High Performance Millimeter Wave AlInAs/GaInAs/InP HEMTs with Individually Grounded Source Finger Vias

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ABSTRACT

Millimeter wave AlInAs/GaInAs/InP HEMTs with individually grounded source finger vias and end source vias have been fabricated and characterized. Although DC IV characteristics of the HEMTs with individually grounded source finger vias and end source vias were similar, RF measurements yielded higher small signal gain on the HEMT with individually grounded source finger vias. Power measurements at 44 GHz further revealed that the HEMT with individually grounded source finger vias produced higher output power, power added efficiency, and associated gain compared to the HEMT with end source vias.

INTRODUCTION

Through-wafer source via technology has been widely recognized as one of the key technologies required for development of high performance monolithic microwave and millimeter wave integrated circuits (MMIC). The main function of through-wafer via holes is to provide grounding paths for active devices and circuits. However, inductance associated with through-wafer source vias must be small to minimize negative feedback effects that degrade device performance at millimeter wave frequencies.

Three types of source via schemes have been demonstrated on GaAs; end vias [1], gate-side vias [2], and individually grounded source finger vias [3]. Gate-side source vias are superior to end source vias due to smaller inductance as a result of grounding individual source pads by airbridges that cross over a gate bus bar. The individually grounded source finger via technique minimizes source inductance and further improves device performance by complete elimination of source airbridges and airbridge-induced parasitic circuit elements. State-of-the-art power performance at millimeter wave frequencies was reported on GaAs PHEMTs with individually grounded source finger vias [4,5].

The first generation of InP-based HEMTs was used predominantly for millimeter wave low noise applications [6,7]. Since then, efforts in InP device and process development areas helped further expand the range of applications for InP-based HEMTs. As a result, state-of-the-art power performances at K-, V-, and W-band have been reported using InP HEMTs [8-13]. Despite these significant advances, conventional InP-based MMICs, to date, have been fabricated with wet etched end source vias. This is due to the lack of a high resolution, high rate dry etch process, as readily available with GaAs-based MMIC technology [4,5]. In this work, a recently introduced InP reactive ion etch (RIE) process [14] has been utilized to fabricate AlInAs/GaInAs/InP HEMTs with individually grounded source finger vias and end source vias. RF characteristics up to 50 GHz and power performance at 44 GHz were compared between the devices with individually grounded source finger vias and end source vias to illustrate the advantages and potential application of the individually grounded source finger via technology for InP HEMT-based MMICs.

DEVICE FABRICATION

Solid source molecular beam epitaxy (MBE) was used for wafer growth of InP HEMT layers. The single pulse doped layer structure consists of an AlInAs buffer, an undoped GaInAs channel, an AlInAs

CH3577-4/95/0000-0465$01.00 © 1995 IEEE

spacer, a Si pulse doped layer, an AlInAs Schottky layer, and an undoped and heavily doped GaInAs cap. Typical carrier sheet density of approximately 3.2×10^{12} cm^{-2} and Hall mobility of 7600 cm^2/V-sec at room temperature were measured on a calibration wafer.

The process sequence for the frontside was identical for HEMTs with individually grounded source finger vias and end source vias. The devices were fabricated on the same wafer to minimize variation in material properties. A H_2SO_4:H_2O_2:H_2O-based wet etch process and a succinic acid etch was utilized for mesa isolation with a channel notch. Ohmic contacts using a AuGe-Au metallurgy was used for the source and drain contacts. Electron beam lithography was used to write 0.2 μm T-gates. After the gate recess to a desired current level using H_3PO_4:H_2O_2:H_2O, Ti-Pt-Au metal was deposited and lifted off. A plasma enhanced chemical vapor deposition (PECVD) process was used for SiN_x passivation. Source airbridges were fabricated on all devices to focus on the effects of source inductance alone.

After the thick metal liftoff, the wafer was lapped and polished to a nominal thickness of 50 μm. Using a high resolution RIE process, both individually grounded source finger vias and end source vias were etched simultaneously. Following the etch, Ti-Au sputtering and Au electroplating techniques were employed for via hole metallization. The wafer was diced into chips to accommodate fixtured measurements for RF and power characterization.

DEVICE RESULTS

Devices with 10 gate fingers and 60 μm unit gate width (600 μm total gate periphery) were used for small signal RF and power characterization. Gate-to-gate spacing was 30 μm. The HEMT with individually grounded source finger vias has 15x15 μm^2 via holes on each of the 6 source pads while the HEMT with end source vias has 50 μm-diameter via holes only at the ends of the source airbridge. DC IV characteristics were measured on devices with individually grounded source finger vias and end source vias to select a pair of devices with similar electrical properties. Maximum drain-to-source current was 500 mA/mm and pinch-off voltage was in the range, -0.6 to -0.7 V. Typical peak extrinsic transconductance of 600 mS/mm was measured at V_{ds} = 2 V. Gate-to-drain reverse breakdown voltage was in the range, 6-7 V.

Following DC characterization, devices were mounted on a test fixture to facilitate s-parameter measurements up to 50 GHz. The devices were biased at Vds = 2 V and Vgs = 35% I_{max}. The results of RF s-parameter measurements are summarized in Fig. 1 and 2. Fig. 1 shows a comparison of small signal gain (MSG/MAG) between HEMTs with individually grounded source finger vias and source end vias measured as a function of frequency. The device with individually grounded source finger vias exhibited higher small signal gain at higher frequencies, above 10 GHz. Increase in gain with the use of individually grounded source finger vias was as much as 4 dB. This higher small signal gain is mainly due to the significant reduction in reverse transmission (S12) as shown in Fig. 2.

The s-parameter data was fitted to an equivalent circuit model to investigate the differences between the two devices. Most of the circuit element values between the two types of devices appeared to be comparable within a reasonable tolerance. However, source inductance was at least four times smaller on the device with individually grounded source vias (2.9 pH) compared to the device with end source vias (13.5 pH). This significant reduction of source inductance is responsible for smaller source feedback, smaller reverse transmission, and higher small signal gain. The reduction in source feedback also results in more unilateral device characteristics and simplifies the design of matching circuit network.

To compare power performance of the devices with individually grounded source finger vias and end source vias, power measurements were performed at 44 GHz using low loss coaxial fixtures. The devices were mounted onto gold plated alumina carriers using conductive epoxy and gold bond wires were used to connect the gate and drain pads to the input and output tuning structures, respectively. Both HEMTs were biased at Vds = 4 V and Vgs = 35 % Imax and tuned for optimum power. Fig. 3 shows the 44 GHz power performance of the HEMTs with individually grounded source finger vias and end source vias. Compared to the HEMT with end source vias, the HEMT with individually grounded source finger vias exhibited approximately 1 dBm higher output power, 7 percentage points higher power added efficiency, and 1 dB higher associated power gain. Therefore, the power results at 44 GHz indicate that the individually grounded source finger via topology results in superior power performance at millimeter wave frequencies.

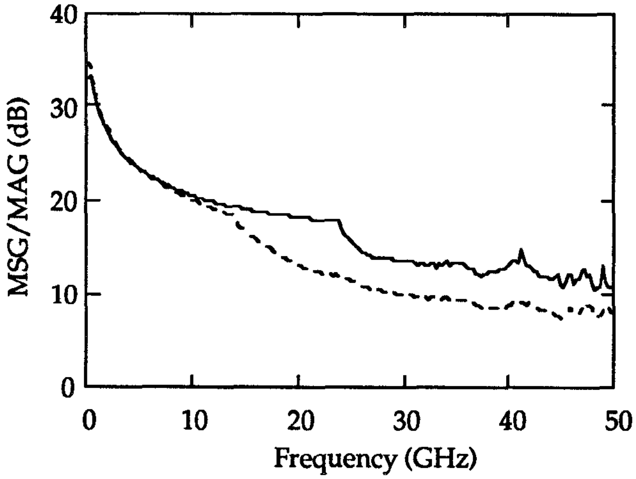

Fig. 1. Small signal gain (MAG/MSG) of HEMTs with individually grounded source finger vias (solid line) and end source vias (dotted line) plotted as a function of frequency. Higher gain is obtained on the device with individual source vias.

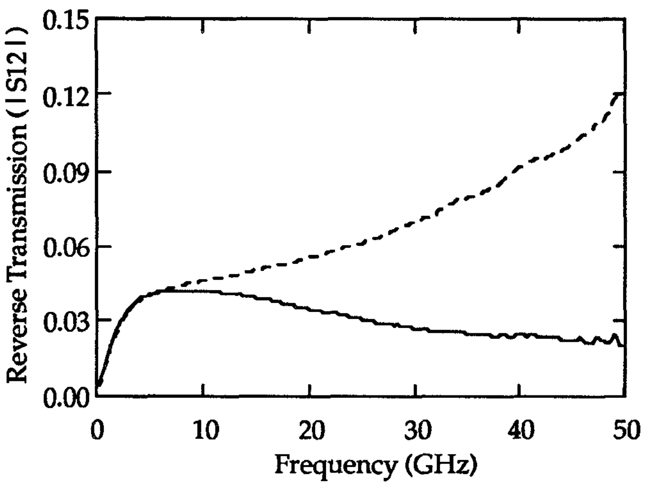

Fig. 2. Comparison of S12 between the HEMTs with individually grounded source finger vias (solid line) and end source vias (dotted line). The use of individual source vias results in smaller S12 at high frequencies above 10 GHz.

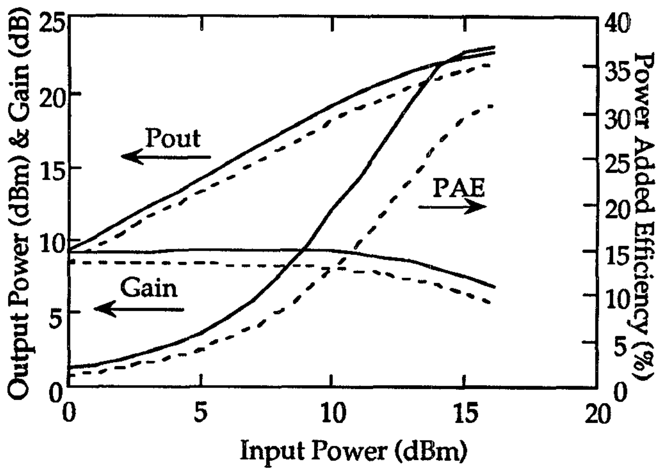

Fig. 3. Comparison of 44 GHz power performance between 10x60 μm single pulse doped InP HEMTs with individually grounded source finger vias (solid line) and end source vias (dotted line). Higher output power, efficiency, and gain are obtained on the HEMT with individual vias.

CONCLUSION

In this paper, small signal RF characteristics and 44 GHz power performance of 600 μm AlInAs/GaInAs/InP HEMTs with individually grounded source finger vias and end source vias were compared. Small signal RF characterization demonstrated lower source inductance, smaller feedback (S12), and higher gain while 44 GHz power measurements revealed higher output power, power added efficiency, and power gain on the device with individually grounded source finger vias. These RF and power results demonstrate the applicability of the individually grounded source finger via technology for InP-based power MMICs at millimeter wave frequencies.

ACKNOWLEDGMENT

The authors would like to thank Dr. W. Hoke and P. Lemonias for MBE wafer growth, D. Shaw and P. Beverage for electron beam lithography, and Dr. S. Shanfield for encouragement and support.

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