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Prospect of Optical Devices with One-dimensional Photonic Crystal Structure

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Abstract
Optical devices constructed with one-dimensional photonic crystals are reviewed. In particular, dielectric thin-film and deeply etched Si photonic crystals are discussed from the viewpoint of their application to optical transmission networks and optical sensing systems.

1. Introduction

Photonic crystals (PhCs) can be classified into one-, two-, and three-dimensional structures. Two- and three-dimensional PhCs are a particularly popular focus of the research because they have unique features such as an ultimate light-confining effect due to their full photonic band gap. One-dimensional (1D) PhCs, on the other hand, have the advantages of being relatively easy to fabricate and being non-polarization dependent. Therefore, 1D PhCs have also attracted a lot of attention in various fields.

Here, we discuss the present status of research on 1D PhCs, particularly dielectric thin-film and deeply etched Si PhCs, which can be used in optical transmission networks and optical sensing systems.

2. Photonic crystals composed of dielectric thin films

One of the functions of PhCs is to control group velocity and its dispersion. Coupled-defect-type photonic crystals are the most promising candidates for such control, which enables extremely small dispersion compensators to be used in optical fiber transmission systems [1]. The structure optimized for obtaining a large group-velocity dispersion was formed with SiO_2/Ta_2O_5 thin films, as shown in Fig. 1 [2]. It was designed for the 1.55-μm, 40-Gbit/s optical communication system. The thin-film structure is substrate-free, which means the device chip can be as small as a 1.4-mm edge cube. To obtain a large group velocity difference, 60 pieces of substrate-free film were stacked. The obtained optical properties are shown in Fig. 2. The hatched area in the figure was used for the 40Gb/s modulation band. The loss was about 10 dB, and the group velocity difference in the band reached 100 ps, which enables fabrication of realistic modules.

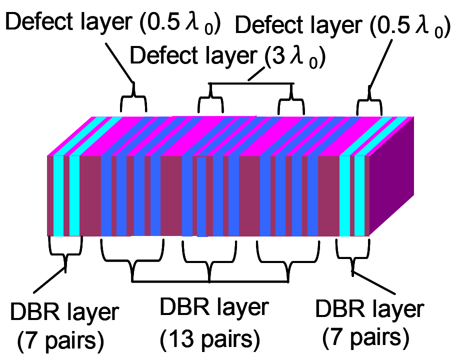

Fig. 1 Optimized structure of 1-D coupled-defect-type photonic crystals.

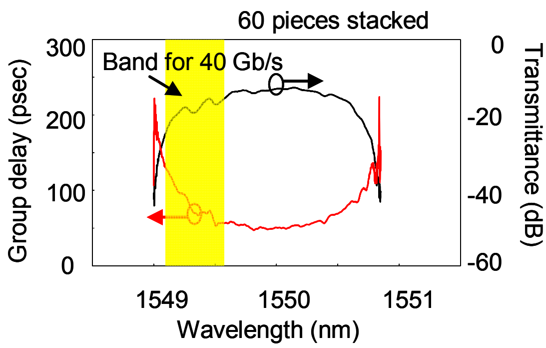

Fig. 2 Optical properties of stacked substrate-free thin films.

The obtained fiber-to-fiber type module is as small as 22 x 40 x 24.5 mm, as shown in Fig.3. We carried out a 40 Gb/s non-return-to-zero (NRZ) optical transmission experiment. The wavelength of the laser emission was 1549 nm and the transmission link was a 10-km standard single mode fiber. The eye diagrams after 10-km transmission are shown in Fig. 4. A clear eye opening was observed when the dispersion compensator was in use, and there was serious degradation in the eye diagram when it was not in use. The corresponding dispersion is 170 ps/nm. We have also recently succeeded in fabricating an extremely compact dispersion compensator module integrated with a photo receiver. The dispersion compensation in this case was also excellent.

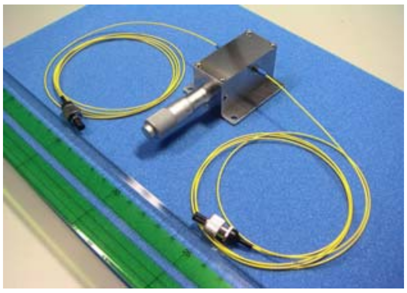

Fig. 3 Assembled 40Gb/s dispersion compensator module (fiber-to-fiber type).

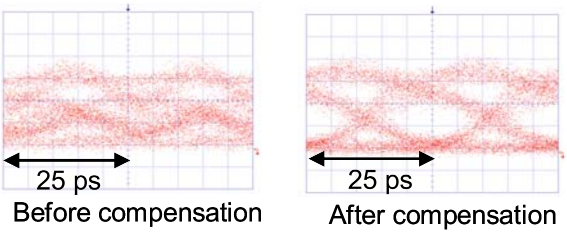

Fig. 4 Eye diagrams for 40Gb/s transmission.

3. Deeply etched Si photonic crystals

Another type of 1D PhCs is composed of periodically aligned semiconductor (typically silicon) walls, thus forming 1D PhCs, in which a light beam propagates parallel to the substrate plane. Si-based 1D PhCs were formed using a cryogenic etching process [3,4]. The etching depth reached about 20 μm, and the etched surface was extremely smooth compared with those produced by conventional etching processes such as the Bosch process, as shown in Fig. 5. A clear transmission band based on defect formation was obtained with the deeply etched Si structure embedded in the polymer medium. The peak position can be artificially controlled by changing the temperature of the PhC, as shown in Fig. 6. Thus, this etching technique enables the formation of various optical elements such as the optical wavelength-tuning filters used in optical transmission networks and optical sensing systems.

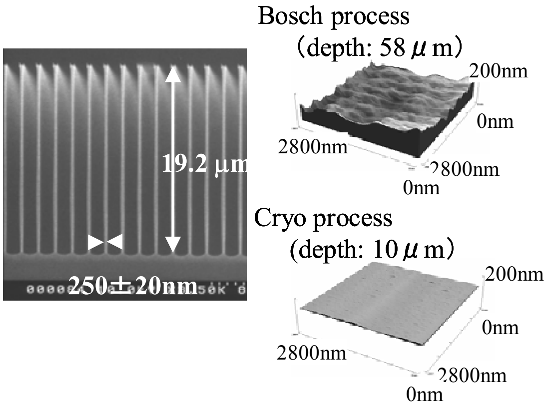

Fig. 5 Deeply etched Si structures and their surface smoothness.

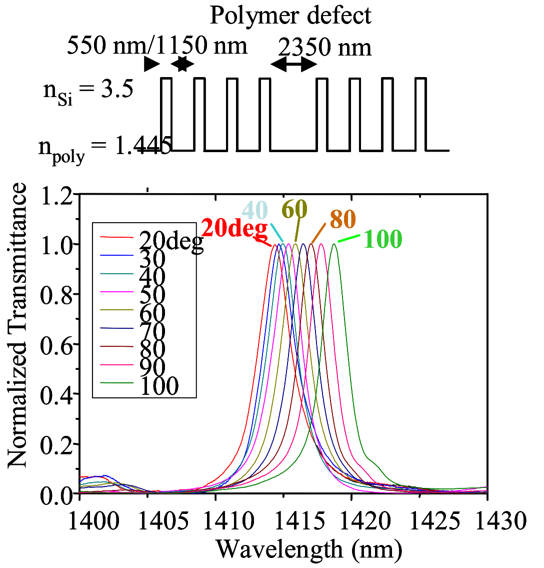

Fig. 6 Control of defect peak by temperature change.

4. Summary

Using dielectric thin-film 1D PhCs, we successfully demonstrated 40-Gb/s dispersion compensation, which can be used in the metro network systems. Deeply etched 1D Si PhCs have also been fabricated using a cryogenic etching process. The Si-based PhCs make it possible to monolithically integrate PhCs with other optical elements, such as the optical waveguides on the substrates. This could lead to realization of the integrated Si-based photonic circuits concept.

Although the structural variations in the 1D PhCs are not that large compared with those of 2D and 3D PhCs, they may still have potential as applications in various optical fields.

Acknowledgements

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