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A New Approach of Photonic Bandgap Formation -Wafer Bonding and Delamination Technique-

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1. Introduction

It has been already one decade since the concept proposal of photonic crystals [1]. The crystal consists of periodic structures of materials pair with two different dielectric constants. This structure creates the Brillouin zone for photons (not for electrons) to form "photonic bandgap (PBG)" where no photons are allowed to propagate besides evanescent modes. Thus, highly efficient lasers, sharp bent optical wave guides, high Q optical filters, and more have been predicted [2].

PBG presents a huge impact to our LSIs community as well. Metallic wiring is a critical issue for LSIs of the next generation. The solution would be on-chip optical interconnection. Multilayer metallic wires among circuits can be replaced by waveguides for wavelength division multiplexing (WDM) which has been proposed for optical fiber communication, so called Fiber-To-The-Home. In order to implementing WDM in LSIs, our challenge is to make everything small. High Q add/drop filters with 0.055 μm^3 have been demonstrated on SOI structures by conventional CMOS technology, whose Q was 235 with a one dimensional (1D) Si based PBG [3].

Challenges are to realize key devices by creating 1D PBGs, such as light emitters, modulators, waveguides and detectors. However, less effort has focused to create 3D PBG devices [4], although most unique properties of PBG have been predicted there[5]. This is due to the lack of substrates with 1D PBG perpendicular to the surface, here we call PBG substrates. If we would have PBG substrates, we could readily design 3D PBG by simply making holes into the substrates.

In the present paper, we will report our recent achievement of the PBG substrates; stacking pairs of CZ-Si layer and thermally grown SiO_2 layer on CZ Si wafers by wafer bonding and delamination technique [6].

2. Experimental

Regarding the dielectric materials, there are two well known materials used in LSIs, i.e., SiO_2 and Si_3N_4. Here, we chose SiO_2 because of its lower refractive index than Si_3N_4 in order to obtain high contrast of refractive indices between Si and dielectrics.

There are two critical demands,structure and quality, for formation methods of PBG substrates for on-chip optical interconnection of LSIs. The method should be capable for precise control the Si and SiO_2 layer thickness and periodicity. The quality of these layers should be of LSIs-grade. Thus, we should utilize CZ silicon wafers or Si epilayers for Si layers, and thermally grown SiO_2 as the dielectrics. However, since SiO_2 is amorphous, it is difficult to grow crystalline Si layer on SiO_2 via epitaxy. Indeed, PBG structures based on Si and SiO_2, reported so far, used amorphous Si and SiO_2 by deposition technique [4]. Here, the techniques employed for fabrication of the stacking structures were delamination called SmartCut® [6] and wafer bonding. The former technique is capable of precise thickness control of the Si layers in terms of hydrogen implantation energy. The SiO_2 layer thickness was also precisely controlled by thermal oxidation conditions. The latter has an advantage over epitaxial growth since there is no need of lattice matching; any materials and phases can be bonded.

The procedure to form stacking structures of several Si/SiO_2 pairs is as follows.

1) Preparation of Substrate A with an SiO_2 layer implanted hydrogen, and Substrate B,
2) Wafer bonding of Substrate A on Substrate B,
3) Delamination of the Si layer of Substrate A, leaving the Si/SiO_2 layer pair on Substrate B,
4) Touch-polishing of the surface Si layer,
5) Procedures 2) to 4) are repeated by using new Substrate A.

The Si and SiO_2 layers were 230 and 400 nm in thickness. The number of pairs used was three. Thereby a 1D PBG substrate should be formed along its stacking direction.

Infrared (IR) transmittance measurements of the present structures were done to reveal the formation of 1D PBG. The sample was in right angle configuration to IR beam to realize normallight incidence.

3. Results and discussions

Figure 1 shows a reflection electron image of the cross-sectional 1D PBG substrate formed by the wafer bonding and delamination technology. The section was prepared by focus ion beam (FIB) implantation method. The structure consisting of three pairs of Si/SiO_2 layers on the Si substrate is clearly visualized. The light layers are Si and the dark are SiO_2. The Si layers are 230 nm in thickness, while SiO_2 layers are 400 nm. Bonded interfaces are shown by arrows. There is no apparent difference between bonded and grown interfaces.

Figure 2 shows the IR transmittance spectrum in the wavenumber between 1000 and 8000 cm^{-1}. It is clearly seen that a PBG is created in the wavenumber region between 3000 and 4500 cm^{-1}. Transmittance is almost entirely suppressed in this region, indicating realization of a high quality PBG substrate. The energy range and value

oftransmittance were in good agreement with theoretical calculation [7]. This is a first demonstration of PBG by crystalline Si and thermally grown SiO_2 layer pairs.

The present paper has clearly proven the potential of wafer bonding and delamination technology to achieve 1D PBG substrates.

4. Conclusions

The wafer bonding and delamination technique reveals its potential to fabricate 1D PBG substrates with crystalline Si and thermally grown SiO_2 layer pairs. The quality of the PBG is high enough to suppress photons of 3000 and 4500 cm^{-1}. This is the first report on achievement of 1D PBG substrates with device-quality Si/SiO_2 layers.

Acknowledgments

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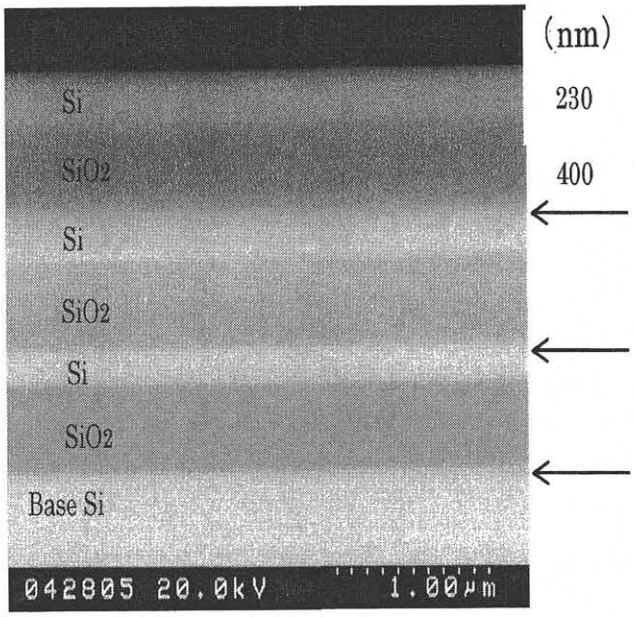

Fig. 1 Cross-sectional image of the photonic substrate (Reflection electron miscroscope).

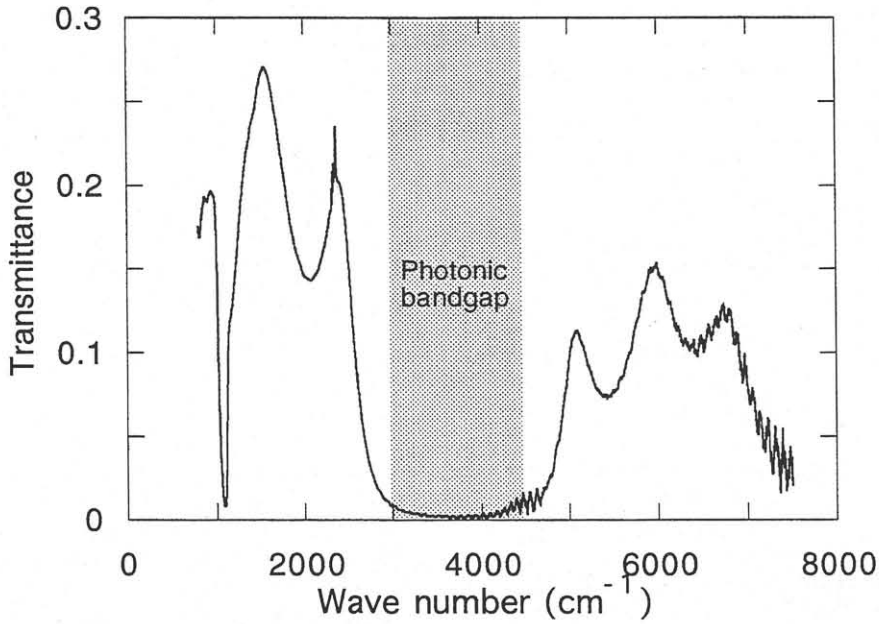

Fig. 2 IR transmittance spectrum of 1D PBG substrates.