Modulation Depth Dependence of Timing Jitter and Amplitude Modulation in Mode-Locked Semiconductor Lasers

모드잠김 반도체 laser의 타이밍 지터및 크기 변조의 변조 신호 크기 의존성

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In a recent years, a number of approaches have been studied, including passive, active, and hybrid mode-locking of semi-conductor lasers for short pulse generation and research has been devoted to achieve low timing-jitter operation since the timing jitter is unfavorable for system applications. Among the methods of mode locking, passive mode locking does not need external rf drives, and therefore the operation and fabrication procedures are simplified. In spite of these attractive advantages of passive mode-locked laser, it has critical drawbacks such as large timing jitter and the difficulty in synchronization with external circuits. Their inherent large timing jitter value was shown to be suppressed to certain levels by means of hybrid mode-locking technique[1], where the saturable absorber section was modulated by an external signal with the cavity round trip frequency. Furthermore, the subharmonic mode-locking (SHML) technique alleviates the restrictions of high speed driving electronics. It has been demonstrated experimentally[1] that the hybrid subharmonic mode-locking technique has lead to significant reduction of the timing jitter.

The theoretical model is based on the large-signal dynamic model[2] with Langevin noise sources and includes the gain nonlinearities, and self-phase modulation. In passive mode-locking configuration, the saturable absorber remains reverse biased without rf driving signal. On the other hand hybrid mode-locking is achieved by applying a sinusoidal rf modulation to the saturable absorber. The rate equations[2] for this problem take into account the spatial variations of photon and carrier densities by discretizing the laser cavity into small segments along the propagating direction. The reflection boundary conditions are applied to the facets. The rate equations therefore are written in the following traveling wave form.

$$\frac{1}{v_g}\frac{\partial E^{\pm}(z,t)}{\partial t} \pm \frac{\partial E^{\pm}(z,t)}{\partial z} = \left(\frac{\Gamma}{2} g(z,t) - j\delta - \alpha\right)E^{\pm}(z,t) + \sqrt{\beta R_{sp}}\,\xi^{\pm}(z,t) \quad (1)$$

$$\frac{dN(z,t)}{dt} = \frac{J}{ed} - v_g g(z,t) P(z,t) - \frac{N(z,t)}{\tau_{n/sa}}, \quad g(z,t) = \frac{g_N(N(z,t) - N_0)}{1 + \varepsilon_{g/a} P} \quad (2)$$

where $\xi^{\pm}(z,t)$ is complex Langevin noise terms accounting for the stochastic nature of spontaneous emission processes[3], and $\tau_{n/sa}$ is carrier life time in the gain section or absorber section which is given by

$$\tau_n = 1/(An + Bn^2 + Cn^3\ ),\quad \tau_{sa} = \tau_a(1 - a\sin(2\pi ft)) \tag{3}$$

where a is the modulation depth of the external RF driving signal. The rms timing jitter can be determined from [3].

$$\sigma_{rms} = (1/2\pi f_{\text{mod}})\sqrt{\int_{-f_{low}}^{f_{high}} \frac{L(f)}{n^2 - 1^2}\, df + \int_{f_{high}}^{f_{low}} \frac{L(f)}{n^2 - 1^2}\, df} \tag{4}$$

where f_{low} , f_{high} are limits to the integration with respect to the offset frequency. The calculated timing jitter is 3.1ps in the case of passive mode-locking which is reduced down to 0.54 ps for fundamental hybrid mode locking(FHML, n=1) case at the modulation depth a = 0.3. But there is a trade-off relationship between the timing jitter and the AM under subharmonic modulation. The modulation depth should be increased to reduce the timing jitter, whereas it worsens the amplitude modulation. To reduce the amplitude modulation under subharmonic mode locking, we changed the sinusoidal modulation signal to half-wave rectified sinusoidal function. Fig. 1 shows timing jitter under FHML and 2nd order SHML condition for the above two cases. The amplitude modulation as a function of modulation depth is shown in Fig. 2.

In this paper it is shown theoretically that the timing jitter is reduced by changing general sinusoidal modulation signal into half rectified signal. Also amplitude modulation is reduced by half rectified signal.

*References

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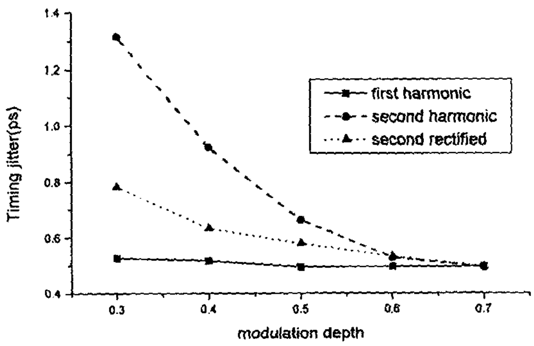

Fig1.Timing jitter of the pulse trains as a function of modulation depth

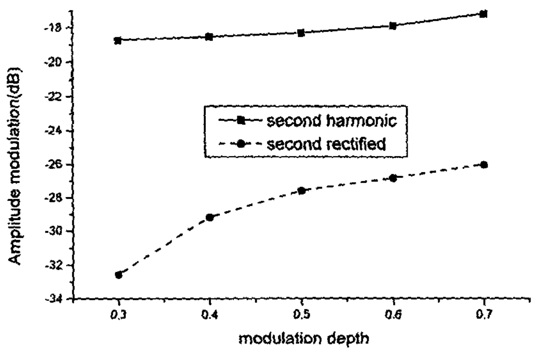

Fig 2. Amplitude modulation as a function of modulation depth