Phase correlation in self-pulsating distributed Bragg reflector semiconductor lasers for all-optical clock recovery

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Abstract: Self-pulsation around 40 GHz with narrow spectral linewidth is obtained in distributed Bragg reflector semiconductor lasers. A theoretical model demonstrates that four-wave mixing is responsible for linewidth narrowing, an experimental signature of phase correlation.

All-optical clock recovery, a crucial element for all-optical regeneration, attracts much attention as it would supercede hybrid optoelectronic schemes [1]. Among the different approaches investigated so far, a scheme based on a single self-pulsating (SP) distributed Bragg reflector (DBR) laser is of particular interest. The phase noise of the self-pulsating signal, the key parameter determining the quality of the recovered clock, needs to be addressed. In this paper, we report experimental results of phase noise measurement, and demonstrate theoretically that the measured low phase noise is due to the phase correlation of adjacent modes in DBR lasers induced by Four-Wave Mixing (FWM).

The studied DBR laser has 3 sections: active, phase and Bragg, as shown in Fig. 1 [2]. The total length of this laser is about 1 mm in order to obtain SP at 40 GHz. The measured electrical spectra after photo-detection of such a component provides a clear self-pulsation signature for a large range of injected currents in the active and Bragg sections. Fig. 2 shows a typical example of optical spectrum exhibiting a 3 mode operation. Figure 3 shows the measured electrical spectra after photo-detection around the SP frequency with a fixed injected current in the active section (200 mA), while increasing current I_B in the Bragg section between two mode jumps. The insert of Fig. 3 shows that the measured spectral linewidth of the photocurrent is about 500 kHz, much smaller than the sum (~20 MHz) of those of individual modes measured by using a self-homodyne technique. This result demonstrates that the different modes involved in the SP signal are partly correlated in phase, which results in passive mode locking or self-pulsation. Another interesting feature shown in Fig. 3 is that the spectral linewidth of the SP signal becomes narrower with increasing I_B between two mode jumps.

In order to provide more insight into the locking mechanism between modes, a theoretical model, treating DBR lasers with three-modes such as shown in Fig. 2, has been developed. The model involves coupled rate equations and takes into account non linear phase effects, including FWM [4,5]. Frequency modulation (FM) noise spectra S_a(ω) have been calculated for each mode phase ϕ_i (i =1,2 and 3) and for each phase difference ϕ_i - ϕ_j by Fourier transformation of the linearized rate equations. Fig. 4 gives an example of the simulation results for a 200 mA injected current to the active section, showing clearly larger than 15 dB reduction of the FM noise spectrum of ϕ_2 compared to the uncorrelated case. Since the spectral linewidth is directly related to this FM noise spectrum at zero frequency for a lorentzian lineshape, such a result indicates that the narrow SP signal linewidth observed experimentally is the signature of phase correlation induced by FWM. Furthermore, it has been demonstrated theoretically that the dominant mode has a larger contribution to the phase noise of the SP signal, as it transfers its phase noise to other modes. The decreasing SP linewidth with increasing I_B shown in figure 3 can then be attributed to the decrease of the linewidth of the dominant optical mode with increasing I_B [3].

In conclusion, self-pulsation around 40 GHz has been characterized experimentally using a 1.5-µm DBR semiconductor lasers operating with three longitudinal modes. The narrow spectral linewidth (~500 kHz) measured from photocurrent spectra demonstrates passive mode-locking. The theoretical model developed to study mode-locking shows that FWM is responsible for phase correlation between adjacent modes, leading to self-pulsation with...
highly reduced spectral linewidth. This result is of importance to design future DBR lasers with higher performance for the all-optical clock recovery application.

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References