Observation of 60 GHz and 20 GHz Multiple Photon-Photon Resonances Using Active Multimode Interferometer Laser Diodes

Murakami, Shingo
Interdisciplinary Graduate School of Engineering Sciences, Kyushu University

Hong, Bingzhou
Interdisciplinary Graduate School of Engineering Sciences, Kyushu University

Jiang, Haisong
Interdisciplinary Graduate School of Engineering Sciences, Kyushu University

Hamamoto, Kiichi
Interdisciplinary Graduate School of Engineering Sciences, Kyushu University

https://doi.org/10.15017/2552954

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 5, pp.109-110, 2019-10-24. 九州大学大学院総合理工学府
バージョン：

Observation of 60 GHz and 20 GHz Multiple Photon-Photon Resonances Using Active Multimode Interferometer Laser Diodes

Shingo Murakami, Bingzhou Hong, Haisong Jiang, and Kiichi Hamamoto
Interdisciplinary Graduate School of Engineering Sciences, Kyushu University.
murakami.shingo.050@s.kyushu-u.ac.jp

Abstract: *1 × N active multimode interferometer laser diodes to achieve two photon-photon resonances (PPRs) have been designed and fabricated. Very high frequency of 60 GHz in addition to 20 GHz PPR peaks were confirmed.*

Keywords: Active MMI-LD; Photon-Photon resonance; High speed modulation

1. INTRODUCTION

Optical inter-connection is highly developed due to computer technology advancing [1], and direct modulation laser diode (DML) may be one of the transmitter candidates especially for the future mobile IT-devices which speed is required around 100 Gbps [2, 3], whereas the modulation speed of DML has been limited up to around 50 Gbps. One way to improve the maximum modulation rate beyond 100 Gbps is photon-photon resonance (PPR) [2-7]. In this paper, the design concept and the experimental results of multiple photon-photon resonances based on active-MMI configuration is reported. This scheme of multiple photon-photon resonances enables plural PPR peaks which may achieve higher modulation speed in the future. As a result, two PPR resonance frequencies of around 20 GHz, and 60 GHz have been successfully confirmed experimentally.

2. CONCEPT OF ACTIVE-MMI LDs

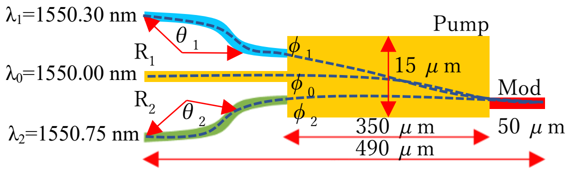

Fig. 1. Schematic view of active-MMI LD

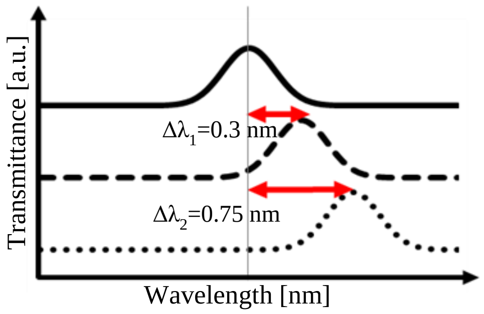

Fig. 2. Schematic concept of PPRs using 1×N active-MMI

The PPR peak is designed using wavelength differences between center wavelengths of each arm at *N*-side of MMI [8]. As shown in Fig. 1, there are three arms at LHS of the 1 × *N* active-MMI configuration. In case of $N \geq 3$, the phase must be matched at the MMI edge to avoid non self-image at the RHS of the MMI. This phase-matching requirement causes free spectral range in the transmission spectrum of the 1 × *N* MMI. To secure this phase-matching condition, bending regions in the both top and bottom arms are introduced. The bending region also induces wavelength dependency which gives the center wavelengths of each arm. Each center wavelength slightly different as indicated in Fig. 1 as to achieve two different PPR peaks in the emission wavelength is designed.

The relation between three different center wavelengths are schematically illustrated in Fig. 2. In the case of center wavelengths arranged as Fig. 1, two different peak shifts are designed. The corresponding wavelength differences are derived in the following equation (1);

$$\Delta\lambda = \lambda_m - \lambda_{center} = \frac{2\Delta L}{n_{eq}} \cdot \frac{1}{2\phi + 2\pi m} - \lambda_{center} \qquad (1)$$

Here, λ_{center}: the center wavelength, which is given by the transmittance peak wavelength of the MMI waveguide, ΔL: Path length difference between center and bending waveguide, n_{eq} : equivalent refractive index of waveguide, λ_m: wavelength, m: positive integer, and ϕ: initial phase for 1 × *N* MMI waveguide (For instance in case of 1 × 3 MMI shown in Fig. 1, $\phi = 1/3\pi$.). From eq. (1), ΔL is derived as eq. (2):

$$\Delta L = \frac{n_{eq}}{2} \cdot (\lambda_{center} + \Delta\lambda) \cdot (2\phi + 2\pi m) \qquad (2)$$

And according to the eq. (2), to obtain two different PPR peaks are designed as summarized in Table 1. PPR frequency F_{PPR} corresponded according to the following eq. (3);

$$F_{PPR} = \frac{\Delta\lambda \cdot c}{\lambda^2} \qquad (3)$$

Table 1. The PPR designs in this work

λ_{center} [nm]	ΔL [mm]	Δλ [nm]	F_{PPR} [GHz]
1550.00	-	-	-
1550.30	0.02	0.30	35
1550.75	0.04	0.75	80

As shown in Tab.1, PPR frequencies at around 35 GHz and 80 GHz, respectively, were designed for the devices.

3. RESULTS AND DISCUSSIONS

For the implemented devices, InGaAsP multi-quantum well was used for the active layer. The waveguide structure was a high mesa are formed by using dry-etching.

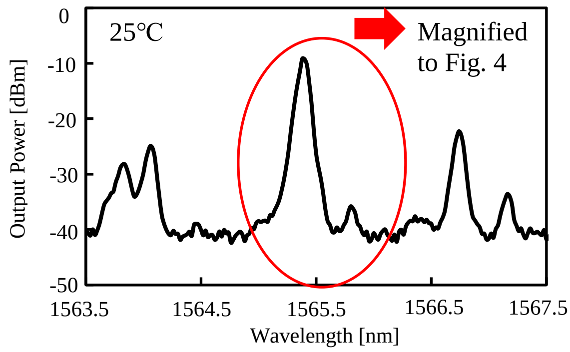

Fig. 3. Emission spectrum

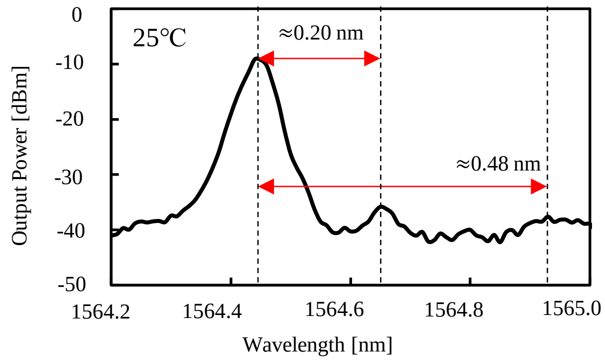

Fig. 4. Emission spectrum

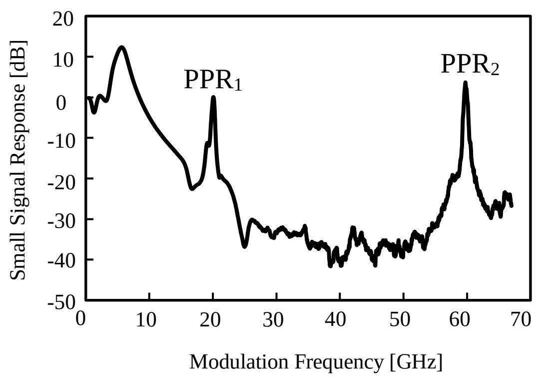

Fig. 5. Small signal response of the fabricated active-MMI LD

Figure 3 shows the emission spectra of the implemented 1 × N active multimode interferometer laser diodes. DC currents were injected as follows; pumping region (MMI section): 172 mA, bias: 53 mA, lower arm: 57 mA, upper arm: 43 mA respectively. As shown in Fig. 4, two peaks beside the main peak were observed at 1564.65 nm and 1564.93 nm, respectively. The wavelength difference between main emission peaks are 0.20 nm and 0.48 nm, respectively. These wavelength differences are not exactly same with the designed ones, however, relatively agreeable. From eq. (3), FPPR appears at the positions of 25 GHz and 59 GHz from these wavelength differences. Figure 5 shows the evaluated small signal frequency response of the fabricated devices. As shown in the figure, the limitation of resonance frequency of LD (CPR peak) at 6 GHz, and two PPR peaks of 20 GHz and 60 GHz were clearly observed successfully. There PPR peaks were corresponding to the emission spectrum in Fig. 4, therefore, these two peaks are concluded that came from photon-photon resonances. In addition, the intensity of the second PPR at higher frequency of 60 GHz are high of more than 0 dB in the response, whereas the response between two peaks completely dropped down below -30 dB. Right now, the determination factors of PPR peak intensity are not so clear, however, we hope we may keep the frequency response flat at entire frequency band by introducing this effect.

Table 2. Design and evaluated PPR frequencies

	PPR_1	PPR_2
Monitored wavelength	1564.65 nm	1564.93 nm
Calculated F_{PPR}	25 GHz	59 GHz
F_{PPR} in Fig. 3	20 GHz	60 GHz

4. CONCLUSION

Two PPRs of 20 GHz and 60 GHz based on 1 × N active-MMI LDs configuration was be able to successfully confirm. Presently, we still investigate the reason of the intensity recovery mechanism especially at high frequency. This approach of multiple PPRs is hoped that will realize flat frequency response up to very high frequency region of more than 100 GHz in the future.

ACKNOWLEDGEMENT

This work has been financially supported by SUPOIN and Kakenhi-B 19H02201. The authors greatly thank to Dr. Yasuhiro Matsui, Finiser Corp., for the future discussion.

Reference to a journal publication:

[1] S. Rumley, et al., "Optical interconnects for extreme scale computing systems," Parallel Computing, Vol. 64, 65-80, 2017.

[2] U. Troppenz et al., "40 Gbit/s directly modulated lasers: physics and application," SPIE 2011, Vol. 7953, 79530F1-F10, 2011.

[3] Y. Matsui, et al., "55-GHz bandwidth short-cavity distributed reflector laser and its application to 112-Gb/s PAM-4," OFC2016, PDP Th5B.4, 2016

[4] M. Dumitrescu, et al., "High-speed directly-modulated lasers with photon-photon resonance," OFC2013, JW2A.33, 2013.

[5] 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 2017, P1.SC2.22, 2017.

[6] B. Hong, et al., "Mode selective active multimode interferometer laser diode with over 40 GHz Direct Modulation Bandwidth," OFC 2018, Th3B.4. 2018.

[7] K. Hamamoto, et. al., "Active-MMI laser diode toward high-speed direct modulation based on multiple photon-photon resonance," SPIE 10682, Semiconductor Lasers and Laser Dynamics VIII, 106820X; doi: 10.1 1 17/12.2306018, 2018.

[8] K. Hamamoto, et. al., "Mode-selective active-multimode-interferometer laser diode -mode-selection principle and high-speed modulation-," IEICE Tans. Electron., Vol. E102-C, No.4, pp. 364-370, 20