2011
Annual Report

Opto-Electronics Laboratory
(Prof. Hamamoto Group）

Applied Science for Electronics and Materials

Interdisciplinary Graduate School of Engineering Sciences,

Kyushu University

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1. Personnel

- **Head**

  Kiichi Hamamoto, Professor, Dr. Sc. Techn.

- **Doctor Course Students**

  Zhigang Zang, Ms. Eng.
  Haisong Jiang, Ms. Eng.
  Takaaki Kakitsuka (NTT Photonics Laboratory) , Ms. Sci.
  Daisuke Nakashima, Ms. Eng.
  Yasuhiro Hinokuma, Ms. Eng.
  Jiao Chen, Ms. Sci.

- **Master Course Students**

2nd Year

  Takuma Hagio, Bc. Eng.
  Kazuya Kobukata, Bc. Eng.
  Yutaka Chaen, Bc. Sci.
  Seiki Nakamura, Bc. Eng.

1st Year

  Kazuki Ikeda, Bc. Eng.
  Takaaki Kizu, Bc. Eng.
  Hirohito Hokazono, Bc. Eng.
  Makoto Jizodo, Bc. Eng.
  Zhao Zhao, Bc. Sci.

- **Bachelor Course (4th year)**

  Tetsuya Kawata
  Kanako Tagawa

2. Research Summary

We research and develop so called opto-electronic devices including photonic integrated circuits, laser diodes, and others. We got first three doctors on the fiscal year 2011 from this laboratory.

【Highlight 2011】

- Waveguide Gas-Cell for compact breath sensing system

We research photonic integrated circuits for future ultra-compact breath sensing system. The key technology of this is high-mesa waveguide for the gas-cell. We have realized very low propagation loss of 1dB/cm at the width=800nm, and more than 50% optical field profile out of the waveguide are confirmed so far. On the year of 2011, the theoretical research on novel strip high-mesa waveguide has been proposed to realize lower loss characteristics. The results were presented at IEICE conference.

- Single longitudinal mode active-MMI laser diodes for next generation transmission

We research single-wavelength emission active MMI laser diodes for next generation transmission. On the year of 2011, we have realized the world first CW single wavelength active-MMI LD on RT (SMSR>30dB) by using asymmetric active-MMI configuration. We have presented these results at post-deadline paper on OECC 2011.

- Integrated Optical Memory Elements Using Novel Active MMI

Optical RAM is a key device for next generation all optical router. We research the memory elements for the optical RAM. We have successfully confirmed the very high speed responses on the memory operation. We have presented these results at IPRM 2011, ECOC 2011, IEICE conference, and others. Ms. Haisong Jiang has successfully got her doctor degree.

- High-Power Super-luminescent Diodes by Using Active Multi-Mode Interferometer

High power SLED is attractive for optical coherent tomography (OCT), optical gyro, and wavelength division multiples (WDM) transmission. We have realized more than 100mW output 1.55 m-SLED (50nm bandwidth) so far.

3. Research Topics

- **Waveguide gas-cell for compact breath sensing system**

Daisuke Nakashima Kiichi Hamamoto

In preparation for the society that ages more and more, we aim at the achievement of ubiquitous, optical sensor that is individual health management possible in easiness. Even the current state, the equipment is large though the expiration sensing device exists. Therefore, we are examining the measurement by the infrared absorption spectroscopy by using the waveguide type gas cell that applies the waveguide that another doesn't have the example to the gas absorption cell that encloses the sample gas for the miniaturization of this device. Figure 1 shows the conceptual diagram of this system. The high mesa waveguide has a feature that the infrared rays absorption spectrum of the gas and the liquid can be measured while light propagates because it propagates the high mesa waveguide while protruding from the waveguide when it propagates. As a result of a current prior examination, if we used the high mesa waveguide, we reported being able the achievement of the optical path length of several m also on the substrate of 1cm2 in the telecom wavelength.

The propagation loss and the optical confinement are important parameters for evaluating the waveguide. The propagation loss shows how much light intensity for each unit length attenuates when light propagates the waveguide. The smaller it is the propagation loss, the better. The optical confinement shows the overflow degree from the waveguide of the light intensity distribution. It becomes easier to measure the gas sensing large the optical confinement. Figure 2 and 3 shows the waveguide width dependency of the propagation loss and the optical confinement[1]. We have proven it to be a low-loss waveguide at the highest level of 0.9dB/cm (the waveguide width : 0.8μm) in the world. And, the value for the optical confinement to exceed 50% is confirmed for the first time experimentally in the world. We will seek further enlightenment, and we aim at the optical integrated device achievement that can be used for the breath sensing.

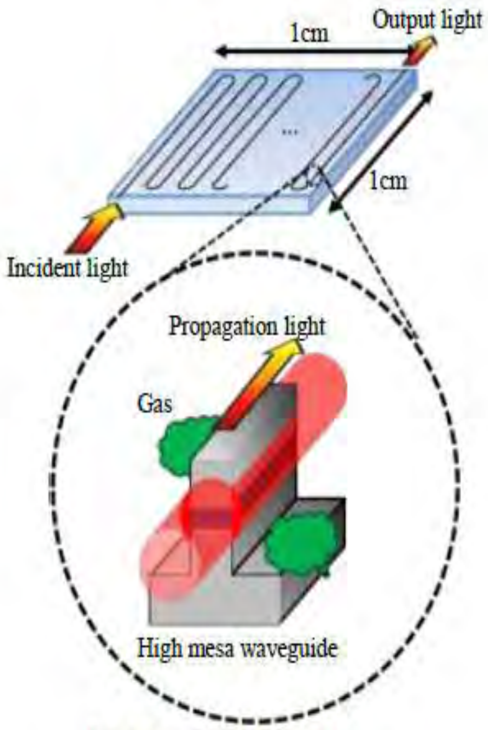


Fig. 1 Conceptual diagram of optical sensing system

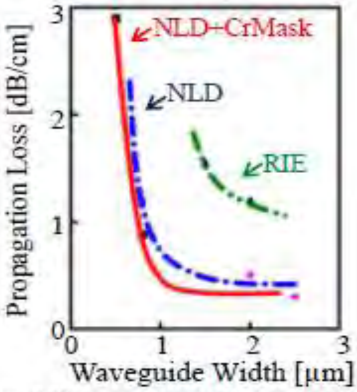


Fig. 2 Waveguide width dependency of Propagation Loss

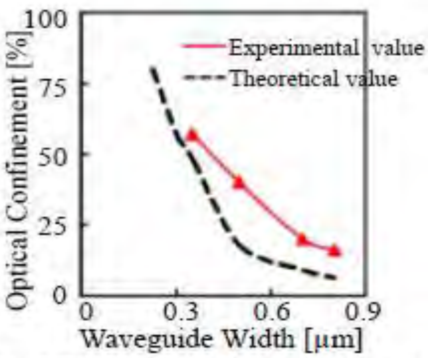


Fig. 3 Waveguide width dependency of Optical confinement

Reference：
[1] I. Alam, Y. Matsunaga, S. Hirofuji, T. Mitomi, T. Murayama, Y. Kokaze, H. Wado, Y. Takeuchi, K. Hamamoto, "Low loss high-mesa Si/SiO2 wire waveguides fabricated using neutral loop discharge plasma etching for infrared absorption spectroscopy", MOC 2009, 2009.

3. Research Topics

● Proposal of Novel Strip High-Mesa Waveguide for Infrared Absorption Sensing

Daisuke Nakashima Kiichi Hamamoto

For realizing compact infrared absorption sensing device, a gas-cell-utilizing optical waveguide is attractive due to the possibility of long optical path integration[1]. The higher optical power portion out of the waveguide (we define this portion as "Γair") is the key feature for the infrared absorption[2]. We evaluated the optical field profile and Γair of the waveguide eigen-mode by using finite element (FEM) electromagnetic field analysis. The optical field profile depends on the waveguide geometry, in particular on the width w and the etching depth in the lower cladding layer d, and therefore Γair needs to be estimated depending on these parameters.

As is shown in Fig. 1(b), the core layer of the strip waveguide is formed on top of the lower cladding layer. The required etching depth is sufficient with only the core layer thickness. Therefore, this waveguide structure offers a benefit of relatively simple processing compared with the high-mesa waveguide shown in Fig. 1(c). For instance, in the case of using Si for the core and SiO2 for the cladding, as is shown in Fig. 1, the typical etching depth of the high-mesa waveguide approximately reaches to 1.6 μ m, while an etching depth of 300nm is sufficient for the strip waveguide. However, one critical issue remains in the strip waveguide for sensing applications. As shown in Fig. 1(b), the optical field profile is more strongly concentrated in the substrate due to its refractive index configuration[3]. To overcome this problem, here, we newly propose a strip high-mesa waveguide, as shown in Fig. 1(a). In the strip high-mesa waveguide, of which a part of the lower-cladding layer was etched down slightly, most of the optical field comes out of the waveguide, and the optical field becomes similar compared to the high-mesa waveguide shown in Fig. 1 (c).

We examined the dependence on the waveguide width w. Figure 3 shows the results. Here, we use Si for the core layer with a thickness of 260nm and a refractive index of 3.48 at λ = 1550nm, SiO2 for the cladding layer with a refractive index of 1.44 at λ = 1550nm, and the etching depth in the lower cladding layer d = 500nm for the strip high-mesa waveguide. As shown in the figure, Γair exceeds approximately 71% at the waveguide width w = 290nm. This value was higher than that of the high-mesa waveguide of 56%.

In addition, an excess loss at waveguide bending was also estimated by using finite difference time domain method (FDTD method). Figure 3 shows the result. The estimated excess loss at the micro-bending was almost similar compared to the high-mesa waveguide. We could successfully confirm that the micro bending of the curvature radius below 10μm can be exploitable in case of the strip high-mesa waveguide, as well as the high-mesa waveguide.

From these result, we could successfully confirm the potential of utilizing strip high-mesa waveguide especially for infrared absorption sensing

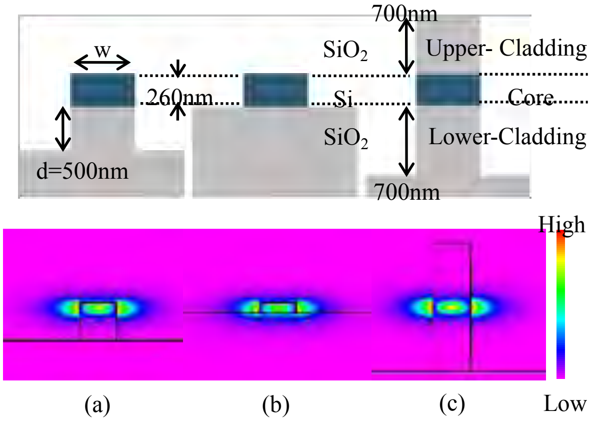


Fig. 1. Schematics of waveguide cross section and the simulated optical profiles.

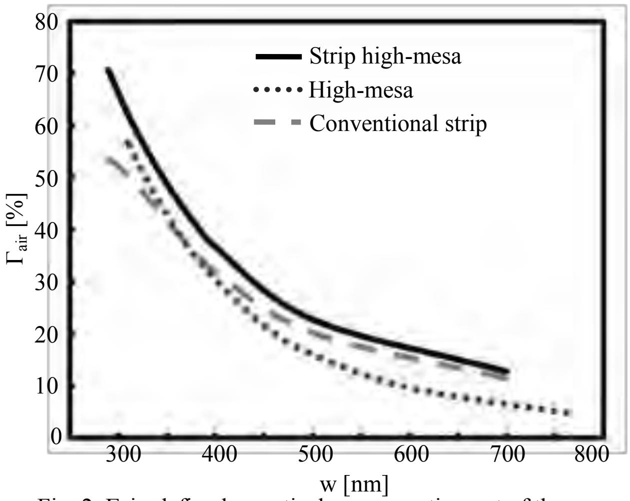


Fig. 2. Γair, defined as optical power portion out of the waveguide, as a function of waveguide width w.

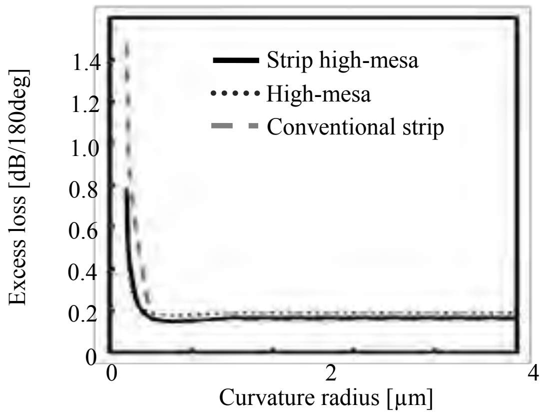


Fig. 3. Excess loss at waveguide

References :
[1] S. Yano et al., IPNRA, IWA7, 2007
[2] S. Yano et al,. IEICE, 106 (284), 27, 2006
[3] A. Intekhab et al., JJAP, 49 (12), 122503, 2010

3. Research Topics

● Optical Random Access Memory based on Active-MMI BLDs

Haisong Jiang, Takuma Hagio, Yutaka Chaen, Makoto Jizoudou and Kiichi Hamamoto

Current internet routers consume huge amount of electrical power due to OE (optical to electrical) and EO (electrical to optical) signal exchanges. This leads to the necessity to develop all-optical routers that could result in energy conservation. Optical random access memory (RAM) is a key device for realizing such that all-optical routers especially for the buffering function. We have proposed and demonstrated wide hysteresis window bi-stable laser diodes (BLDs) based on active multimode interferometer (MMI) utilizing different lateral modes leads to wide hysteresis, which allows common single-current driving for the integrated devices [1]~[4]. Figure 1 shows the schematics of active-MMI BLDs. In this design, bi-stability characteristics depend mainly on the cross-gain saturation between fundamental and first-order modes [1]. This schema offers superior controllability in the portion of cross-gain saturation region, which leads to wide hysteresis window that allows common single-current driving for the integrated devices. By using this principle, we have realized low hysteresis threshold current (39mA), with maintaining sufficient hysteresis window (7mA, 18% of the hysteresis threshold) in the cavity length of only 305μm (see Fig. 2) [2], and demonstrated relatively low common operation current for 4-bit memory elements in a single chip (see Fig. 3) [3].

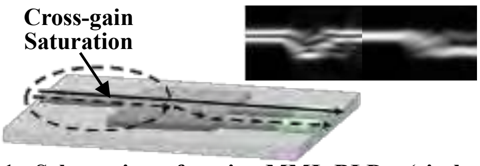


Fig. 1. Schematics of active-MMI BLDs (circle indicates cross-gain saturation region).

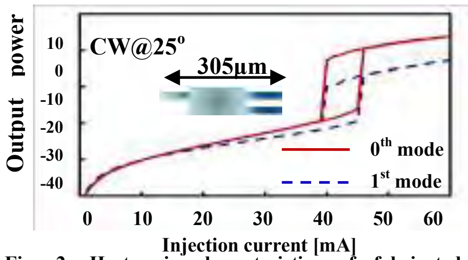


Fig. 2. Hysteresis characteristics of fabricated

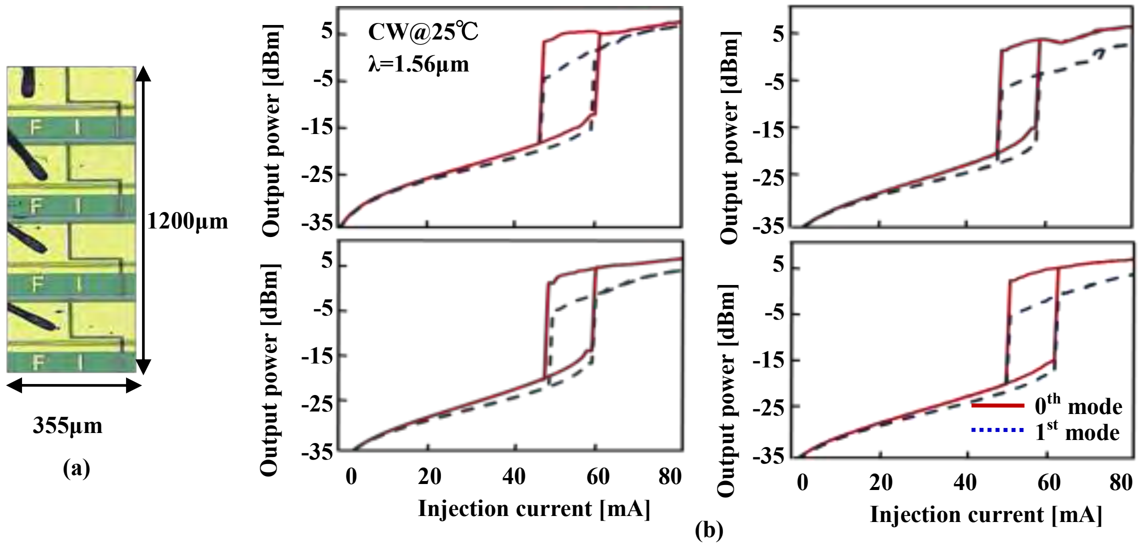


Fig. 3. (a) Microscopic top photograph of integrated 4-bit optical memory elements and (b) the hysteresis

References

[1] H. Jiang et al, Enginee. Science Reports, Kyushu University, 31, 1-6 (2009).

[2] H. Jiang et al, J. Sel. Top. Quantum Electron. 17, 1258-1263, (2011).

[3] H. A. Bastawrous et al, Proc. ECOC2008, P.2.15 (2008).

[4] H. A. Bastawrous et al, in Techn. Dig. OFC, JWA34 (2010).

3. Research Topics

● High Speed All Optical On-Off Operation based on High-mesa Asymmetric Active-MMI BLDs

Haisong Jiang, Takuma Hagio, Yutaka Chaen, Makoto Jizoudou and Kiichi Hamamoto

We have proposed and demonstrated wide hysteresis window bi-stable laser diodes (BLDs) based on asymmetric active multimode interferometer (MMI) utilizing different lateral modes leads to wide hysteresis, which allows common single-current driving for the integrated devices [1]~[4]. We utilized high-mesa waveguide structure for this time. The very high contrast in the refractive index of the high-mesa structure and un-centered configuration obtain not only lateral, but also sufficient longitudinal interference, may result in single wavelength emission [5]. The device is switched to the "on" state by injected lasing wavelength light which corresponding to the 0th order mode light due to cross-gain saturation, and the device is switched to the "off" state by injected different lasing wavelength light which corresponding to the 1st order mode light [4] due to cross-gain saturation.

Figure 1 shows the schematics of high-mesa asymmetric active-MMI BLDs. Fig. 2 and Fig. 3 show the power-current (P-I) characteristics and emission spectrum of the implemented devices. It can be seen that a low hysteresis threshold Ith of 60 mA, and a wide hysteresis window 10mA could be realized. Remarkable single wavelength emission performance, has been successfully obtained at a wavelength of λ= 1549 nm, with a side-mode suppression ratio of 25 dB. Fig. 4 shows the Dynamic memory operation results of implemented devices. It can be seen that the high-mesa asymmetric active-MMI BLDs could realize all optical on-off switching using 25 ps pulses. Furthermore, the switching energies of the set and reset pulses were only 7.1 fJ and 3.4 fJ respectively. The fast rise time 121ps and fall time 25ps were evaluated in this work. (see Fig. 4 (c), and (d)) [3~4].

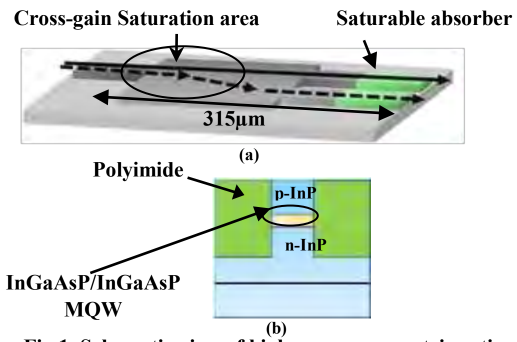


Fig 1. Schematic view of high-mesa asymmetric active-MMI BLDs. (a) Waveguide configuration, (b) cross-section.

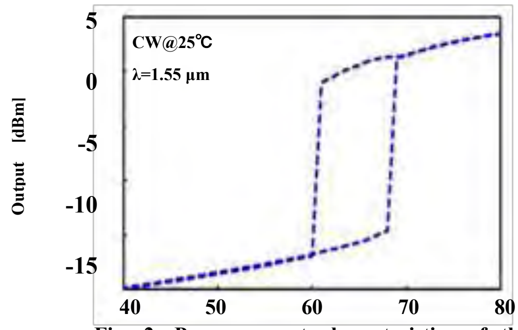


Fig. 2. Power-current characteristics of the implemented devices.

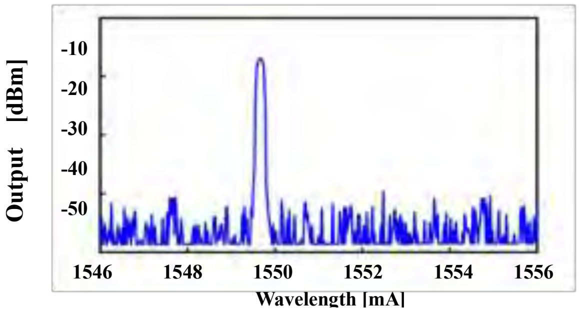


Fig. 3. Emission spectrum in the "on" state of the implemented devices.

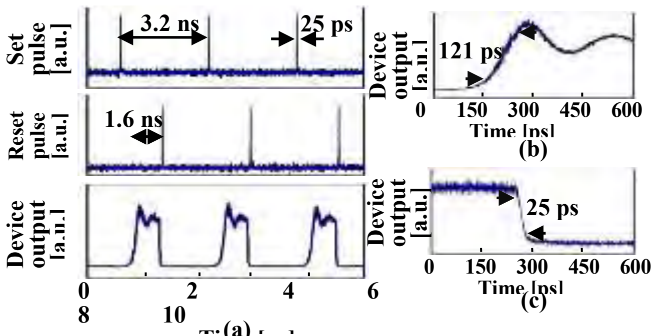


Fig. 4. Dynamic memory operation of high-mesa asymmetric active-MMI BLDs using 25 ps switching pulses. (a) Set and reset pulses, as well as device output,

References

[1] H. A. Bastawrous et al,Tech. Dig. OFC 2010, JWA34 (2010). [2] H. Jiang et al, Proc. IPRM 2011, P32 (2011). [3] H. Jiang et al, Tech. Dig.. ECOC2011, Th.11.LeSaleve (2011). [4] H. Jiang et al, Opt. Express, B119 (2011) . [5] Y. Hinokuma et al, Proc. OECC 2011, PD6 (2011).

3. Research Topics

● Low wall-plug consumption high power SLED

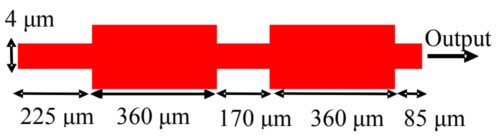
Zhigang Zang, Keisuke Mukai, and Kiichi Hamamoto

Superluminescent diodes (SLEDs) with high power and broad bandwidth have been attracting much interest for wavelength division multiplexing [1]. Here, we report the first demonstration of high power SLEDs by utilizing active multi-mode interferometer (Active-MMI) [2]. The implemented active-MMI SLEDs structure consisted of two 1x1 multi-mode interference couplers, which were connected to regular single-mode waveguides, as shown in Fig. 1 (a). By proper design of the MMI section, the amplified spontaneous emission (ASE) should also behave according to active MMI phenomena, which results in a regular single-transverse-mode output, as shown in the simulated optica1 field of Fig. 1 (b). We used MQWs (λ = 1.55 μm) as the active layer. The waveguide structure was tilted to suppress the feedback combined with antireflection coating. For comparison, regular SLEDs with the same length 1200 μm were also fabricated simultaneously on the same wafer. Figure 2 shows the power and voltage against current characteristics. The maximum output power of the active-MMI SLEDs was 115 mW, while the one of regular SLEDs was 75 mW. This result corresponds to a significant output power improvement of 40 mW, i.e., 54%, compared to the maximum output power of the regular SLEDs. High output power is achieved due to the wider actively pumped area, which contributes to improving the power saturation level. Moreover, the driving voltage of the active-MMI SLEDs was much lower than that of regular SLEDs. From this point, active-MMI SLEDs are also superior in wall-plug consumption, as shown in Fig. 3. At the same output power of 70mW, the wall-plug consumption of active-MMI SLEDs has a reduction of 19%, compared to regular SLEDs. The emission spectrum of the devices at the same current density of 9 kA/cm^2 is shown in Fig. 4. The active-MMI SLEDs showed relatively wide and flat spectrum (FWHM = 50 nm, λcenter = 1.55 μm) as same as regular SLEDs. The ripples in the spectrum were below 0.03 dB for the active-MMI SLEDs, and 0.05 dB for the regular SLEDs respectively.

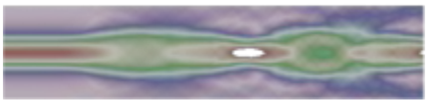
In conclusion, 115 mW high power SLEDs with a wide 3 dB bandwidth of 50 nm, utilizing active-MMI configuration, was achieved successfully. In addition, active-MMI SLEDs are also superior in wall-plug consumption, compared to regular SLEDs.

Reference:

[1] S. S. Wagner et al, Electron. Lett., vol. 26, pp. 696–697(1990).
[2] K. Hamamoto et al, Electron. Lett., vol. 36, pp. 138-139 (2000).



(a)



(b)

Fig.1. (a) Schematics of Active-MMI SLEDs, (b) Simulation of optical field in Active-MMI LEDs.

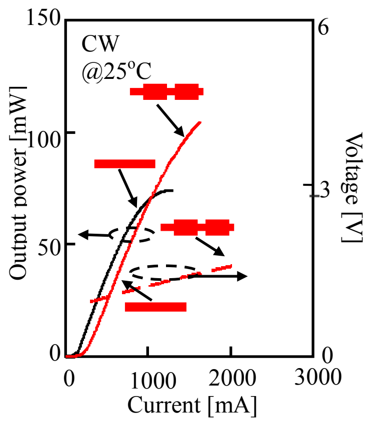


Fig. 2. Light output power against current and voltage against current characteristics

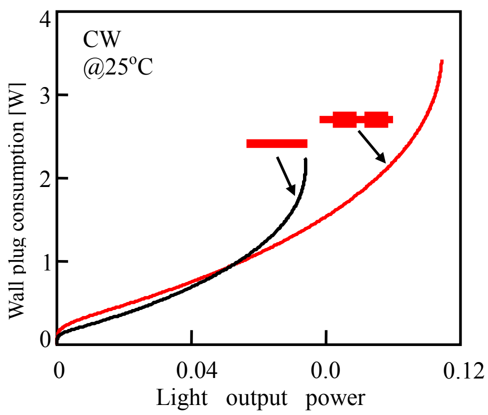


Fig. 3. Measured wall-plug consumption.

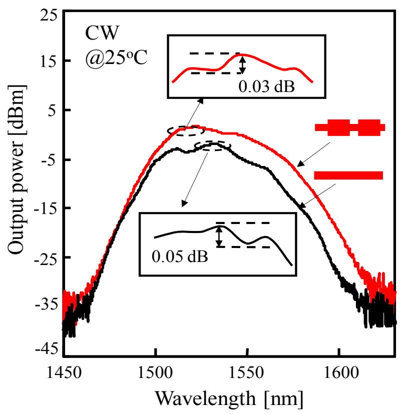


Fig.4. Spectrum of the fabricated SLEDs.

3. Research Topics

● Single wavelength CW emission by using asymmetric active-MMI LD

Yasuhiro Hinokuma, Seiki Nakamura, Takaaki Kidu, and Kiichi Hamamoto

The low cost technologies of light source have been needed for developing of optical communication. We propose a single wavelength emission LD (Laser Diode) without any grating structure by using asymmetric 1x1 active MMI (Multi-Mode Interferometer) LD.

Figure 1 shows an active MMI LD. Two single mode waveguides are connected with MMI waveguide. In this device, optical beam propagates like Fig. 2. Therefore, the novel active MMI LD which is designed as un-center configuration leads to not only lateral phase matching but also longitudinal one. As a result, active MMI LD obtains single wavelength emission.

Figure 3 shows the typical emission spectrum of the fabricated novel asymmetric active MMI LD. As is shown here, the spectrum showed CW single wavelength emission at RT (Room Temperature) with sufficient SMSR (Side Mode Suppression Ratio) =31dB. This is the first time to obtain CW single wavelength emission by using active MMI LD by using any grating in the world. Moreover, Figure 4 shows the eye-diagram which was confirmed the fabricated devices when the modulation section was modulated by using current injection with 1.25Gbps signal (PRBS: 27-1, back to back).

Reference:

[1] Y. Hinokuma, et. al., IEICE Technical Report, OPE-116, 2010
[2] W. Yuan, et. al., ISLC, ThC5, 2010
[3] J. Zhao, et. al., IPRM, Tu-5.2.1, 2011
[4] Y. Hinokuma, et. al., OECC, PDP6, 2011

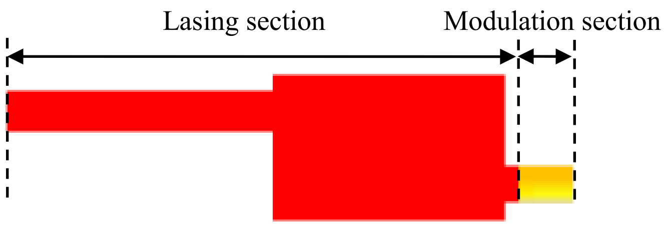


Fig. 1. Schematic of asymmetric active MMI LD

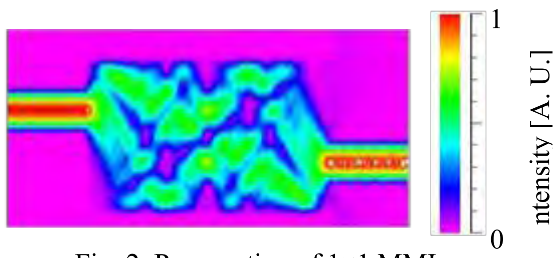


Fig. 2. Propagation of 1×1 MMI

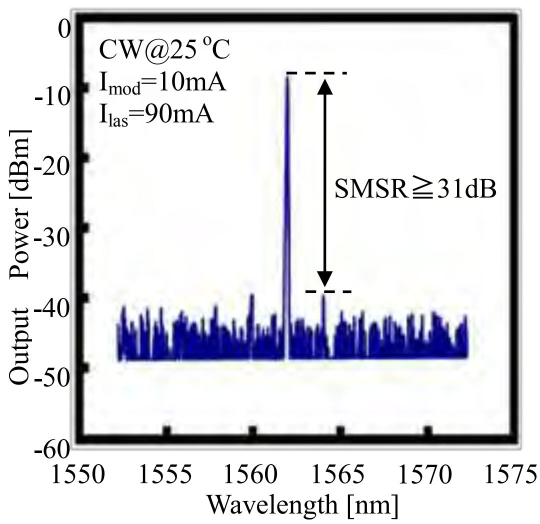


Fig. 3. Emission spectrum

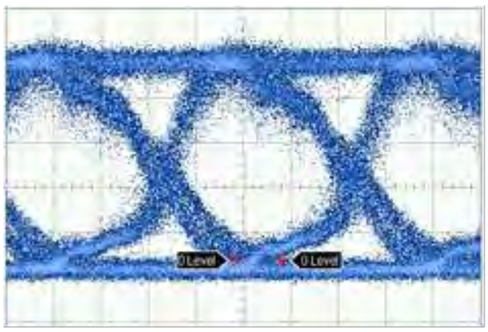


Fig. 4. Eye-diagram
(1.25Gbps, PRBS: 2^7-1, back to back)

4. Paper List

- **Thesis**

(1) Zhigang Zang, "High Power Superluminescent Light Emitting Diode (SLED) by Using Active Multi-Mode Interferometer (MMI), Sep. 2011

- **Journal Publications**

(1) Haisong Jiang*, Yutaka Chaen*, Takuma Hagio*, Kazuisao Tsuruda*, Makoto Jizodo*, Shinji Matsuo**, Jing Xu***, Christophe Peucheret***, and Kiichi Hamamoto*, "All Optical Fillip-Flop Operation Based on Asymmetric Active-Multimode Interferometer Bi-stable Laser Diodes", Optics Express, Vol. 19, No. 26, pp. B119-B124, Nov. 2011
*Kyushu University ** NTT Photonics Laboratories ***DTU Photonik

(2) Takaaki Kakitsuka* **, Shinji Matsuo**, Kiichi Hamamoto*, Toru Segawa**, Hiroyuki Suzuki**, and Ryo Takahashi**, "Injection-Locked Flip-Flop Operation of a DBR Laser", IEEE Photonics Technology Letters, Vol. 23, No. 17, pp. 1261-1263, Sep. 2011
*Kyushu University ** NTT Photonics Laboratories

(3) Haisong Jiang*, Hany Ayad Bastawrous*, Takuma Hagio*, Shinji Matsuo**, and Kiichi Hamamoto*, "Low Hysteresis Threshold Current (39mA) Active Multi-Mode-Interferometer (MMI) Bi-stable Laser Diodes Using Lateral-Modes Bi-stability", IEEE Journal of Selected Topics in Quantum Electronics, Vol. 17, No. 5, pp. 1258-1263, Sep. 2011
*Kyushu University ** NTT Photonics Laboratories

(4) Zhigang Zang*, Keisuke Mukai*, Paolo Navaretti**, Marcus Duelk**, Christian Velez**, and Kiichi Hamamoto, "High Power and Stable High Coupling Efficiency (66%) Superluminescent Light Emitting Diodes by using Active Multi-mode Interferometer", IEICE Transactions on Electronics, Vol. E94-C, No. 5, pp. 862-864, May 2011
*Kyushu Universtiy **EXALOS AG

- **Conference Publications (International)**

(1) Haisong Jiang*, Yutaka Chaen*, Takuma Hagio*, Kazuisao Tsuruda*, Makoto Jizodo*, Jing Xu**, Chirstophe Peucheret**, Shinji Matsuo***, and Kiichi Hamamoto*, "High-Speed and Low-Energy Flip-Flop Operation of Asymmetric Active-Multimode Interferometer Bi-Stable Laser Diodes", Proceedings of 37th European Conference on Optical Communication (ECOC 2011, Geneva, Switzerland), Th.11.LeSaleve.4, 22nd September 2011
* Kyushu University **DTU Fotonik ** NTT Photonics Laboratories

(2) Yasuhiro Hinokuma*, Yutaka Chaen*, Haisong Jiang*, Takuma Hagio*, Akio Tajima**, and Kiichi Hamamoto*, "First Single Wavelength (CW@RT, SMSR>30dB) Active-MMI LD (Non-Grating) Based on Longitudinal Interference", Technical Digest of 16th OptoElectronics and Communications Conference (OECC 2011, Kaoshung, Taiwan), PD6, 7th Jul. 2011
*Kyushu University ** NEC System Platform Laboratories

4. Paper List

(3) Haisong Jiang*, Yutaka Chaen*, Takuma Hagio*, Kazuisao Tsuruda*, Makoto Jizodo*, Shinji Matsuo***, and Kiichi Hamamoto*, "Single Wavelength (Non-Grating) High-Mesa Asymmetric Active-MMI All Optical Bi-Stable Laser Diodes", Conference Proceedings of 23rd International Conference on Indium Phosphide and Related Materials, (IPRM 2011, Berlin, Germany), P32, pp. 174-177, 23rd May 2011

* Kyushu University ** NTT Photonics Laboratories

(4) Yutaka Chaen, Zhao Zhao, Haisong Jiang, and Kiichi Hamamoto, "Full C-Band Spatial Multi-Mode Combiner Based on Multi-Mode Interference", Technical Digest of 17th Microoptics Conference (Sendai, Japan),H-13, 1st Nov 2011

(5) Makoto Jizodo, Haisong Jiang, Kazuisao Tsuruda, Takuma Hagio, Yutaka Chaen, Shinji Matsuo, and Kiichi Hamamoto, "Integrated 4-Bit Active-MMI High-Mesa Bi-Stable Laser Diodes Coupled with Hemispherical Lens Fiber Array", Technical Digest of 17th Microoptics Conference (Sendai, Japan), H-29, 1st Nov 2011

(6) Daisuke Nakashima, and Kiichi Hamamoto, "Proposal of novel strip high-mesa waveguide for infrared absorption sensing", Technical Digest of 17th Microoptics Conference (Sendai, Japan), H-60, 1st Nov 2011

- **Conference Publications (Domestic)**

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