Tailoring the dynamics of multisection lasers for 40 Gb/s direct modulation

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Outline

- Main goals;
- Basic methods to increase the speed potential;
- Finding the Photon-Photon resonance;
- Small and large signal analysis;
- Conclusions.
Main goals
Our aims

Conventional high-speed lasers are mainly limited by:
- interaction speed of carriers & photons (CP resonance frequency)
- and/or by insufficient damping of relaxation oscillations

We seek to have a required laser performance at a current modulation with 40 Gb/s PRBS.
Main requirements for open eye:

- Opening height: \( h > \bar{h}/2 \);
- Width of digital “1” and “0” layers: \( |P_j^\pm - P_j^-| < \bar{h}/4 \);
- Opening duration: \( \tau > T/5 \);
- Extinction: \( 10 \log \left( \frac{P_1}{P_0} \right) \geq 3(dB) \).
Basic methods to increase the speed potential
Fast transition between “0” and “1” states

To increase a bit transmission rate one needs to make transitions between \( P_0 \) and \( P_1 \) layers faster.

Say, \( P(t) - \bar{P}_1 \sim \Re(e^{(i\omega - \gamma)t}) \).

To achieve fast transitions between states one needs:

- large damping \( \gamma \)
- or/and high relaxation frequency \( \omega \).

However, if \( \omega/\gamma \) is too big, overshootings are expected!
Improving extinction $10 \log(\bar{P}_1/\bar{P}_0)$ of the eye diagram

Mean $\bar{P}_0$ and $\bar{P}_1$ states correspond to the constant current injection at “0” and “1” levels and are given by PI-characteristic.

To achieve 3dB extinction one needs to have

- low mean injection
- or/and large enough modulation amplitude

But, CP resonance frequency at low injections is not very high!
Concept: to enhance resonance frequency

- Increase \( f_{CP} \sim \sqrt{g'(I - I_{thr})} \) (up to 30 GHz) by increase of \( g' \) when optimizing transversal design (M.N. Akram ..., Semicond. Sci. Technol., 19, 2004)

but: to get a required high \( f_{CP} \) one still needs to apply large enough injection where extinction can be low!

- Increase of 3 dB bandwidth of modulation response function by, e.g.,
  - optical injection locking (L. Chrostowski ..., Proc. OFCC, OThM2, 2005)

but: is damping of low frequency components (CP resonance) high enough for good performance of the laser at current modulation with large amplitude signal?
Concept: to improve damping

- Increase of damping of cw state by, e.g.,
  - injected beam at transparency wavelength of gain media
    (G. Morthier ..., IEEE PTL, 16, 2004)
  - optical feedback from resonator
    (V. Tronciu ..., submitted to Phys. Rev. A)

but: resonance frequency remains the same (dominated by CP resonance). Is improvement of damping alone high enough for system applications at 40 Gb/s modulation rate?

We shall show, that multisection laser concept allows both: enhancement of PP resonance and improvement of damping rate!
Finding the Photon-Photon resonance
The simplest of possible *multisection* lasers admitting dominance of the PP resonance with $f_{PP} \sim 40$ GHz is the single-mode laser with a short external cavity. (A. Tager ..., IEEE JQE, 30, 1994)

To simulate and to analyze the performance of this device we use the Traveling Wave model and its mode approximation system (Tutorial MB1)

(LDSL-tool, http://www.wias-berlin.de/software/ldsl)
Photon-Photon resonance

Suitably selecting optical field feedback strength and phase one can achieve dominance of the PP resonance.

This resonance is induced by frequency separation of longitudinal modes

Finding intervals with dominant PP resonance on parameter axis

(a) Hopf bif. mode-beating pulsations tori & irregular continuous wave state

(b) PP resonance pulsations CP resonance

(c) CP damping of solitary DFB CP damping PP damping

Phase tuning parameter $\varphi/2\pi$

Frequency, GHz

Damping, 1/ns

Output, mW

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Finding regions with dominant PP resonance in parameter space

- PP resonance at ~45-30 GHz
- PP ~75 GHz

Feedback phase, rad./2π

Feedback strength

Dominant RO resonance

Mode-beating pulsations

Q-switching pulsations

TB transition frequencies

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Small and large signal analysis
Current modulation with periodic signal

Small signal analysis

Large amplitude modulation

-8
-6
-4
-2
0
2
4

modulation frequency, GHz

-8
-6
-4
-2
0
2
4

modulation response, dB

0
10
20
30
40

amplitude power, mW

IM = 40 mA
IM = 20 mA
IM = 10 mA

φ = A
φ = B

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Current modulation with 40 Gb/s $2^7 - 1$ PRBS
Above: unmodulated laser. PP resonance frequency and relative suppression of CP.

Below: directly modulated laser with 40 Gb/s PRBS. Open eye extinction and amplitude.
Conclusions
The PP resonance can dominate over the CP resonance in multisection lasers;
For dominance of the PP resonance we need large enough feedback and a possibility to tune the feedback phase;
Need to select the conditions where PP resonance dominates and the damping is improved;
Opened eyes at 40 Gb/s current modulation with PRBS;
Best extinction of eye diagrams at lower currents;
Better performance of lasers with higher differential gain.
Other multisection laser configurations are also possible!