ICP Etching of InP and its Applications in Photonic Circuits

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Abstract:

Smooth and vertical sidewalls ridge waveguides are essential for applications in photonic circuits. We have investigated reactive ion etching of InP and InP-based structures using a SiN_x in a $Cl_2/H_2/CH_4$ chemistry in an ICP plasma. Depending on ICP power and RF power, etching rates can be monitored between 50 nm/min up to > 2µm/min. A maximum etching selectivity of InP vs SiNx of 12 was obtained at 2000 W of ICP power. Deep etched waveguides, fabricated in an InP/InGaAsP double heterostructure, show typical losses of 2 dB/cm. This low value allows the use of ICP technique in the fabrication of photonic circuits.

Introduction

In the fabrication of photonic integrated circuits people use mostly a CH_4-H_2 chemistry in a reactive ion etching mode (RIE) for etching the shallow and deep waveguides in InP-based structures [1]. In the last few years Inductively Coupled Plasma (ICP) RIE is getting more popular among researchers as a powerful dry etching technique used in photonic circuits and in photonic crystals devices [2-3]. In this work we have looked at ICP etching of InP and InP-based structures using Cl_2-CH_4-H_2 chemistry. This technique results in high etching rates while maintaining a smooth morphology. Moreover the chlorine prevents the formation of polymers in the chamber and on the sample, leading to a higher throughput and hence less cleaning of the chamber. We have inspected systematically all etching processes using a scanning electron microscope and have selected two processes with the best morphology to be used for etching deep waveguides in an InP/InGaAsP passive double heterostructure. Fabry-Perot resonance measurements were performed to determine the optical losses of those waveguides.

ICP Experiments

All etching experiments were performed in a load-locked 100 system from Oxford Plasma Technology equipped with a 180 ICP source. A PECVD SiN_x layer of 400 nm thickness was used as a mask. Gas flows and pressure were kept constant (Cl_2-CH_4-H_2 : 7-8-5.5 sccm and 4 mTorr respectively). We have varied the ICP and RF power and looked at etching rates of InP and SiN_x. Figure 1 shows the etching rates at various ICP and RF powers. The etching selectivity between InP and SiN_x was around 10, except at low ICP power where the selectivity can be as low as 4 at 400 W ICP power. The DC bias varies between 150 up to 420 V. As expected a higher DC bias resulted in a lower etching selectivity.

All etched samples were inspected in a SEM to investigate the shape and morphology of the sidewalls as well as the bottom surface. Figure 2 show photographs of 3 samples at different ICP and RF powers, with etching rates from left to right: 3, 1.2 and 0.68 µm/min. To be noticed the rough morphology at 2000W ICP power while the other two samples at 1000W and 800W ICP powers show a very smooth morphology. A slight shoulder effect is seen at the edge of the mesa bottom, which is quite common in RIE experiments.

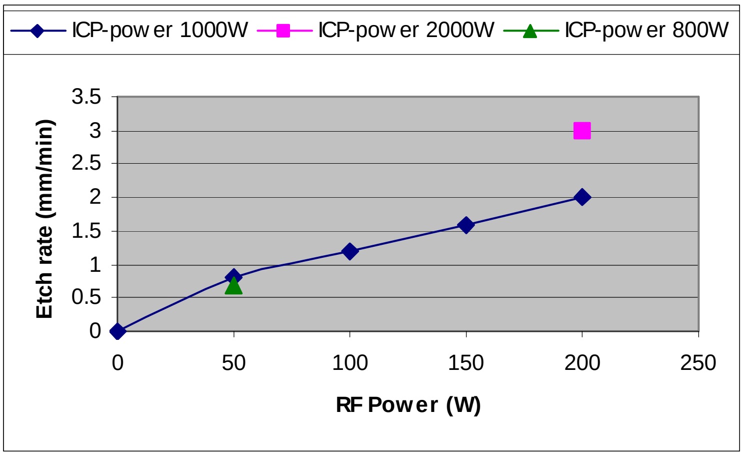

Figure 1- Etching rates at various ICP and RF powers.

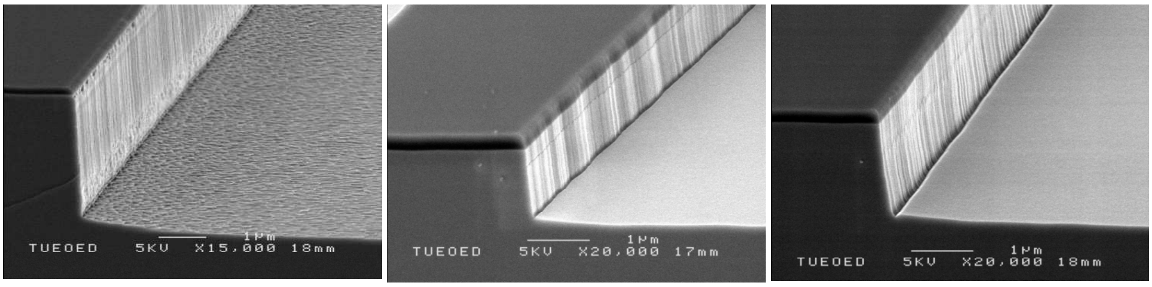

Figure 2- SEM photographs of etched samples at ICP and RF powers of 2000W, 200W (left), 1000W, 100W (center) and 800W, 50W (right).

Fabrication and characterization of deep waveguides

From the etching experiments described above we have selected the two processes shown in figures 2 (centre and right) to fabricate deeply etched waveguides in a double heterostructure of InP/InGaAsP. The aimed etch depth was 2 µm or higher. SiN_x was again used as masking material for these experiments. Fabry-Perot measurements were carried out to determine the losses. Figure 3 shows the losses of the TE mode at ICP and RF powers of 1000 and 100W. The losses in the TM mode are a bit higher. The inset shows a SEM photograph of the waveguide.

Figure 4 shows the TE losses of the sample etched at an ICP power of 800W and an RF of 50W (top). Losses between 1 and 2 dB/cm are obtained. A SEM photograph of the waveguide is shown in the inset. Moreover the losses in the TM are slightly higher but still very good (bottom figure). Notice that all these processes have been preceded by a pre-cleaning process of one minute using 50 sccm of SF_6 at 1000W ICP and 50W RF powers.

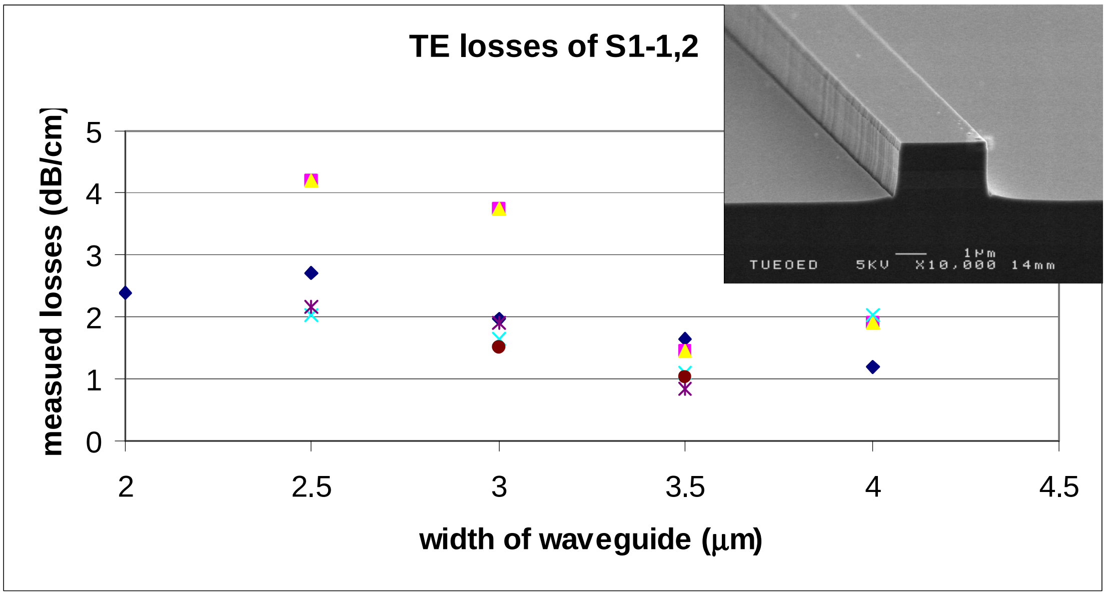

Figure 3- TE losses of deep waveguides etched at 1000 ICP power and 100 W RF power.

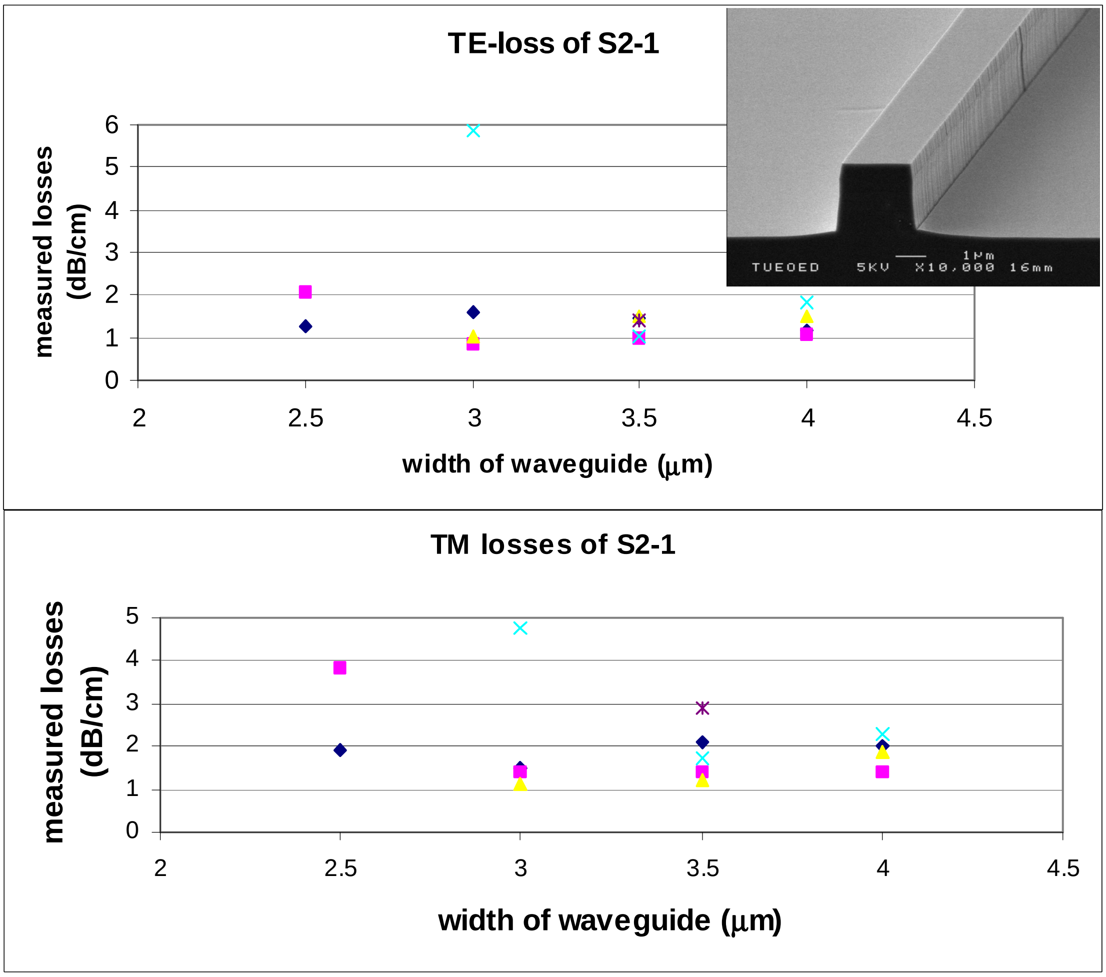

Figure 4- TE losses of the deeply etched waveguide at 800W ICP and 50W RF powers (top) and the TM losses of the same waveguide (bottom).

Replacing the SF_6 pre-cleaning with an O_2-plasma pre-cleaning led to an increase of the selectivity of etching between InP and SiN_x. Therefore we also tried to make deep etched waveguides after an O_2-plasma (50sccm) for two minutes at 500W and 100W of ICP and RF powers respectively, followed by an etch of the waveguide structure at 1000W and 100W of ICP and RF powers. Higher TE losses of this waveguide are obtained and shown in figure 5.

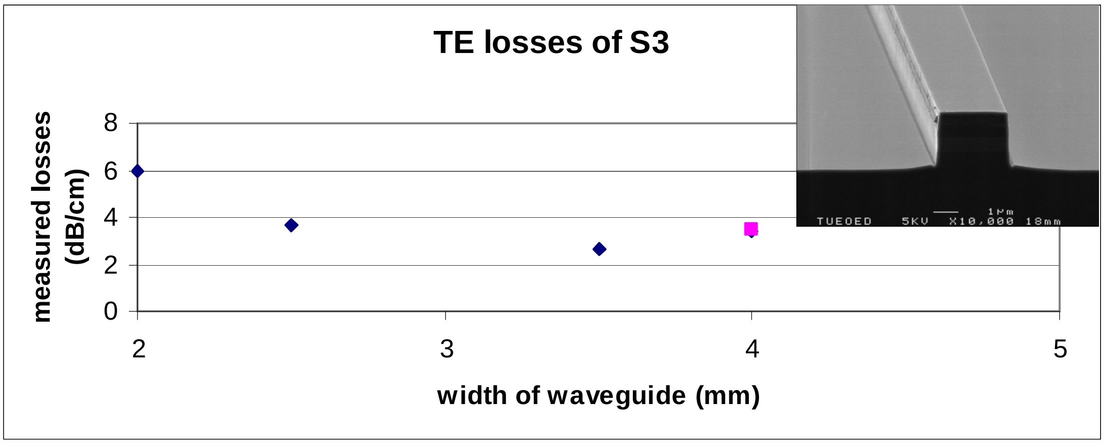

Figure 4- TE losses of a deep waveguide etched after a 2-minute O_2 plasma.

Conclusions

ICP etching experiments were reported and we have shown that this technique can be used to fabricate deep waveguides in InP-based heterostructures with very low TE and TM losses. The choice of the pre-cleaning process influences the losses appreciably.

References

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