San Diego facility. The amplifier circuit used on the 40 to 69 GHz reflectometer was centered at 38 GHz but had useful gain to approximately 47 GHz. Results from some of the devices are presented in Figure 2. The devices were all measured in the same circuit.

The 45 GHz frequency limit is circuit determined. Gain in this same circuit can extend to 33 GHz. This gives an approximate available bandwidth of 12 GHz or 30 per cent. Similar circuits centered in Ka-band have yielded the same relative bandwidths.

Hybrid Coupled Millimeter Wave Amplifier

As InP Gunn devices are considered for use in higher frequency bands (above 40 GHz) as reflection amplifiers, the problem of successfully coupling the RF signal into and out of the amplifier in a nonreciprocal manner becomes more difficult. Ferrite circulator limitations, specifically the $4\pi M_s$ of the ferrite material, limit fundamental mode wide band low loss operation to frequencies below 40 GHz.

One alternate approach that was evaluated in upper Ka-band was that of using a 3 dB hybrid coupler. Two amplifiers were measured in the reflectometer setup and diodes were selected to give identical gain responses. Phase shift was not measured.

The two circuits were then placed on ports A and C of the 3 dB hybrid coupler. The output at port D due to input applied at port B is shown in Figure 3. As can be seen from the figure, the overall gain level looks identical to either one of the individual stage amplifiers in terms of both bandwidth and gain level. Input port return loss which is a measure of phase match of the two amplifiers was 8 dB which is adequate but indicates that further improvement could be obtained by phase matching the two amplifier circuits.

Low Noise, Lower Doped Wafers

Very low noise performance was obtained with three wafers (EE44, 66 and 71) having lower nL products. Doping levels for these devices are all below $1.0x10^{15}$ with slightly graded doping profiles. As a result of the low doping levels, the negative resistance was correspondingly lower, as were the gain levels. Wide band gains were typically below five dB, although one wafer showed higher gains in the 5 to 6 dB range. In order to obtain meaningful noise figure information, a narrowband circuit was utilized to give higher gain

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levels. Figure 4 presents gain pictures for devices from these wafers. Noise figures for two wafers (EE44 and 66) are in the 10 to 13 dB range for the gain levels shown in the figure.

Devices from one wafer (EE71) have provided exceptional performance in wideband amplifier circuits. Judging by the doping level, wideband gains were higher than anticipated. A typical gain response in the 38 GHz half-band amplifier circuit is also shown in Figure 4. Noise figures for devices from this wafer were measured by both manual and automatic methods and using a variety of equipment to improve confidence levels. Lowest noise figures are consistently in the 8 to 10 dB range increasing to 12 dB near the passband edges. Noise measures are correspondingly higher in 9 to 14 dB range.

Device Impedance Characterization

Devices from several wafers were characterized in the half band amplifier circuits using slotted line techniques to measure the active reflection coefficient. In this procedure, the circuit Z-matrix is measured with a slotted line using three offset shorts in place of the packaged device in the amplifier circuit; the circuit is characterized to the TEM reference plane at the top of the diode package. The active device is then substituted for the offset short and biased to the desired stable operating point. This information is then reduced to R and X impedance data using computer programs.

Plotted in the next figure (5) is the negative of the terminal impedance for devices from several InP wafers measured in the 33 to 40 GHz range. Also plotted in the figure is the measured circuit impedance for the 38 GHz half band amplifier circuit. An interesting feature displayed by devices from the later InP wafers is that the packaged device is resonant at much higher frequencies than either GaAs or early InP. The InP devices resonate in mid to upper Ka-band, whereas the GaAs devices resonate in K-band usually about 23 GHz. This is as expected because of the increased physical length of the device (due to higher electron velocity) and resulting decreased capacitance.

A device model has been developed following Getsinger [5] and using computer optimization of chip parameters which matches closely the measured terminal impedance for lower doped, low noise devices. This model incorporates TEM to radial line transition and associated parasitic reactances as well as diode package contributions. The chip can be represented quite well by a series combination of a frequency dependent R and C whose values are calculated as shown in Figure 6. This figure presents the model schematic as well as origins of circuit elements used in the model. Also plotted in the figure are the negatives of the measured and calculated impedances.

Conclusions

InP devices have been shown to provide a viable means of providing very low noise and wide band amplification in the millimeter wave frequency region. Gain levels and noise contributions are directly related to device material doping levels. Modified doping structures should provide further reductions of noise figure and improve negative resistance levels. An alternate means of coupling signals to a reflection amplifier without a ferrite material limitation was evaluated. A device model which uses frequency dependent chip elements and fixed element values for package and mount parasitic contributions was developed.

This work was performed under Contract Number N00123-76-C-0265 from the Naval Electronics Laboratory Center, San Diego, California under the direction of Mr. D. Rubin, Program Monitor. The authors would like to acknowledge the help of Mr. R. Fairman and Dr. M. Omori with material growth and evaluation and Messrs. T. Hierl and J. Andrews with device and circuit evaluation. They would also like to thank Mr. D. Rubin and NELC for the use of their facilities and test equipment for measurements at frequencies greater than 40 GHz.

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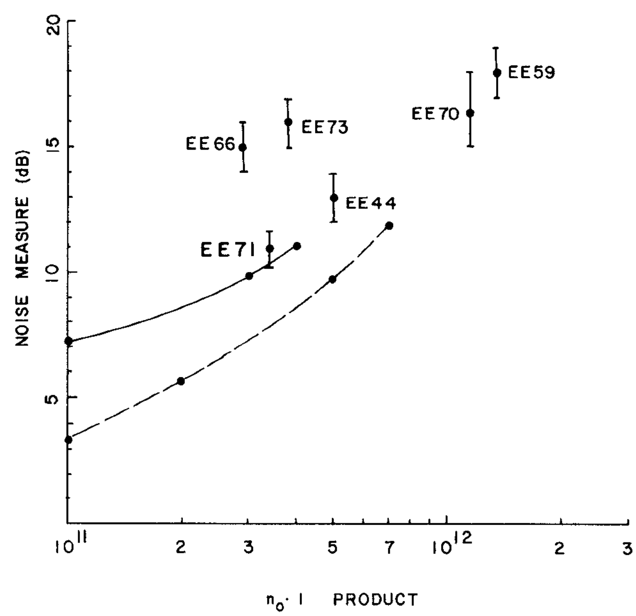

Fig. 1–Noise measure vs doping length product for several n^+-n-n^+ InP devices. Solid line is theoretical curve for n^+-n-n^+ structure at 20 kV/cm average field [2]. Broken line is theoretical curve for uniform field case [3].

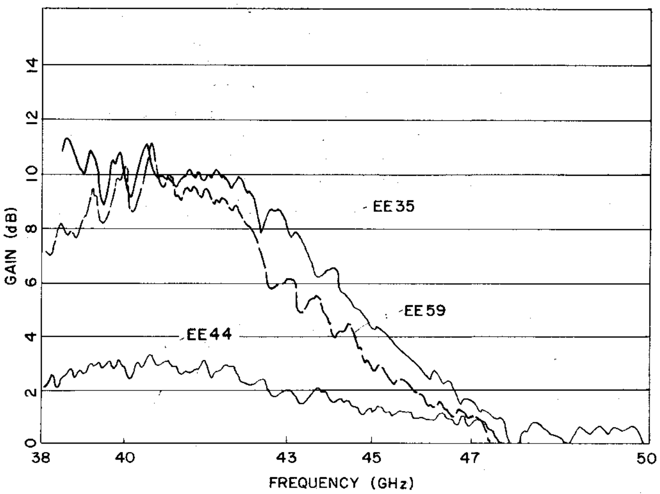

Fig. 2- Gain responses for InP amplifier devices at frequencies above 40 GHz.

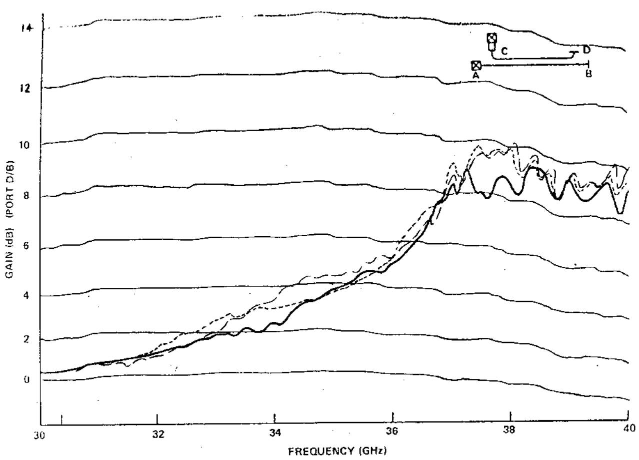

Fig. 3- 3 hybrid coupled amplifier gain response. Output measured at Port D, input applied at Port B. (Dashed and dotted curves are individual amplifiers)

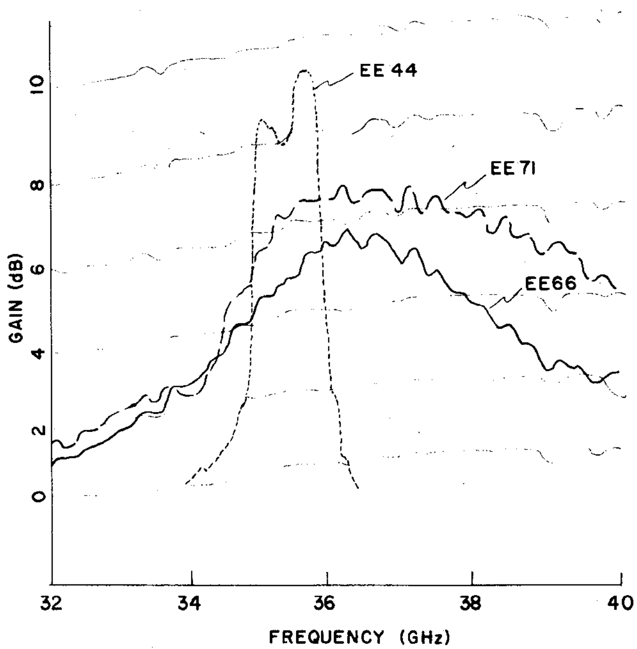

Fig. 4-Typical amplifier gain responses for devices from several low noise, lower doped InP wafers

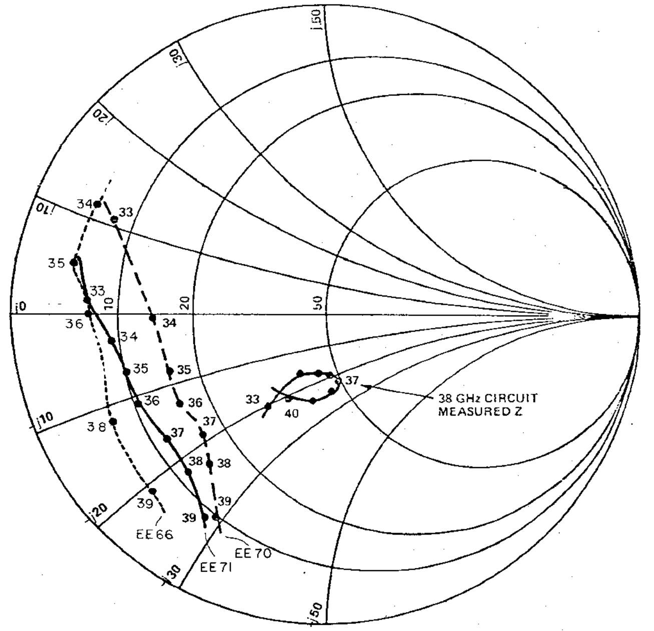

Fig. 5-Negative of the terminal impedances for typical devices from three lower doped InP amplifier wafers. Also plotted is the circuit impedance of the measurement circuit.

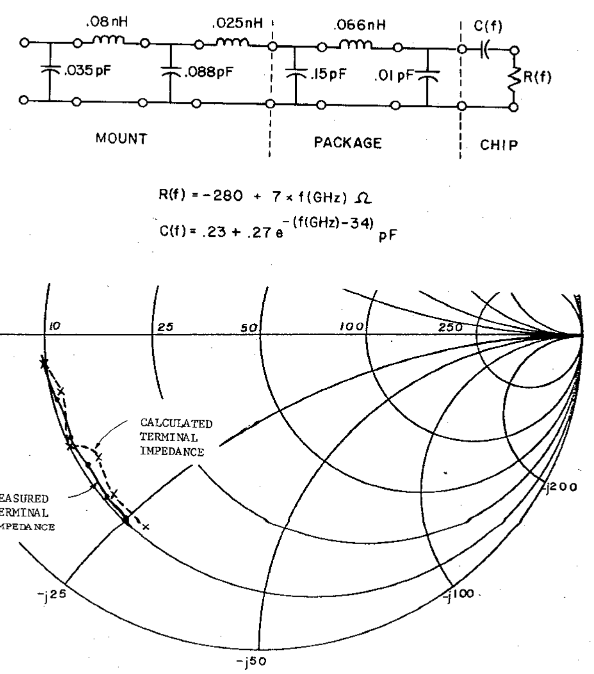

Fig. 6-InP low noise device model (typical device wafer EE71) including mount contributions and measured and calculated impedance comparison.