

Losses of the unstable cavity in tapered laser diodes: estimation from numerical simulations

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The University of
Nottingham

□ Introduction

- Tapered Lasers
- Definition of taper losses
- Goals of the work

□ Estimation of taper losses

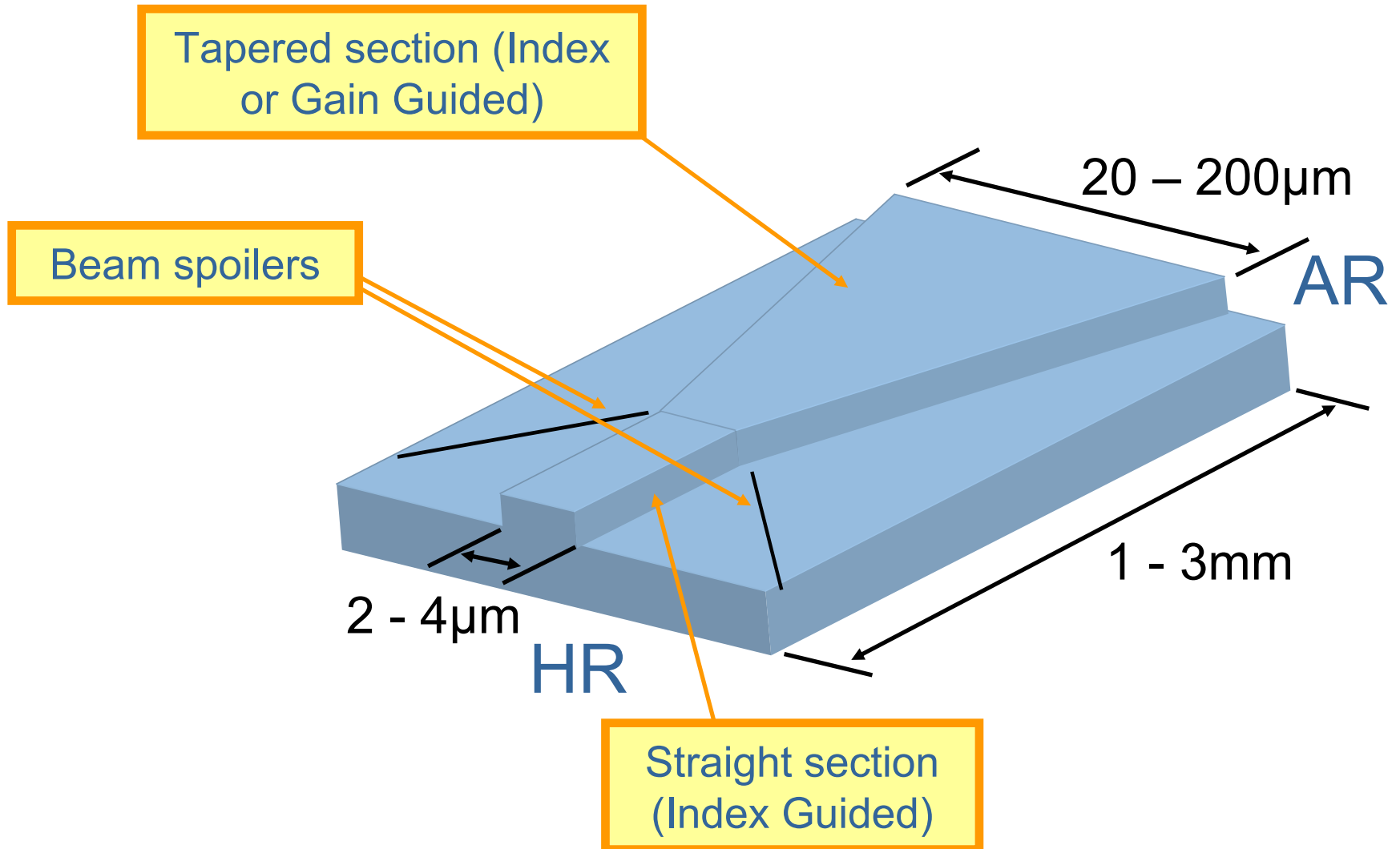
- Simulation model
- Method

□ Results

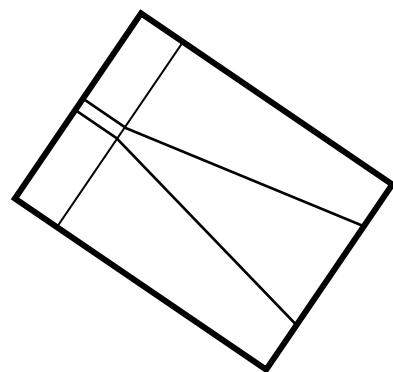
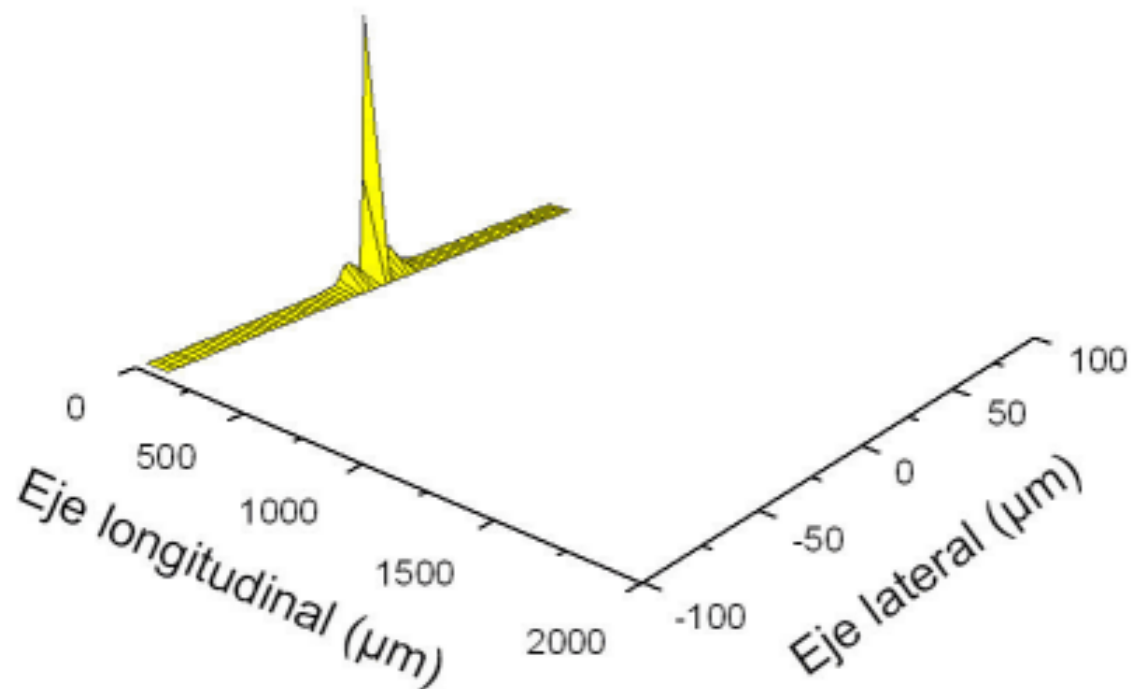
- Influence of design parameters
- Index vs Gain Guided Tapered lasers

□ Conclusions

Tapered lasers



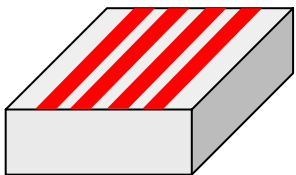
Tapered lasers



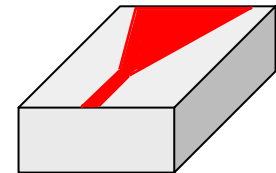
Types of tapered lasers

Small Angle Index Guided		Large Angle Gain Guided
2-3 mm	Total cavity length	2-3mm
$< 1^\circ$	Taper full angle	$4-8^\circ$
20-40 μm	Output aperture	100-200 μm
200-500 μm	Straight section length	500-1000 μm

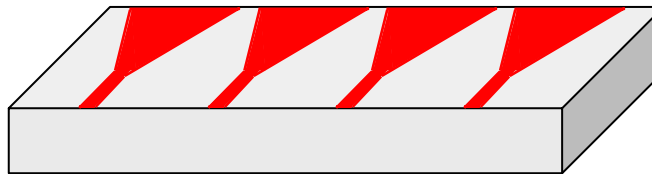
Arrays



Single Emitters



High Brightness Laser Bars



STANDARD BROAD AREA FP LASER

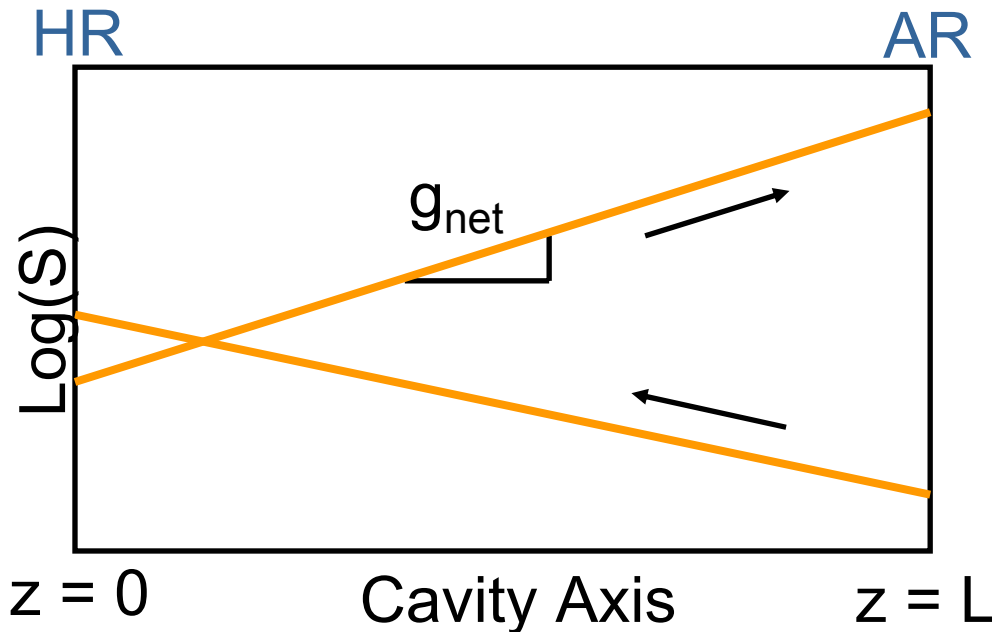


Assuming uniform gain:

$$g_{net} = \Gamma g_{mat} - \alpha_{in}$$

Threshold condition:

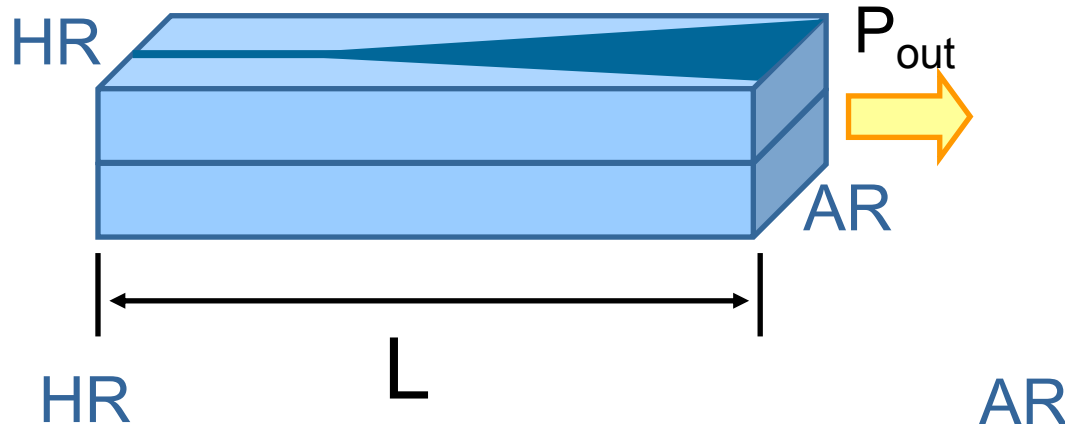
$$g_{net}(J_{th}) = \frac{1}{2 \cdot L} \cdot \ln\left(\frac{1}{R_1 \cdot R_2}\right) = \alpha_m$$



where g_{net} : net modal gain; Γ : vertical confinement factor; g_{mat} : material gain; α_{in} : internal losses; α_m : mirror losses; S : photon density.

Taper Losses: Definition (II)

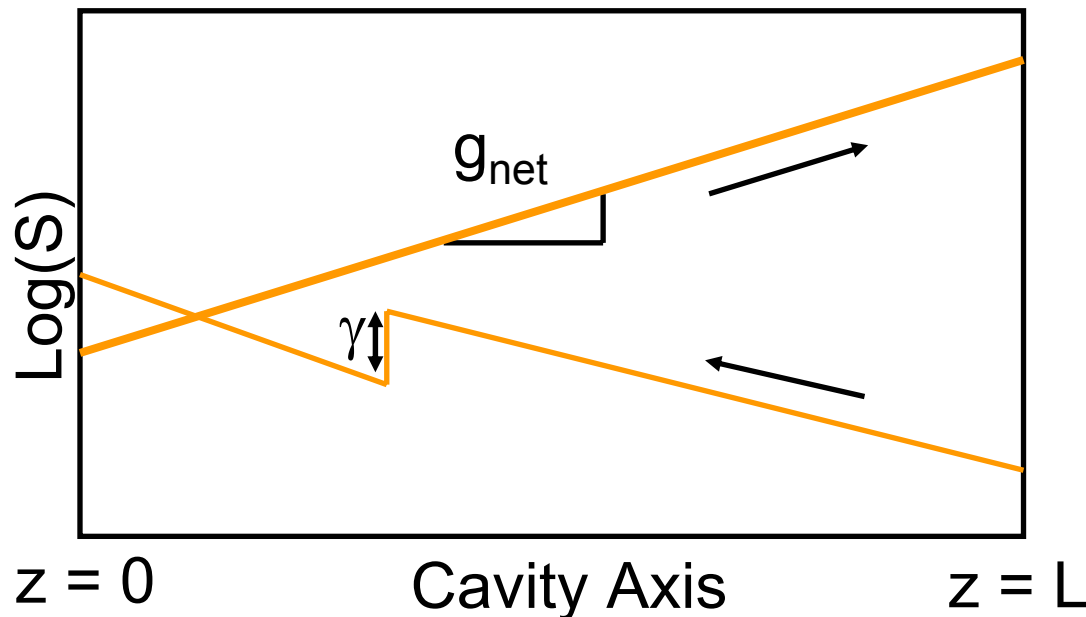
TAPERED LASER



$$g_{net}(J_{th}) = \alpha_m + \alpha_{tap}$$

$$\alpha_{tap} = \frac{1}{2 \cdot L} \cdot \text{Ln}\left(\frac{1}{\gamma}\right)$$

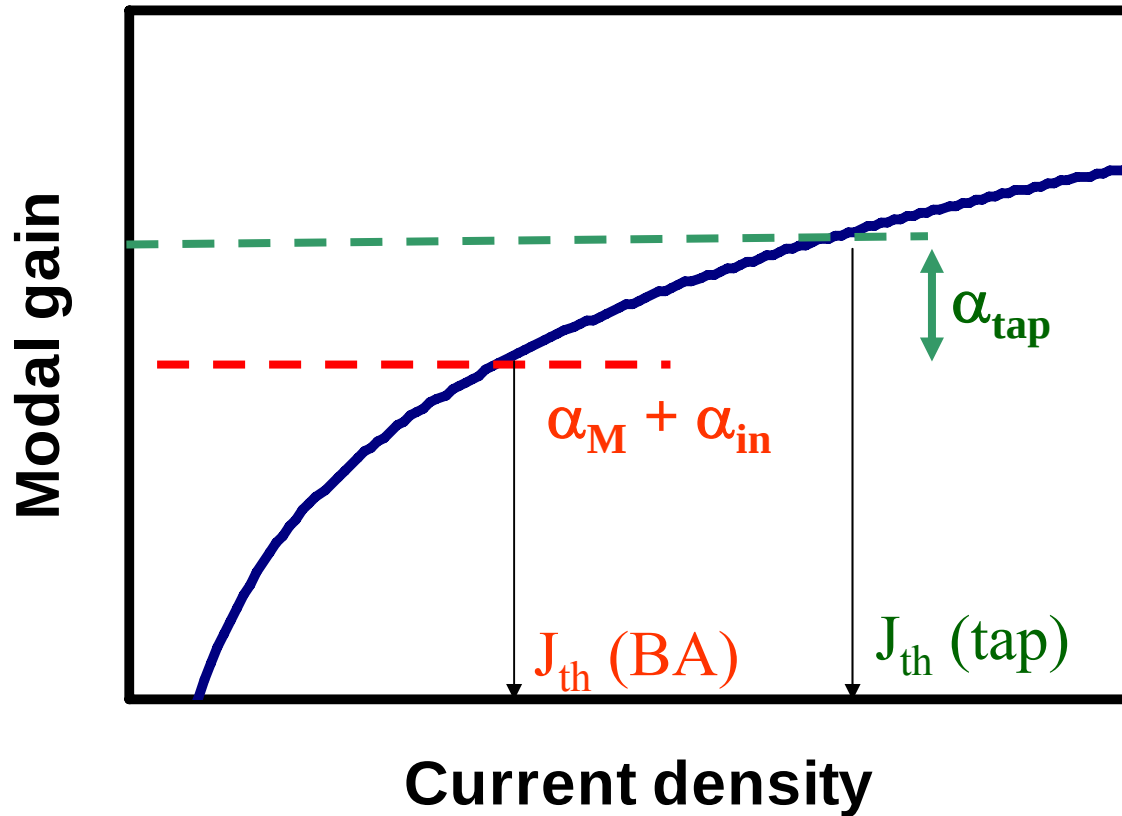
where α_{tap} : taper losses; γ : coupling coefficient



Taper losses: excess of losses in the cavity, in comparison with uniform laser, due to the geometrical losses of the unstable cavity design.

Taper Losses: Why are they important?

Increase of threshold current, and therefore internal temperature, linewidth enhancement factor...



$$L = 2 \text{ mm}; R_1 = 0.95; R_2 = 0.03 \Rightarrow \alpha_M \sim 9 \text{ cm}^{-1}$$

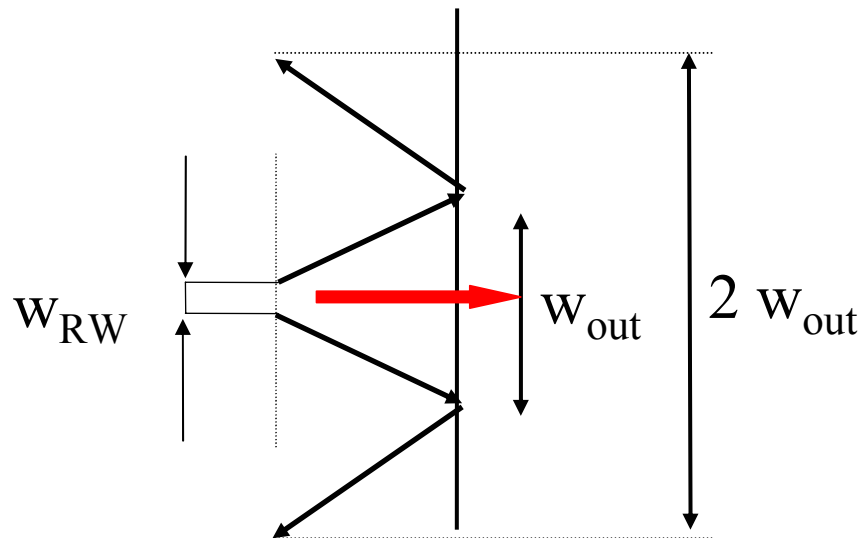
Taper Losses: Previous work in literature

S. Delepine et al., IEEE STQE, 7,111 (2001)

Estimation of taper losses for the free-diffraction of a Gaussian beam:

$$\gamma = \frac{W_{RW}}{2 \cdot w_{OUT}}$$

where W_{RW} : width of the beam launched into tapered section; W_{OUT} : width of the output aperture assuming free diffraction.



- ✓ Development of method to estimate taper losses, based on simulations
- ✓ Application to Index and Gain Guided tapered lasers with different geometries

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 - ❑ Tapered Lasers
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 - ❑ Goals of the work
- ❑ **Estimation of taper losses:**
 - ❑ Simulation model
 - ❑ Method
- ❑ Results
 - ❑ Influence of design parameters
 - ❑ Index vs Gain Guided Tapered lasers
- ❑ Conclusions

Electrical model (3D)

**Continuity equations (electrons y holes), Poisson,
and QW capture/escape**

Thermal model (3D)

Heat flow equation + local heat sources

Gain / Spontaneous Emission model

Parabolic bands (VB parameters fitted to 4x4 kp)

Optical model (2D)

Wide-angle beam propagation method (WA-BPM)

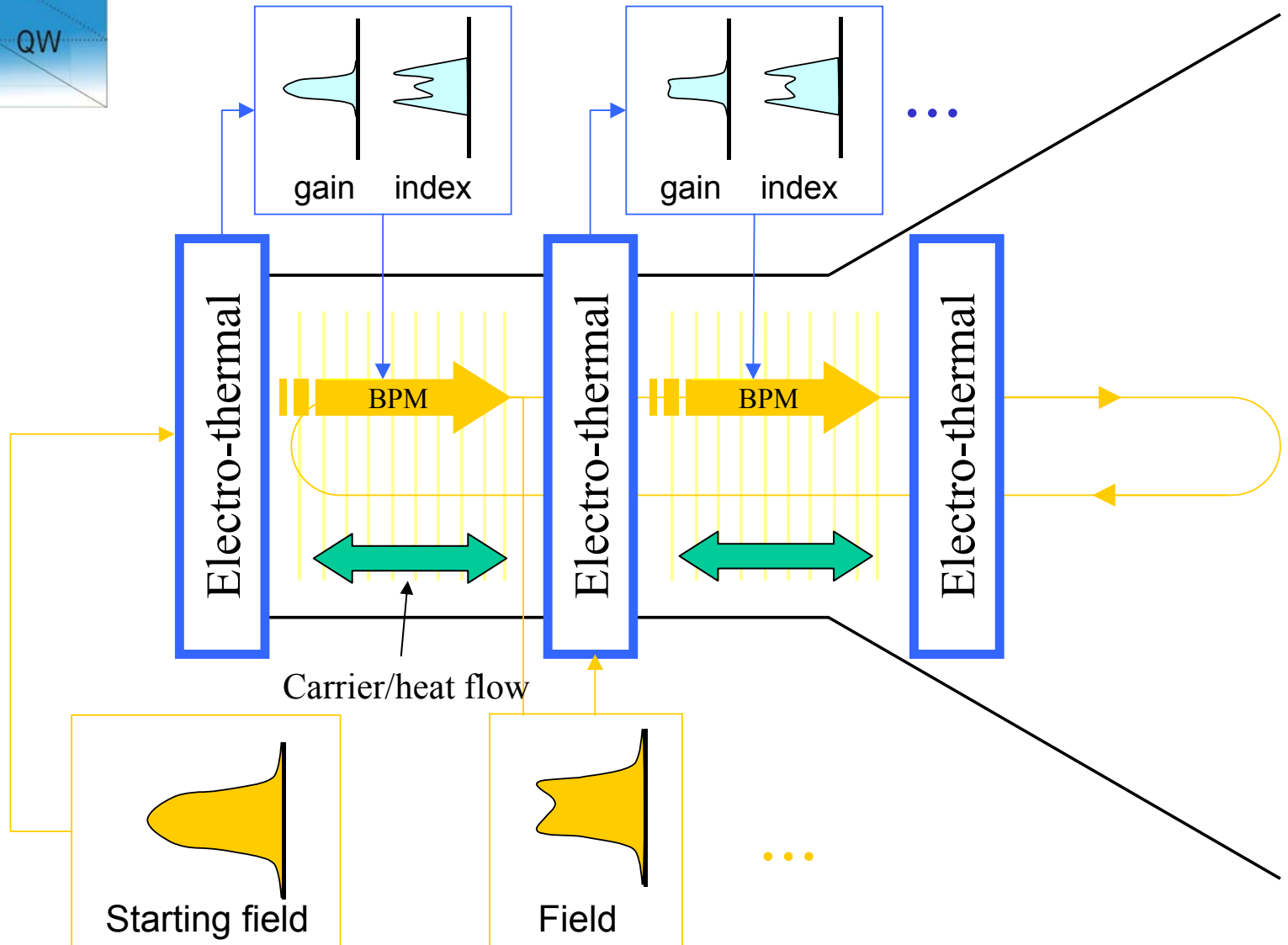
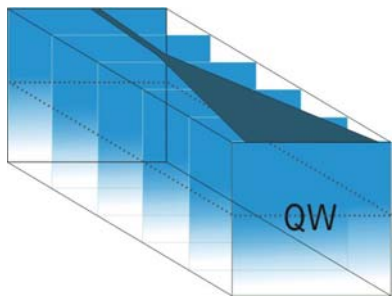
Steady-state

Single wavelength

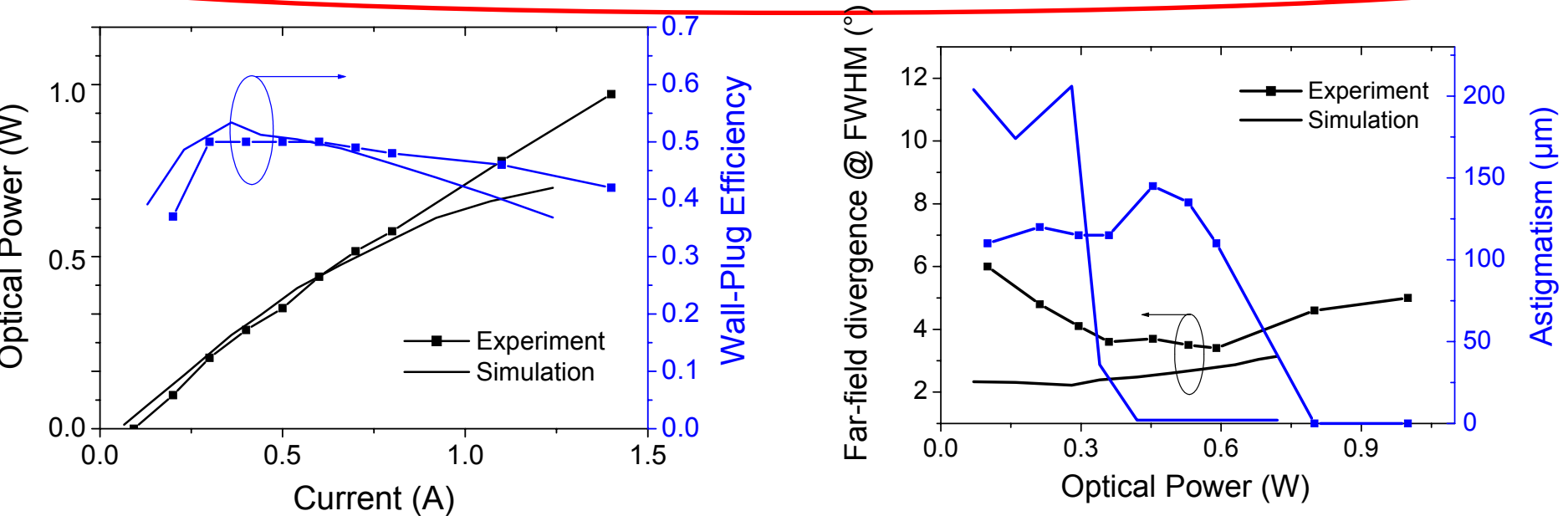
*L. Borruel *et al*, IEEE JQE, 40, 463 (2004)

*S. Sujecki *et al*, IEEE JSTQE, 9, 823 (2003)

Simulation model (II)



Simulations performed previously than experiments

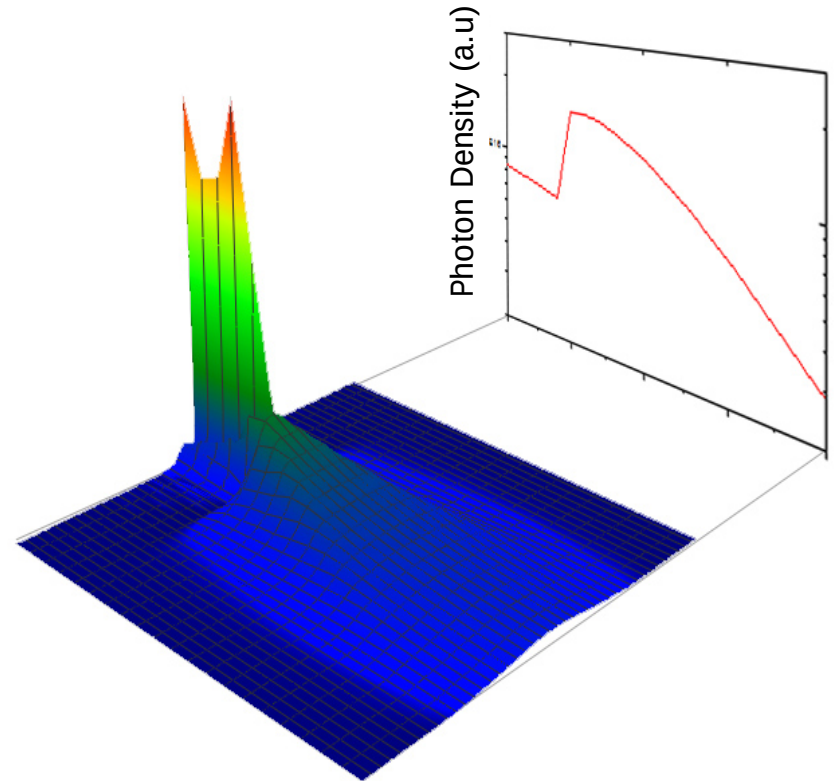
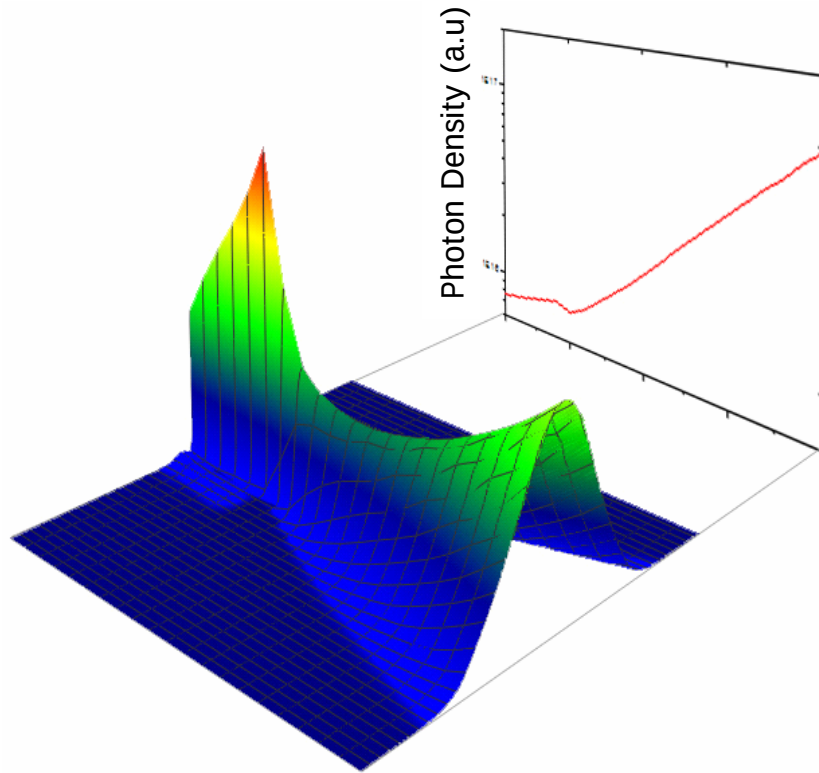


New tapered laser design*:
CLARINET LASER



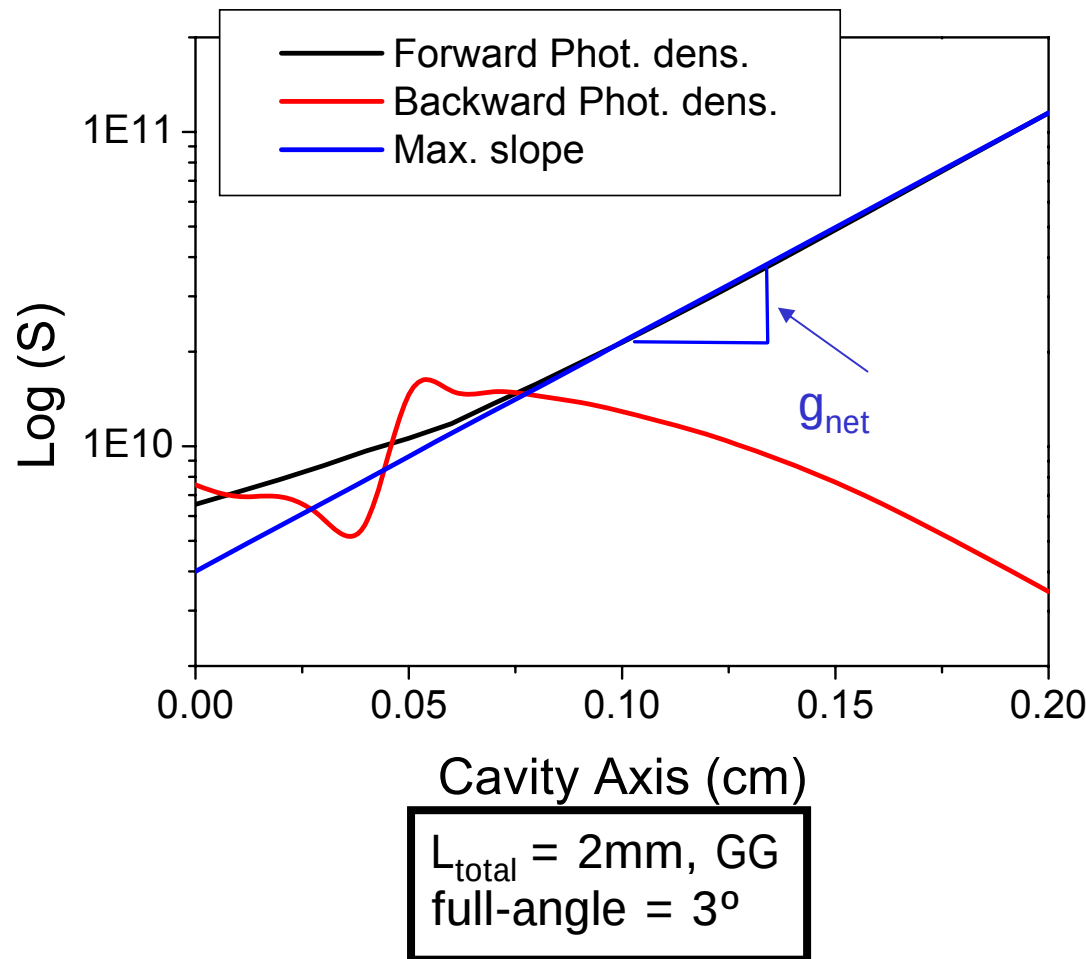
*L. Borruel *et al*, Appl. Phys. Lett., 87 (10), September 2005

Estimation of Taper Losses (I)



- Step I: Simulation of the tapered laser close to threshold
- Step II: Integration of the photon density along lateral axis, yielding $S^+(z)$ and $S^-(z)$

Estimation of Taper Losses (II)



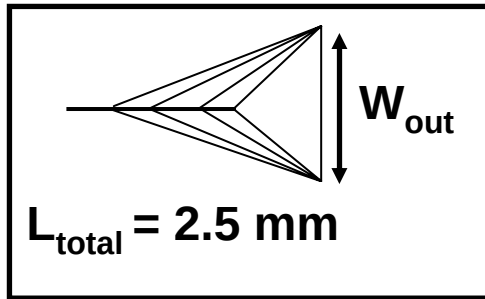
- Step III: the net modal gain is estimated from the maximum slope
- Step IV:

$$\alpha_{\text{tap}} = g_{\text{net}} - \alpha_{\text{m}}$$

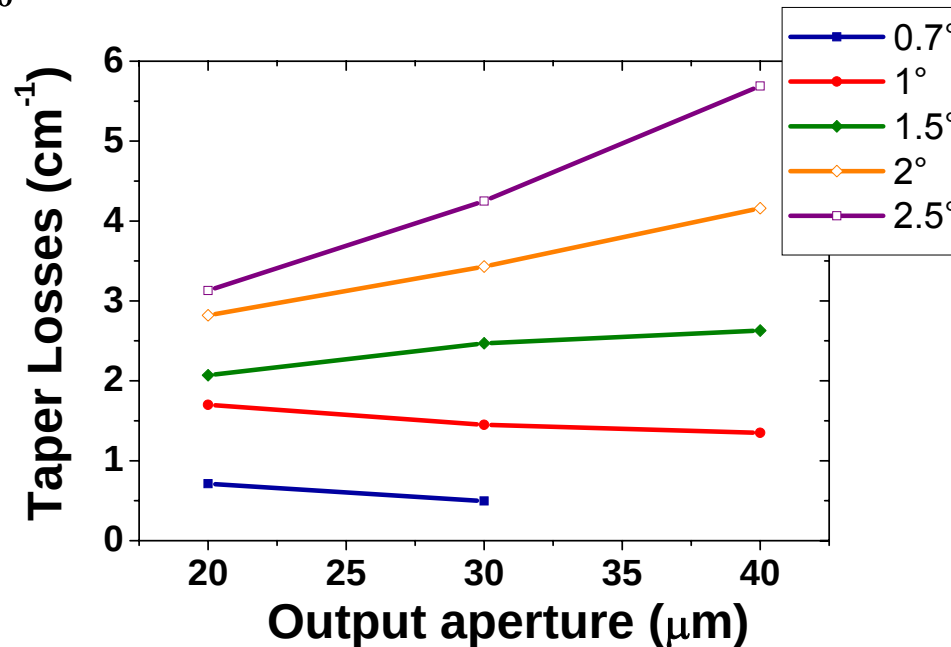
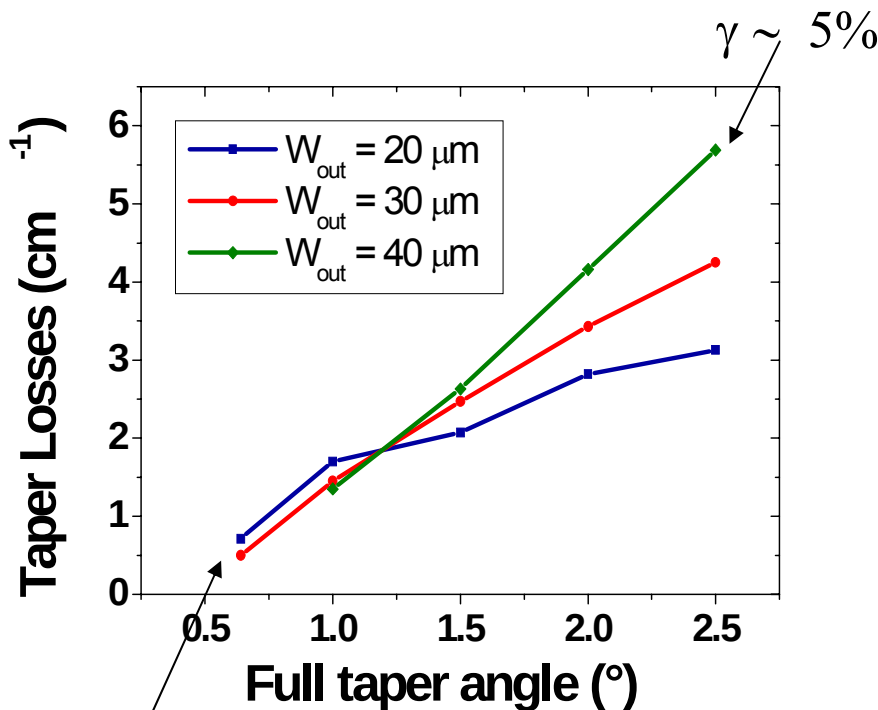
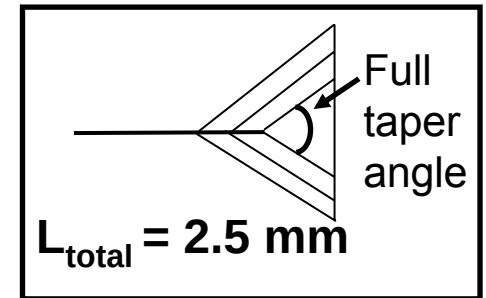
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Results: Index Guided Tapered Lasers

Fixed W_{out}



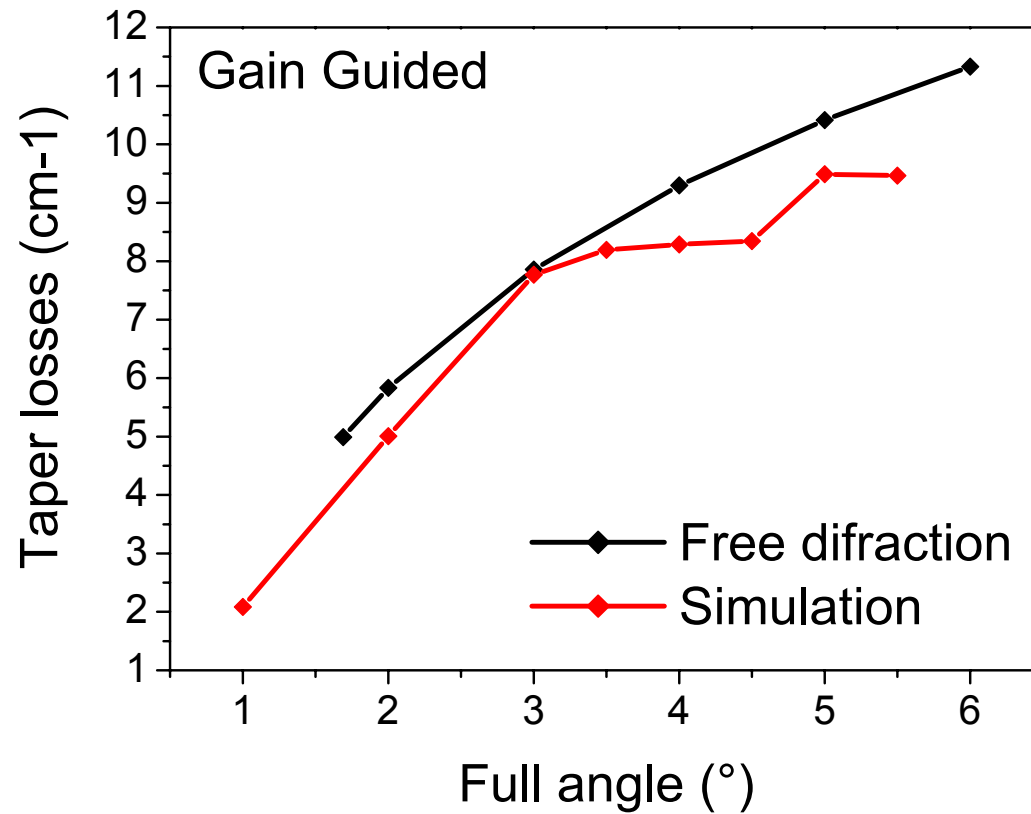
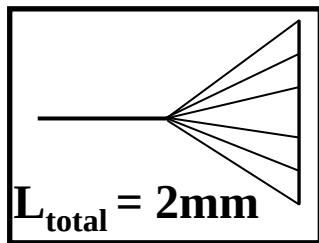
Fixed full taper angle



$\gamma \sim 80\%$

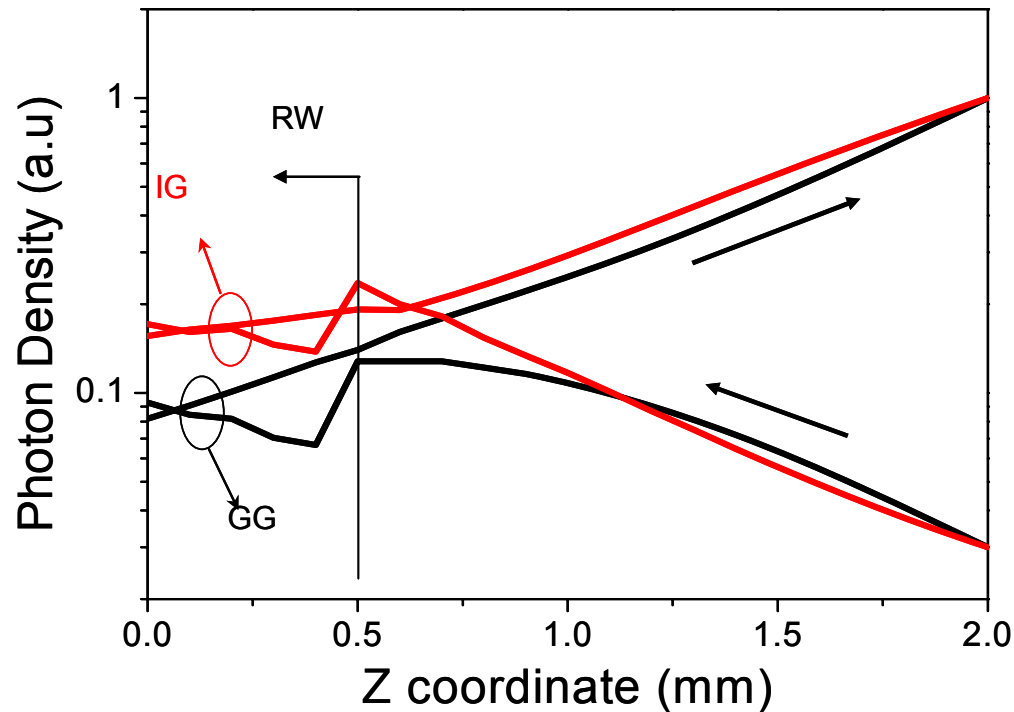
975 nm, Al-free InGaAs QW

Results: Gain Guided Tapered Lasers



Results: Index vs Gain Guided Tapered Lasers

L = 2 mm ; Taper angle = 2°



Taper losses

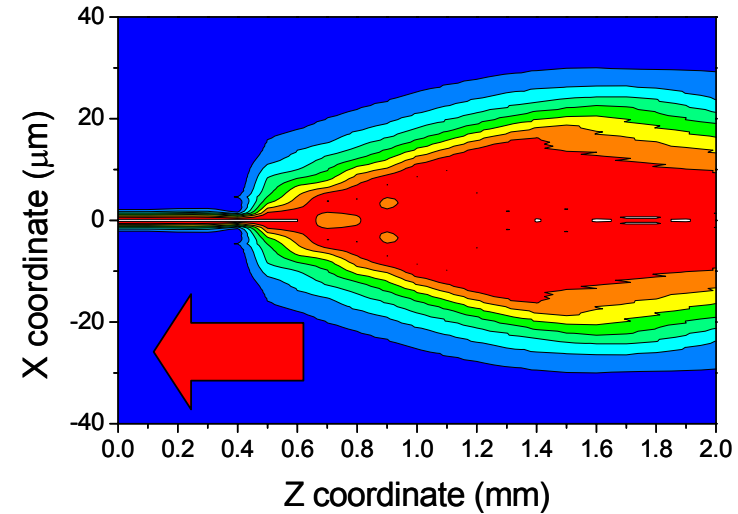
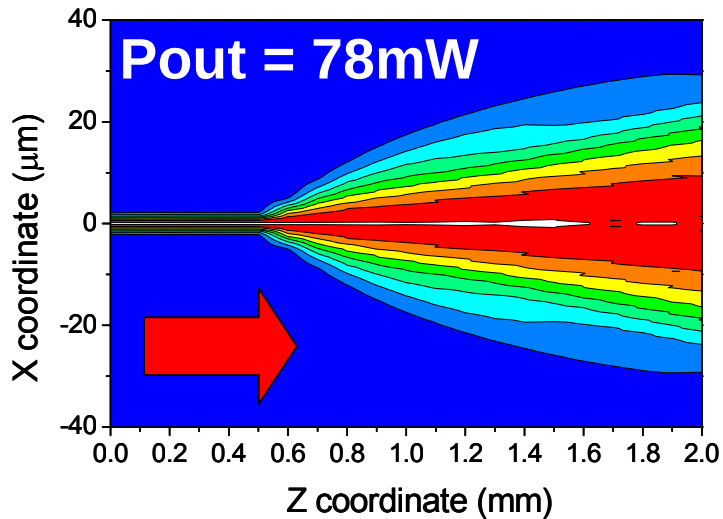
IG: 3.3 cm⁻¹ ($\gamma \sim 20$ %)

GG: 5.0 cm⁻¹ ($\gamma \sim 8$ %)

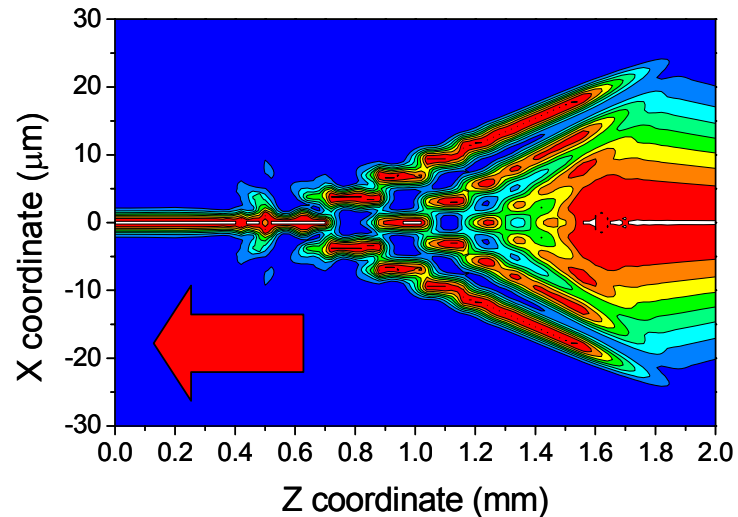
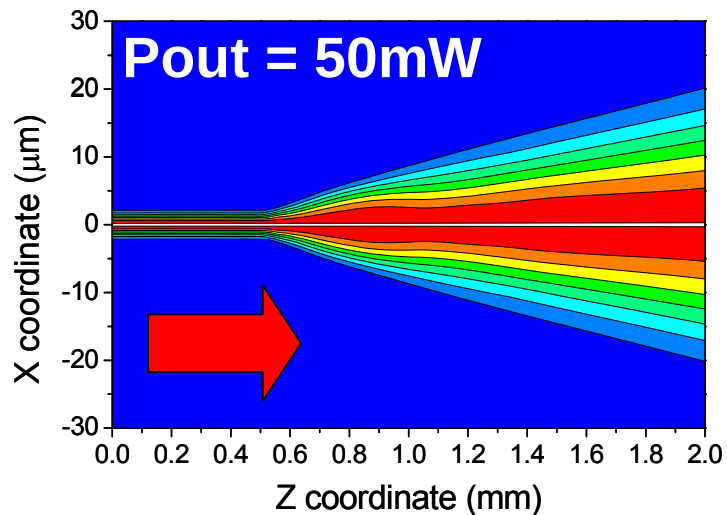
Results: Index vs Gain Guided Tapered Lasers

Normalized Optical Intensity

GG



IG



$L = 2 \text{ mm}$; Taper angle: 2°

- ✓ **New method to estimate taper losses from numerical simulations**
- ✓ **Index Guided devices: low taper losses**
- ✓ **Gain Guided devices: high taper losses, slightly lower than those of free-diffraction approximation**
- ✓ **Main parameter: taper angle**