P-15

# Multiple Photon Photon Resonance by Using Active-Multimode Interferometer Laser Diode

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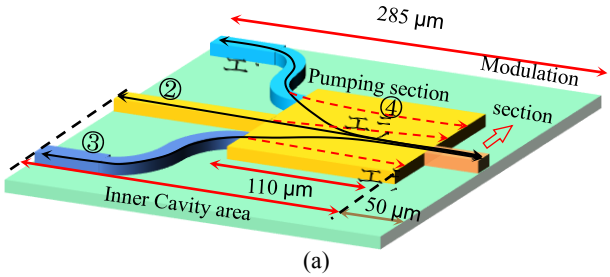
**Abstract**
Active-multimode interferometer laser diode that integrates at least six oscillating cavities has been achieved successfully. Multiple cavities contribute to multiple longitudinal mode spacings as well as multiple PPR frequencies. Device aiming 100 GHz bandwidth design principle is proposed.

## 1. Introduction

Utilizing photon photon resonance (PPR) can extend direct modulation bandwidth [1-3]. In this work, we report multiple PPRs using active-multimode interferometer laser diode (active-MMI LD). The most important issue to achieve multiple PPRs is to integrate multiple longitudinal cavities within single laser. Main cavities and inner cavities (caused from the high-mesa waveguide structure) contribute to complex cavities as well as free space ranges (FSRs). Multiple longitudinal wavelength differences exist in emission spectrum, which directly lead to multiple PPR frequencies. Direct modulation bandwidth up to at least 34 GHz is successfully confirmed. Proposal of new device aiming 100 GHz bandwidth is also given.

## 2. Device design

The device structure is shown in Fig.1(a). Two curved-waveguides and straight waveguide are connected to MMI section of 10 μm width. Radii and bending angles are slightly different to ensure cavity length with slightly difference. Width of both straight waveguide and bending waveguide is 2 μm. Designed modulation section length is 50 μm. As shown in Fig. 1, 1 by 3 -MMI are designed (main cavities, black solid lines). Each cavity length corresponds to a FSR. Mismatch and overlap between each FSR generate different wavelength differences. Delicate wavelength mismatch arrangement lead to preferred PPR




(a)

Fig. 1 Device structure

frequency. Figure 1 (b) shows optical propagation path calculated by beam propagation method (BPM). Optical power distributes in 3 ports equally. Meanwhile, optical loss at joint position are supressed because of such design. High mesa structure is used for waveguide structure. Previous active-MMI LD demonstrate that high mesa structure enables inner reflection at the edge of MMI section [5], which contributes to inner oscillating cavity. Thus, at least three more oscillation cavities exist (inner cavity area in Fig. 1(a)). The two curved waveguides and straight waveguide together with MMI section consist the three inner cavities (red dot lines). Consequently, at least 6 different FSRs exist. Moreover, slightly mismatch of these FSRs generates much more wavelength difference when compared to the case only two FSRs exist.

P-15

### 3. Experimental results and discussion

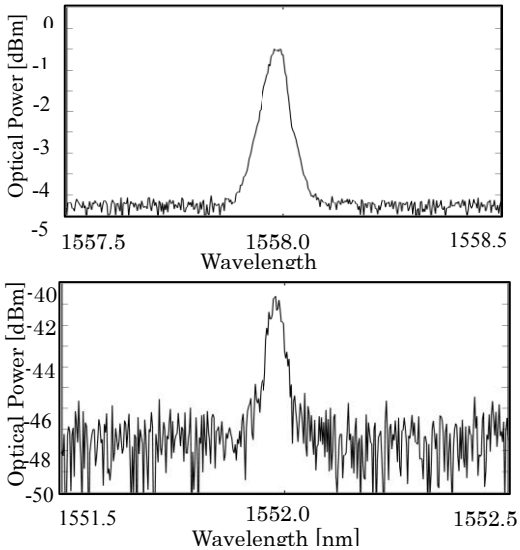



**Fig. 2:** (a) Central wavelength and (b)wavelength apart from central lasing peak

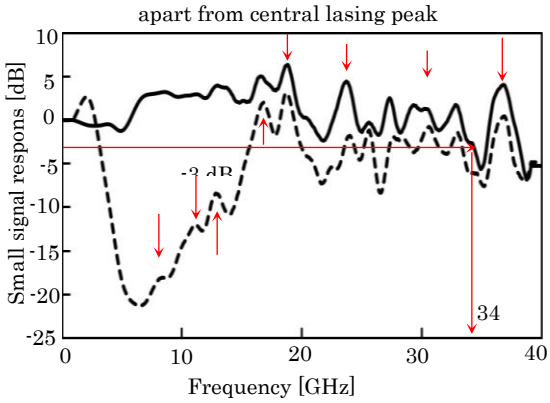



**Fig. 3:** Measured small signal response

Fig. 2 (a) shows the central wavelength emission peak at 1558 nm. Obviously, the central wavelength peak consists of several longitudinal modes and multiple adjacent peaks are visible. Such sub-peaks are caused from the FSR mismatch. It is, however, still difficult to judge exact longitudinal cavity components in side laser diode because some of them are merged with each other at central wavelength. The mismatch is much more obvious at wavelength apart from central lasing peak. In Fig. 2 (c), the mismatches are obvious at wavelength of 1552 nm. At least 6 sub-peak components (wavelength differences) caused from different cavities exist at longer wavelength side. This result reveals that complex cavities indeed exist and overlap between several FSRs generates multiple longitudinal mode spacings even if they are not visible at central wavelength. The wavelength differences clearly indicate the existence of multiple PPRs in the small signal response. Note the fact that not all wavelengths that might induce PPR are visible, and that means at least 6 higher order resonance peaks must be observed in frequency response (FR). Measured FR results are shown in Fig. 3. Multiple higher order PPR peaks are clearly observed. Damping between peaks are suppressed because of multiple PPR. The modulation bandwidth is extended to at least 34 GHz in Fig. 3. Such bandwidth may provide direct modulation speed of at least 45 Gbps. The frequency resonance peaks reflect exact the longitudinal mode spacing itself. The higher order resonance peaks observed at 8 GHz, 10 GHz, 13 GHz, 19 GHz, 23 GHz and 36 GHz correspond to longitudinal wavelength difference in Fig. 2(b). Such wavelength differences are visible near main lasing peak. Moreover, another several frequency response peaks are observed in Fig. 3. This indicates that more longitudinal mode spacings must exist although they are not visible in the static emission spectrum.

### 4. Conclusion

Active-MMI LD with multiple PPRs was demonstrated. Main and inner cavities contribute to complex FSRs. Multiple wavelength differences at central wavelength are observed.

### References

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