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Fabrication of InP and InGaAs air-hole type Two-dimensional Photonic Crystals by Selective Area MOVPE

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1. Introduction

Photonic crystals (PhCs), which have periodically modulated dielectric structures whose pitch are near the light wavelength, have been paid much attention, because they can control propagation and radiation of the light utilizing photonic bandgaps and bandstructures. Method for fabrication of two dimensional (2D) PhCs include dry etching, anodic chemical etching, and selective area metal organic vapor phase epitaxy (SA-MOVPE) [1]. Among these methods, SA-MOVPE is effective method because we can obtain highly-uniform structures with smooth interfaces surrounded by crystal facets without process induced damages [2]. Furthermore, as SA-MOVPE method has already been applied to the fabrication of semiconductor lasers, it is suitable to fabricate various opto-electronic devices. We have been reporting on the formation of GaAs-based 2D PhCs [3.4], while InP-based materials and devices are important for the optical communication.

In this paper, we describe the fabrication of InP and InGaAs air-hole type 2D PhCs structure on InP (111) substrates by using SA-MOVPE. We investigated the optimum growth conditions for InP and InGaAs air-hole arrays.

2. Experimental procedure

We used InP(111)A and InP(111)B substrates covered with SiO_2 by plasma sputtering. For the selective area growth, the SiO_2 mask was partially removed periodically by using electron-beam (EB) lithography and wet chemical etching techniques based on buffered hydrofluoric acid (BHF).The pattern forms triangular lattice arrays. The period ranges from 400nm to 1μm (Fig.1). Selective area growth of InP or InGaAs were carried out by using a horizontal low-pressure MOVPE system with TMIn, TMGa, TBP and AsH_3 as source materials. The partial pressure of AsH_3 was changed from 3.1×10^{-5}atm to 2.5×10^{-4}atm, that of TMGa was changed from 2.74×10^{-7}atm to 5.48×10^{-7}atm, that of TBP was changed from 2.2×10^{-6}atm to 2.2×10^{-5}atm and that of TMIn was changed from 4.4×10^{-7}atm to 4.4×10^{-6}atm. The growth pressure was 0.1atm. We changed growth temperature from 475°C to 700°C. After SA-MOVPE growth, scanning electron microscopy (SEM) was used for observing the structural characterization.

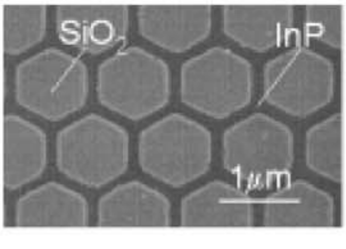

Fig.1 SEM images of a mask pattern for SA-MOVPE

3. Experimental results and discussion

3.1 InP air-hole PhCs structures

The result of the growth of InP on the masked InP (111)B substrates is shown Fig.2. Here, the growth temperature was 650°C, V/III ratio was 50, and growth time is 15 min. We could obtain uniform InP air-hole arrays on InP(111)B substrates. In this growth condition, periodicity of air-holes down to 500 nm was obtained. Note that the shape of the air-hole is hexagonal, and mostly follows the initial mask pattern. This means the vertical {110} sidewall facets are formed, as similar to the case of GaAs on GaAs(111)B [4], showing the possibility for formation of InP-based 2D PhCs. On the other hand, for InP (111)A masked substrates, the holes are became filled due to the lateral overgrowth (LOG) on the mask took place, when it was grown simultaneously in the same growth condition (not shown here).

Present result shows a clear contrast to our previous result for InP pillar arrays on (111)B InP. To form 2D PhCs of pillar arrays, we attempted SA-MOVPE on masked InP (111)B substrate with circular mask openings, but were not able to get uniform growth on the opening regions. Furthermore, three-directional growth to the [111] A direction took place, and as a result, "tripod" like structure was observed in some opening region [5], suggesting that the growth mode is somewhat abnormal one. However, in the present case, we successfully obtained uniform growth and vertical {110} side facets on (111) B substrates as expected. We think this difference originates from the difference in the geometry of mask opening. For air-hole

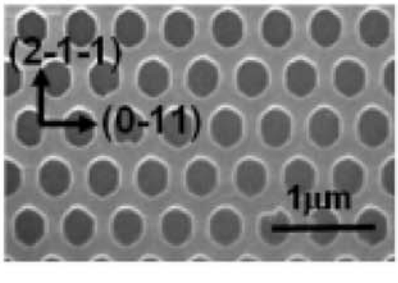

Fig.2 SEM images of 500 nm pitch InP air-hole type 2D PhCs

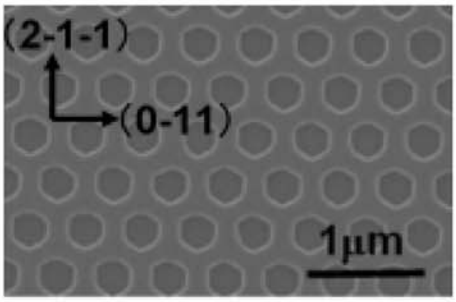

Fig.3 SEM images of 500 nm pitch InGaAs air-hole type 2D PhCs

type arrays, the masks are isolated each other, that is, the opening of the mask was connected throughout the patterned regions, so the growth mode does not differ significantly from the layer-by-layer growth on ordinal substrates without patterning.

3.2 InGaAs air-hole PhCs structures

The problem of 2D PhCs is that the confinement of the light in 2D PhCs is smaller than within three dimensional (3D) PhCs. To overcome such shortcoming, photonic crystal slab (PhCS), where thin layer of 2D PhC used as a core and is sandwitched by clad layers with lower refractive index, is proposed and demonstrated including air-bridge structures [6]. In InP-based materials, InGaAsP is one of a candidate for cladding layers as well as for a sacrificial layer to make air-bridges. In addition, InGaAsP is used for the active regions lasers operating at optical communication wavelength. For these reasons, we also attempted the growth of InGaAs air-hole arrays by SA-MOVPE.

Fig.3 shows an SEM image of the InGaAs air-hole arrays grown on a (111)B InP substrate under growth temperature of 650 and V/III ratio of 42. We obtained reasonably uniform InGaAs air-hole arrays with pitch 500nm and thickness 120nm.

We should mention, however, that we required more stringent optimization to obtain air-hole arrays of InGaAs than in the case of InP. Fig.4 summarizes SEM images of InGaAs air-hole array on InP(111)B substrates grown on various growth temperatures. Here, the period of the

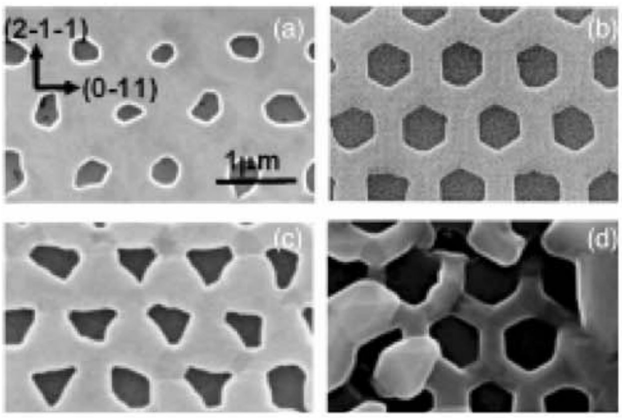

Fig.4 SEM images of 1μ m pitch InGaAs air-hole type 2D PhCs grown at various temperatures. (a) 600 °C. (b) 625 °C, (c) 650 °C, and (d) 700 °C.

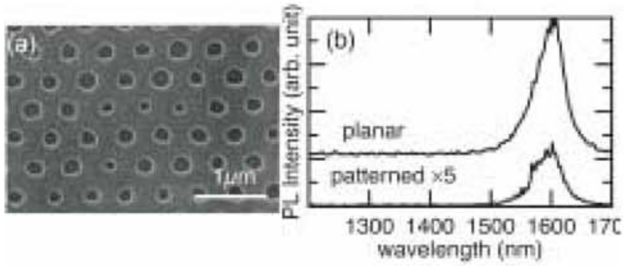

Fig.5 (a) SEM images of 500 nm pitch InP/InGaAs/InP double heterostructured air-hole type 2D PhCs. (b) PL spectra of air-hole array. PL from planar region is also shown for a reference

mask is 1μm and V/III ratio is 42. The growth time is 30min and the thickness of the grown layers was 250nm. We got rough (111) surfaces for growth temperatures higher than 650 °C. On the other hand, the amount of LOG decreased and vertical {110} sidewalls facets became apparent as the growth temperature. It was also found that the amount of LOG enhances as the arsine partial pressure or V/III ratio. The tendency of LOG on growth temperatures and V/III ratio can be explained by the effective As coverage at the corners of the air-holes, which was identically applied for the case of GaAs [7]. Note, in the application to PhCs, that the LOG should be low enough to ensure large filling fraction of air-holes, which is required to realize wide photonic bandgaps. Needless to say, the top as well as sidewall surface should be flat. Our experimental results suggest that optimized growth conditions for obtaining InGaAs air-hole arrays are very stringent. Further optimization of the growth conditions are required to obtain InGaAs air-hole arrays with sufficient thickness particularly when we need thick layers.

Nevertheless, we attempted the growth of InP/InGaAs/InP double heterostructures on InP (111)B patterned substrates, and the result is shown in Fig.5(a). Uniform air-hole array with InP/InGaAs double heterostructures is obtained. Furthermore, we confirmed photoluminescence from InGaAs layers at 77K, as shown in Fig.5(b). Therefore, our SA-MOVPE approach for air-hole array is thought to be promising for the application to InP-based PhCs.

4. Summary

In summary, we successfully formed InP and InGaAs air-hole type structure by using SA-MOVPE on InP(111)B substrates for application to 2D PhCs. Although we need further optimization of the growth of thick InGaAs layer, air-hole array of InP/InGaAs/InP could be grown with satisfying structural and optical quality.

References

[1] T.Hamano et al , Jpn J. Appl. Phys. **36** L286 (1997).
[2] S.Ando et al , Jpn J. Appl. Phys. **32** L1293 (1993) .
[3] M.Akabori et al , Physica E. **13** 446 (2002).
[4] J.Takeda et al , Appl. Surf. Sci. **190** 236 (2002).
[5] M.Inari et al , Physica E. **21** 620 (2004).
[6] O.painter et al , Science. **284** 1819 (1999).
[7] S.S.Chang et al , Surf. Sci. **267** 214 (1992).