2017
Annual Report

Opto-Electronics Laboratory
(Prof. Hamamoto Group)

Applied Science for Electronics and Materials Interdisciplinary

Graduate School of Engineering Sciences,

Kyushu University

High-light 2017

On 2017, we have carried NEDO FS program via OITDA, and researched about 3 dimensional waveguide circuits. It was also the last FY for support industry program (METI), and we have researched high speed and mode-selective laser diode (LD) by using active-MMI. The results were accepted for ECOC 2017. We have made several invited talks at IEICE society conferece, APC/PS, and OSJ symposium to make single dimensional mode-set and its related devices including optical mode switch and mode selective light source. In addition, we made two presentations at ICO-24 by master course students. And we newly introduce dicing-saw machine which wad donated from Yokohama National University.

On 2017, we run the following 5 topics. Please see the following pages in detail.

1. Optical sensing by using photonic integrated circuit
2. Optical mode switch
3. High speed mode selective light source by using active-MMI laser diode
4. ICP dry-etching
5. Highly-coupled waveguide

Gas Sensing Using Silica High-mesa Waveguide

Wenying Li, Yu Han, Haisong Jiang and Kiichi Hamamoto

The desire of mall size health-check system is raised due to the population aging. Compact breath sensor for daily health care may be welcomed because breath test is non-invasive, real time and there are various disease-markers contained in human breath. High-mesa waveguide can be used for gas sensing due to its unique structure that its core can contact to the outside gas, and waveguide can realize compact breath sensing system [1-2]. We have realized CO_2 sensing by using a 4.5cm high-mesa waveguide successfully [3].

Figure 1 shows the CO_2 sensing results from 40% to 80%. As shown in the figure, the light intensity decrease faster while the CO_2 concentration increasing. This figure proves that CO_2 sensing by using silica high-mesa waveguide really happened. CO_2 concentration is estimated by using the difference of the ring-down time [3] between "with CO_2" condition and "Without CO_2" condition. Figure 2 shows the CO_2 sensing result at 40%. By using the ring-down time of 5.95μs and 5.74μs, the concentration is estimated as 39%. The other estimated results and ring-down times are shown in Tab.1. The accuracy of all the cases were within 2%.

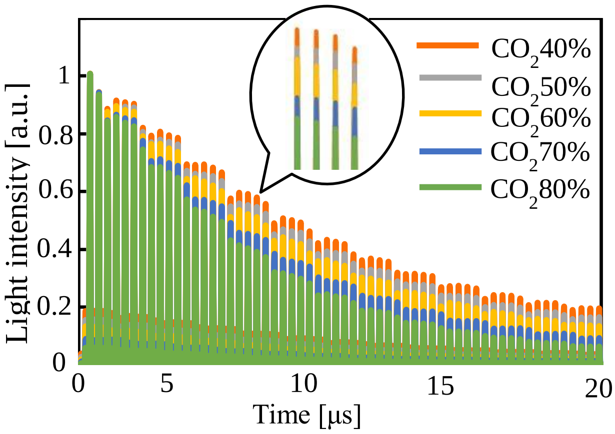

Fig. 1 CO_2 (40-80%) gas sensing results.

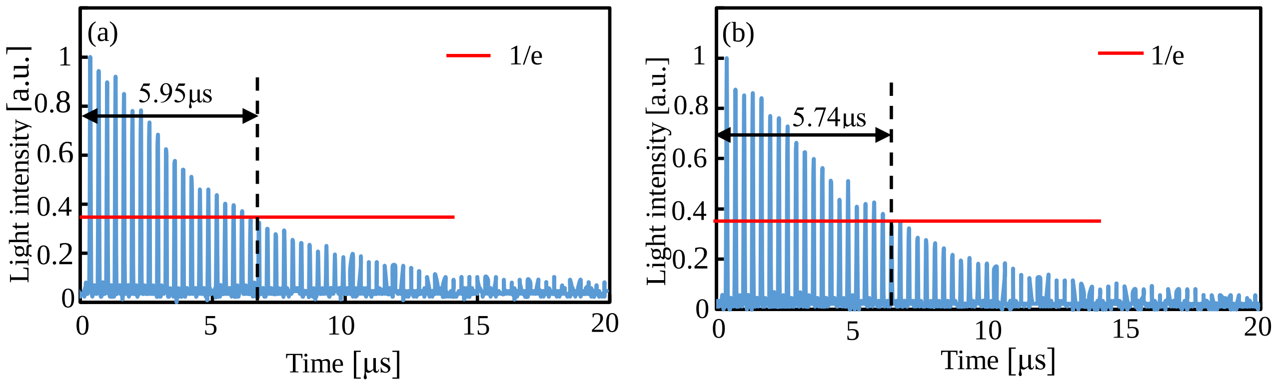

Fig.2 40% CO_2 ring-down waveform. (a) Without CO_2. (b) With CO_2.

Tab. 1 Estimated concentration of CO_2 and ring-down times

Absolute concentration of CO_2 [%]	Estimated result of CO_2 [%]	Ring-down time [μs]	
		Without CO_2	With CO_2
70	70	11.38	9.47
60	58	10.05	8.93
50	51	16.46	14.28
40	39	5.95	5.75

Reference

[1] A. Wilk et al., Vol. 402, Issue 1, pp. 397-404, 2012

[2] S. Yano et al., Con. Proc. IPNRA, IWA7, 2007.

[3] H. Hokazono et al., IEICE Electronics Express, Vol. 12, No. 15, pp. 1-8, 201.

Optical Mode Switch

Ryan Imansyah, Oe Shota, Morita Yuto, Ogawa Kei, Haisong Jiang and Kiichi Hamamoto

Switching technologies in data centers are getting much attention because the conventional electrical switches lead to high power consumption in order to support the growth of network data traffic. Thus, optical router by using optical switch has been studied intensively to eliminate electrical-to-optical (OEO) signal exchange [1]. We proposed optical mode switch that switches the "optical mode" that is orthogonal in principle [2,3]. Optical modes propagate in the same waveguide, thus, it only needs single input and output ports, as it is shown in Fig. 1 (b).

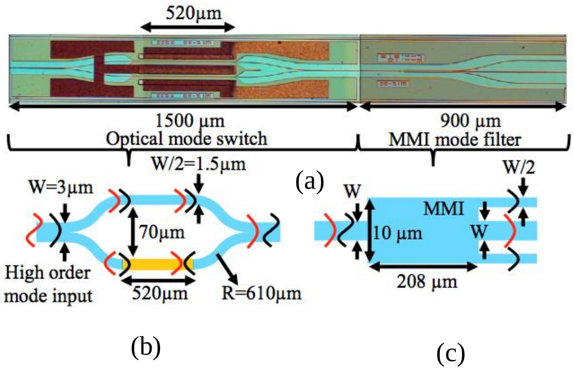

Fig.1 Device configuration. (a) Top view of implemented device, (b) configuration detail of optical mode switch. and (c) MMI mode filter.

In order to evaluate the optical mode switching, MMI mode filter was used, so that the power of each mode and the crosstalk between them could be evaluated. The top view of the MMI mode filter is shown in Fig. 1 (c). MMI mode filter was used only for the purpose to distinguish the fundamental and first-order mode.

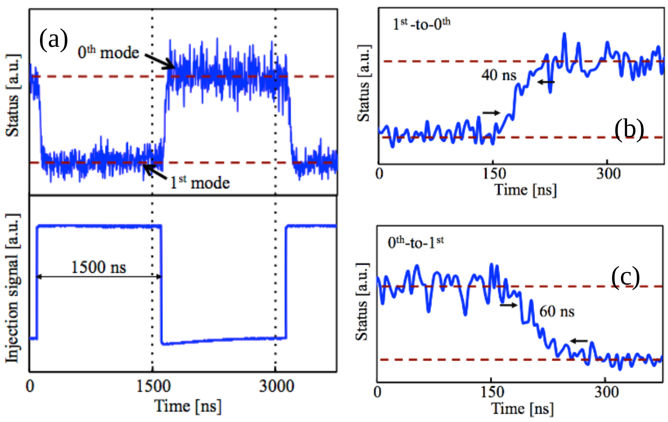

Fig. 2 Dynamic mode-switching result. (a) Injection signal and device status, (b) rise time, and (c) fall time.

Figure 2 (a) shows device status from the injection signal of a 1500 ns with 2 V peak-to-peak square pulse. The status was evaluated by monitoring the output power at the fundamental mode port of MMI filter. When the current is set to cross-state (approx.60 mA), the device status shows the lower optical power level, which corresponds to the first order mode, while the device status shows higher optical power level, which corresponds to fundamental order mode, in the case of current is set to bar-state. Figure 2 (b) shows the switching time of 40 ns for 1st-to-0th switching, while the switching time of 60 ns for 0th-to-1st switching was observed as shown in Fig. 2 (c). The improving of switching time and also reducing the power consumption is now being investigated. Optimization of ion implantation, bridge layer in pin structure, and also the optimization of electrode layer is now being investigated.

Reference

[1] D. J. Blumenthal et al., IEEE Opt. Comm. (2003)
[2] R. Imansyah et al., IBP2014, 82. (2015).
[3] R. Imansyah et al., MOC2015, 50. (2014).

Extremely High Direct Modulation Bandwidth Mode Selective Light Source Based on Active-MMI

Bingzhou Hong, Tomotaka Mori, Haisong Jiang and Kiichi Hamamoto

The mode selective light source extends the communication speed of inner links of machines such as super computer, mode division multiplexing (MDM) systems is one of the solutions [1]. Mode selective light source based on active-Multimode interferometer (MMI) has been proposed and demonstrated for such system. Targeting bandwidth such as 100 GHz level, BW enhancement scheme utilizing multiple PPRs has been proposed and demonstrated on active-MMI LD in 2017 and at least 34 GHz bandwidth was obtained [2]. In this work, mode selective active-MMI LD was fabricated to realize high speed modulation on the both 0th and 1st order modes simultaneously. As a result, individual stable lasing of 0th mode and 1st mode was obtained. Experimentally measured 3 dB modulation bandwidth of the both modes exceeded 40 GHz.

Figure 1 shows the schematic view of the active-MMI LD. Three arms joint with an MMI section as well as

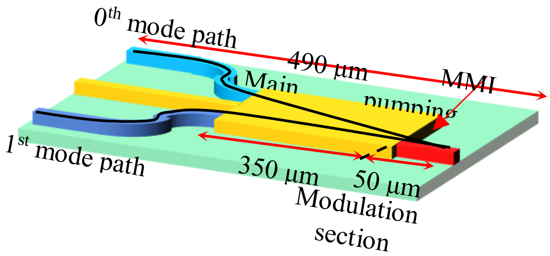

Fig. 1. Schematic view of active-MMI LD

Fig. 2. (a) Only 0th mode lasing. (b) Only 1st mode lasing.

modulation section provides three different lengths oscillating cavities. High mesa configuration was introduced for the waveguide structure. Such structure provides inner reflection at MMI edge, which enables another three inner oscillating cavities consist of three arms and MMI section. Thus at least six oscillating cavities exist within single laser. Consequently, multiple PPRs are introduced by such structure. By switching on/off current of bending arms, 0th mode and 1st order mode lasing is selected. Figure. 2 shows the near field pattern results of the device at different current injection conditions. Small signal frequency response (FR) of mode selective active-MMI LD was evaluated under single mode operation condition for both 0th and 1st order modes. Figure. 3 (a) and (b) shows measured FR results. Different colors represent different pumping current. It is clearly shown in the figure that, for the both 0th and 1st order modes, FRs were enhanced as pumping current increase. For both modes, 3 dB bandwidths were extended over 40 GHz with pumping current above 170 mA.

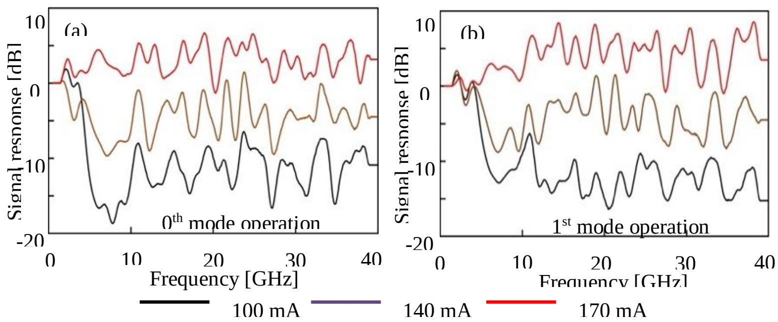

Fig. 3. Bandwidth enhancement scheme and measured small signal response results. (a) Measured frequency response at 0th mode operation. (b) Measured frequency response at 1st mode operation

References

[1] R. Ryf, et al., “Mode-Division Multiplexing Over 96 km of Few-Mode Fiber Using Coherent 6 × 6 MIMO Processing,” *J. Light. Tech.*, vol. 30, no. 4, pp.521–531, 2012.

[2] B. Hong, et al., “Bandwidth Enhancement Scheme Demonstration (from 5 GHz to 34 GHz) on Direct Modulation Laser Diode using Multiple PPR (Photon-Photon Resonance) Active MMI,” *ECOC*, P1.SC2.22, 2017.

Single Step ICP (Inductively Coupled Plasmas) Dry-Etching Condition for Lateral *pin* Waveguide

Yuto Morita, H. Jiang and K. Hamamoto

Normally, when two different depths are required such as a current injection region and a waveguide region as in the lateral pin structure, it is necessary to etch twice or more. Therefore, we focused on the RIE-lag phenomenon[1-2] in which the etching rate varies depending on the mask opening space. We can simplify the etching process because the trench pin structure with the narrow gap between the ion implantation region and the optical waveguide region can realize two or more depths by one etching. Si wafers with various aperture widths of 0.8 to 15.0 μm were used, and the optimum etching conditions were studied by changing the conditions and corresponding to multiple mask opening widths. As a result, we obtained the condition that the etching rate is constant and fast with a wide opening width at ICP power 1000 W/Bias power 50 W, and the etching rate is low at narrow opening width. We fabricated a trench pin structure by using that condition.

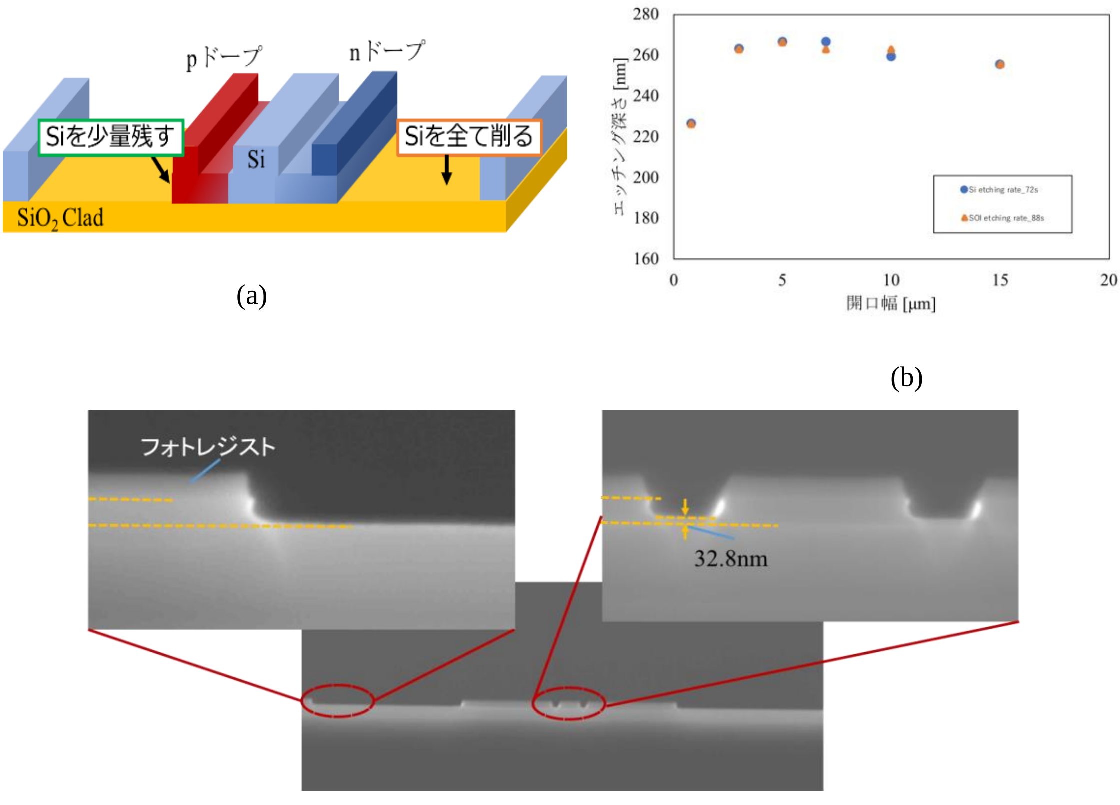

Fig.1(a)trench pin structure (b)Single step ICP dry etching condition(c) The fabricated trench pin structure

Reference

[1] M. F. Doemling et al, "Observation of inverse reactive ion etching lag for silicon dioxide etching in inductively coupled plasmas," Appl. Phys. Lett, Vol.68, No.1, pp. 10-12, January 1996.

[2] Henri Jansen et al, "RIE LAG IN HIGH ASPECT RATIO TRENCH ETCHING OF SILICON," Mieroeleetronie Engineering, pp. 45-50, 1997.

Mode-maintaining Slit Waveguide

K. Fujimoto, H. Jiang and and K. Hamamoto

Mode division multiplexing (MDM) has been widely researched to realize much higher transmission capacity on single fiber [1-4]. One of the critical issues is, however, mode crosstalk on waveguide that prevents proper preservation of individual mode transmission. One main cause of its crosstalk has been a mode excitation phenomenon at bending waveguide. Figure 2(a) illustrates this phenomenon, and shows a schematics of un-centered light propagation in regular multi-mode waveguide. Because the beam-center goes outside at the bending region, higher order mode may be exited at bending region especially in case of small bending radius. Once such kind of higher order mode excitation happens, significant mode crosstalk occurs. MIMO is exploited to demonstrate MDM transmission capability, however, it is deal in case of utilizing mode-maintaining waveguide that leads to MIMO less transmission.

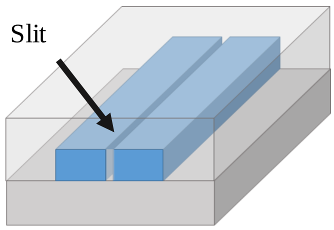

Fig.1. The schematic of slit waveguide

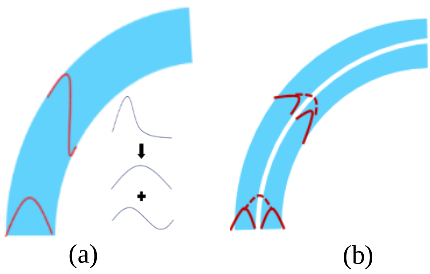

Fig.2. Modepropagation at bending wavegide
(a) Regular waveguide (b) Slit waveguide

For this reason, we propose slit waveguide. Slightly introduced slit in core layer prevents un-centering of the propagation beam center (Figure 1), therefore, low mode crosstalk is expected at bending waveguide. In this paper, we simulated mode propagation in the proposing slit waveguide when 0th mode was input, and verified mode crosstalk suppression effect of the proposing slit waveguide.

When 0th mode propagates in the regular (non-slit) waveguide, the beam-center of the propagating light goes outside at the bending region, and 1st mode is excited (Figure 2(a)). However, in the case of slit waveguide, 0th mode beam consisting of two small wave propagates, and higher order mode is not excited because beam-center doesn't go outside. So low mode crosstalk is expected at bending region in case of slit waveguide.Figure 3 shows simulation result in case of 0th mode is input.From this result, below -20.0dB was achieved even at bending radius of 50μm in case of slit waveguide structure, therefore, we could successfully confirm that slit waveguide structure is useful to prevent high order mode excitation at bending waveguide region.

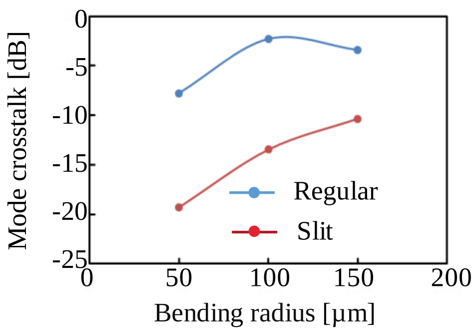

Fig.3. Result of Mode crosstalk

Reference

[1] R. Essiambre et al., JLT., 28 (2010).
[2] R. Ryf et al., OFC 2014, Th5B. 1 (2014).