Laser gain compact model for photonic integrated circuit simulation

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About Lumerical

Lumerical empowers R&D professionals with industry leading design software and support service to develop next generation photonic technologies
Motivation

Si photonics for photonic integrated circuits (PICs)

- Leverages mature, scalable, low-cost, high yield processes
- Lasers are required for most applications
  - External laser sources driving PICS
  - Hybrid tunable/switchable lasers sources
- No optical isolation $\rightarrow$ Distant reflections/resonances
  - Unintentional
  - Intentional: Passive (tunable) external resonant mirrors for single-wavelength lasers
- Distant/long resonators $\rightarrow$ 3D models inefficient
- 1D Compact Model for Gain
Motivation - Examples

CEA-LETI

Skorpios

Kotura

UCSB Intel Aurriom
Motivation - Examples cont’d

Time-Domain 1D Traveling Wave Model

Overview

- Time samples of slowly-varying envelope of optical mode amplitudes and time-samples of carrier densities
  - Complex baseband sampling according to bandwidth (not absolute frequency) of laser
- 1D spatial elements that can scatter light forward ↔ backward
- Frequency dependencies implemented as IIR TD digital filters
e.g., Fabry-Perot Laser

![Diagram of a Fabry-Perot Laser](image)

- **Optical Element**
- **Carrier Element**

- **Facets** $R_L$ and $R_R$
- **Gain** $L$
- **Gain** $\Delta L$

- **Carriers**
- **Photon Density**
- **Phots (Mode Amplitude)**
- **Carrier Density**
e.g., Fabry-Perot Laser
Results: Fabry-Perot Laser

FP cavity modes (Gain off) and Gain Curve

FP Laser Spectrum modes
Results: Fabry-Perot Laser Turn-On

Simple DBR Laser

Gain medium

Gain Section

Phase tuning section

DBR section (freq selective mirror)

Grating

I_G

I_P

R_1
DBR Laser Spectrum
Hybrid Laser Integration into PIC

Conclusions

- Developed 1D TD Traveling Wave Gain Model
- Used to Model Fabry-Perot Laser
  - Results compare favorably with previously published results
- Combined with a waveguide Bragg grating to model external cavity laser
  - Design, single mode spectrum
- Can be used to model effects of other external reflections both for hybrid laser design and integration into complex photonic circuits
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Schematic of 1D Element

Optical Element
- $G(n_c)$, TD Filter
- $\mathcal{N}(n_c)$ TD filtered noise source

Photon (Mode Ampl)
Carriers
Optical Power
Carrier Density

Carrier Element

$n_c(t_i) = n_c(t_{i+1}) + \Delta t \{ J(t_i) - \Delta P/(\hbar \nu d \Delta L) - n_c(t_{i+1})R_{in}[n_c(t_{i+1})] - n_c(t_{i+1})R_{rad}[n_c(t_{i+1})] + D_g(t_i) \}$

$I_f(t_i) = e.g., I(t_i)/(\# \text{ of elements}) w d \Delta L$
e.g, Fabry-Perot Laser-2Modes/Polarizations

![Diagram](image-url)
Phase Section – Tune FP Mode Frequencies