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First Observation of Photon-Photon Resonance in Active Multimode Interferometer Laser Diode

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Abstract: Active multimode interferometer laser diode (MMI-LD) with split pump section have been fabricated to achieve high 3 dB bandwidth. Higher photon density using split pump scheme and high-frequency photon-photon resonance has been exploited to extend the direct modulation bandwidth. The split pump active MMI design allows interaction between the lasing mode and a second mode used as catalyst in the pumping section to achieve PPR peak along with the higher photon density delivered by the MMI pumping section towards the modulation section, which allowed us to reach a more than 15.2 GHz of extended 3 dB bandwidth for the active MMI LD.

Introduction: Due to recent rapid growth of data traffic, direct modulation laser diode has been widely researched especially for short distance application [1]. Some of the promising approaches to enhance the modulation bandwidth are increasing the photon density in the modulation section and exploration of the photon-photon resonance. By utilizing the split pump section in 1.55 μm active multimode interferometer laser diode (active MMI LD), combination of higher photon density and photon-photon resonance (PPR) has been achieved. Significant enhancement of 3 dB bandwidth up to 15.2 GHZ from 2.6 GHz has been confirmed successfully for a directly modulated MMI LD.

Device Concept: Figure 1 shows a schematic view of the actually implemented active multimode interferometer laser diode. Pumping region, separated from modulation region, is consisted of MMI waveguide that enables the emission of larger optical power compared to single stripe waveguide [2]. The MMI, which enables the single-mode optical field at the input to be identically imaged at the MMI output, has a wider area than the single-mode waveguides. The larger active area contributes to the enhancement of the output power. As the existence of multiple mode is necessary condition for the PPR, so the advantage of having multimode section in active MMI LD allows us to design lateral mode locking for exploration of photon-photon resonance (PPR) [3]. The photon density in the modulation region is enhanced significantly from this MMI configuration, which enhances the carrier photon resonance (CPR) [4] peak and eventually helps us to get CPR peak close to the PPR peak to achieve a flat response between them. The designed MMI is connected asymmetrically to single mode high mesa waveguides. For the actually implemented devices, the total length of the cavity was 315 μm. The MMI section width was set to 8 μm. The length of the MMI section was 133 μm and with both edges connected to a 2 μm oppositely off-centered single mode waveguide of 3 μm width. The length of the pumping section was set to be 265 μm and the modulation section was set to be 50 μm. The high mesa asymmetric configuration ensures single wavelength characteristics for the actual implemented device.

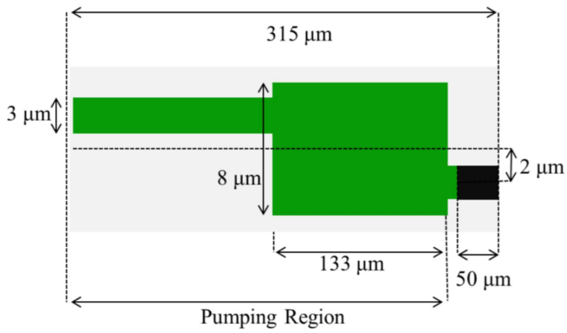

Fig. 1: Schematic view of pumping region split active multimode interferometer laser diode

Results and discussion: Semiconductor lasers carrier photon resonance (CPR) is limited by the relaxation time of the excited electrons. However it is possible to extend the cutoff frequency beyond usual limitations by using a higher order resonance like the PPR, which is related to the roundtrip time of the photons in the laser cavity. A necessary prerequisite for the PPR is the existence of a weak additional mode used as a catalyst. The second mode has to be placed on the longer wavelength side of the main mode in a distance equal to the desired position of the PPR [5]. To excite a PPR peak at around 11 GHz, the distance of the main mode and the second mode has also to be 11 GHz, corresponding to a wavelength difference of ~ 0.08 nm. The device emits at a wavelength of 1561.95 nm with a side mode suppression ratio (SMSR) of about 35 dB as shown in Fig. 2. Inset picture shows the magnified peak of the emission. Inset picture in Fig. 2 also shows the wavelength difference of the phase locked mode, which is around 0.08 nm. Figure 3 (a) shows the experimental data of small signal response of an asymmetric active MMI LD with photon-photon resonance. A second strong resonance peaks can be seen in the figure, which is due to multiple lateral mode phase locked condition. For having PPR peak the mode locking must be stable over time. So the existence of PPR peak verifies the constant phase difference for long time [6]. Large enhancement in modulation bandwidth of over 15.2 GHz can be experimentally obtained, which corresponds to more than 12.6 GHz improvement compared to 2.6 GHz previously reported for MMI LD [7]. The amplitude of the second resonance can be tuned, depending on the injected pump current, from a relatively strong peak to a relatively flat response (Fig. 3 (a)). With increasing pump current flat response between CPR and PPR can be achieved. This second resonance peak is caused by the interaction of the main mode and a weak additional mode on its long wavelength side. Change of the amplitude of second resonance (PPR) influenced by the pump current is presented in Fig 3 (b). This shows the linear increasing trend of the PPR peak with increasing pump current. This may cause due to the contribution of the increasing coupling of the phase locked weak mode with the increasing pump current. Figure 3 (b) also shows the frequency shift of the PPR peak with increasing pump current. From this figure it is evident that the PPR frequency is not much affected by any variation of pump current. Which is expected for photon-photon resonance peak, if the phase tuning section is not present in laser [8] and experimentally verified.

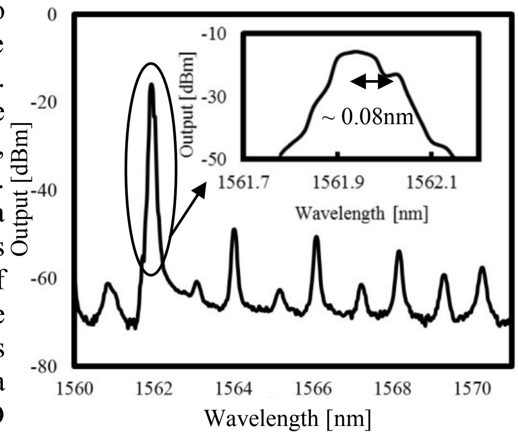

Fig. 2: Optical spectrum

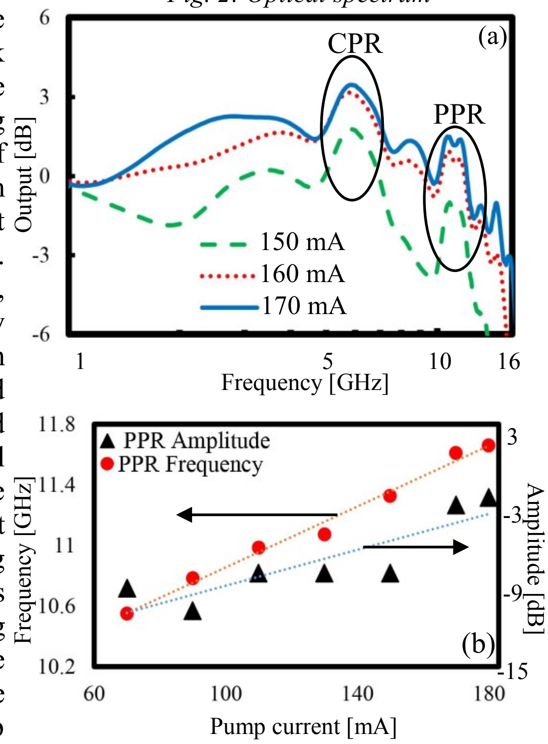

Fig. 3: (a) Small signal frequency response of MMI LD (b) PPR peak amplitude with increasing pumping current and dependency of PPR frequency on pump current

Conclusion: Extended 3dB modulation bandwidth of more than 15.2 GHz has been experimentally verified for the first time in active MMI LD. The Modulation response shows a second resonance peak above the relaxation oscillation frequency with a value that corresponds the lateral mode frequency separation showing an evidence of lateral mode locking.

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