Extended Abstracts of the 2006 International Conference on Solid State Devices and Materials, Yokohama, 2006, pp. 42-43

B-2-1 (Invited)

Integrated Photonic Network Node-Chip with Photonic Crystals

Hirohito Yamada[1,2], Tao Chu[2], Akiko Gomyo[1,2], Jun Ushida[1,2], Satomi Ishida[3], and Yasuhiko Arakawa[3]

[1]NEC Corporation, Fundamental and Environmental Research Laboratories
34, Miyukigaoka, Tsukuba, Ibaraki 305-8501, Japan
Phone: +81-29-850-1183 E-mail: h-yamada@az.jp.nec.com
[2]Optoelectronic Industry and Technology Development Association
34, Miyukigaoka, Tsukuba, Ibaraki 305-8501, Japan
[3] Univ. of Tokyo, Research Center for Advanced Science and Technology
4-6-1 Komaba, Meguro-ku 153-8505, Japan

1. Introduction

In photonic network systems that use optical wavelength for transmitting many data channels, node functions such as optical add/drop multiplexers (OADMs) are indispensable. Furthermore, in order to route optical channels dynamically, a reconfigurable function is also required for the OADMs. However, today's reconfigurable OADM (R-OADM) systems are very large and consuming more electric power. Therefore, we are studying integration of node functions in order to realize compact and low power consumption R-OADM systems.

For fabricating such integrated node-chips, 2D photonic crystal (PC) slabs are promising platforms because various optical devices can be realized on the PC slab platform. Thus far we have demonstrated an optical switch [1], a channel dropping filters [2], [3] and an OADM device [4] with the PC slabs. In this paper, we describe an integrated node-chip constructed with an optical switch and an OADM device with PCs.

2. Structure and Fabrication

The integrated node-chip was constructed with a Si PC slab based OADM device with wavelength tuning mechanism and a 2 x 2 optical switch. They are both formed with Mach-Zehnder interferometers (MZIs), on a SOI substrate, as shown in Fig. 1. The branches of the MZIs are formed with PC line-defect waveguides, and 3 dB couplers with Si photonic-wire waveguides [5] connect the PC waveguides.

In the OADM device, the PC waveguides have a narrow photonic band-gap for polarization electric field perpendicular to the substrate [4]. Therefore, they work as Bragg reflectors, and the OADM device drop out a specific wavelength signal. The drop-out wavelength can be tuned by controlling refractive index of the PC waveguides through thermo-optic effect. We evaporated metal thin-film heaters above the PC waveguides. On the other hand, in the 2 x 2 optical switch, the heater changes output port of optical signals.

In device fabrication, SOI substrates were first patterned with electronic beam lithography. Then, the device patterns were formed by etching the top silicon layer down to the buried oxide (BOX) layer with an inductively coupled plasma dry etcher. Next, the top silicon layer was covered with silica material to form a silica cladding PC slab waveguide and Si photonic-wire waveguide structures. Finally, above the covered silica layer, metal thin-film heaters and their electrode pads were sputtered. The device we fabricated was very compact with a net device footprint size of 500 x 140 square microns, excluding the electrode pads, which was about 1/1000 of the size of available R-OADM devices based on PLC or optical fibers [6]-[9].

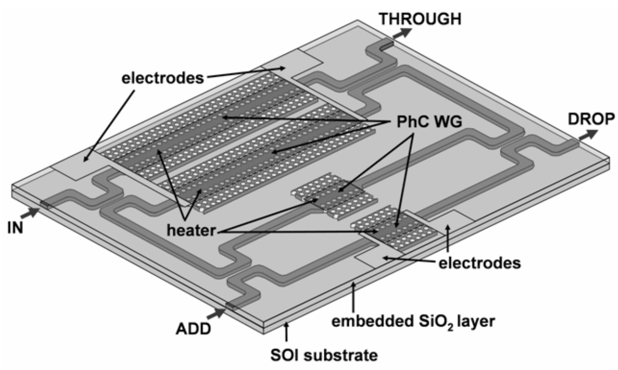
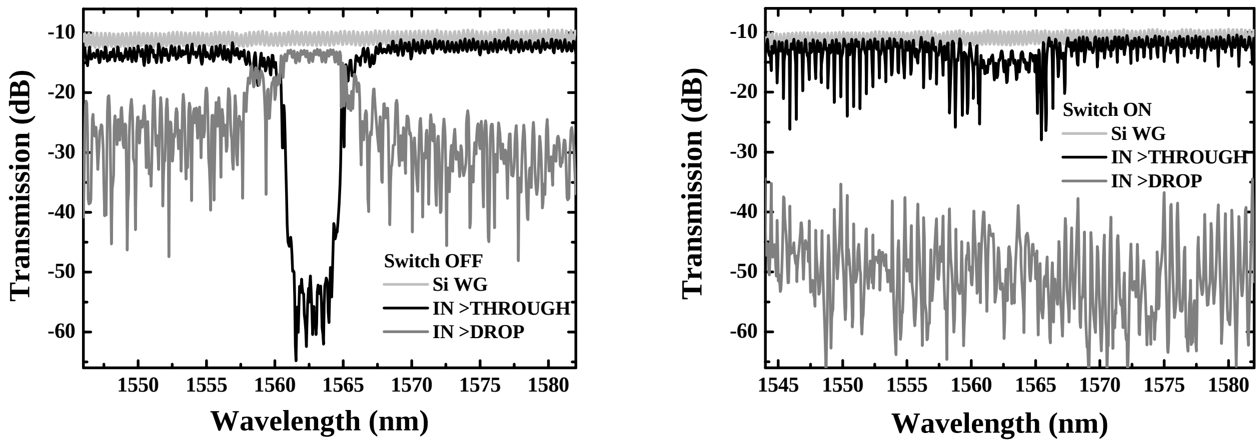


Fig. 1 Structure of the node-chip based on photonic crystal slab

3. Measurements

The node-chip was characterized with a wavelength tunable laser and a spectrum analyzer. Tapered optical fibers were used for coupling light in the input ports (IN and ADD) of the node-chip, and for collecting the light signal from the output ports (THROUGH and DROP) for analysis. The polarization of the incident light was kept as electric field perpendicular to the substrate, due to the polarization dependence of the device. DC power supplies were used in operating micro-heaters.

First, by introducing light signal in the ports IN and ADD, the node-chip was measured for its transmission loss spectra of the THROUGH and DROP ports, respectively, when no heating current was applied for any heater. Fig. 2 (a) shows the transmission loss spectra from IN port to the THROUGH and DROP ports, as well as that of a reference straight Si photonic-wire waveguide. The insertion losses were about 14 dB for both the THROUGH and DROP ports, including the coupling losses between the optical fibers and Si photonic-wire waveguides of about 5 dB/port. The dropping central wavelength was 1562.8 nm. The channel drop-



(a) (b)

Fig. 2 Transmission spectra of the node-chip

ping bandwidth, i.e. the 3 dB bandwidth of the drop channel was about 5 nm. The extinction ratio at dropping wavelength for the THROUGH port was about 40 dB.

Next, the transmission loss spectra of the THROUGH and DROP ports were measured when 2 x 2 optical switch operating (ON state). Fig. 2 (b) showed the transmission loss spectra of a reference straight silicon waveguide and the THROUGH and DROP ports of the node chip. In the figure, the optical signal at dropping wavelength was switched and returned to the THROUGH port. The heating power for the optical switch was 82 mW.

Finally, the transmission loss spectra for the THROUGH and DROP ports were measured by changing heating power added to the OADM heaters. When heating power was increased, the dropping central wavelength was shifted to longer wavelength. The dropping wavelength shift dependence on heating power was found to be linear. At the heating power of 0.9 W, a 10.8 nm wavelength shift was obtained. Since the thermo-optic efficiency of silicon material is about 20 times larger than that of silica used in PLC and optical fiber based devices, the tuning power efficiency was about 12 nm/W, which was almost 3 times larger than that of previously reported [6], [8], [10]. The tuning response speeds were estimated to be approximately 0.1 ms.

4. Conclusions

Based on silicon photonic crystal and photonic-wire waveguides, a compact node-chip (R-OADM) was for the first time demonstrated through thermo-optic effect. The device we fabricated was compact with a net device footprint size of 500 x 140 square microns, which was about 1/1000 of the today's PLC or optical fiber based R-OADM devices. The dropping central wavelength was 1562.8 nm. The channel dropping bandwidth was about 5 nm. The extinction ratio at dropping wavelength for the THROUGH port was about 40 dB. At the heating power of 0.9 W, a 10.8 nm wavelength shift was obtained with a high tuning efficiency of 12 nm/W. The add-drop function was realized at a 82 mW switch heating power of the 2 x 2 optical switch.

The integrated node-chip offers significant opportunity in realizing compact and low power consumption photonic node systems, as well as that indicating a possibility of applying various kinds of photonic integrated circuits.

Acknowledgements

The authors wish to thank M. Tokushima for fruitful discussions. This study was carried out as a part of the 'Photonic Network Project' under contract to the New Energy and Industrial Technology Development Organization (NEDO) and 'Focused Research and Development Project' for the Realization of the World's Most Advanced IT Nation, IT Program, MEXT.

References

[1] T. Chu, H. Yamada, S. Ishida and Y. Arakawa, IEEE Photon. Technol. Lett., vol. 17, pp. 2083-2085, 2005.

[2] A. Gomyo, J. Ushida and M. Shirane, Thin Solid Films, vol. 508, pp.422-425, 2006.

[3] T. Chu, H. Yamada, S. Ishida and Y. Arakawa, The 17th ann. meet. of IEEE laser & electron-optics society, THL2, 2004.

[4] A. Gomyo, J. Ushida, H. Yamada, T. Chu, S. Ishida and Y. Arakawa, Proc. of SPIE, vol. 6050, pp. 60500B-1-7, 2005.

[5] H. Yamada, T. Chu, S. Ishida and Y. Arakawa, IEEE Photon. Technol. Lett., vol. 17, pp. 585-587, 2005.

[6] D. Gauden, E. Goyat, C. Vaudry, P. Yvernault, and D. Pureur, Electron. Lett., vol. 40, pp. 1374-1375, 2004.

[7] R. E. Scotti, C. Madsen, C. H. Henry, G. Lenz, Y. P. Li, H. Presby, A. White, in Optical Fiber Communica-tion Conference and Exhibit, 1998. (OFC '98.), Technical Digest 22-27, Feb., pp. 142-143, 1998.

[8] H. G. Limberger, N. H. Ky, D. M. Costantimi, R. P. Salathe, C. A. P. Muller, and G. R. Fox, Photon. Techno. Lett., IEEE, vol. 10, pp. 361-363, 1998.

[9] J. A. Rogers, B. J. Eggleton, R. J. Jackman, G, R, Kowach, and T. A. Strasser, Opt. Lett., vol. 24, pp. 1328-1330, 1999.

[10] B. J. Eggleton, J. A. Rogers, P. S. Westbrook, and T. A. Strasser, Photon. Techno. Lett., IEEE, vol. 11, pp. 854-856, 1999.