Accuracy of 1D Compact Laser Model

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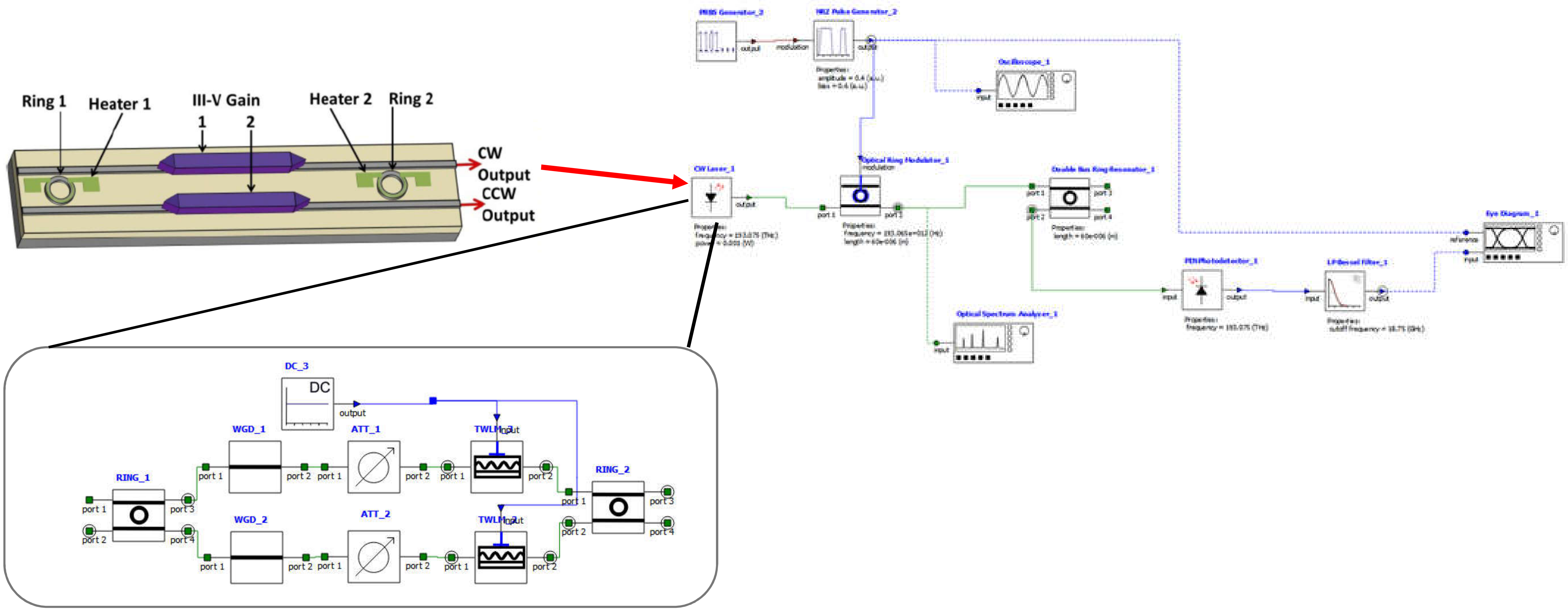
Motivation

Si Photonics

- Leveraging of mature, scalable, low-cost high yield processes for photonic integrated circuits (PICs) incorporating laser sources/optical gain media
  - Laser sources driving PICS
  - Hybrid tunable/switchable lasers sources
- No optical isolation →Distant reflections/resonances
  - Unintentional
  - Intentional : Passive (tunable) external resonances for single-wavelength lasers
- Distant/long resonators → 2D/3D models inefficient/intractable
- 1D Compact Model for Gain

Hybrid Laser Integration into PIC

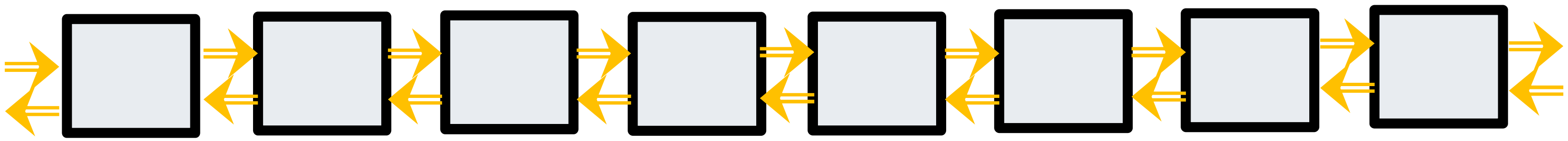
INTERCONNECT Laser Compact Model



Lumerical 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 (currently Lorentzian)



lumerical
illuminating the way

Input Parameters to Lumerical 1D Compact Gain Model

1. w_{act} – width of gain medium
2. l_{act} – length of gain medium
3. d_{act} – depth of gain medium
4. $R_L((f,N)$ – reflectivity of left facet for transverse mode
5. $R_R(f,N)$ – reflectivity of right facet transverse mode
6. α_c^i – cavity losses for transverse mode exclusive of absorption

(1–6: inputs)

7. $n_{grp}(f,N)$ – group index
8. $\Gamma_{act}(f,N)$ – confinement of transverse mode to gain transverse mode

(7–8: EM Calculation)

(a bit harder) EM Calculation:

9. $\beta_c^i\,(f,N)$ – spontaneous emission coupling transverse mode

Requires electrodynamic calculation (electron-photon):

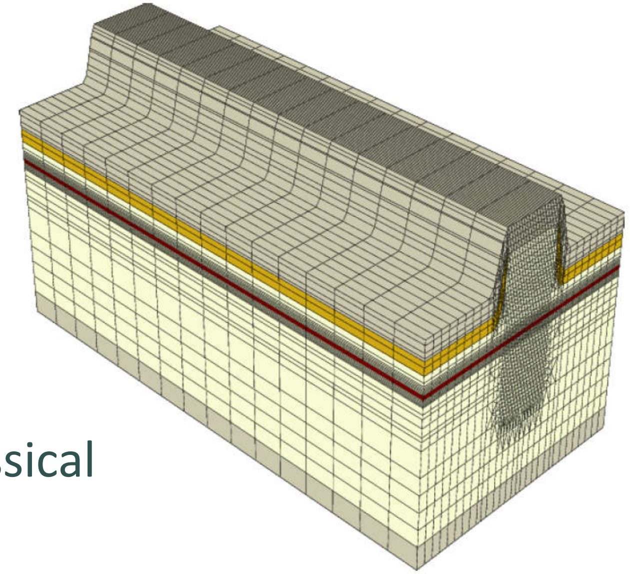
10. $R_r(N)$ – radiative recombination rate
11. $R_{nr}(N)$ – non-radiative recombination rate
12. $g(f,N)$ – gain curves for gain medium
13. $E(f,N)$ – spontaneous emission curves for gain medium
14. ϵ – non-linear gain factor for gain medium

Crosslight 2D & 3D Models

LASTIP 2D is a 2D Simulator for Fabry-Perot Lasers

It solves the semiconductor drift-diffusion equations coupled with the photon rate equation using the finite-element method

The optical gain/absorption of quantum wells and quantum dots is obtained by solving the Schrödinger and Poisson equations.



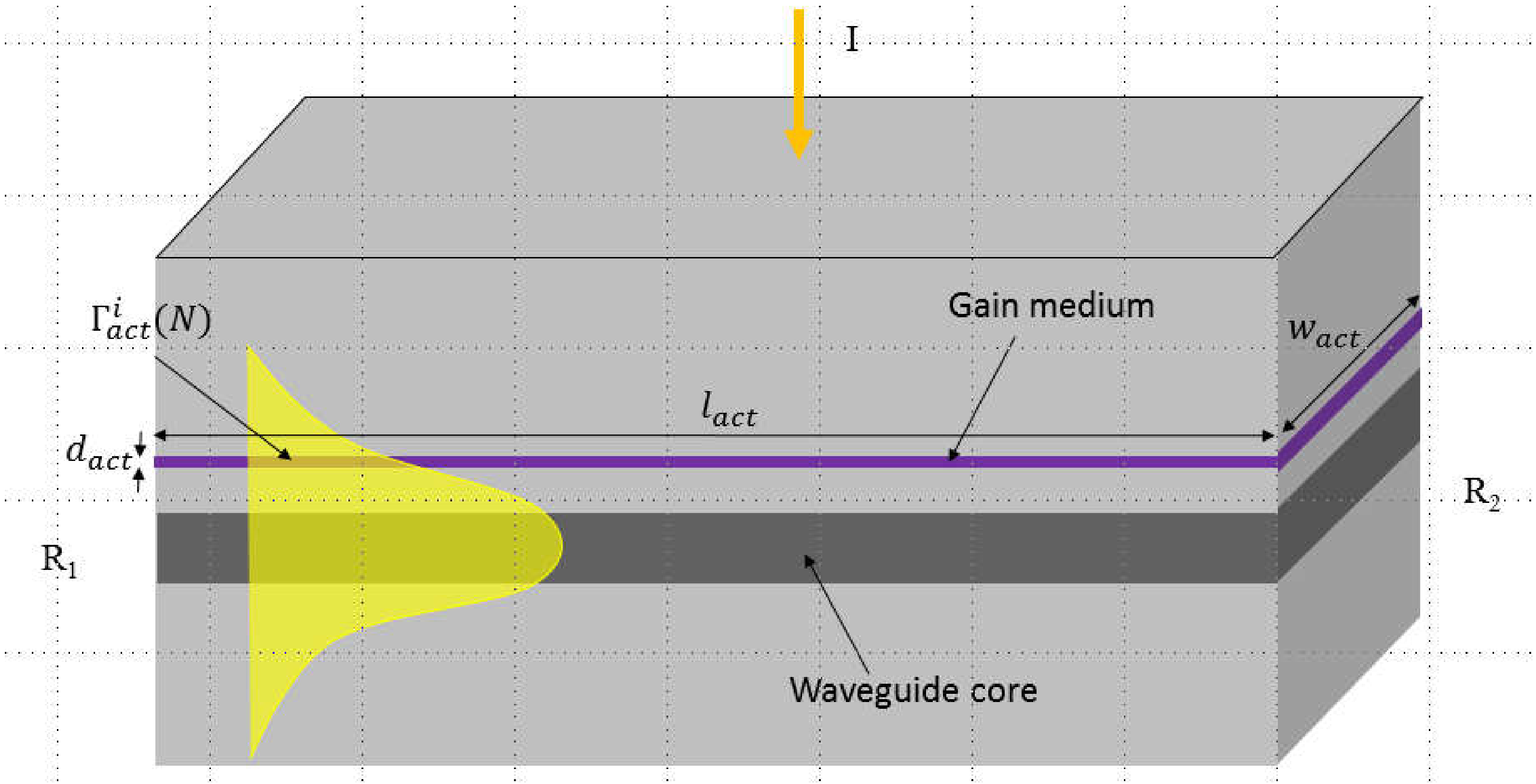
SEMI-CLASSICAL APPROACH

Quasi-equilibrium approximation: electron and hole treated using classical drift-diffusion model with some quantum-mechanical corrections.

Optical wave described by classical Maxwell's equations.

Interaction of light and electron-hole is treated quantum-mechanically.

Preliminary Test: Model Fabry-Perot Laser



$R_1 = R_2 = 0.32$

$l = 400\mu m$

$w = 1\mu m$

$d = 7.6\ nm$

Expected lasing wavelength of approximately $\lambda_0 = 850$ nm

Methodology

1) Crosslight modeled the laser at various drive currents

2) Crosslight exported their calculated values:

As a function of carrier density and frequency (as a family of curves vs frequency):

a) Gain curves

b) Spontaneous emission curves

As a function of carrier density:

c) Radiative recombination rates

d) Non-radiative recombination rates

e) Confinement factor

SINGLE-VALUED PARAMETERS

Parameter	Value
length of cavity and active region	400 µm
width of active region	1 µm
depth of active region	7.6 nm
non-linear gain factor	0.0 m^3
spontaneous emission factor	1×10^{-3}
cavity losses	500 /m
reflectivities of the facets	0.32
the group index of the optical mode	3.56

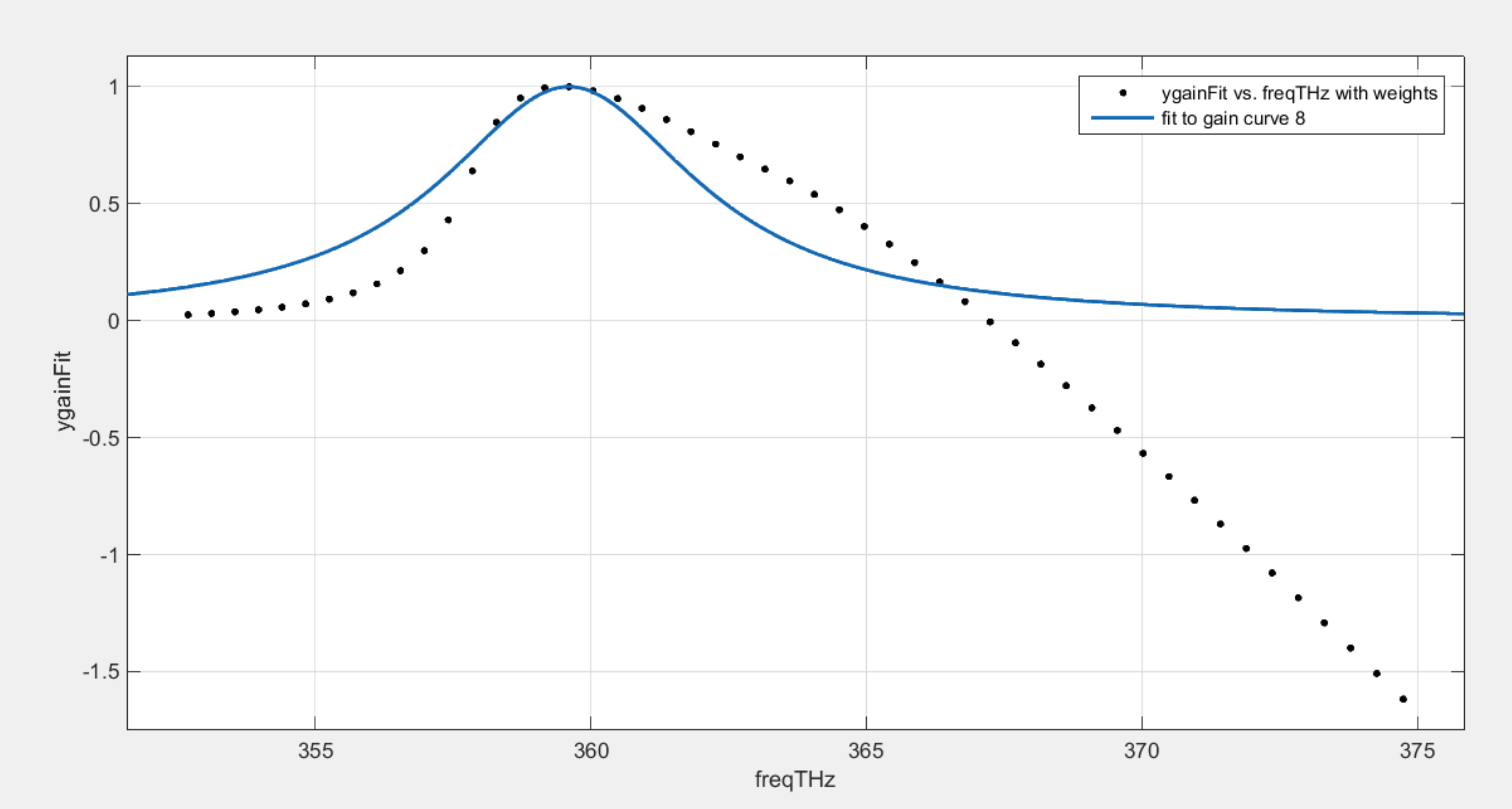
Methodology

3) Lorentzian fit as a function of frequency was performed on each gain curve and spontaneous emission spectral shape curve to obtain:
   - Peak values (for gain curve only)
   - Centre frequencies
   - Widths (quality factors)

4) A linear fit was performed to the peak values of gain as function of carrier density to obtain the gain coeffcient, a_g, and transparency carrier density N_{tr} such that:

$$g_{peak} = a_g(N \quad N_{tr})$$

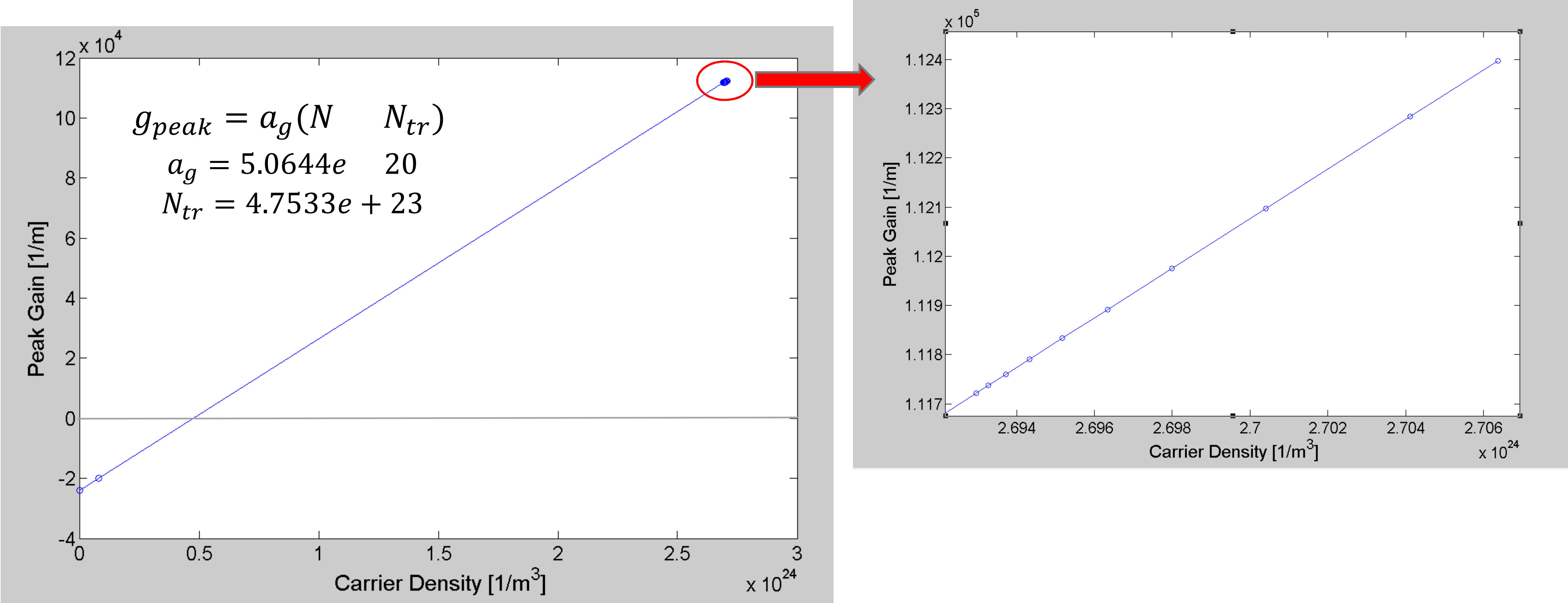
Fit Results: Typical Gain Curve Fit



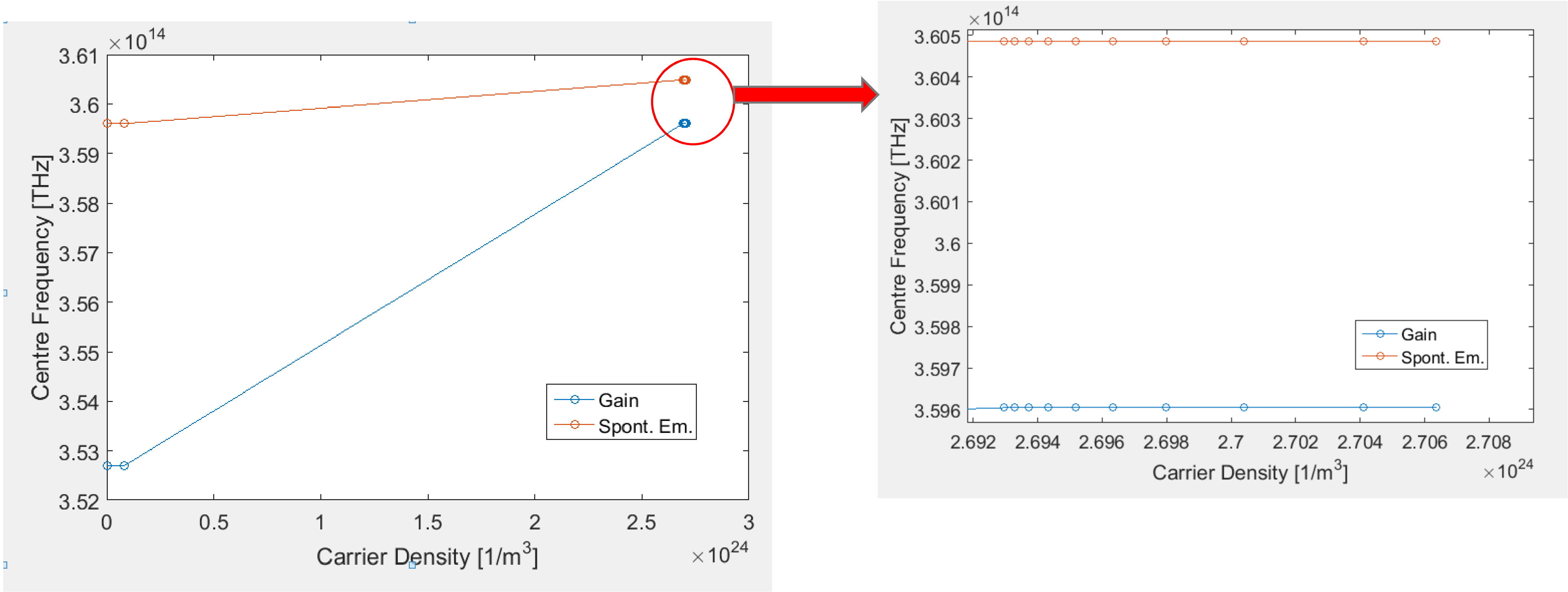
Weighted fit ignoring the negative gain regions

(this weighting makes virtually no difference)

Results: Peak Gain vs Carrier Density

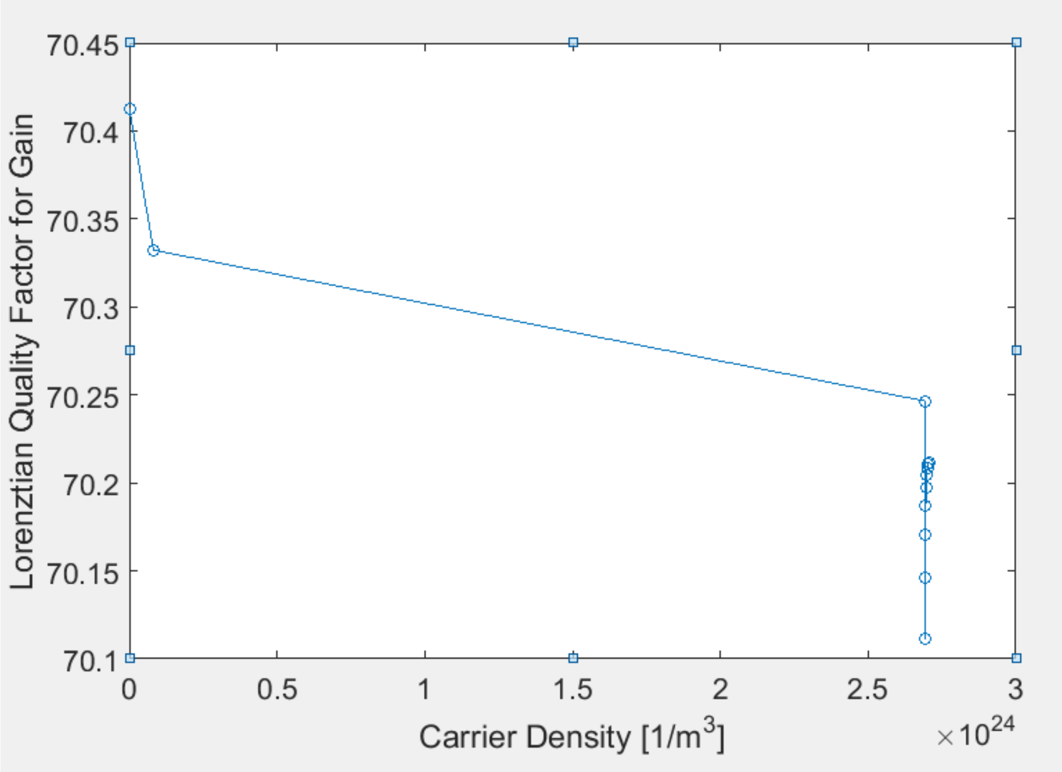


Fit Results: Lorentzian Centre Frequency

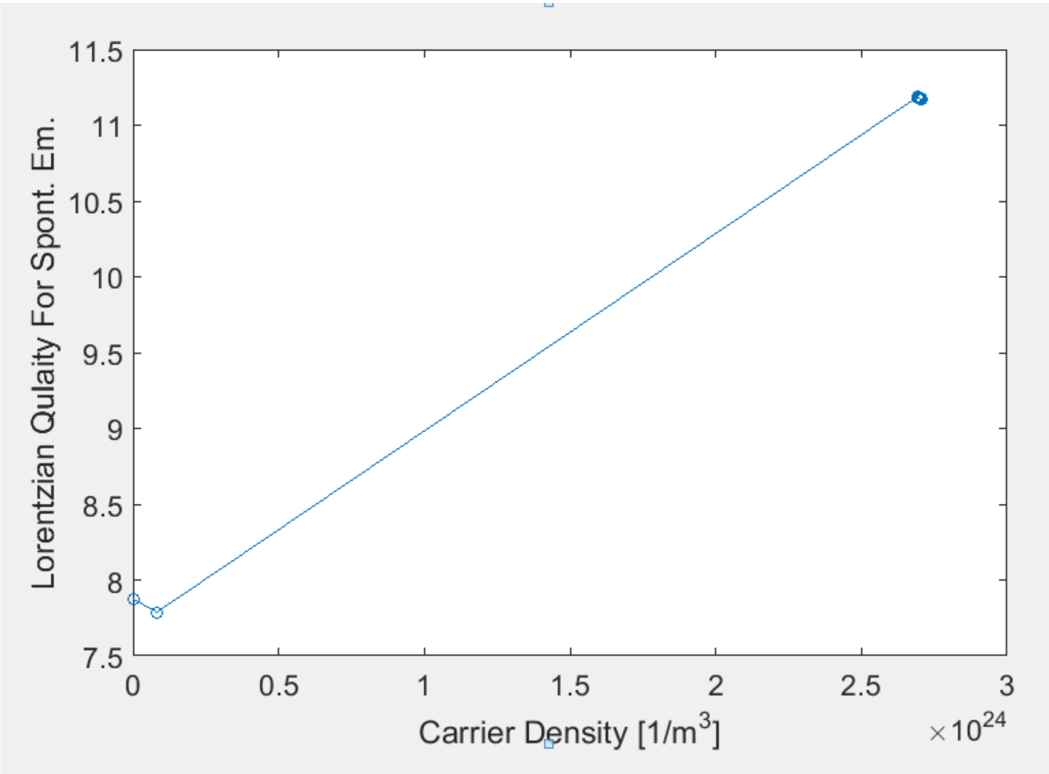


Results: Lorentzian Quality Factor

Gain



Spontaneous Emission



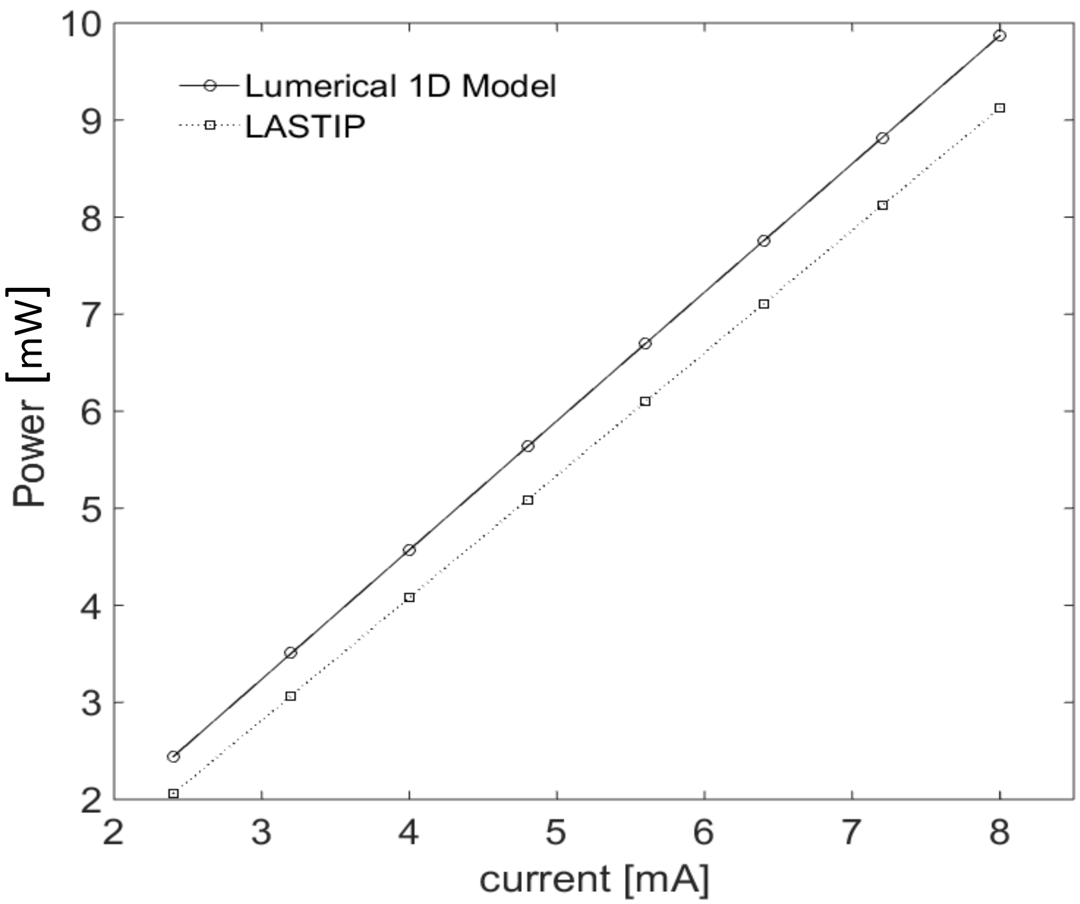
Methodology

There we also fit the radiative and non-radiative lifetimes but they did not fit well to the cubic model $\mathrm{R} = AN + BN^2 + CN^3$ so we just entered LASTIP's exported calculated values at each drive current.

We did the same thing for all the gain shape parameters.

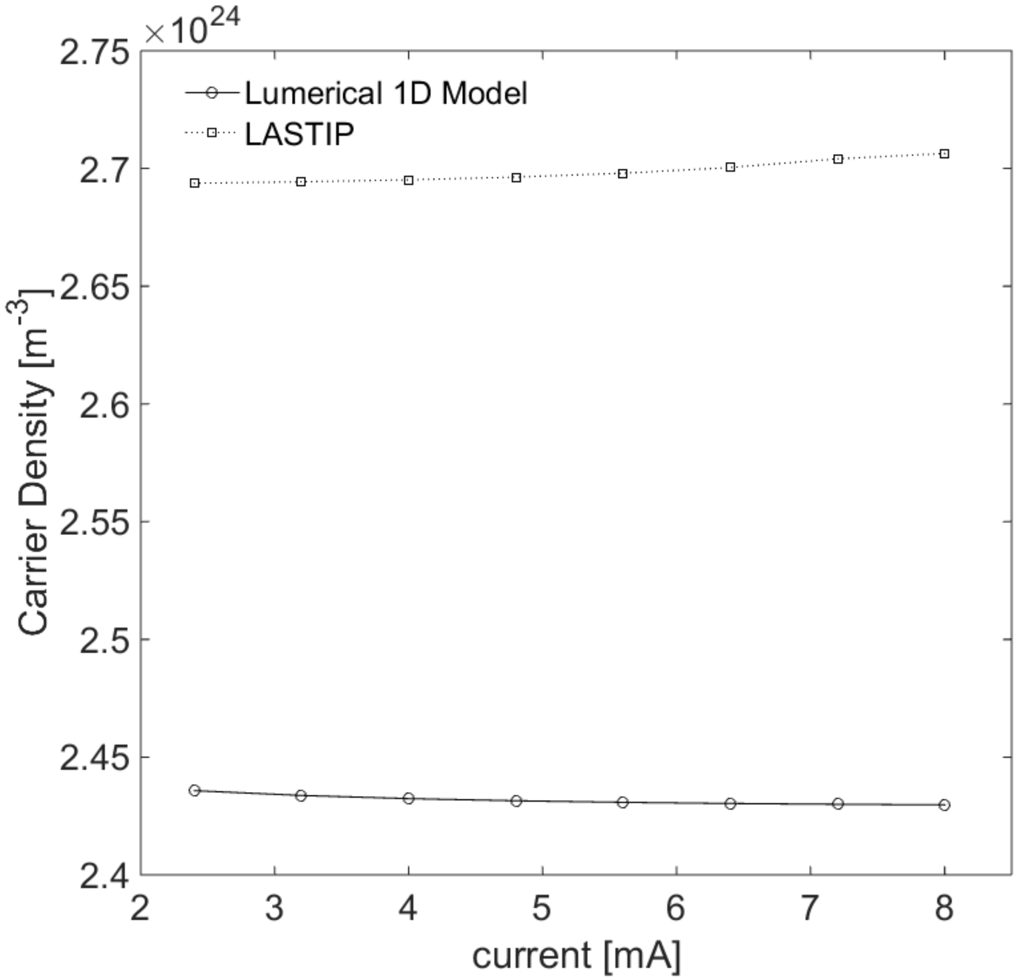
The fit values of gain coefficient, and transparency value were entered such that the gain could vary dynamically.

Results: LI Curve



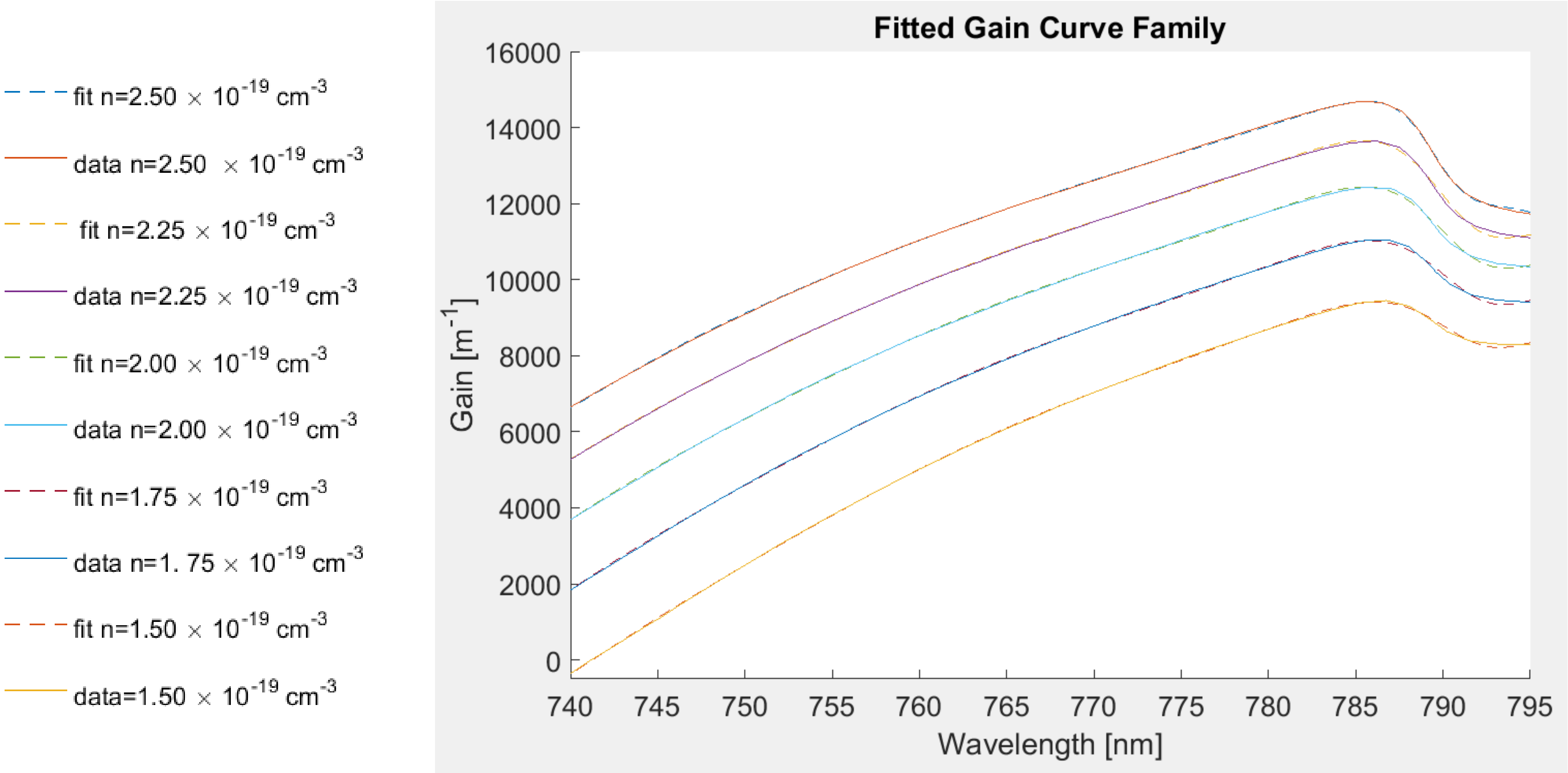
Maximum discrepancy of approximately 12%

Results: Threshold Carrier Density



Maximum discrepancy of approximately 11%

Future Work: MCM Gain Curve Fitting



Ref: M-L *Ma et al.,* Optics Express, Vol. 21, No. 8 , p.10335, OSA 2013

Summary & Conclusions

Compared *steady state results* for a Fabry-Perot Laser from a semi-classical 2D fully coupled model to 1D traveling model running with data extracted from 2D model

Obtained agreement to within 12%

Discrepancy likely due to oversimplified functional forms of gain and spontaneous emission spectral shapes and carrier density dependancies

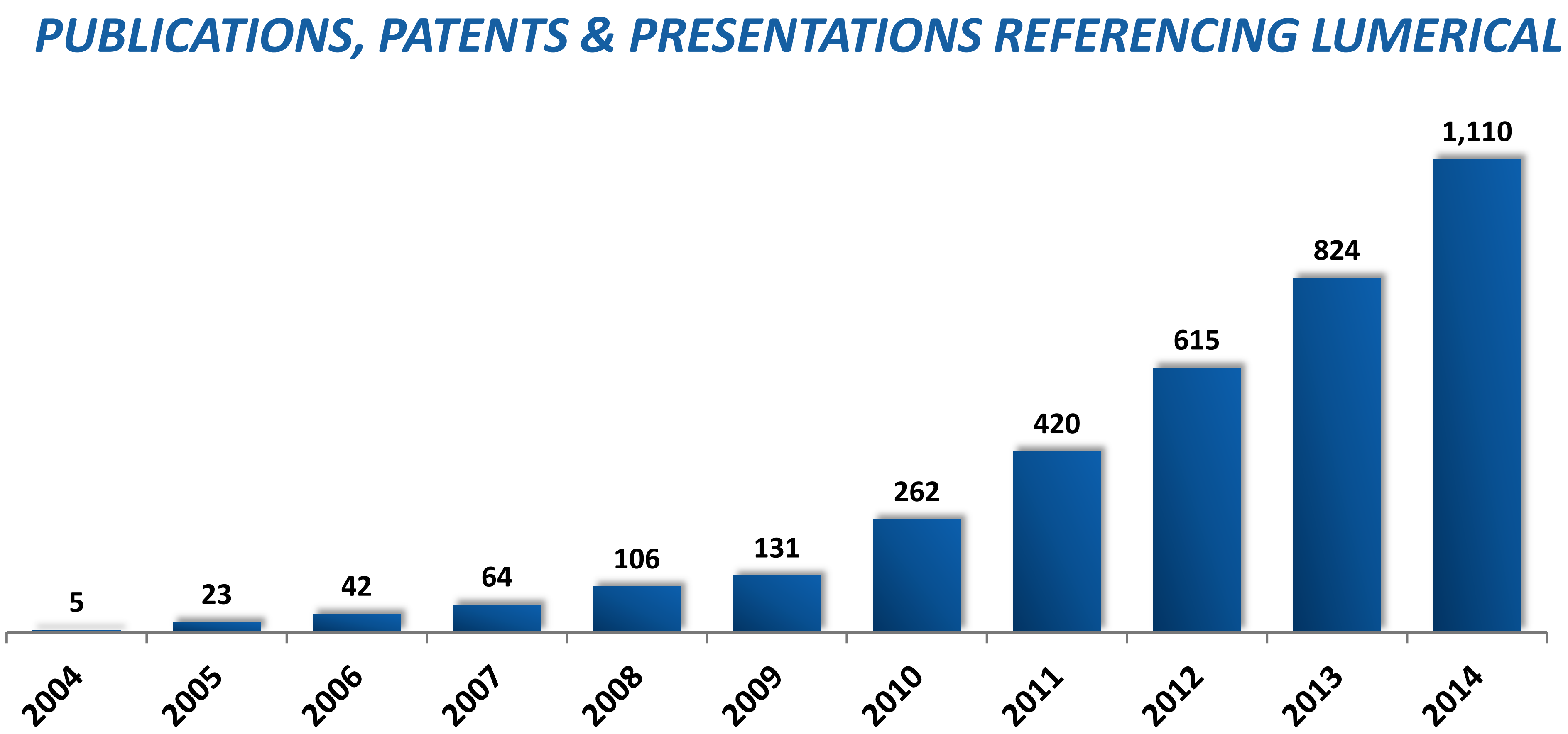
Improvements feasible and impending

Considering interoperability

About Lumerical

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

Mindshare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