2:30pm - 2:45pm
MSFL3.3

Room C2

Explanation of Timing Jitter Mechanisms in Multisegment Mode-Locked Semiconductor Lasers

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Multisegment mode-locked semiconductor lasers offer a simple, high performance solution for short pulse generation [1]. Figure 1 shows six mode-locking techniques used in multisegment mode-locked semiconductor lasers. This paper concentrates on a theoretical explanation of the timing jitter mechanisms in these lasers with supporting experimental measurements. The analysis covers passive, hybrid, and active mode-locking techniques for both monolithic and external cavity devices. Timing jitter is a very important system consideration for most applications of mode-locked lasers.

1. The origins of timing jitter. If there were no spontaneous emission noise in a mode-locked semiconductor laser, the time delay of an optical pulse through the laser sections would be fixed. Figure 2 illustrates three paths that link spontaneous emission noise to timing jitter. Spontaneous emission noise leads to photon density fluctuations, carrier density fluctuations, and index of refraction fluctuations through the linewidth enhancement factor. Index of refraction fluctuations directly cause the time delay through the laser to be a random variable. The carrier density and photon density fluctuations also lead to timing jitter through a conversion process which is illustrated in Figure 3. The pulse shapes at the input and output of an optical amplifier are illustrated for several values of the input pulse energy. As the input pulse energy changes, the "center of gravity" of the optical pulse changes. Therefore if the gain of the laser is randomly changing, or if the input pulse energy of the laser is randomly changing, timing jitter will result. The saturable absorber also has an analogous timing jitter conversion process. Theoretical analysis of these paths show that the conversion processes dominate the timing jitter in multisegment mode-locked semiconductor lasers.

2. Theoretical analysis method. To analyze the jitter process, the rate equations for carrier density and photon density are linearized and expressions for the spectral density of the carrier density fluctuations, index of refraction fluctuations, and photon density fluctuations are obtained under the approximation of steady state conditions. Figure 4 gives an example of a result of these calculations for the spectral density of the carrier density fluctuations in a passively mode-locked monolithic cavity device used for modeling path B of Figure 2. The gain to phase modulation and pulse energy to phase modulation conversion constants were calculated numerically using large signal rate equations. The spectral density plots such as those shown in Figure 4 together with the conversion constants are used to calculate the single sideband phase noise, L(f). The L(f) information can be converted to timing jitter by integration [1].

3. Example results. The theoretical and experimental L(f) for external cavity passive and hybrid mode-locked lasers at the same repetition rate is given in Figure 5. The theory for passive mode locking matches the 20dB per decade slope found in experimental measurements. The low frequency fluctuations have a longer time to build up pulse position errors in passive mode-locking. The theory also predicts the increase in timing jitter with repetition frequency found in experimental results [1,2,3]. Figure 5 shows the suppression of phase noise produced when active gain modulation is added to passive mode-locking to obtain hybrid mode-locking. The active gain modulation pulses confine the location of the optical pulse if the electrical drive period is chosen to be slightly longer than the effective cavity round trip time .

4. Conclusion. Theoretical and experimental comparisons will be presented for all of the mode-locking configurations of Figure 1. Device characteristics such as active region composition, segment length, and segment bias will be discussed for making mode-locked lasers with minimum timing jitter.

[1] D. J. Derickson et al., IEEE Journal of Quantum Electronics, **QE-28**, 2186-2202, (1992)
[2] S. Sanders et al., Applied Physics Letters, **59**, 1275-1277 (1991)
[3] K. Y. Lau et al., Applied Physics Letters, **61**, 133-135 (1993)

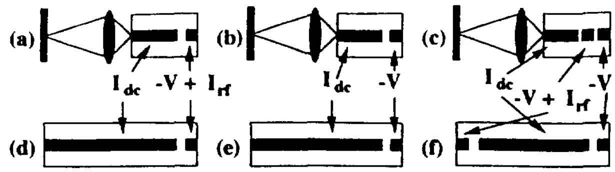

Figure 1. Multisegment mode-locked lasers used in this analysis. (a) two-segment active external cavity (b) two-section passive external (c) three-segment hybrid external cavity (d) two-segment active monolithic (e) two-segment passive monolithic (f) three-segment hybrid monolithic.

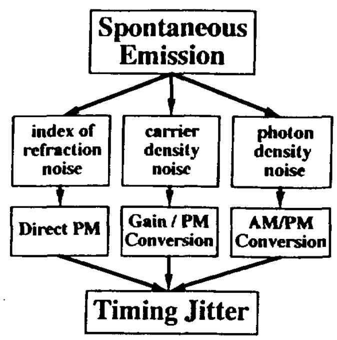

Figure 2. Spontaneous emission can take several paths to cause timing jitter.

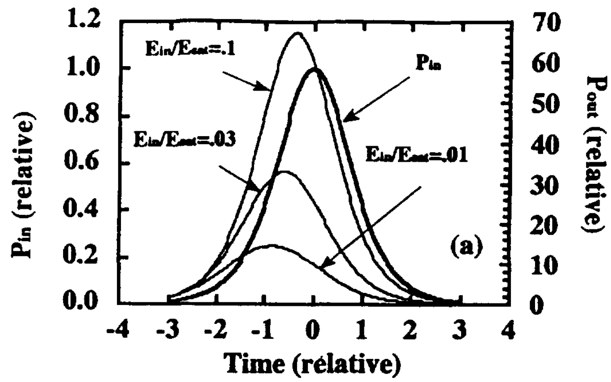

Figure 3. Input and output pulse shapes in an optical amplifier as a function of the input energy, E_{in}. E_{sat} is a measure of the amplifier saturation energy.

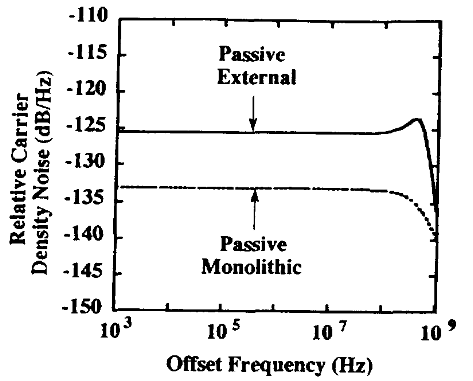

Figure 4. The spectral density of carrier density fluctuations in a 1 Hz bandwidth normalized to the carrier density and plotted against frequency of the noise.

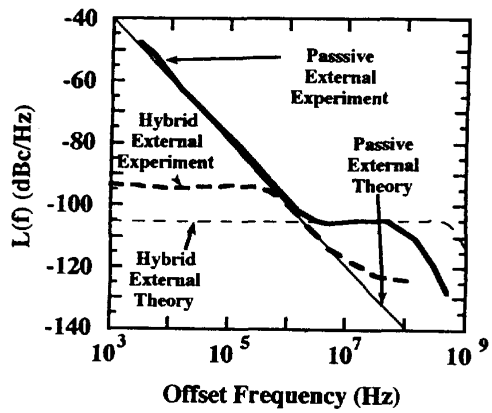

Figure 5. Experimental and theoretical data for an external cavity mode-locked laser with a 5 GHz repetition rate. Results for passive and hybrid mode-locking are shown.