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Dry Etching of InGaAsP/InP Structures by Reactive Ion Beam Etching Using Chlorine and Argon

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Very smooth InGaAsP/InP surfaces and sidewalls were obtained by using the enhanced sputtering effect of Ar addition to Cl_2 etching gas in RIBE. The substrate temperature was raised to ~180°C in order to remove involatile chlorides and impurities. Moreover, a vertical sidewall with no side etching under the mask was realized at the same time. This enables submicron dry etching for heterostructure devices.

1. Introduction

The application of dry etching to many varieties of InGaAsP/InP devices has been investigated.[1-7] However, it has been restricted by the difficulty of obtaining smooth vertical clean etched surfaces. Smooth and nearly vertical InP surfaces have been obtained by reactive ion etching (RIE) using Cl_2 and Ar.[8] However, the etching process in a relatively high pressure region reduces verticality for fine structures. So, reactive ion beam etching (RIBE) with low pressure is indispensable for vertical etching. However, the formation of some sorts of involatile chlorides on the etched surfaces or impurities sputtered from the chamber acts as an etching mask and makes the etched surfaces rough. In order to obtain both vertical and smooth surfaces, thermally enhanced RIBE using Cl_2 by raising the substrate temperature to about 180°C has been investigated.[9] However, the etched surfaces were not so smooth because the sputtered impurities were not thoroughly removed. Moreover, it has been difficult to use dry etching on wafers including InP and InGaAsP layers because of their generally different eching rates.

In this paper, very smooth etched surfaces and sidewalls of InGaAsP/InP structures were attained by Ar addition to Cl_2 and by heating the wafers in RIBE.

2. Experimental

The substrates used were Sn-doped (100)InP (n-type, carrier concentration : $1\text{-}3\times10^{18}$ cm^{-3}) , Si-doped (100)GaAs (n-type, carrier concentration: $>10^{18}$ cm^{-3}), and InP/InGaAsP wafers with heterostructures. The etching mask used was a 5000 A thick CVD-SiO_2 film formed on the substrates. 1-10 μm wide windows were formed on the SiO_2 along the [011] and [0$\bar{1}$1] directions. RIBE was performed with 200 W microwave power, 875 gauss magnetic field, and 400 V ion beam extraction voltage. The etching gas was Cl_2 only and a Cl_2+Ar mixture with $0.4\text{-}2.4\times10^{-3}$ Torr total pressure. The Ar partial pressure was 1.1×10^{-3} Torr. The etching time was 20-30 minutes. The substrate temperature was intentionally raised to about 180°C in order to evaporate the chlorides and impurities. Chemical etching of InP and GaAs with only Cl_2 gas was also investigated in order to extract the chemical effects from the RIBE process.

The etched depth and etched sidewall shapes were measured by an SEM and an optical microscope for the cross section perpendicular to the stripe windows.

3. Results and discussion

3.1 Chemical etching of InP and GaAs with Cl_2 gas

For InP, the etching rate drastically decreased below 200°C. In this temperature region, the etching rate is determined mainly by the substrate temperature rather than the Cl_2 pressure and is considered to be restricted by the vapor pressure of indium chlorides. This is suggested by the fact that the experimental values were near the curve calculated from the free evaporation of $InCl_3$. The surface was rough below 200° C. This is considered to be due to the low vapor pressure of indium chlorides preventing uniform evaporation. On the other hand, the etching rate for GaAs is determined by the Cl_2 pressure even below 200 ° C. Very flat surfaces were obtained above 100 ° C, which may be due to the high vapor pressure of gallium chlorides.

3.2 RIBE of InP and GaAs with Cl_2 only and with a Cl_2+Ar mixture

3.2.1 Etching rate

The Cl_2 partial pressure dependence of the etching rates with and without Ar are shown in Fig.1. A significant difference between the etching rate of the striped channel-like trench along [011] and along [0$\bar{1}$1] was not observed. In the case without

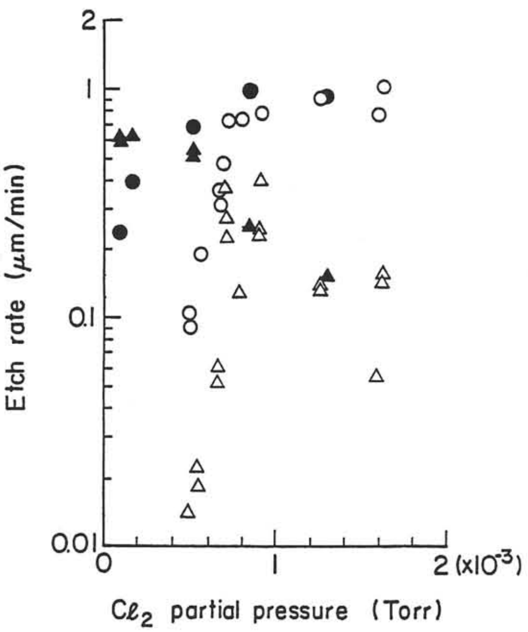

Fig. 1 Cl_2 partial pressure dependence of etching rate of InP (△,▲) and GaAs (○,●) with (black) or without (white) Ar addition. Ar partial pressure was $1.1X10^{-3}$ Torr.

Ar, the etching rate of GaAs drastically increased at about $6x10^{-4}$ Torr Cl_2 pressure, and the etching rate tended to saturate above this pressure. The etching rate of InP had a peak around $8x10^{-4}$ Torr Cl_2 pressure. The chemical etching results show that RIBE is dominated mainly by chemical reactions for GaAs and by ion sputtering for InP. The etching mechanism for GaAs changed between the region dominated by Cl_2 supply and the region dominated by vaporization of gallium chlorides at $6x10^{-4}$ Torr Cl_2 pressure. For InP, etching was determined by both the Cl_2 supply and the sputtering effect below $8x10^{-4}$ Torr Cl_2 pressure. The decrease in the etching rates above $8x10^{-4}$ Torr Cl_2 pressure may be due to the reduced sputtering effect induced by the decreased ion current density.

In case with Ar addition, the etching curves shifted to the low pressure region. In spite of the same Cl_2 pressure, Ar addition made the etch rate high for both InP and GaAs in the low Cl_2 pressure region. This can be explained by the enhanced sputtering effect by additional Ar ions. The etching rates with and without Ar were almost the same in a high Cl_2 pressure.

Moreover, the difference in the etch rates between GaAs and InP was reduced by Ar addition which was effective for increasing the etching rate of InP. Around $5x10^{-4}$ Torr Cl_2 pressure, almost the same etch rates between InP and GaAs were attained, which is advantageous for the iso-etching of InGaAsP/InP structures.

3.2.2 Sidewall angle

Figure 2 shows the sidewall angle for GaAs and InP without Ar. Different sidewall angles perpendicular to the [0$\bar{1}$1] and [011] directions were obtained. Generally, the former was smaller than the latter. The InP sidewall angle was 90° near the peak of the etching rate curves. Difference in the etching rates between GaAs and InP was smallest when the sidewall angle was 90°.

In case with Ar addition, the InP sidewall angle was 90° below $1x10^{-4}$ and with $5\text{-}8x10^{-4}$ Torr Cl_2 partial pressure. The verticality below $1x10^{-4}$ Torr is considered to be due to the enhanced sputtering effect by increasing Ar mole fraction, which is suggested by the rough etched surfaces. On the other hand, the GaAs sidewall angle was 90° below $1x10^{-4}$ Torr Cl_2 partial pressure, which is lower than the threshold value without Ar. At the Cl_2 partial pressure where difference in the etching rates between GaAs and InP was smallest, the InP sidewall angle was 90°, which is considered to be desirable for etching InP/InGaAsP structures without steplike features near the heterojunction

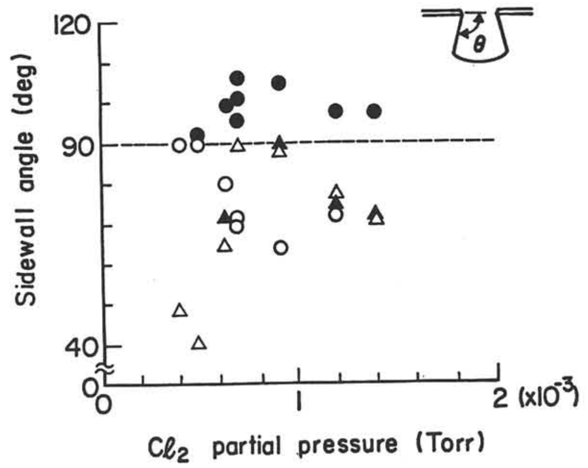

Fig. 2 Cl_2 pressure dependence of sidewall angle for InP (△,▲) and GaAs(○,●).

▲,●: sidewall perpendicular to [011]

△,○: sidewall perpendicular to [0$\bar{1}$1]

(a)

(b)

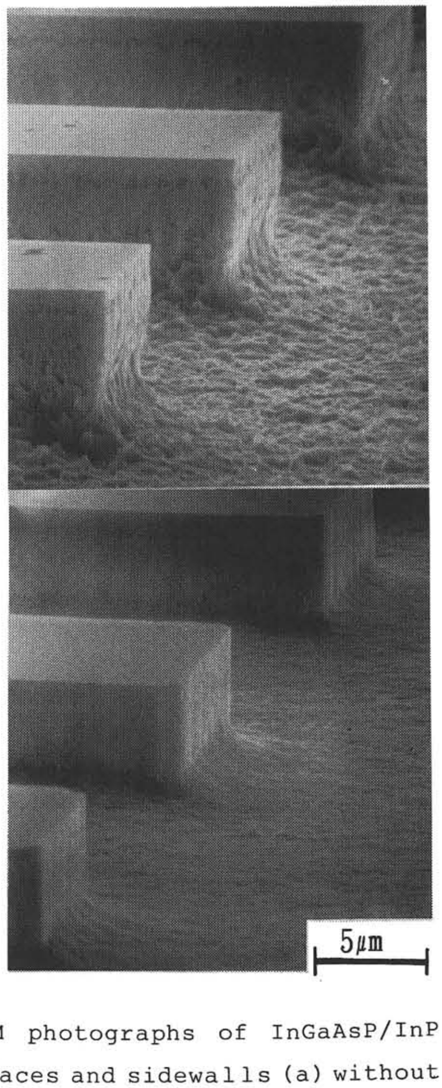

Fig. 3 SEM photographs of InGaAsP/InP etched surfaces and sidewalls (a) without and (b) with Ar addition.

3.2.3 Surface morphology and submicron dry etching

Quite a large difference was obtained for the surface morphology of the surfaces etched with (Fig. 3(b)) and without Ar addition (Fig. 3(a)). The reason may be that the impurities absorbed on the surfaces were effectively removed by Ar sputtering. No side etching under the mask was observed.

Once a smooth vertical etching without lateral etching for wafers with heterostructures was realized, the application of dry etching to submicron structures is also easy to be achieved. Figure 4 shows smooth submicron vertical InGaAsP/InP fences formed by RIBE with Ar addition.

4. Summary

Very smooth surfaces and sidewalls have been obtained by a simple method of adding Ar to Cl_2 gas in RIBE. Moreover, a vertical sidewall has been realized at the same time.

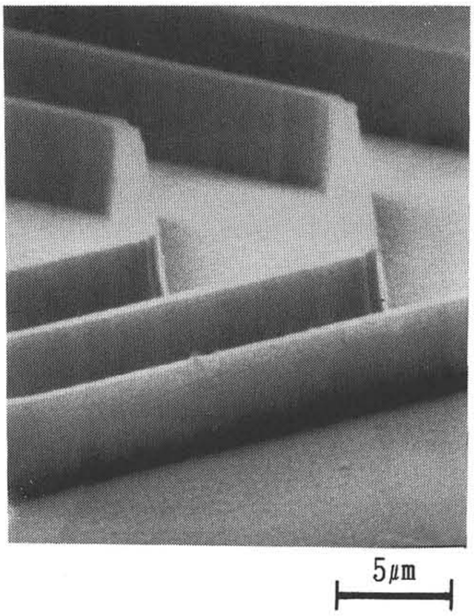

Fig. 4 Submicron smooth vertical InGaAsP/InP fences.

Acknowledgments

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