Reactive Ion Etching of InP using Hydrocarbons

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Abstract:

This paper deals with the development of an etch recipe for the etching of InP by Reactive ion etching (RIE), a vital process step in the fabrication of microstructures. RIE is a dry etching scheme, wherin effective pattern transfer can be achieved due to its inherent anisotropic characteristics for certain process conditions. RIE is preferred to other dry etching schemes since it is simple, robust and is widely used in industry. The main aim of our research is to design micromechanically tunable optical filters for wavelength division multiplexing (WDM) systems. In this system, transmission takes place in the second and third optical communication window, namely in the region of zero material dispersion (1300 nm) and minimum attenuation (1550 nm) respectively. InP based devices are widely used for this application since they are compatible with the above mentioned WDM transmission wavelengths. The key properties investigated in this thesis were the material etch rate, the selectivity of the material with respect to the mask, the side wall steepness and the surface morphology. The examined process parameters have been the rf-power, the flow rate, the pressure inside the chamber, the substrate temperature and the various ratios of gas combinations. Improved values of etch rate and selectivity have been achieved with respect to past results by optimizing the process conditions. Etch rates as high as 120 nm/min have been achieved using CH_4 / H_2 with infinite values of selectivity for certain process parameters. Measurements have also been made on InP samples using the scanning electron microscope and the atomic force microscope for determining the side wall steepness and the roughness of the etched surface. Side wall slopes close to 90° and surface roughnesses below 0.4 nm (rms) have been achieved. The earlier reported problems of polymer deposition on top of the mask was strongly suppressed. In addition measurements have been carried out on various samples to establish process stability, an absolute necessity for realising a novel recipe.

Introduction:

RIE is the most common form of dry etching of microstructures due to its simlicity, low cost, and robustness in construction. RIE combines the advantages of chemical etching (selectivity) with physical etching (anisotropy). According to earlier reports, low etch rates of less than 50 nm/min were reported using RIE. Reasonably high etch rates were difficult to achieve with hydrocarbons. Although Halogen gases are ideal for high etch rates, they are toxic in nature and are harmful to the ozone layer and should therefore be avoided. This paper deals with the design and development of a suitable etch recipie in order to obtain smooth and damage free surfaces with a high etch rate and selectivity. A good etch recipie gives rise to a high performance device. A novel etch recipie for InP is obtained using RIE for various plasma source combinations by varying certain process parameters namely rf - power, flow rate, substrate temperature and pressure. Various groups have performed RIE on hydrocarbons with etch rates ranging from 30 nm/min to 50 nm/min. We have however achieved an etch rate of more than 100 nm/min without the use of either an additional microwave power source or inclusion of argon gas. Moreover surface roughnesses of less than 0.4 nm with vertical walls (by the suppression of polymer formation) without additional substrate heating.

Experimental Setup and Measurements:

RIE system:

The set up comprises of two electrodes one on top which is grounded and one at bottom which is connected to the hf-power source of 13.6 MHz. The sample is placed on the

lower electrode which is 240 mm in diameter and is smaller than the electrode on top. This disparity in electrode size causes most of the voltage drop between the electrodes to appear across the plasma sheath at the smaller electrode which carries the sample. This causes ions to be accelerated to the sample at a faster rate as compared to plasma etching when the top and the bottom electrodes are of the same size. The gas inlet is at the top of the chamber and gases enter into the chamber via it and are trapped in the chamber during the etching process. For a suitable plasma to be generated the chamber must be kept at a specified pressure range. A series of experiments were carried out in the RIE chamber. (see figures 1 (a) and (b)). The etch depth was determined by a surface profiler (Dektak).The etch rates and selectvity were calculated from the etch depth (see figure 2).

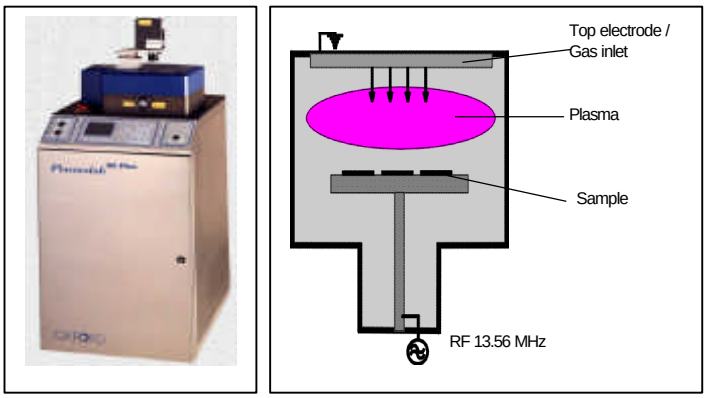


Figure 1: (a) RIE machine (b) Cross sectional view.

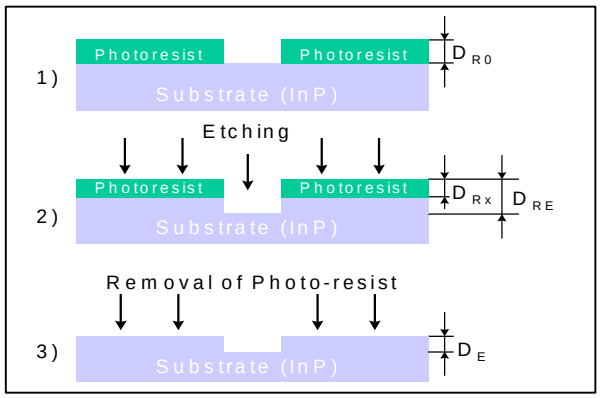


Figure 2: Etching process of InP

Atomic force Microscope **(AFM)** measurements were performed on an etched InP sample. The process conditions were: CH_4 (20 sccm) , H_2 (70 sccm), p = 35 mtorr, T = 20°C, t = 15 min. The surface roughness of the etched surface is 0.345 nm which is compairable to the works of Whelan et al., wherin the rms roughness of < 0.5 nm was achieved (see figure 3). The steepness of the etched side walls and the surface smoothness is determined by means of a scanning electron microscope **(SEM).** The steepness is ideal especially when compared to an earlier result wherin the parameters from Schramm et al. were V= 500 volts, 0.125 torr and 4:20:10 for CH_4:H_2:Ar and from Whelan et al. wherin the process parameters were 40:25:10 sccm for CH_4:H_2:Ar respectively. We have achieved an excellent steepness (see figure 4) and an excellent etch rate of 70 nm/min despite the absence of argon for the process conditions given below. <u>This performance is better than what is achieve so far for RIE without an external microwave souce .</u>

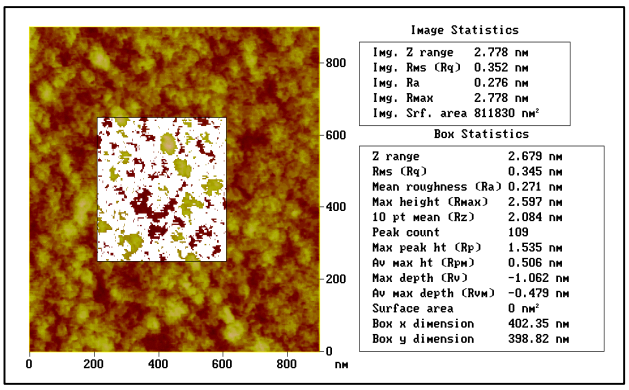


Figure 3: Determination of surface roughness using AFM

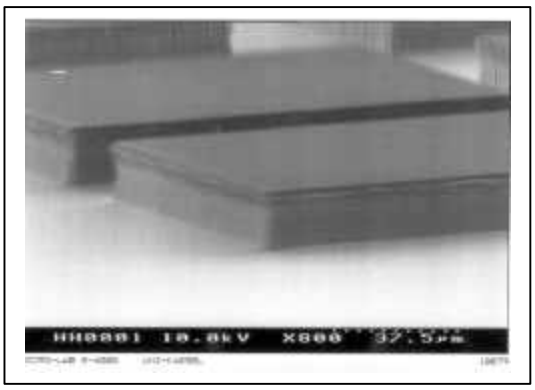
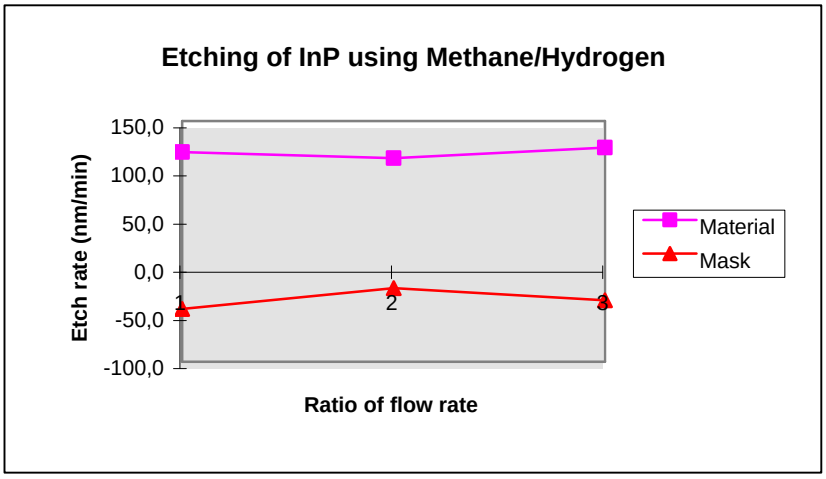


Figure 4: SEM micro graph after etching

Process conditions:
RF power=200 Watts, pressure=0.035 torr, Time= 6 hours, $T_{substrate}$=20 °C
Process gases: CH_4 (20 sccm)/H_2 (70 sccm)

In addition to aforesaid novel result, etch rates of 120 nm/min have also been achieved subsequently by increasing the flow rate of methane (see figure 5). We have established perfect process stability by measuring the etch rate on many samples as well as across the wafer under identical process conditions. We have determined the standard deviation for the different the measured etch rates. The standard deviation does not exceed 0.4%.



1. $CH_4(40)/H_2(20)$
2. $CH_4(40)/H_2(40)$
3. $CH_4(40)/H_2(60)$

Figure 5: Etch rate (nm/min) vs flow rate (sccm)

Conclusion:

In this paper, we have developed a novel etch recipe for the etching of InP based semiconductors using reactive ion etching (RIE). The key properties determined in this paper were the etch rate, the selectivity, side wall steepness and the surface roughness. By varying process parameters namely the power, flow rate, pressure, temperature and various ratios of gas combinations improved values of etch rate and selectivity were achieved with respect to past results without compromising on the anisotropy and the surface morphology. The CH_4 / H_2 process (vide SEM graphs) revealed almost vertical etched side walls (even without the heating the substrate) and smooth surfaces (vide the AFM plot) with rms surface roughness values less than 0.4 nm. These results have been compared to earlier results and has been found to be very promising. The known problem of polymer deposition on top of the mask was also suppressed. Etch rates as high as 120 nm/min were achieved with infinite selectivity using CH_4 / H_2 sources.

The process stability using methane and hydrogen process gases has been established and is therefore recommended for the fabrication of InP based micromechanically tunable filters or any other optoelectronic device which is the main basis of the experiments carried out.

Recommendation:

Having carried out a series of experiments to determine the etch rate with respect to pressure, it is seen that the etch rates drops with increase in pressure and hence it is recommended that the same setup be followed under lower conditions pressure (as low as 0.125 torr from Whelan et al) in the RIE chamber in order to get even a higher etch rate.