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AN X-BAND "PEELED" HEMT AMPLIFIER

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ABSTRACT

A discrete peeled high electron mobility transistor (HEMT) device was integrated into a 10 GHz amplifier. The discrete HEMT device interconnects were made using photo patterned metal, stepping from the 10 mil alumina host substrate onto the 1.3 um thick peeled GaAs HEMT layer, eliminating the need for bond wires and creating a fully integrated circuit. Testing of devices indicate that the peeled device is not degraded by the peel off step but rather there is an improvement in the quantum well carrier confinement. Circuit testing resulted in a maximum gain of 8.5 dB and a return loss minimum of -12 dB.

INTRODUCTION

Epitaxial lift off of GaAs based layers allows for the removal of the active layer from the growth substrate and reattachment of the thin film discrete device to various host substrates. The thin film layers are of the order of microns thick and allow for the integration of a thin film active GaAs layer into normally incompatible device technologies such as indium phosphide, silicon or sapphire.

Various discrete devices have been peeled off and attached to host substrates. As examples, solar cell [1][2] and laser structures [3] were first demonstrated using the peel off technology. FET [4] devices were also peeled and tested on host substrates with a reported F_{max} of 14 GHz for a 1.3 um GaAs MESFET.

To determine the effects of the peel off step on HEMT devices, data was presented by this author [5],[6] and the devices showed a quantum well electron carrier confinement improvement of the order of 10% after peel off. When designing a HEMT based circuit the effects of the peel off step are required to predictably design and fabricate a microwave circuit.

To date, there has been no reported integration of a peeled HEMT device into a microwave circuit due to processing problems and the lack of

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device characterization. This paper will demonstrate an integrated X-band amplifier on alumina utilizing a peeled HEMT discrete device. The microwave circuit uses microstrip lines optimized for the alumina substrate and the peeled device is connected to the microstrip lines via photo patterned metal stepping over the thin film active device, thus eliminating the need for bond wires.

FABRICATION

The HEMT structure was MBE grown material, provided by QED Corporation, consisting of a $Al_{0.3}Ga_{0.7}As/GaAs/Al_{0.3}Ga_{0.7}As$ square quantum well structure with silicon pulse doping in the wideband $Al_{0.3}Ga_{0.7}As$ region. A 500A AlAs release layer was grown between the GaAs substrate and the superlattice to facilitate the "peel off" (See figure 1.)

Devices were fabricated using a mesa etch procedure for device isolation. Ohmic contacts were formed using a standard metal liftoff process and sequentially e-beam evaporated Au/Ge/Au/Ni/Au contacts. Alloying of the contacts was done in a RTA system for 15 seconds at 400C. Gate photo patterning was followed by gate recessing to reduce exposure of the undoped wide bandgap AlGaAs material. Ti/Au was used to form 1.0, 1.2, and 1.4 um gate lengths. The structure uses a dual 100 um gate finger design to form a 200 um gate width with a source to drain separation of 4 um.

The peel off process was done using an apiezon wax coating of approximately 30 um thickness. The wax was cured at 150 C for 30 minutes to give a compressive force to the wax to help facilitate the peel off step. The sample edges were cleaned and subjected to a hydrogen peroxide:ammonia hydroxide etch to remove the exposed active edge layer, leaving to AlAs release layer exposed. The samples were then allowed to etch in a diluted HF solution overnight at room temperature to release the active layer from the GaAs substrate.

Samples were attached to the alumina substrates and adhesion of the device was achieved via Van der Waals forces. To improve adhesion for further circuit processing and to allow for more stable device measurements, the devices are coated with a spin on glass and cured at 250 C for 4 hours (see figure 2(a)). Contacts were then opened using standard photo processing and metal pattering was complete as shown in figure 2(b).

A classical narrowband, high gain amplifier was designed with a center frequency of 10 GHz and optimized on a 10 mil thick alumina substrate. The microstrip circuit consists of quarter-wavelength coupled line DC blocks, series/shunt microstrip matching networks and bias networks which use a 1/4 wavelength high impedance line cascaded with a 1/4 wavelength radial stub to provide rf isolation. The finished amplifier is shown in figure 3.

RESULTS AND DISCUSSION

To do the circuit design, an analysis of the discrete device performance is required to evaluate the rf response after peel off. Figure 4 illustrates the measured gain response before and after peel off for a discrete HEMT device. As can be seen, the device experiences an improvement in the low frequency gain of approximately 2 dB but F_{max} doesn't appear to be improved in this devices structure. An analysis of H_{21} before and after peel off indicate F_T values of 26 and 30 GHz, respectively, with H_{21} showing a positive shift of 2 dB for the peeled sample.

Analysis of the S-parameters before and after peel off show a 5 dB decrease in S_{12} and an increase of .5 dB for S_{21} after peel off. Based on a lumped element equivalent circuit model of the peeled and unpeeled device, it was concluded that the intrinsic transconductance increased from the before peeled value of 194 mS/mm to 204 mS/mm. The most significant parametric change was a decrease in the drain-source resistance from 725 to 557 ohms before and after peel off.

Hall measurements were also conducted on peeled and non peeled Hall bars and the increase in the device performance for the peeled device is attributed to an improvement of the quantum well electron carrier confinement [5] resulting in an increased intrinsic transconductance.. While there was an improvement in the transconductance, it's effect on F_{max} was offset by the decrease in the source-drain resistance. Consequently, F_{max} remained the same while F_T experienced a 4 GHz enhancement after peel off.

DC characteristics of the amplifier circuit is shown in figure 5 for a device using one of the two 100 um gate fingers. As is illustrated by the DC performance, metal step coverage was achieved from the alumina substrate onto the 1.5 um thick GaAs HEMT device resulting in a fully integrated circuit.

Circuit performance of the X-band circuit was measured and is compared to modeled results (see figure 6). The design indicates a gain maximum response of 12 dB at 9.2 GHz while the measured gain was found be 8.5 dB at 9.3 GHz for the peeled HEMT amplifier. Further deviations from the designed response are seen in the measured circuit at frequencies greater than 9.3 GHz. Best return loss for the peeled circuit at 10.3 GHz was -12 dB as compared to the modeled value return loss at 10.3 GHz of -18 dB.

Based on the circuit model, the origin of the gain curve spike is attributed to source to ground inductance. Additionally, losses of the circuit can also be traced to connector losses and a imperfect rf ground scheme. The grounding used in this design utilizes low impedance, 1/2 wavelength stubs to ground rather than industry standard via holes to ground.

CONCLUSION

This paper presents the first reported use of a peeled HEMT device in a microwave integrated circuit. A X-band amplifier was modeled and fabricated using a discrete HEMT device on an alumina substrate. A fully integrated circuit was achieved eliminating the need for bond wires.

The discrete device performance was evaluated for a GaAs square channel structure and the discrete device response did experience a parametric change. An increase in the intrinsic transconductance and decrease of source-drain resistance after peel off was seen.

Amplifier performance was evaluated and the maximum gain was 8.5 dB at 9.3 GHz. Amplifier performance did follow the modeled trend but there was circuit loss which decreased the overall amplifier gain.

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REFERENCES

1. M.Konagai,M.Sugimoto,K.Takaashi,"High Efficiency GaAs Thin Film Solar Cells by Peeled Film Technology",J.Cryst.Growth(Netherlands), 45,pp.277-280,1978
2. D.Wilt,F.DeAngelo,R.Thomas,S.Bailey,G.Landis,D.Brinker,N.Fatemi, "Peeled Film GaAs Solar Cells for Space Power",NASA Tech. Memo.,103125,1990
3. E.Yablonovitch,E.Kapon,T.Gmitter,C.Yun,R.Bhat,"Double Heterostructure GaAs/AlGaAs Thin Film Diode Lasers on Glass Substrates",IEEE Photonics Technol. Lett.,vol.1,no.2,pp.41-42,1989
4. D.Shah,W.Chan,T.Gmitter,L.Florez,H.Schumacher,B.Van der Gaag,"DC and RF Performance of GaAs MESFET Fabrication on Silicon Substrate using Epitaxial Lift-off Technique",Electron.Lett.,vol.26, no.22,pp.1865-1866,1990
5. P.Young,S.Alterovitz,R.Mena,E.Smith,"Microwave Properties of 'Peeled' HEMT Device on Sapphire Substrates",International Semiconductor Device Research Symposium Proc.,pp.689-692,1991
6. P.Young,R.Mena,S.Alterovitz,E.Smith,"Device Characterization of 'Peeled' HEMT Devices on Insulating Substrates",to be published.

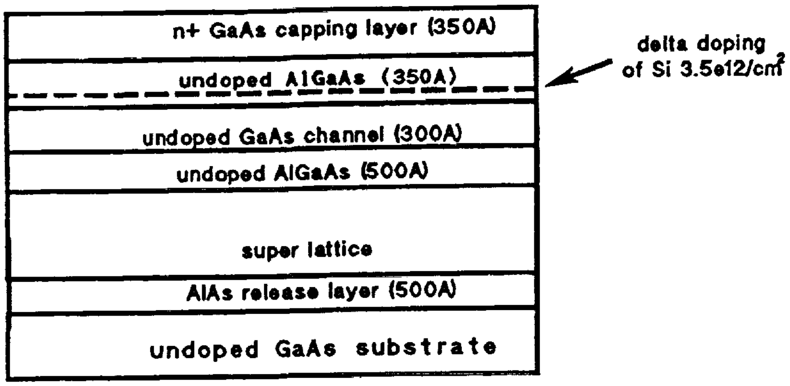

Figure 1. Square well, GaAs channel peel HEMT structure.

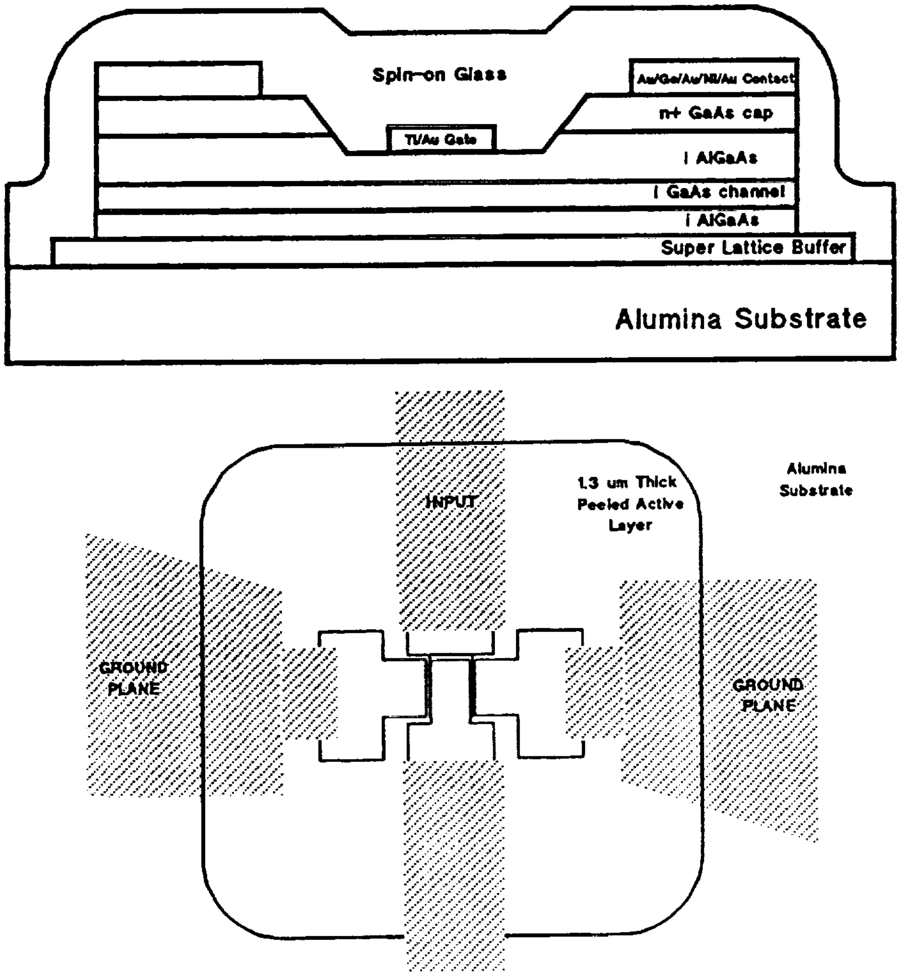

Figure 2. a.) Finished device structure with spin-on glass,
b.) Discrete device structure showing metal contact method.

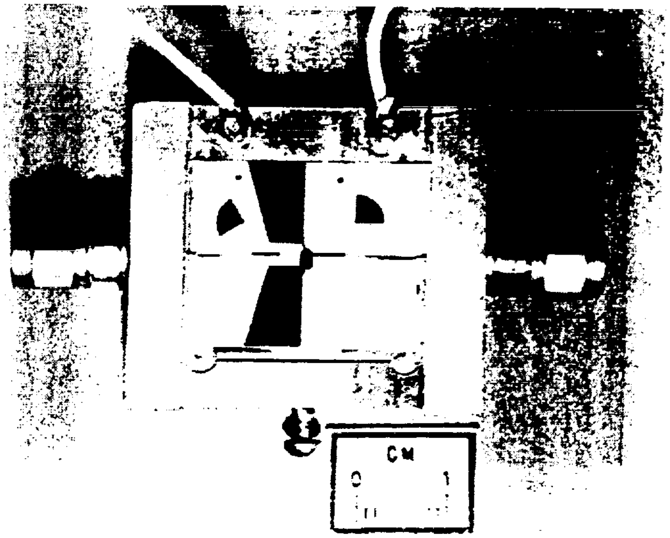

Figure 3. Finished X-band amplifier.

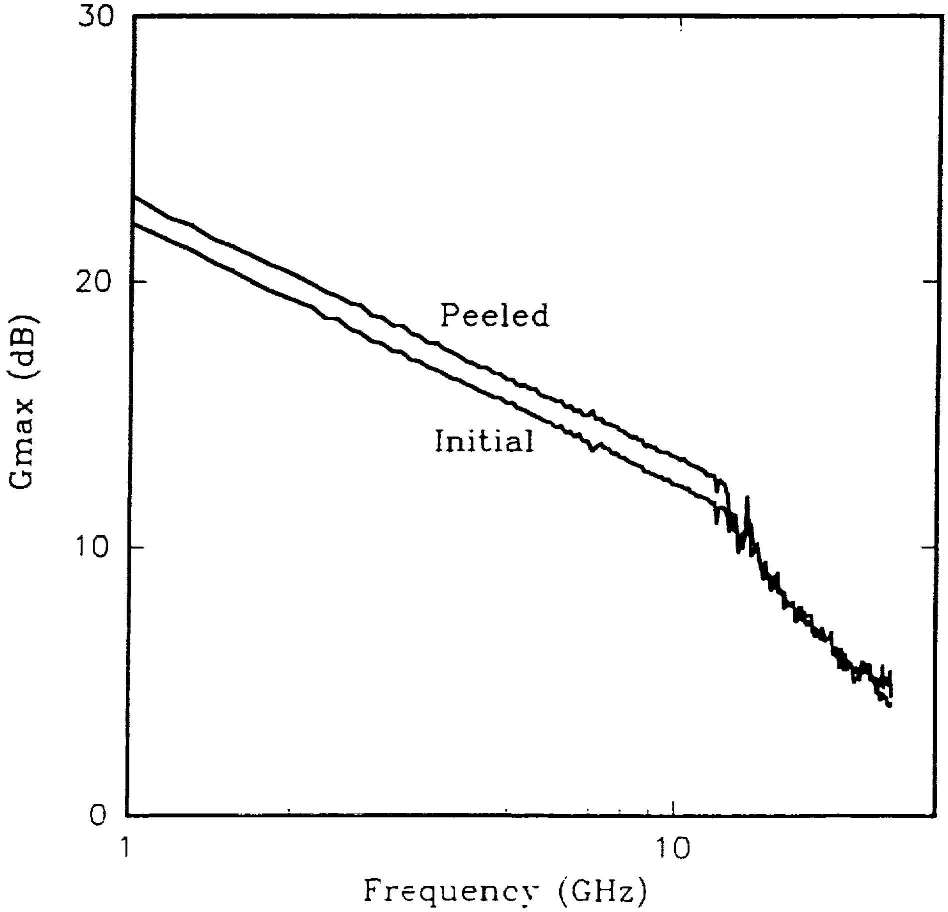

Figure 4. Measured G_{max} before and after peel off for a discrete square well HEMT device.

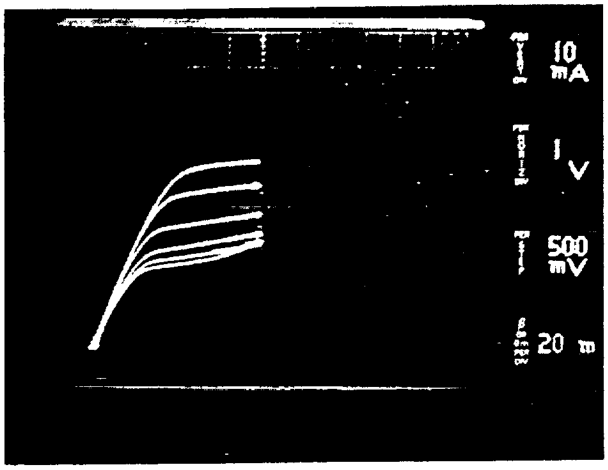

Figure 5. Measured DC characteristics of Amplifier for a one of the two 100 um gate fingers.

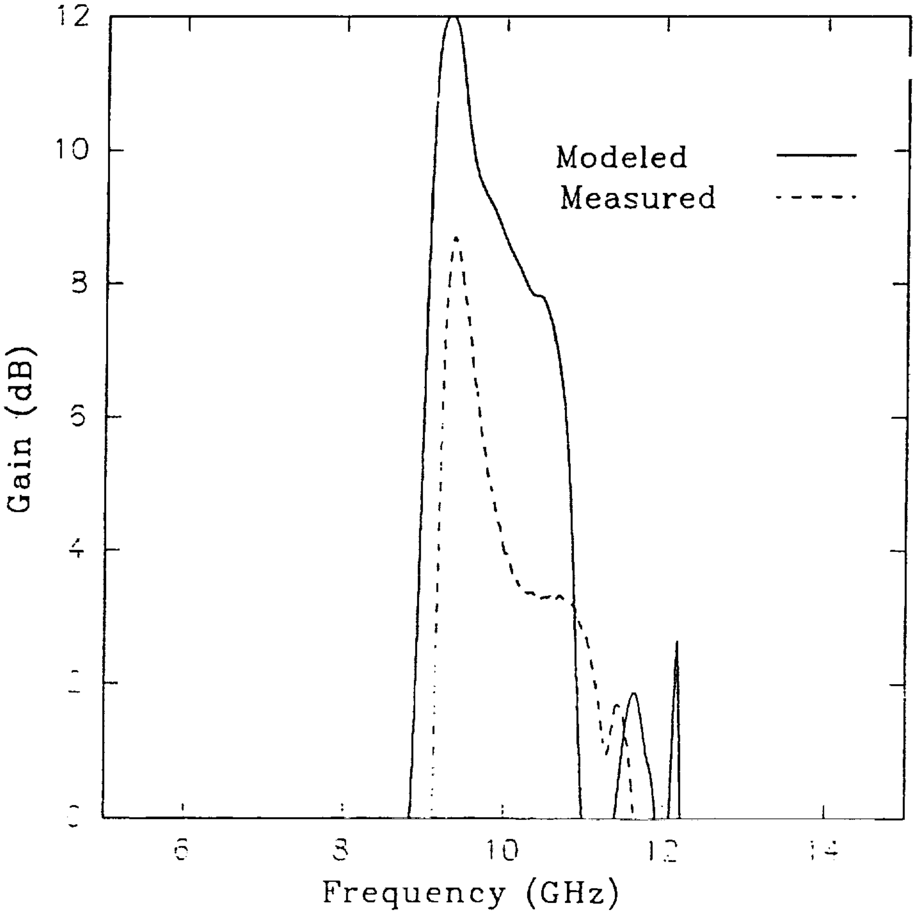

Figure 6. Measured and modeled gain response for the X-Band amplifier.