ONE WATT, VERY HIGH EFFICIENCY 10 AND 18 GHz PSEUDOMORPHIC HEMTs FABRICATED BY DRY FIRST RECESS ETCHING

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ABSTRACT

We report on record 10 and 18 GHz power performance of double recessed 1.2 mm periphery pseudomorphic HEMTs where the critical first recess was formed with exceptional uniformity using dry etching and an AlGaAs etch stop layer. Simultaneous power, gain, and power-added efficiency, representative of many devices, is summarized below:

Frequency	Power	Gain	Efficiency
10 GHz	0.97 watt	10 dB	70%
18 GHz	0.97 watt	6.8 dB	48%

INTRODUCTION

Pseudomorphic High Electron Mobility Transistors (PsHEMTs) have demonstrated superior simultaneous power, gain, and power-added efficiency at X-band and Ku-band frequencies [1-4]. Record power-added efficiency has recently been reported at 18 GHz for a 400 μm periphery device.[1], [3] However, the total output power for this device was low (300 mW). A 1.6 mm periphery PsHEMT has achieved record gain and efficiency (50%) at 15 GHz (not 18 GHz), but with moderate output power (575 mW) and low power density (360 mW/mm).[4] In addition to low unit power as a limit to practical utilization, PsHEMTs devices are in general more difficult to fabricate with uniform electrical characteristics than lower performance microwave power devices such as GaAs MESFET. Some of the difficulty can be traced to non-uniformity in the gate recessing step, which is conventionally performed using a wet etchant. Recess depth variation associated with wet etching ultimately results in substantial variation of device characteristics, and channel to channel variation within a single large periphery device can affect power combining efficiency.

Practical applications for high performance power microwave amplifiers require transistors with high power in addition to high associated gain and efficiency in their band of operation. In addition, uniformity in device electrical characteristics is a key feature for maximizing multi-stage power amplifier performance. We have succeeded in fabricating one watt PsHEMTs with a record power-added efficiency and associated gain at 10 and 18 GHz. We have obtained demonstrably better uniformity in performance than conventionally fabricated PsHEMTs. This was accomplished by incorporating a new approach to recess formation using selective reactive ion etching of the first recess in a double recessed structure.

MATERIAL STRUCTURE AND DEVICE FABRICATION

The device structure shown in Figure 1 is similar to our previously reported power PsHEMT design [1], except for the thickness of the top AlGaAs layer. Selective reactive ion etching of the first recess was done with a BCl_3/SF_6 mixture diluted in argon, as described in [5]. The GaAs:AlGaAs selectivity, a consequence of the formation of relatively involatile aluminum fluoride on the AlGaAs surface, was greater than 1000:1. Pressure and power conditions were

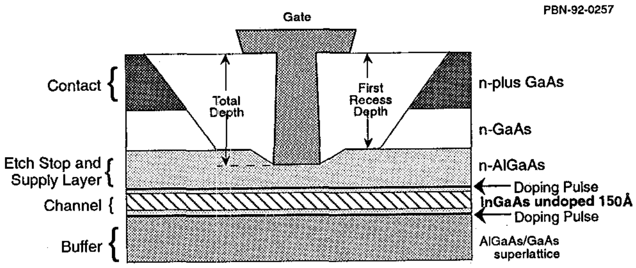

Figure 1. Double recess PsHEMT structure giving high performance

chosen so that the plasma-substrate potential difference was less than 10 V, minimizing substrate damage from ions accelerated through the plasma sheath. Total etch time was chosen to be about 25% longer than required to reach the AlGaAs surface. The gate recess, typically 10-20 nm deep, was formed using a wet etchant. By dry etching a deep first recess, then wet etching a shallow gate recess, the issues of damage and recess shape usually associated with dry gate recessing [5] were avoided.

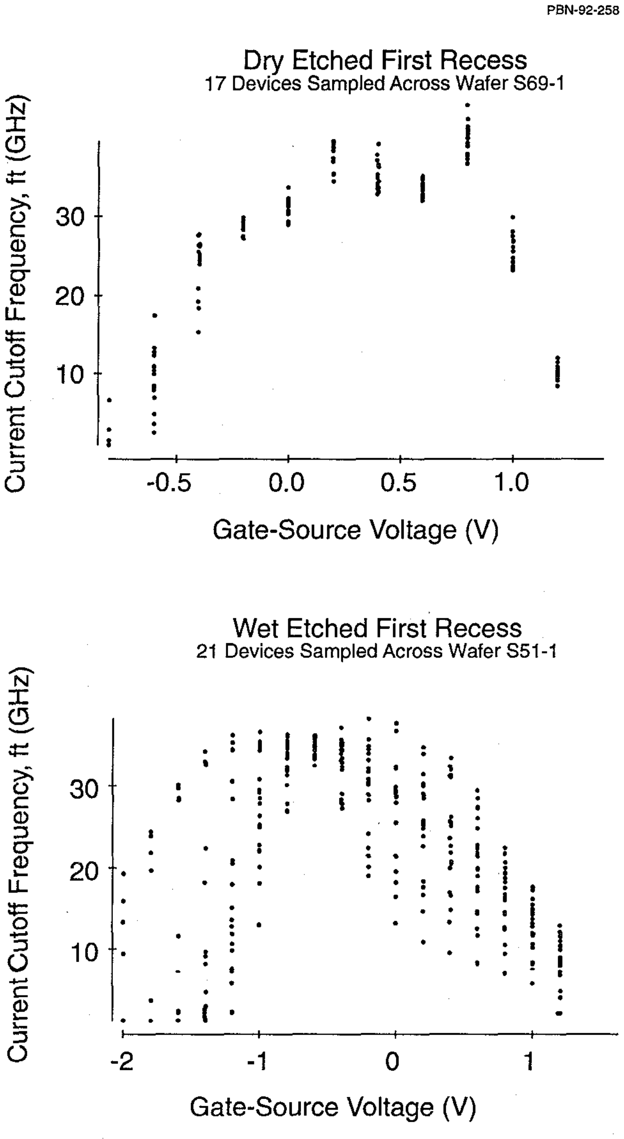

Figure 2. Current gain cutoff frequency for wafer fabricated with dry first recess etch (a, top) and with conventional wet etch (b, bottom).

With selective dry etching, the interface between the AlGaAs and GaAs layer defined the position of the first recess surface. The position of this first recess surface (along with the doping profile underneath) determines reverse breakdown voltage and transient current response in the device, as described in [1]. The optimum upper AlGaAs supply layer thickness was established by processing 75 mm diameter wafers with various upper AlGaAs supply layer thicknesses (10, 20, 30, and 40 nm).

DEVICE CHARACTERISTICS

Saturated current uniformity was measured in process immediately after first recess dry etching. The median saturated current for wafers #1 and #2 was 672 and 618 mA/mm respectively, both with an interquartile range of 3%. This can be compared to 9% interquartile range for first recess current uniformity in a nearly identical wet etched structure. Wafers were characterized for DC and small signal RF performance on 400 μm test devices before wafer thinning. The median peak transconductance for 400 μm test devices on Wafer #1 was 495 mS/mm, measured for $V_{ds} = 4$ V, at a median $V_{gs} = +0.4$ V. Figure 2a and 2b show f_t for about 20 devices as a function of V_{gs} at a fixed drain voltage of $V_{ds} = 3.5$ V. Figure 2a corresponds to a wafer fabricated with dry first recess etching, and Figure 2b, included for comparison,

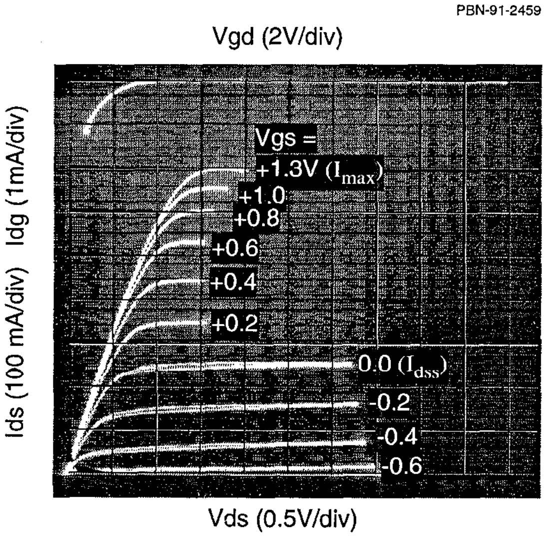

Figure 3. Typical DC curve tracer characteristics for dry recessed device.

was fabricated with conventional wet first recess etching. The value of f_t at a particular gate voltage was considerably more uniform when dry first recess etching was used. Other small signal characteristics of these devices, such as C_{gs} ,were also more uniform. Figure 3 shows typical I_{gs} - V_{gs} and I_{ds} - V_{ds} DC characteristics for a fixtured 1.2 mm device (12 channels, 100 μm long). This device showed a large increase in drain current from I_{dss} to I_{max}, implying high gain at power. The high value of I_{max} is a prerequisite for high power density.[1]

Figure 4 shows output power, gain, and efficiency as a function of input power for 1.2 mm devices at 10 GHz and 18 GHz. In both measurements, V_{ds} = 8 V, and devices were tuned for maximum efficiency. At 10 GHz, power-added efficiency was 70% with 0.97 watt output power and an associated gain of 10 dB. At 18 GHz on another device, power-added efficiency was 48% with output power of 0.97 watt and an associated gain of 6.8 dB. To our knowledge, these results are the best combination of power, efficiency, and gain ever reported for a 1.2 mm periphery device at 10 and 18 GHz.[2] Several other devices from Wafers #1 and #2 achieved similar levels of power, gain and efficiency. Some of the high performance obtained in these devices may be attributable to nearly identical electrical characteristics of each channel of our 12 x 100 μm layout, leading to more efficient power combining.

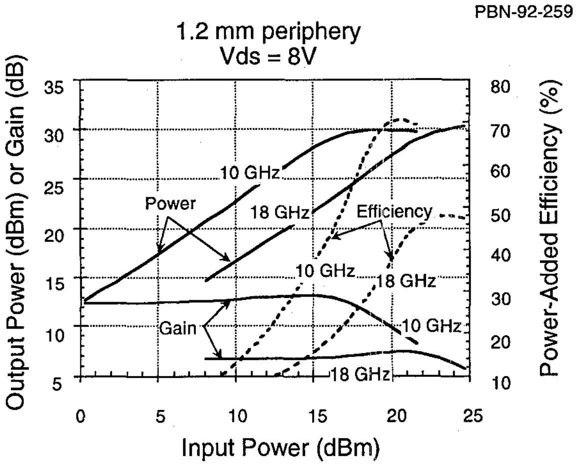

Figure 4. Input power versus output power, gain and power-added efficiency at 10 and 18 GHz for 1.2 mm periphery PsHEMTs.

CONCLUSION

The critical first recess of the double recess PsHEMTs reported in this letter were successfully fabricated with plasma etching and an AlGaAs etch stop. These devices demonstrate the best combination of gain and efficiency at a one watt power level yet reported for any microwave power transistor operating at 10 and 18 GHz. We attribute the performance of these devices to an optimum and uniform first recess depth, as well as excellent material properties and 0.25 μm T gates. The large unit output power and inherent uniformity of these devices makes them particularly useful for practical power amplifier applications.

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