Dry Etching Process in InP Gunn Device Technology Utilizing Inductively Coupled Plasma (ICP)

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Abstract

In this paper we report some recent progress in 77GHz InP Gunn device process development. Specifically, utilizing an advanced dry etching tool to define InP Gunn diode mesas. Unlike $FeCl_3$-based photochemical etches, the Inductively Coupled Plasma (ICP) offers excellent sidewall anisotropy and uniformity, which provides improved process consistency to facilitate mass manufacturablity of millimeter wave Gunn oscillators.

Introduction

One of the long lasting Transferred Electron Devices (TEDs), known as the Gunn diode, is capable of converting direct current (DC) power into radio frequency (RF) power. Typical applications for Gunn diodes include local oscillators (LO), voltage controlled oscillators (VCOs), radar and communication transmitters, Doppler motion detectors, and Automotive Forward Looking Radars (AFLRs). Due to their expended application fields, low cost and high performance GaAs and InP Gunn devices are becoming very desirable for today's millimeter wave markets.

InP has been adopted long time ago for high frequency Gunn diode applications [1]. However, the InP Gunn device process has been struggling to provide adequate fabrication consistency and throughput for high volume production. One of the critical problems lies in the anisotropic mesa etch. A commonly used technique for the InP Gunn mesa definition is the $FeCl_3$ photochemical etch [1]. It employs a $FeCl_3$:H_2O solution assisted by UV light illumination [1,2]. The process often yields rough sidewalls and inhomogeneous mesa definitions, which can lead to low yields and degraded device performance, especially with regard to breakdown voltage and power transfer efficiency.

A dry etch process for InP Gunn mesa definition was first reported by N. Proust, *et al.* [3] in 1992. In their work, a traditional capacitively coupled discharge reactive ion etching (RIE) system was used to perform CH_4/H_2/Ar-based plasma dry etching. The polymerization and the low etch rate are the two major problems associated with the process.

In this paper, we report on using an advanced dry etching tool, Inductively Coupled Plasma (ICP), to etch InP mesas. The ICP offers effective decoupling between the ion density and the ion energy to improve the dry etch control capabilities. It also exhibits over two orders of magnitude higher plasma density than conventional RIE systems to enhance the chemical reactions[4]. Our results show that the ICP is a suitable tool to perform consistent and high yielding InP mesa etch.

Device Structure and Process

A MBE grown InP two-layer nn^+ Gunn diode structure was used for this study. The critical $N_d l$ product of 2×10^{16} m^{-2} and the l - F characteristics of the Stable Depletion layer (SDL) oscillation mode were applied to the epitaxial profile specifications [5]. The N_d and l are the active layer doping level and thickness, the F is the Gunn oscillation frequency.

Devices were fabricated using the modified integral heatsink (IHS) technique [2]. The process is illustrated in Fig. 1. The wafer was first thinned to 40 μm with a series of mechanical lapping and chemical mechanical polishing steps which provides thickness uniformity of ± 3 μm over 80% of a 2 cm^2 wafer. An oxidizing bubble etch was then employed to evenly thin selective areas of the substrate (a recess etch) to ~ 15 μm. This is followed by depositing AuGe:Ni:Au Ohmic contacts on both sides of the wafer, a standard alloy, and Au electroplating of ~ 15 μm to the epitaxial side to form the Heatsink. On the substrate side, regular lithography techniques were used to define circular mesas with diameters ranging from 50 to 64 μm inside the recess. The mesa was etched either using plasma dry etch or the $FeCl_3$ photochemical wet etch. All chips are then separated through a regular solvent clean.

After the process, each individual chip was ultrasonically attached to a standard package and hermetically sealed for the subsequent DC and RF tests. The diode performance was enhanced by subsequent processing resulting in the current limiting SDL oscillation [5].

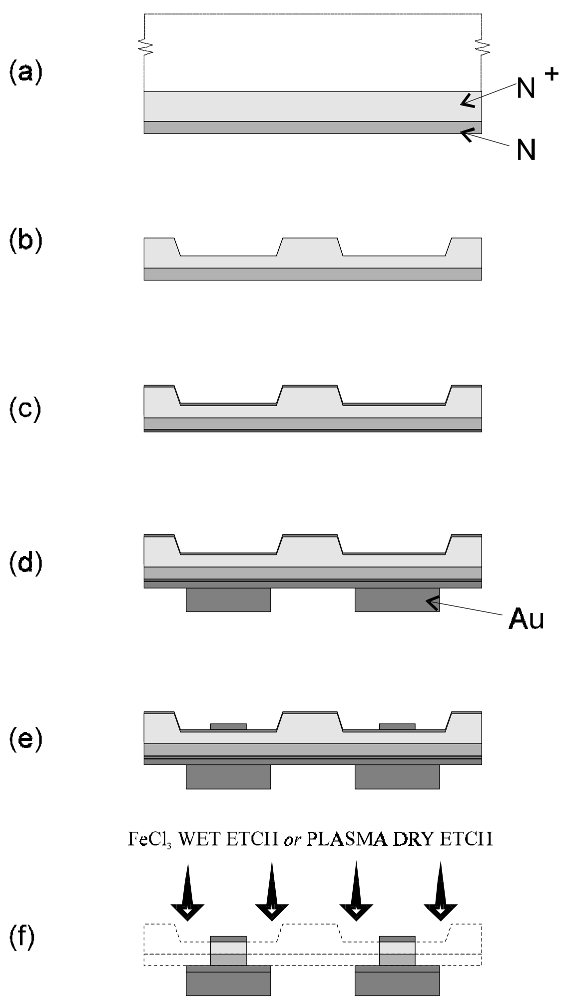


Fig. 1: Schematic of IHS process; (a) substrate thinning, (b) recess etch, (c) Ohmic contact, (d) heatsink plating, (e) mesa masking, and (f) mesa etch.

InP Mesa Etching

Mesa etch was performed using both the $FeCl_3$ wet etch and the ICP plasma dry etch. The wet etch results in a severe overetching on the substrate side and a field-induced undercutting around the active layer. The problem can be viewed in Fig. 2, a SEM picture of a wet etched InP mesa.

There were two dry etching tools employed for this study in two phases. One was the PlasmaTherm 500C, a capacitively coupled

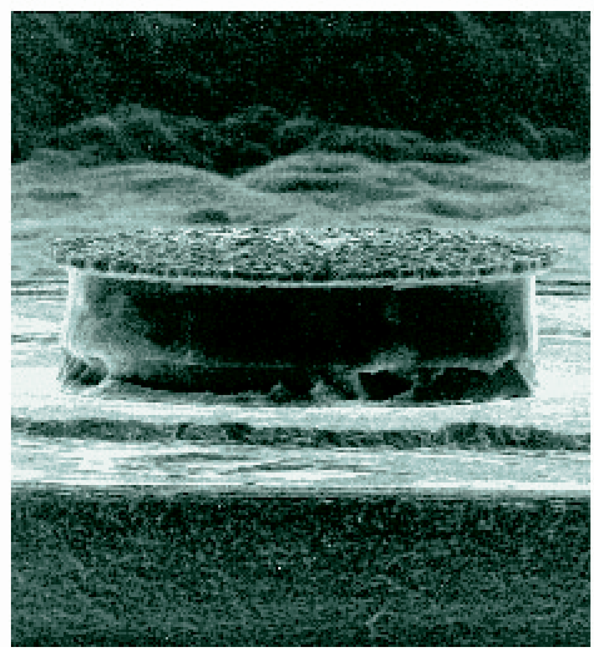


Fig. 2: SEM of $FeCl_3$ wet etched InP 77 GHz Gunn diodes.

discharge reactive ion etching (RIE). The other was the advanced PlasmaTherm SLR 770 load-locked inductively coupled plasma (ICP).

Based on N. Proust, *et al*'s work [3], a traditional RIE tool was first used to perform a $CH_4/H_2/Ar$ plasma dry etching on InP. Since CH_4 tends to form carbonated polymers when the gas flow rate is high, or to form phosphide depleted surface (formation of PH_3 and indium droplets that cause "micromasking") when the gas flow is low, consistent mesa etching is very difficult to achieve. Furthermore, extremely slow etch rates were obtained (normally < 30 nm/min) due to the low density plasma of capacitively coupled RIE systems ($\leq 10^9$ cm^{-3}). It adds to the problem of unstable chemistry and yields very inconsistent mesa profiles from run to run.

Fig. 3 shows the SEM photograph of a typical RIE etched mesa structure. Very rough profile was directly caused by an extended long etching time (> 10 hrs) and the severe deterioration from polymerization and/or micromasking.

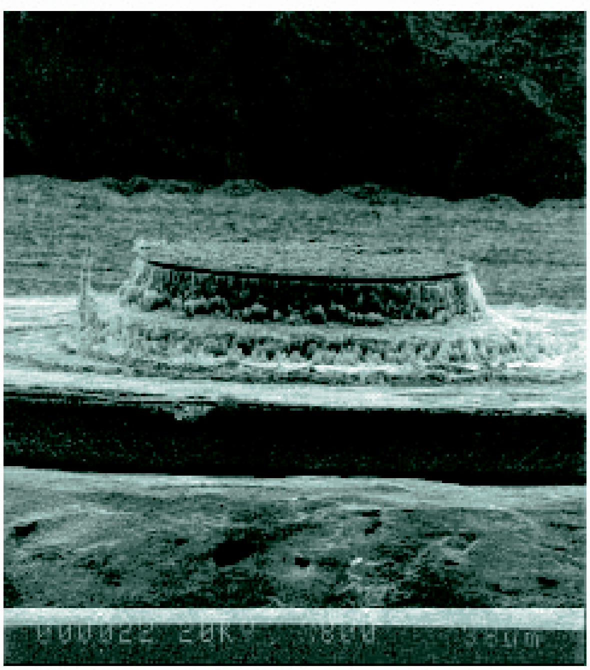
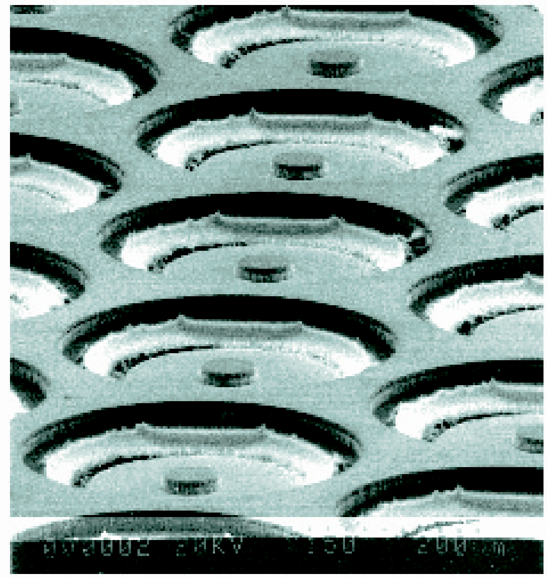
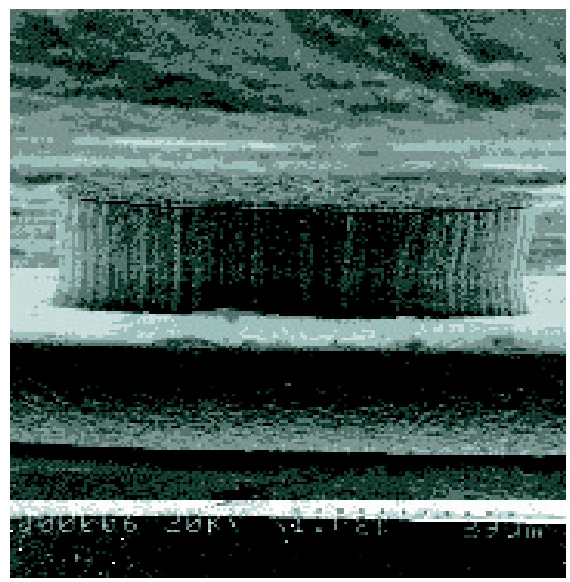


Fig. 3: SEM of conventional RIE etched InP 77 GHz Gunn diodes.

In the second phase, we utilized the advanced ICP system to etch the InP mesas. A gas mixture of $HBr/BCl_3/Ar/CH_4/H_2$ was used to perform the etch. Detailed system setup and etching conditions were reported separately [6]. The SEM photographs of the wafer level mesa definitions and the detailed mesa structure were shown in Fig. 4.



(a)



(b)

Fig. 4. SEM photographs of (a) an overview and (b) a detail of ICP etched mesa of InP 77 GHz Gunn diodes.

There are several unique features on the ICP etched InP mesas: (A) The overetching on the anode side and the undercutting of active layer were significantly reduced comparing to the result of $FeCl_3$ wet etch. (B) Much smoother sidewall was achieved comparing to the $CH_4/H_2/Ar$ RIE etch. (C) The etch rate is more than 10 times higher then that of the RIE etch. By utilizing the ICP we have obtained much consistent mesa diameter distributions across the wafer. This translates to more consistent wafer level I-V characteristics and oscillation frequencies.

Performance Results

Fig. 5 shows the histograms of I_{pulse} (50 ns) and I_{CW} measured at 5 V and 4 V biases, respectively, on both the $FeCl_3$ wet etched and the ICP dry etched diodes. The standard deviations in both cases are substantially reduced, from 0.16A to 0.03A for I_{pulse} (= 1.01A), and from 0.32A to 0.03A for I_{CW} (= 0.87A).

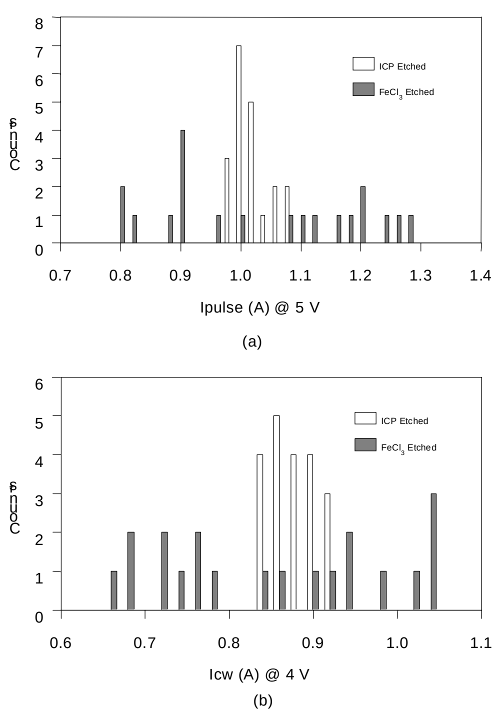


Fig. 5. Histograms of I_{pulse} (a) and I_{CW} (b) measured from ICP etched and $FeCl_3$ etched diodes.

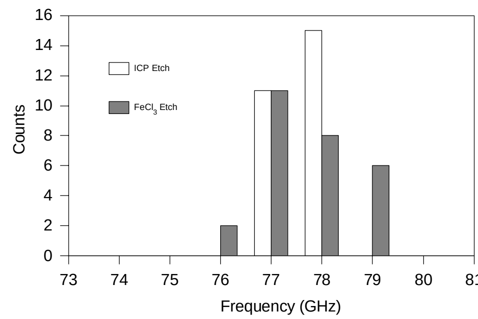


Fig. 6. Histogram of Gunn diode frequencies measured from ICP etched and $FeCl_3$ etched devices.

Enhanced homogeneity was also observed during final RF testing. Fig. 6 shows the histogram of measured oscillation frequency distribution. The standard deviation was reduced from 801 MHz ($FeCl_3$ etched) to 436 MHz (ICP etched). However, RF power is found to be comparable for both mesa etch processes, the same observation was also reported by N. Proust, *et al.* [3] for the work of InP mesa dry etch by conventional RIE and $CH_4/H_2/Ar$ gas mixture.

Conclusion

Excellent anisotropic mesa profiles and diode homogeneity are obtained in this work. The new ICP etch technology has been shown to be suitable for future mass production of millimeter wave AFLR InP Gunn diodes, and provide a fast alternative to perform via-hole etch in InP-based FET/MMIC technologies.

References

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