

Mode-Locked Multi-Quantum-Well Lasers: Comparison between Different FD-TM Models

A. Barletta
P. Bardella
I. Montrosset

Dip. Elettronica and PhotonLab,
Politecnico di Torino, Italy
Paolo.bardella@polito.it



Introduction

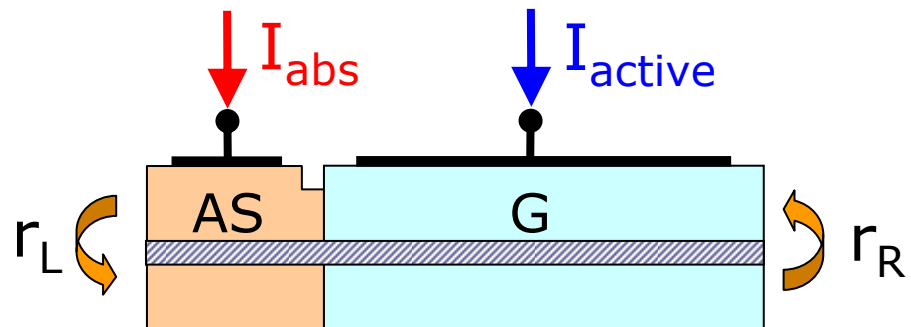
□ Our goals:

- Review the models for MQW active sections reported in the literature and usually applied in combination with a mean field rate equation
 - Improve our Traveling Wave simulator to describe in a more realistic way the carrier densities in MQW sections
 - Use the newly implemented models to simulate Mode-Locking MQW lasers
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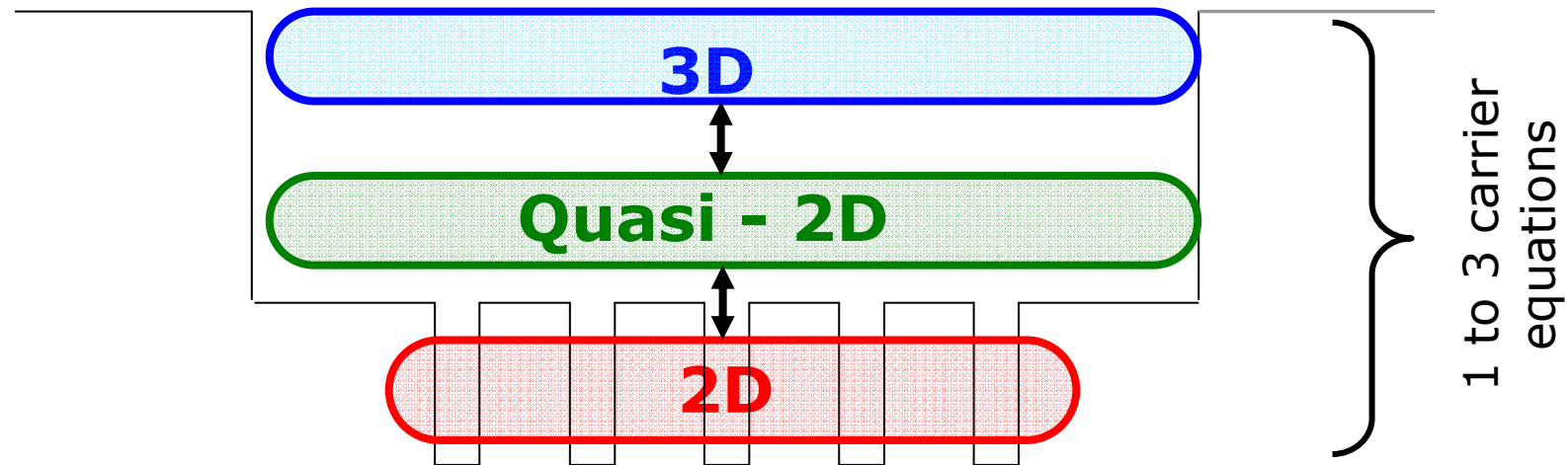
Examples of simulations

- We studied a Mode Locking laser constituted by
 - An active MQW region (G)
 - A Saturable Absorber (AS)

- $L_{\text{ass}} = 50\mu\text{m}$
- $L_{\text{gain}} = 1020\mu\text{m}$
- $L_{\text{barrier}} = 8\text{nm}$
- $L_{\text{well}} = 7.5\text{nm}$
- $L_{\text{SCH}} = 32.5\text{nm}$
- Diffusivity $= 1\text{cm}^2\text{s}^{-1}$
- Inter-well capture time $\tau_c = 10\text{ps}$

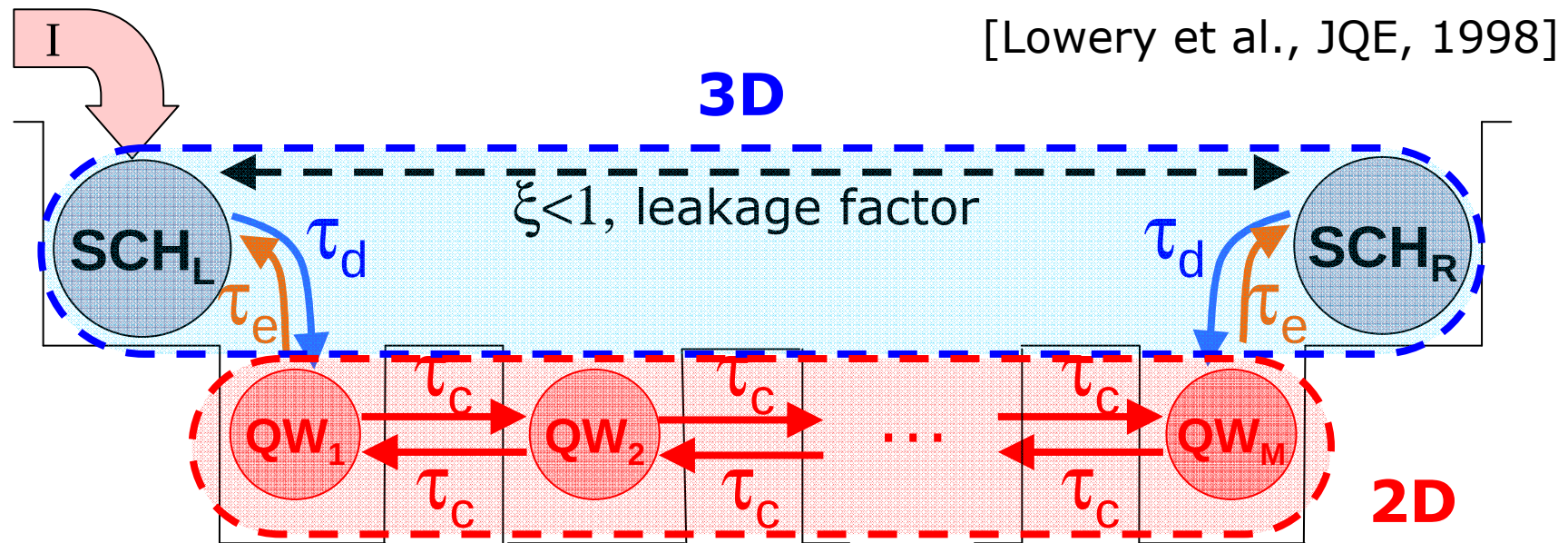


The MQW models with 1 to 3 populations



- ❑ The model considering 2D and 3D carriers (transport effect in the SCH) is the most popular [Nagaragan et al., JQE, 1992]
 - ❑ The model considering also the quasi 2D states ("gateway") is not very popular [McDonald and O'Dowd, JQE, 1995]
 - ❑ These models in their original formulation all assume **uniform filling of the wells**
 - ❑ In currently used FDTW models only the 2D carrier density is considered
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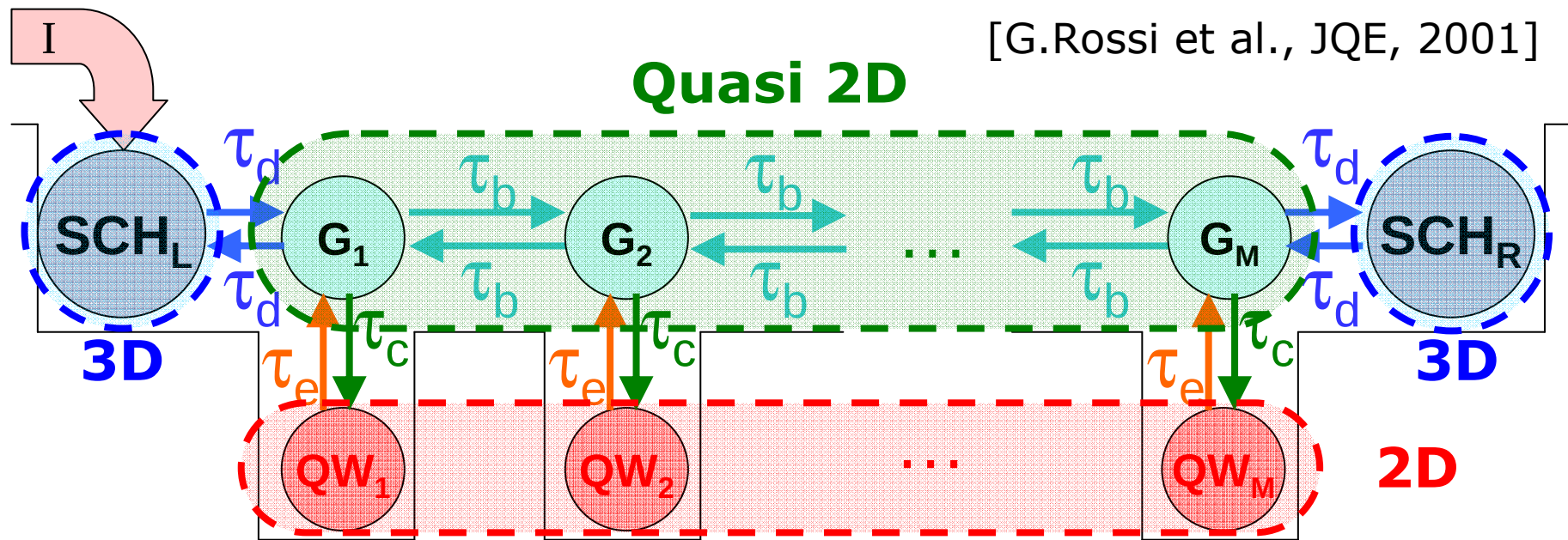
The MQW model with $M+2$ carriers populations



$$\begin{cases} \tau_d \rightarrow \text{diffusion from SCH to the first well} \\ \tau_c \rightarrow \text{capture time from the adjacent wells} \\ \tau_e \rightarrow \text{emission from peripheral wells to SCH} \end{cases}$$

M equations for the wells + 2 equations for the SCH

The MQW model with $2M+2$ carrier populations.



- $\tau_d \rightarrow$ diffusion from SCH to gateway and vice versa
- $\tau_b \rightarrow$ diffusion above the barriers
- $\tau_c \rightarrow$ capture from gateways to the corresponding wells
- $\tau_e \rightarrow$ emission from wells to the corresponding gateways

M eq.s for the wells and the gateways and 2 eq.s for the SCH

The carrier equations: implementation in FDTW simulator

- The 2 populations (2 equations for carriers + 1 for photons):

$$\frac{dN_{QW}}{dt} = \frac{N_{QW}}{\tau_{n,QW}} + \frac{N_{SCH}}{\tau_c} - \frac{N_{SCH}}{\tau_e} - v_g G(N_{QW}, S) S$$

- The M+2 populations model (M+2 for carriers + FDTW for photons):

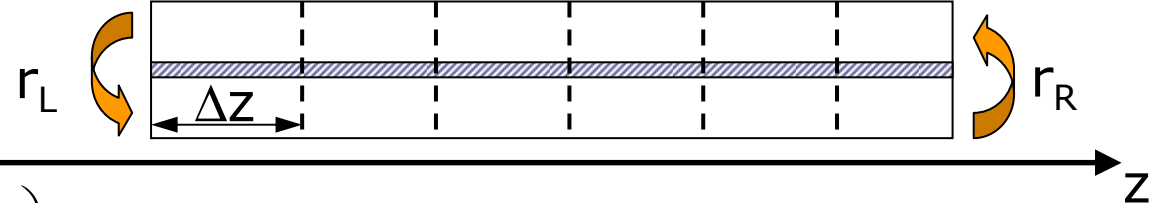
$$\frac{dN_{QW_i}}{dt} = -\left(\frac{1}{\tau_{n,QW_i}} + \frac{2}{\tau_c}\right) N_{QW_i} + \frac{1}{\tau_c} (N_{QW_{i-1}} + N_{QW_{i+1}}) - v_g G_i(N_{QW,i}, S) S$$

- The 2M+2 popolazions model (M+2 for carriers + FDTW for photons):

$$\frac{dN_{G_i}}{dt} = -\left(\frac{1}{\tau_{n,G_i}} + \frac{2}{\tau_b} + \frac{1}{\tau_c}\right) N_{G_i} + \frac{N_{QW_i}}{\tau_e} + \frac{1}{\tau_b} (N_{G_{i-1}} + N_{G_{i+1}})$$

$$\frac{dN_{QW_i}}{dt} = -\left(\frac{1}{\tau_{n,QW_i}} + \frac{1}{\tau_e}\right) N_{QW_i} + \frac{1}{\tau_c} N_{G_i} - v_g G_i(N_{QW_i}, S) S$$

The implemented traveling wave model for the electrical field



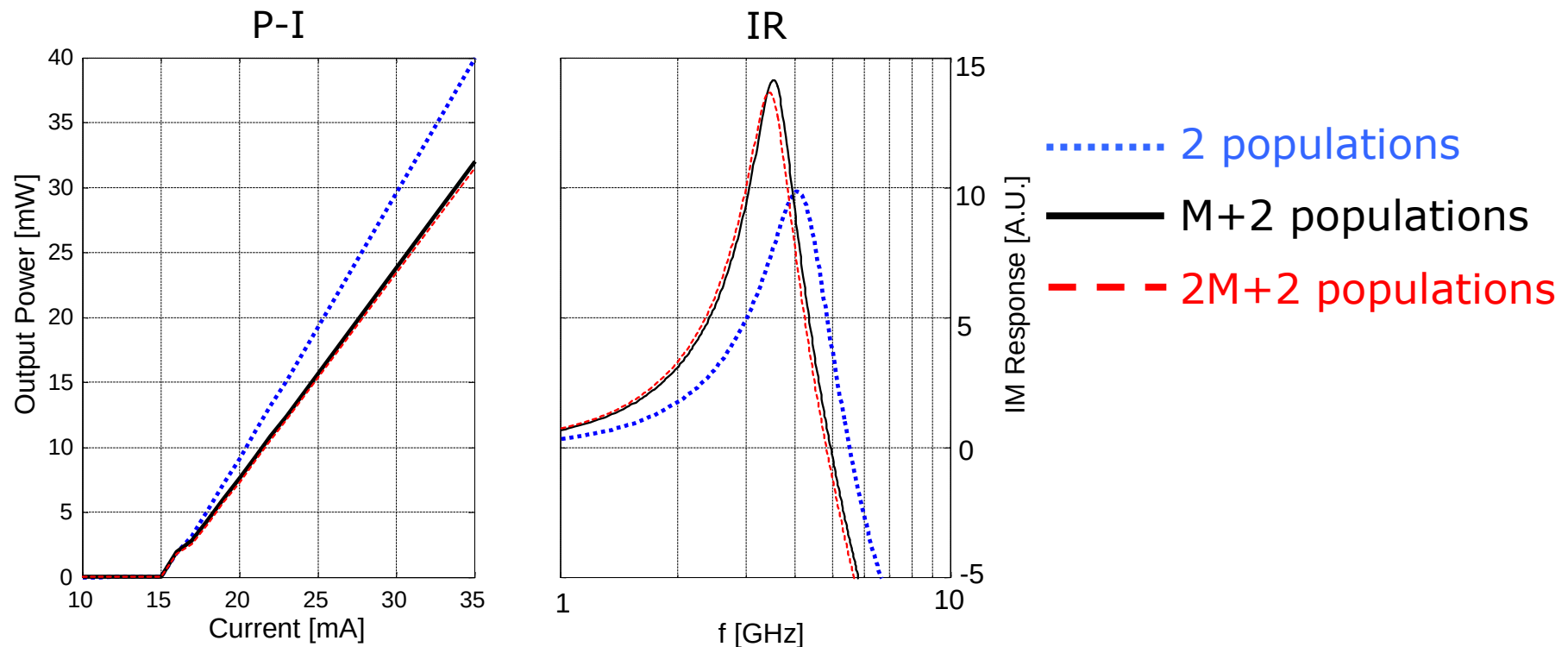
$$\begin{cases} \left(\frac{1}{v_g} \frac{\partial}{\partial t} + \frac{\partial}{\partial z} \right) F(z, t) = \underbrace{(G - j\delta) F(z, t)}_{\text{Gain}} + \underbrace{jk \cdot R(z, t)}_{\text{Coupling term}} + \underbrace{S_{sp}(z, t)}_{\text{Spontaneous emission}} \\ \left(\frac{1}{v_g} \frac{\partial}{\partial t} - \frac{\partial}{\partial z} \right) R(z, t) = \underbrace{(G - j\delta) R(z, t)}_{\text{Gain}} + \underbrace{jk^* \cdot F(z, t)}_{\text{Coupling term}} + \underbrace{S_{sp}(z, t)}_{\text{Spontaneous emission}} \end{cases}$$

$$S(z, t) = |F(z, t)|^2 + |R(z, t)|^2$$

- The system has been solved using a Split Step technique [B.S. Kim et al., JQE, 2000]
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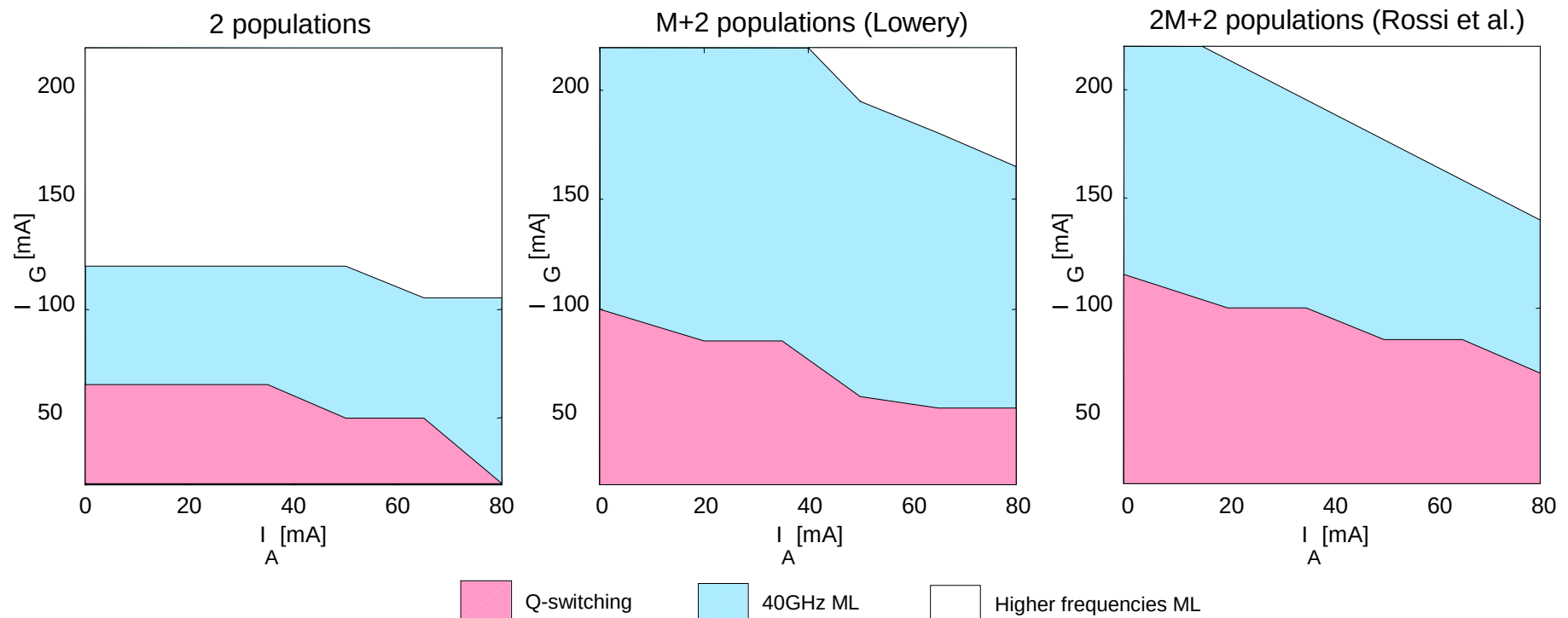
Selection of parameters for the comparison

- The different models require different parameter sets
- The parameters have been chosen in order to have comparable P-I and electro-optic modulation characteristics of a Fabry-Pérot laser



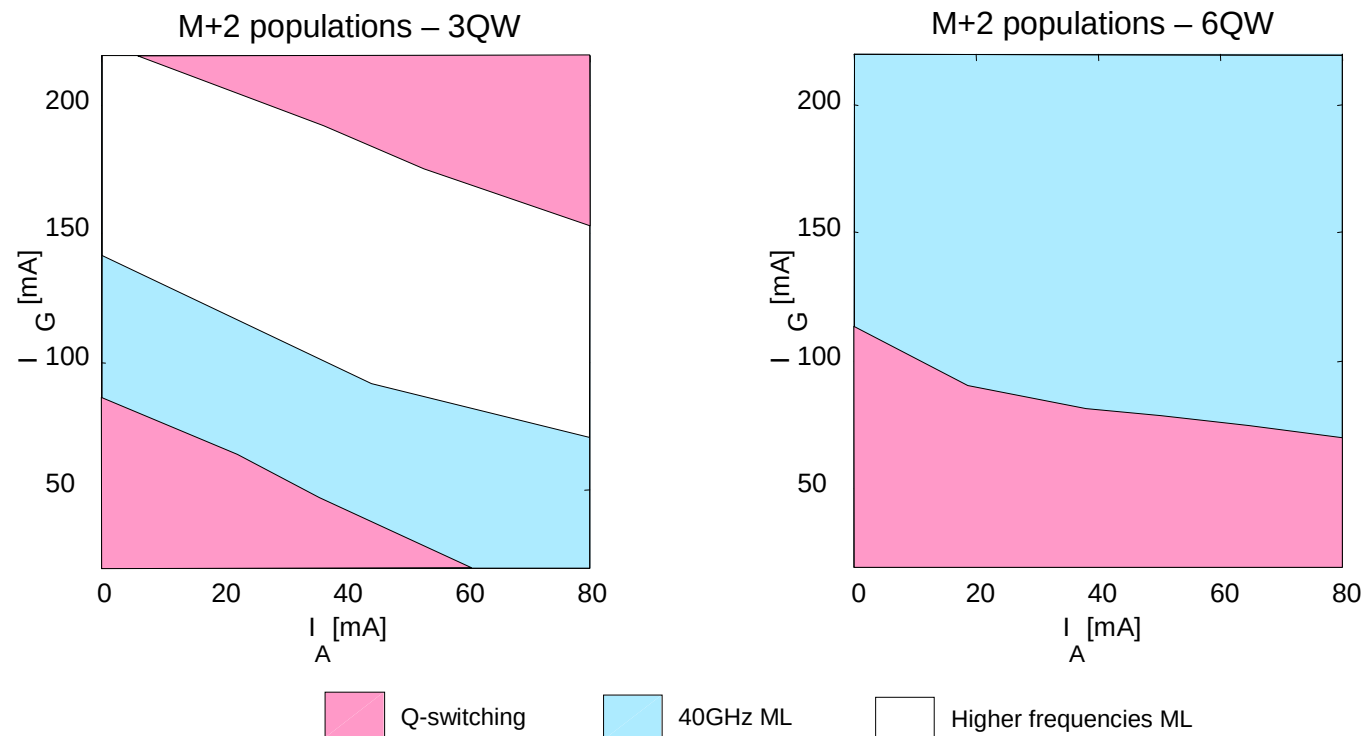
Mode locking maps: models comparison

- The Saturable Absorber is modeled as an active region operating under threshold: with this model changing the “bias” current in the absorber we change the differential absorption
- The working conditions for a 5 wells laser are evaluated in the Saturable Absorber – Gain section currents plane



Mode locking maps: influence of the number of wells

- This model easily allow to investigate the dependence of device behavior on the different parameters
- We report the maps evaluated changing the numbers of wells and keeping all the other parameters unchanged



Conclusions and Future Improvements

- Different existing models of MQW structures have been introduced in a TD TW simulator
 - A comparison of these models has been performed
 - A further improvement is required to model the Saturable Absorber in a more physical way
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