On The Prediction of Self-Pulsations in Two-Section Partially Gain-Coupled DFB Lasers

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Motivation

- DFB Self-pulsating devices –

Two Section: Index- Coupled, Partially gain-coupled.

Three Section: Three DFB sections, Two DFB sections and a center phase section.

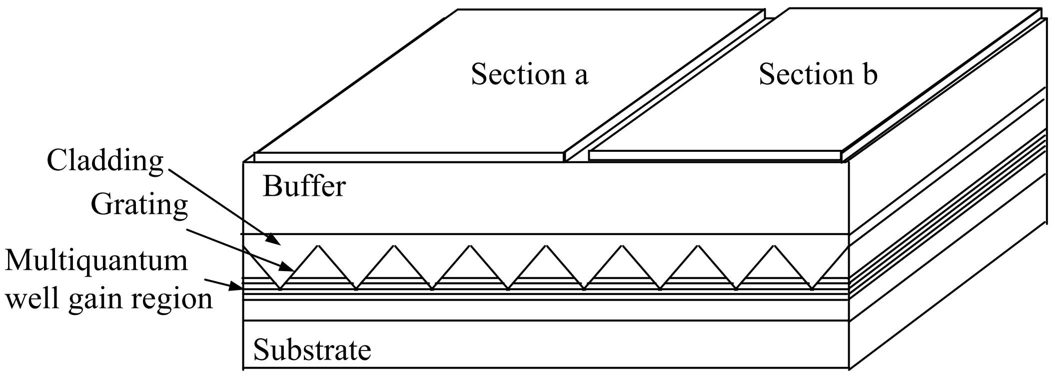
- Application include –
- All-optical clock recovery, Wireless Fiber Links, Terahertz generation.
- Modeling –

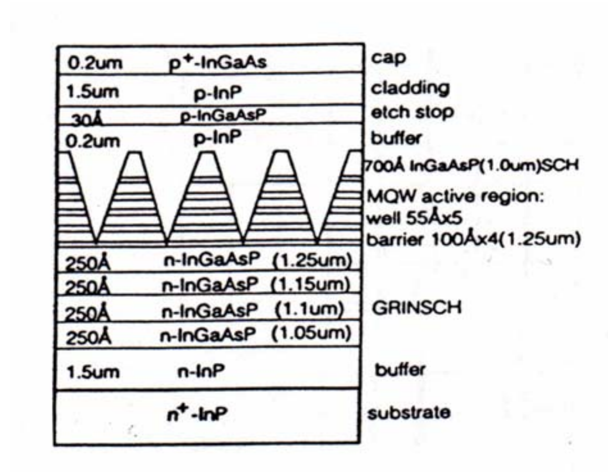
  There is a critical need for understanding device operation and dependence on device characteristics.

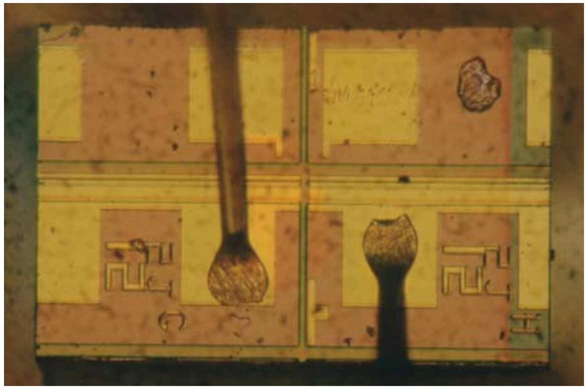
Talk Outline

- Structure and Model.
- Model Prediction –Bulk
- Comparison of model predictions and experimental results.
- SSP and Cavity Conditions
- Quantum vs. Bulk
- Summary

Two-Section Gain-Coupled DFB Lasers: Device Structure







- Two section share one substrate
- Electrically isolated contacts for each section
- Gain Coupling lead to
  - (> 40 dB SMSR in single-section DFB)
  - Relative independent operation in two section
- Proper design/operation lead to self pulsing: Periodic output with DC bias for both sections

Nonlinear Coupled Differential Equations of TS-DFB Lasers

Forward wave $$\frac{\partial F(z,t)}{\partial z}+\frac{1}{v_g}\frac{\partial F(z,t)}{\partial t}=\frac{1}{2}G(z,t)F(z,t)+i\kappa B(z,t)+s_f(z,t),$$

Backward wave $$\frac{\partial B(z,t)}{\partial z}-\frac{1}{v_g}\frac{\partial B(z,t)}{\partial t}=-\frac{1}{2}G(z,t)B(z,t)-i\kappa F(z,t)+s_b(z,t),$$

Carrier density $$\frac{\partial N(z,t)}{\partial t}=\frac{I_{A,B}}{qV}-\frac{N(z,t)}{\tau}-\left[\frac{g_n(N(z,t)-N_0)}{1+\varepsilon P(z,t)}-2f_s(z,t)\right]v_g P(z,t),$$

$$f_s(z,t)=\kappa_g\left(e^{j\varphi_g}F(z,t)B^*(z,t)+c.c\right)/P(z,t),$$

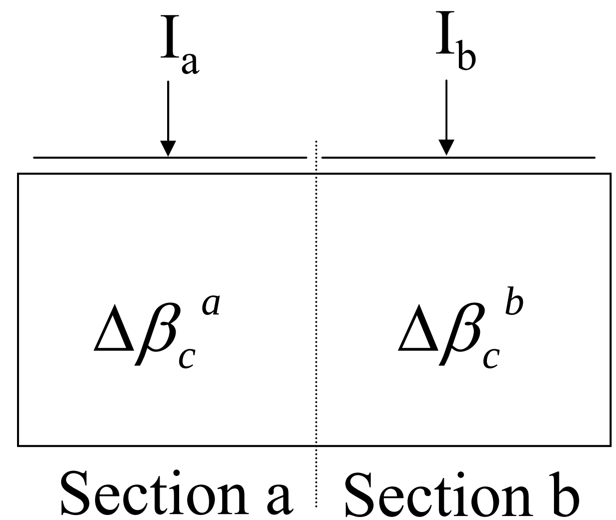
The inclusion of Wavelength Tuning

$$G(z,t) = \Gamma_x g_n \left(N(z,t) - N_0\right)\left[\frac{1}{1+\varepsilon P(z,t)} - i\alpha\right] - \Gamma + i\Delta\beta(z),$$

$$\Delta\beta(a,b) = \Delta\beta_c^{\,a,b} + \frac{\delta\beta}{\delta T}\frac{\delta T}{\delta I} I_{a,b}$$

$$\delta = \Delta\beta_c^{\,b} - \Delta\beta_c^{\,a}$$

$$\Delta\beta_c^{\,b,a}(b,a) = \beta_c^{\,b,a} - \beta_B$$



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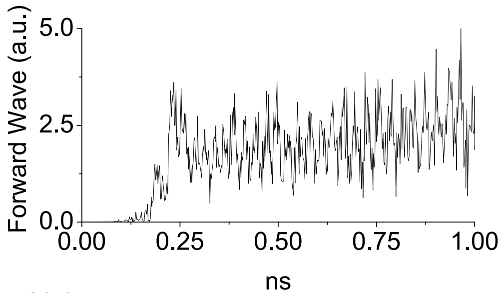
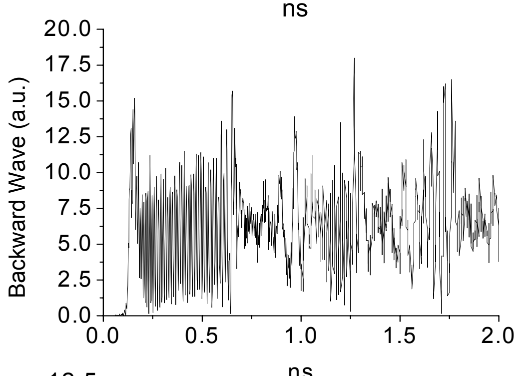
Bulk vs. Quantum Device Parameter

Symbol	Description	Quantity	
		Bulk	Quantum-Well
N_0	Carrier density at transparency	2.1×10^{18} cm^{-3}	1.5×10^{18} cm^{-3}
g_n	Differential gain	3×10^{-16} cm^2	3×10^{-16} cm^2
Γ_x	Confinement factor	0.3	0.068
λ_B	Free space wavelength	1.55×10^{-4} cm	1.55×10^{-4} cm
Γ	Cavity loss	40 cm^{-1}	20 cm^{-1}
α	linewidth enhancement factor	3	3
τ	Carrier lifetime	1.25 ns	1.25 ns
ε	Nonlinear gain coefficient	3×10^{-17} cm^3	1×10^{-17} cm^3
n_{sp}	Spontaneous emission factor	2	2
n_{eff}	Effective refractive index	3.7	3.7
n_g	Group refractive index	3.55	3.55
$\delta\beta/\delta(I/I_{tr})$	Temperature induced shift in Bragg condition	-30 cm^{-1}	-30 cm^{-1}

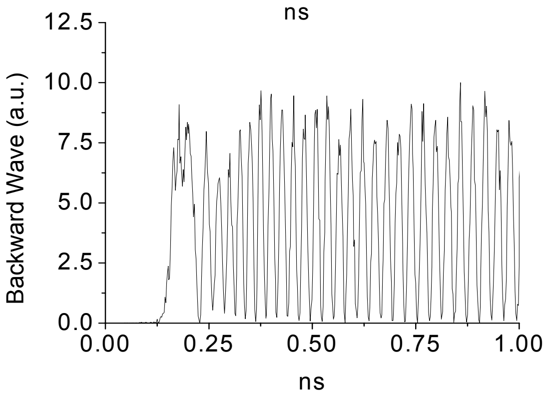
Bulk κL5+i0.5 – Section Length 350μm



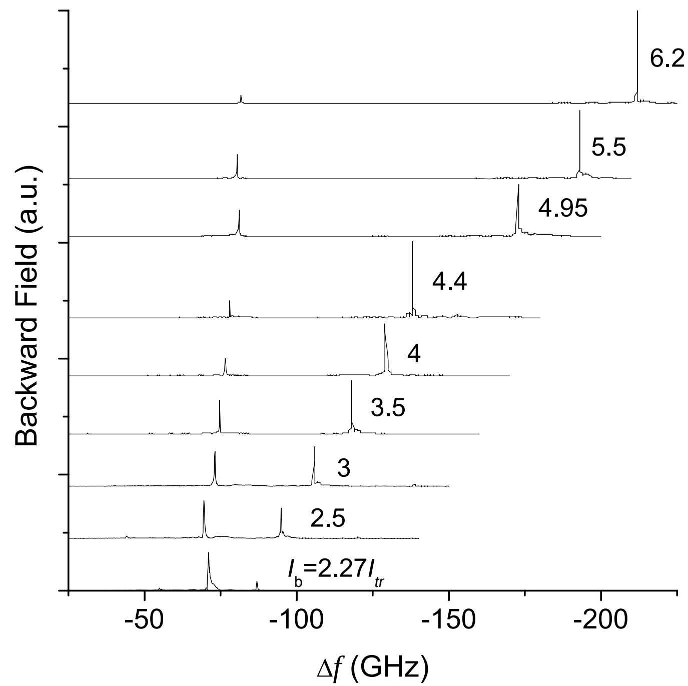
I_b=3



I_b=4.7



I_b=5



δ_{min}=33 cm^{-1}

δ=38 cm^{-1}

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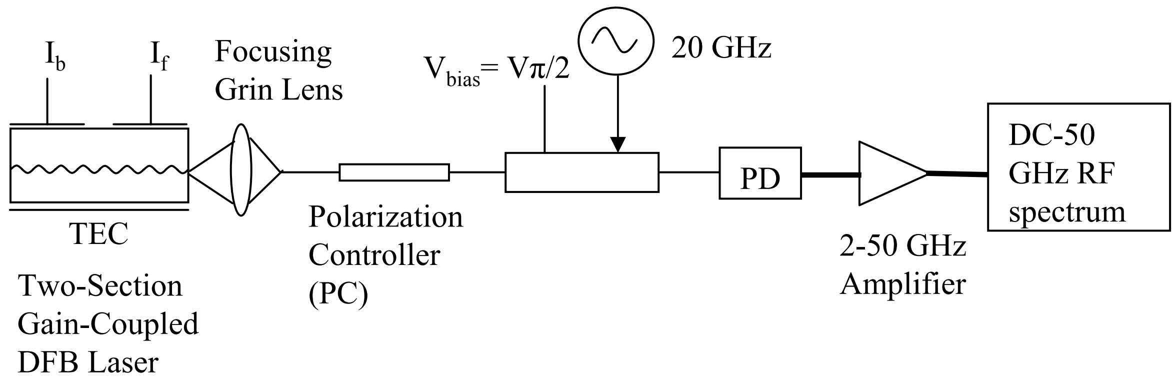
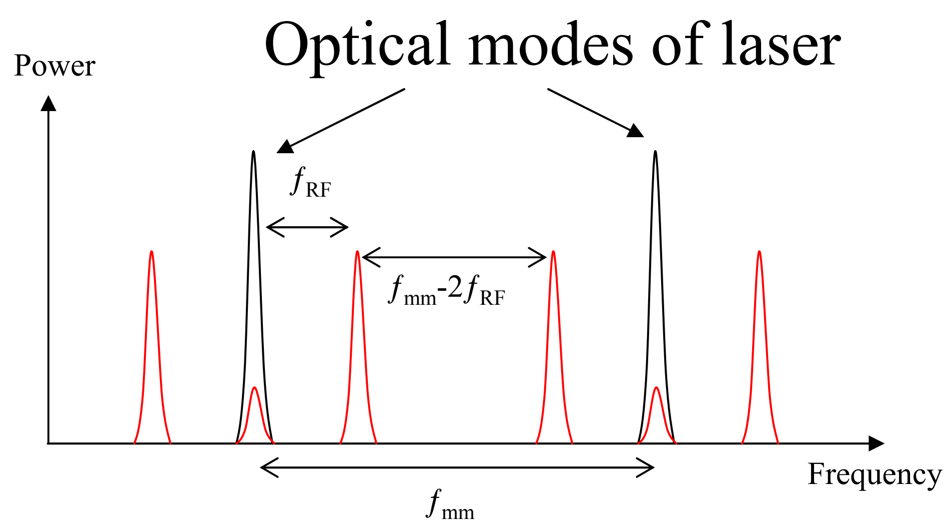
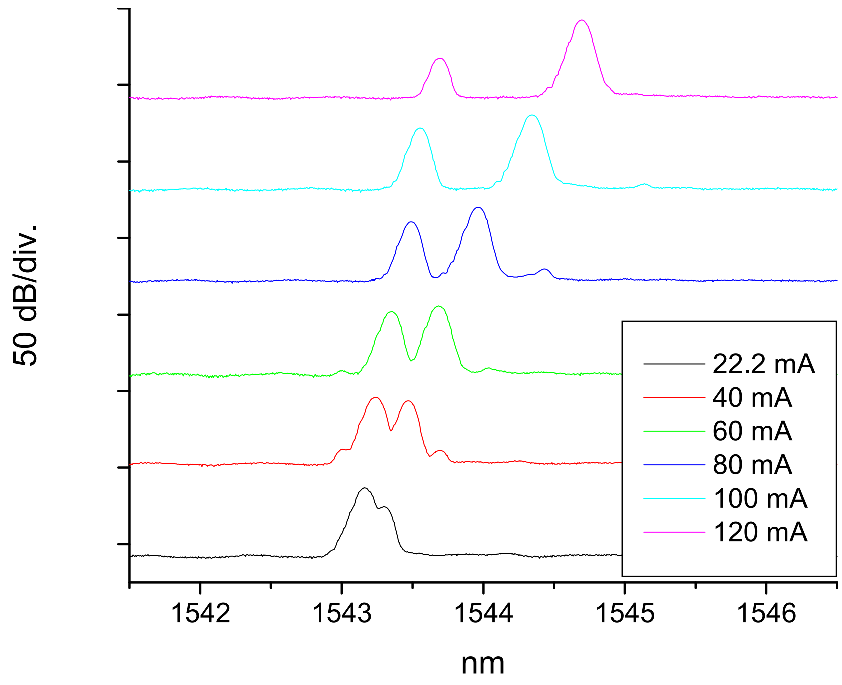
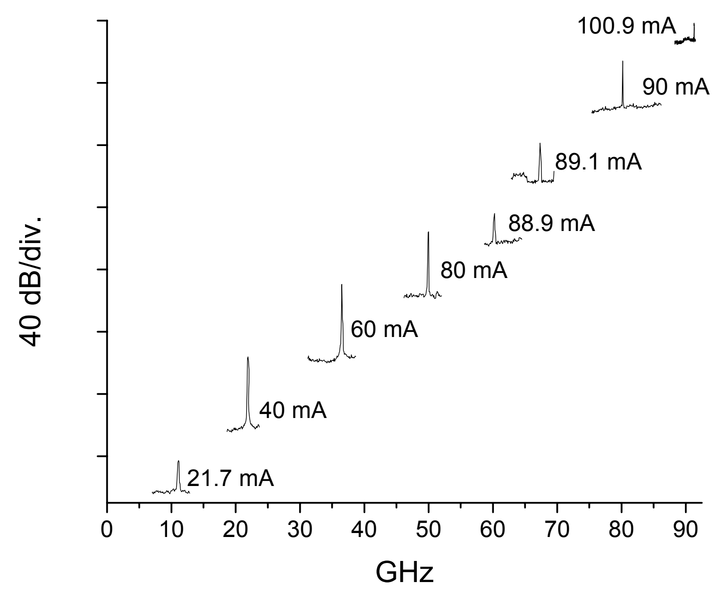
Optical Downconversion Setup





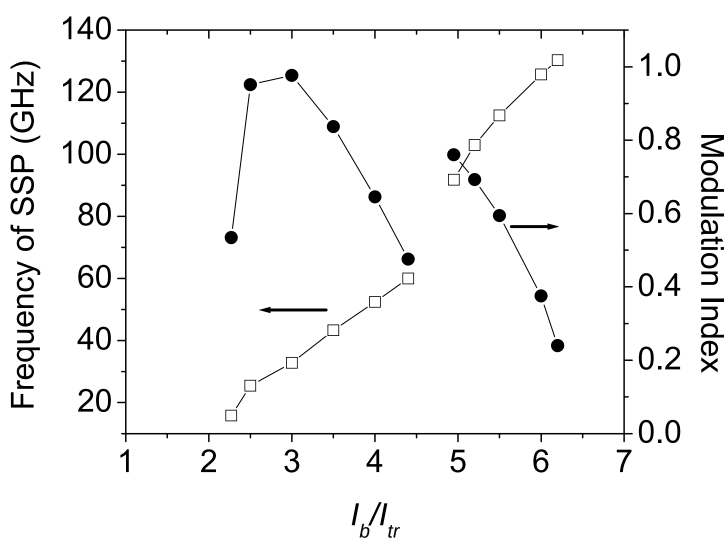
Measured Optical Spectra and RF
$\kappa \approx 45 + i4.5$, L=380 μm, I_a=47 mA



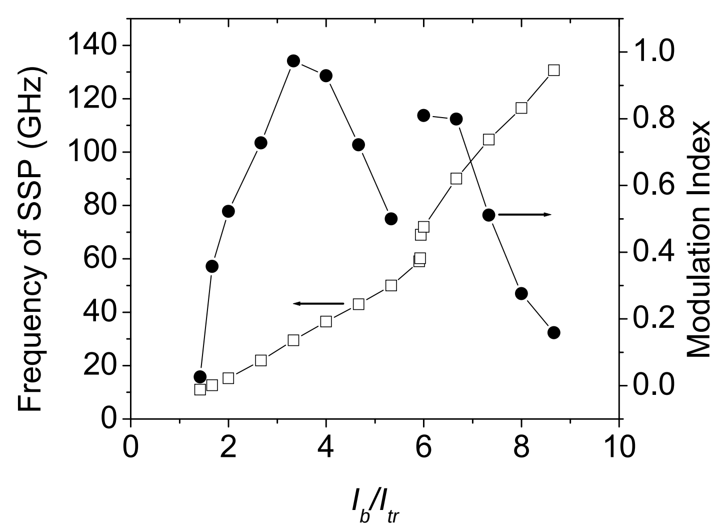


Self-pulsation Tuning Range and Modulation Index

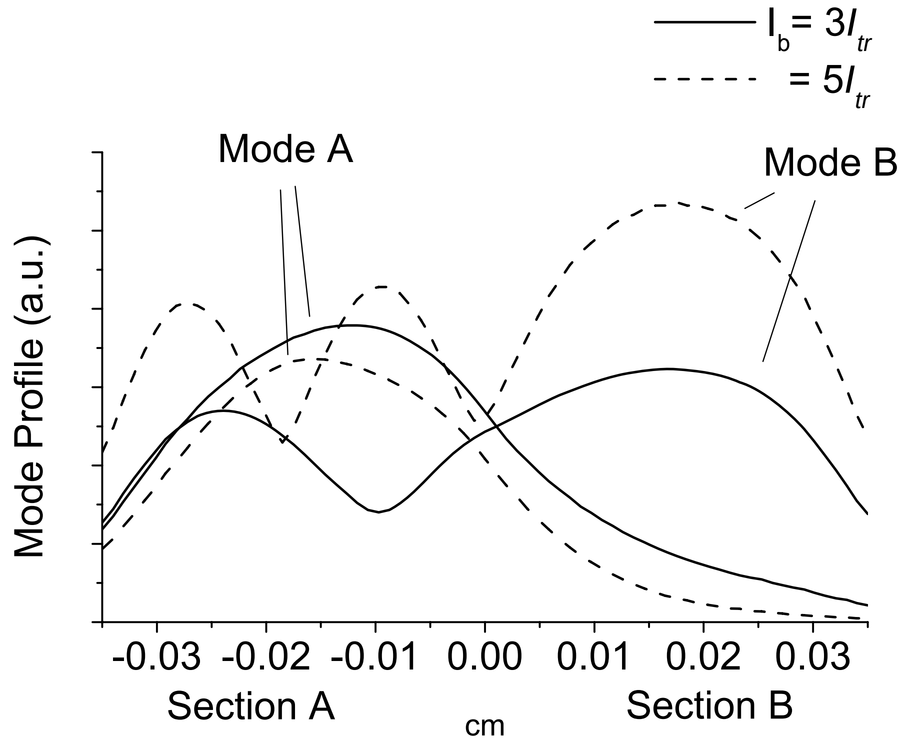
Predicted



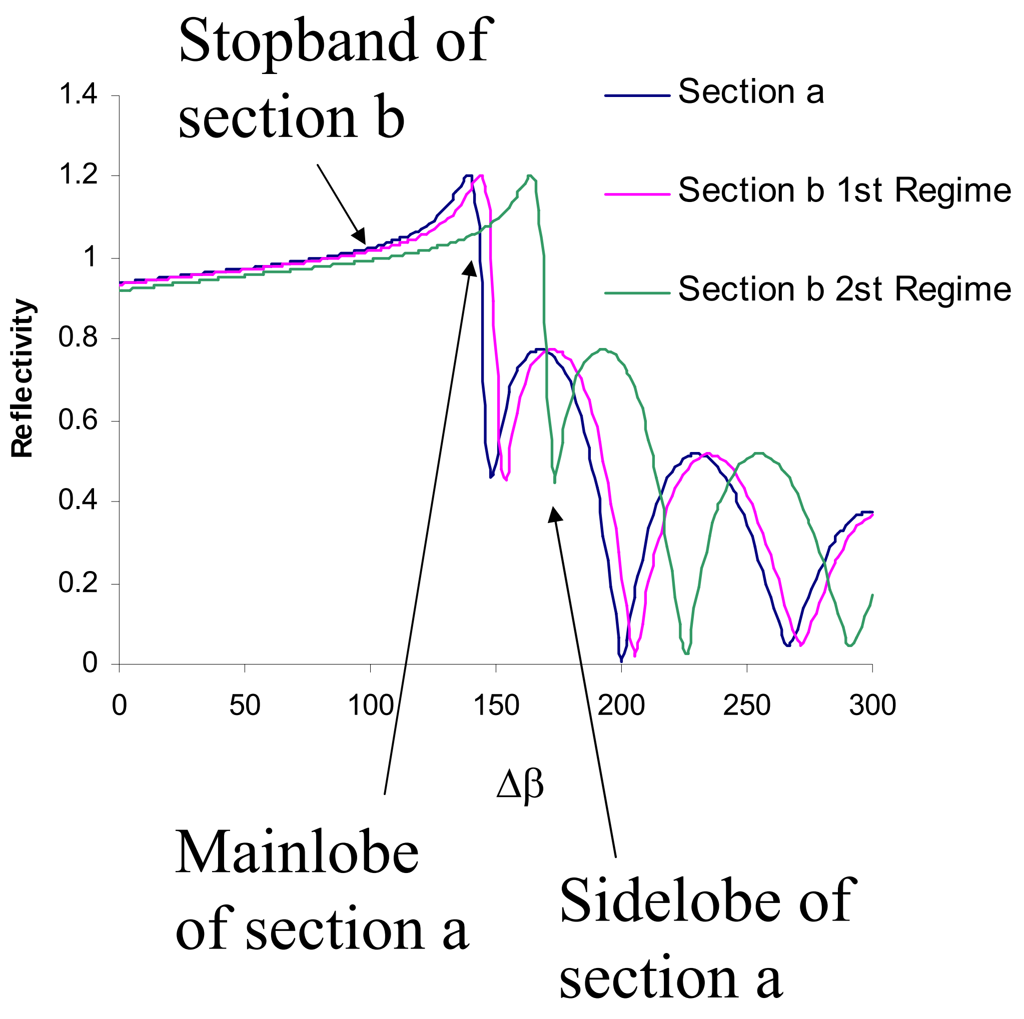
Experimental



Mode Profile



Reflectivity Spectrum of Individual Sections



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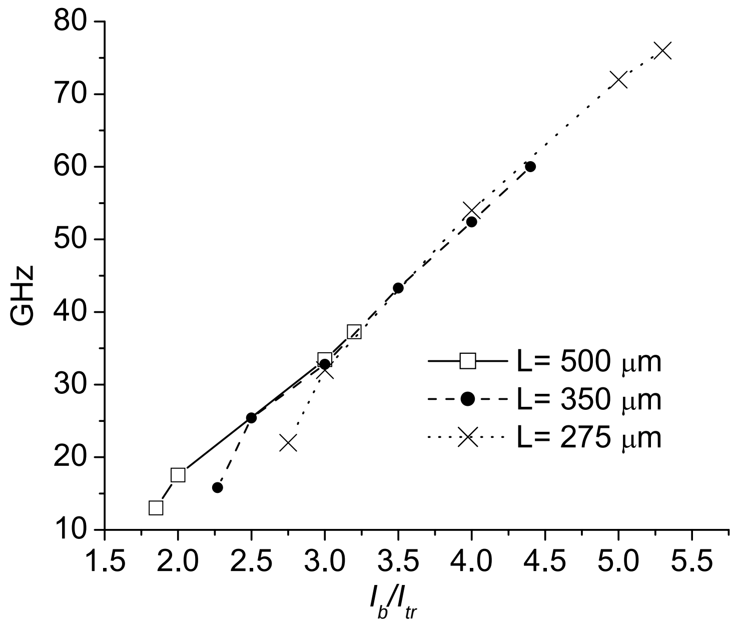
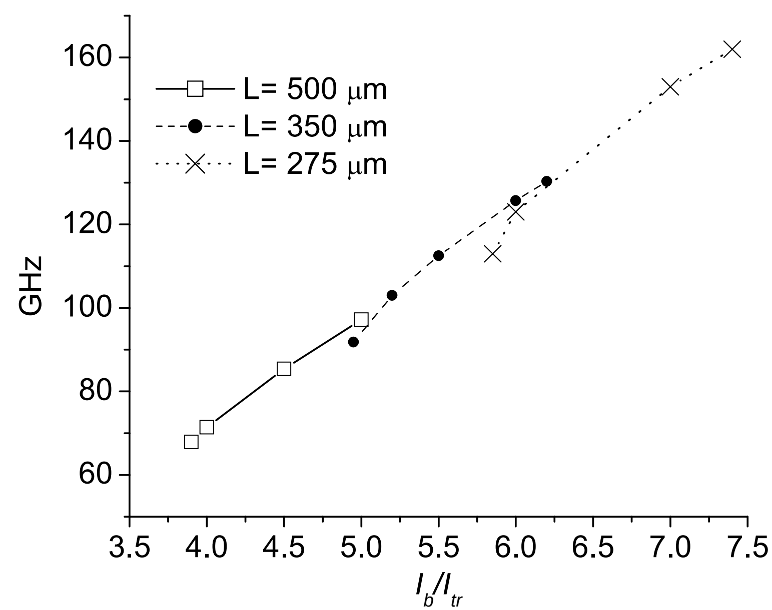
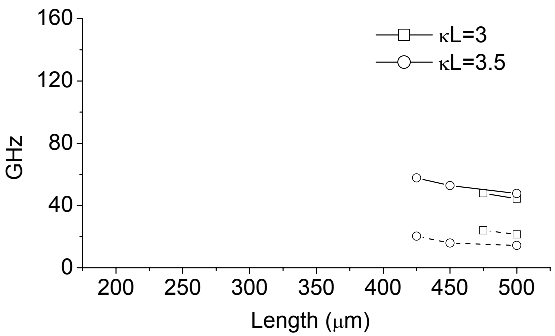
SSP vs. Section Length



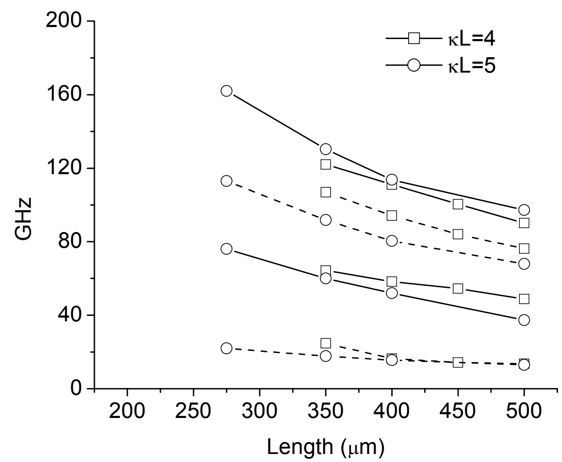


Minimum Section Length ≈275 μm for κL=5+i0.5

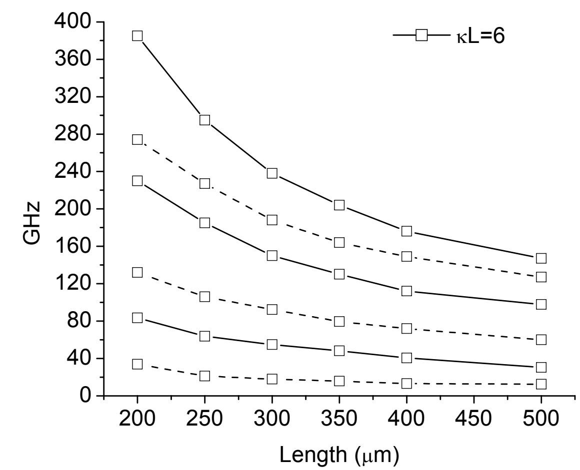
SSP Range vs. Coupling Strength (Bulk) $\delta\beta=38\ cm^{-1}$



Single SSP regime

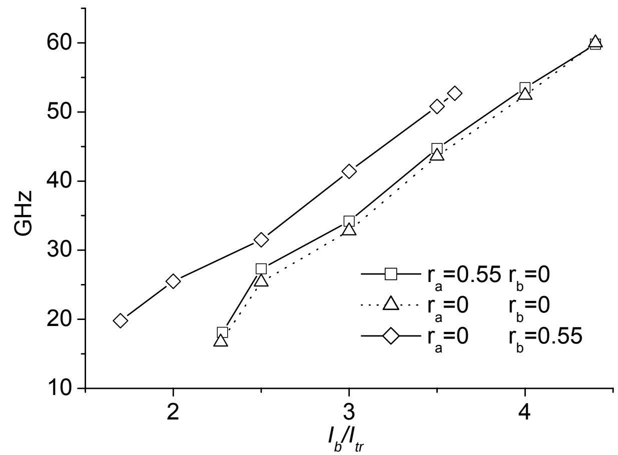


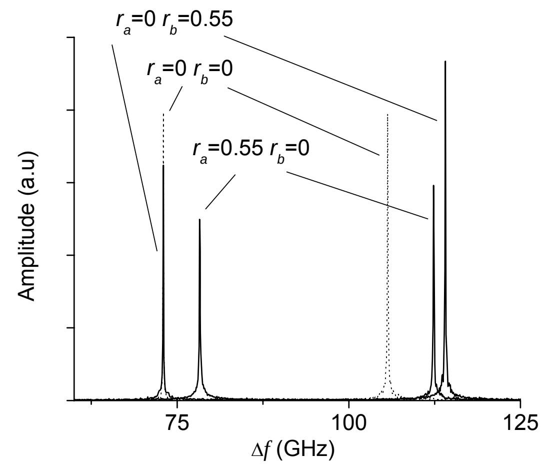
Two SSP regime

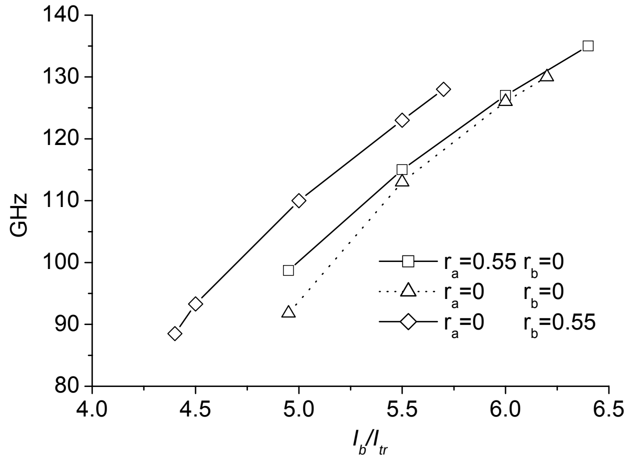


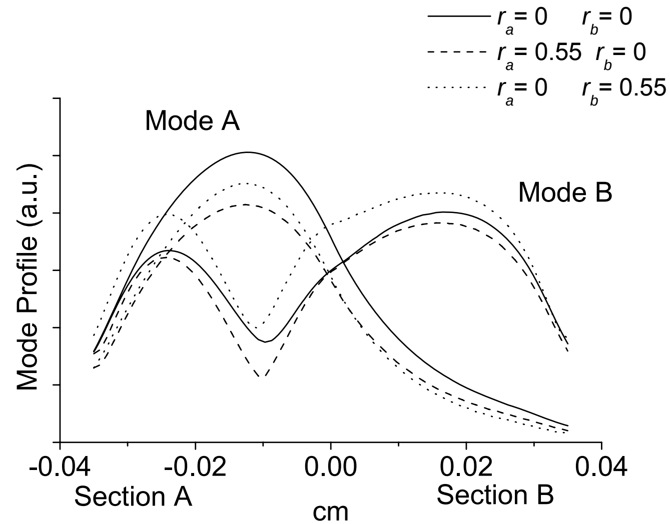
Three SSP regime

SSP and Facet Reflectivity

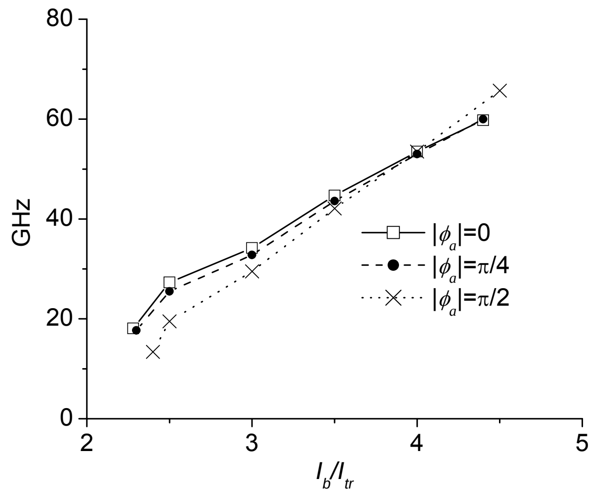


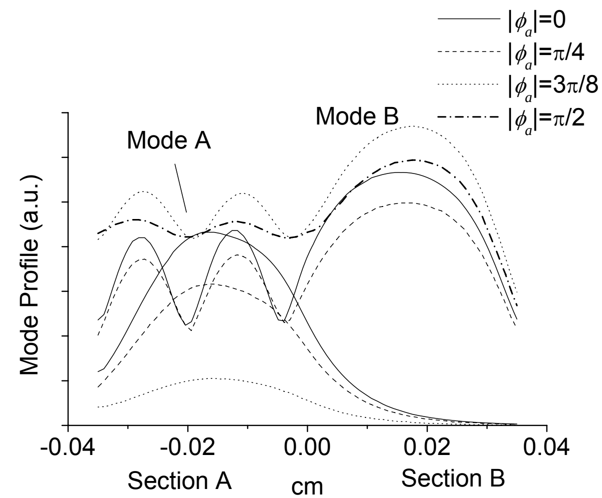


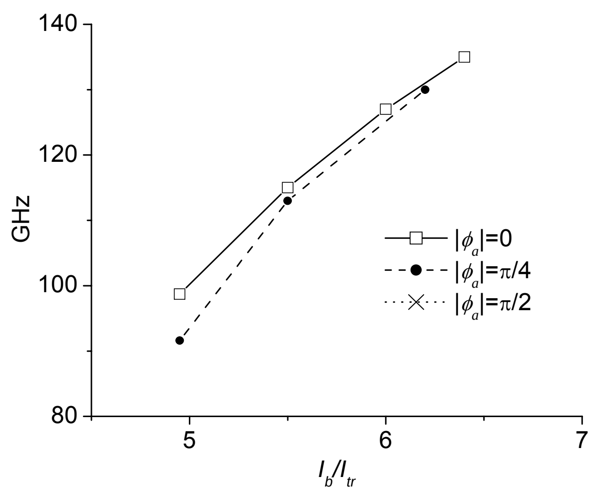


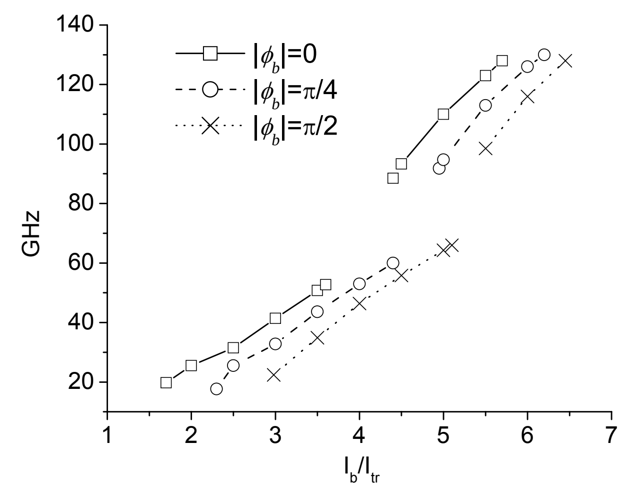


SSP and Facet Phase Condition









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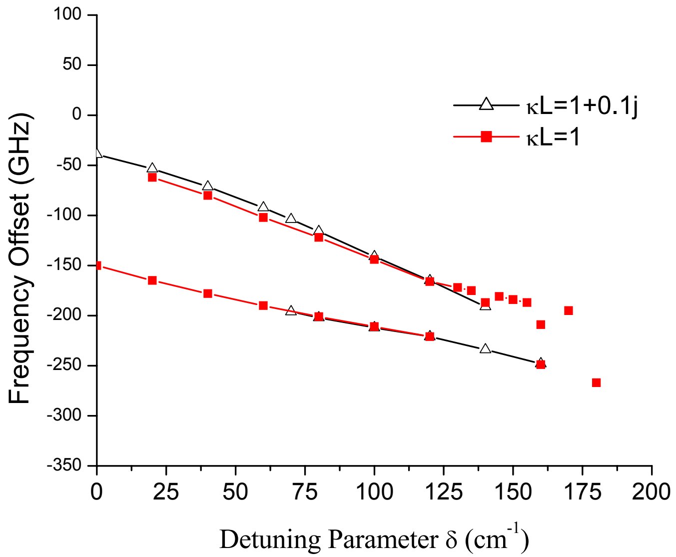
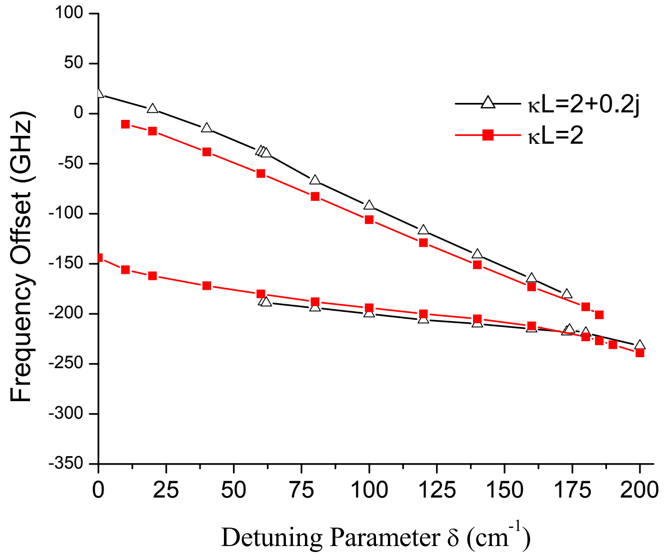
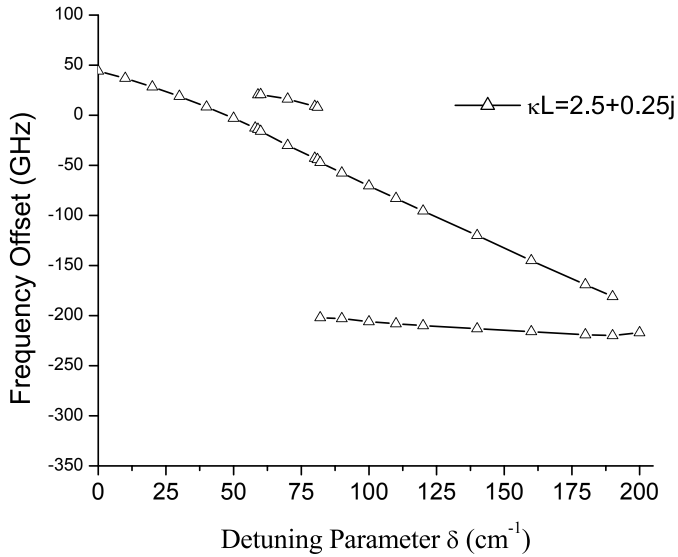
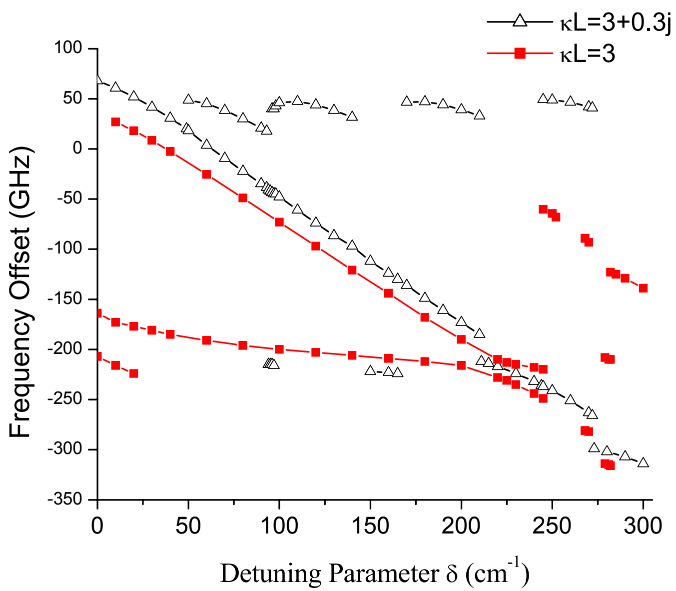
Degenerate Mode Beating –Weakly Coupled DFB lasers



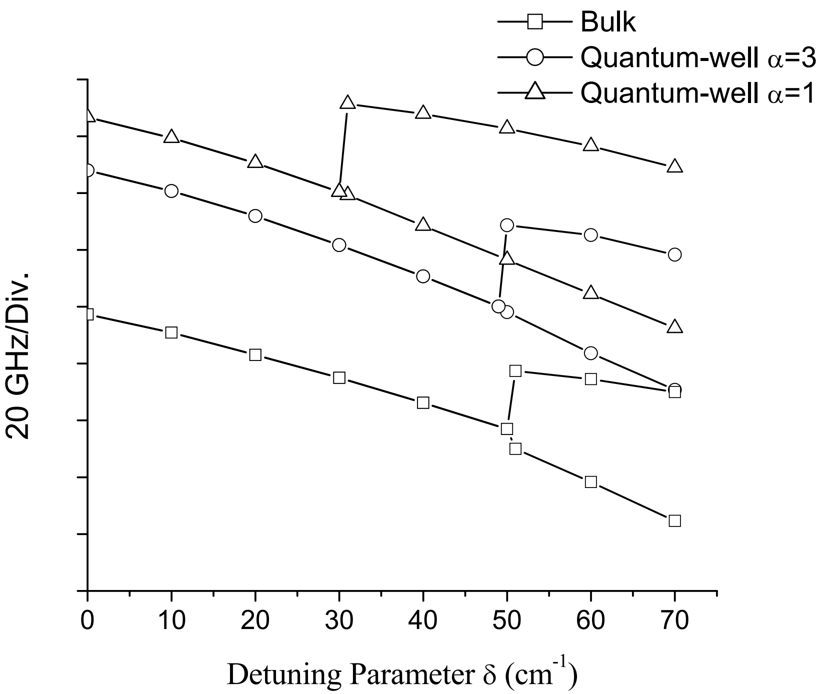


Non-Degenerate Mode Beating – Strongly Coupled DFB lasers

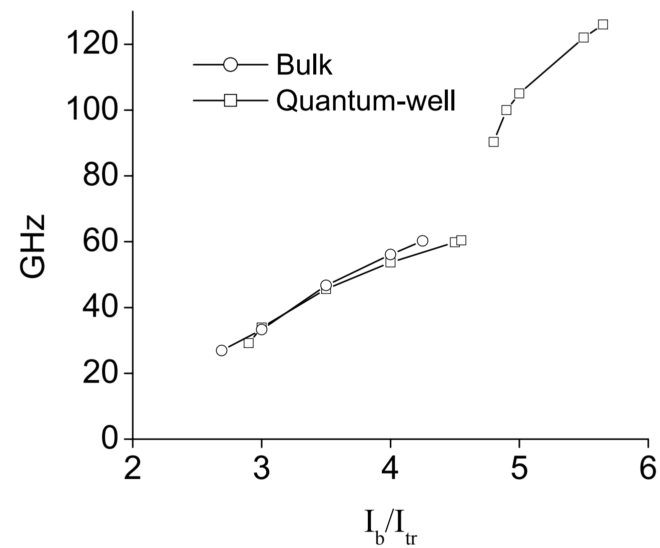




Modal Behavior and SSP frequency (κl=3)



Lasing frequency offset as a function of the detuning parameter δ.



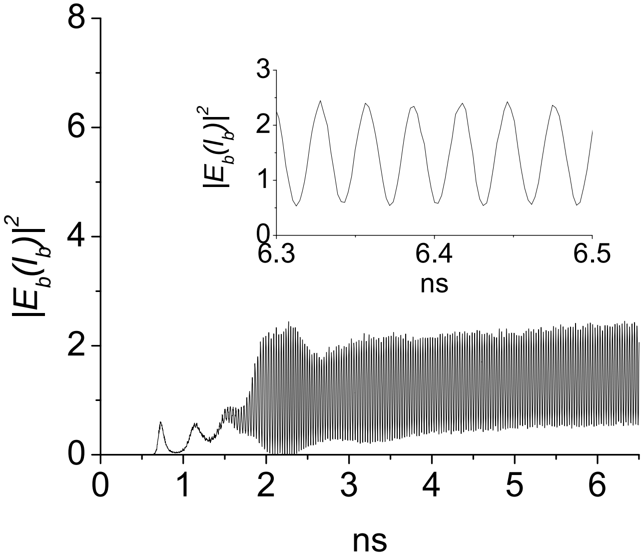
Self-pulsation frequency vs. bias current of section B with $I_a=3I_{tr}$.

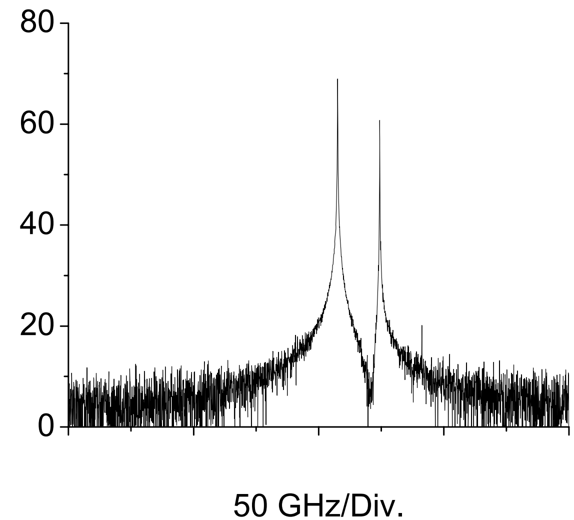
α=1 δ_{min}=31 cm^{-1} Quantum

α=3 δ_{min}=50 cm^{-1} Quantum

α=3 δ_{min}=50 cm^{-1} Bulk

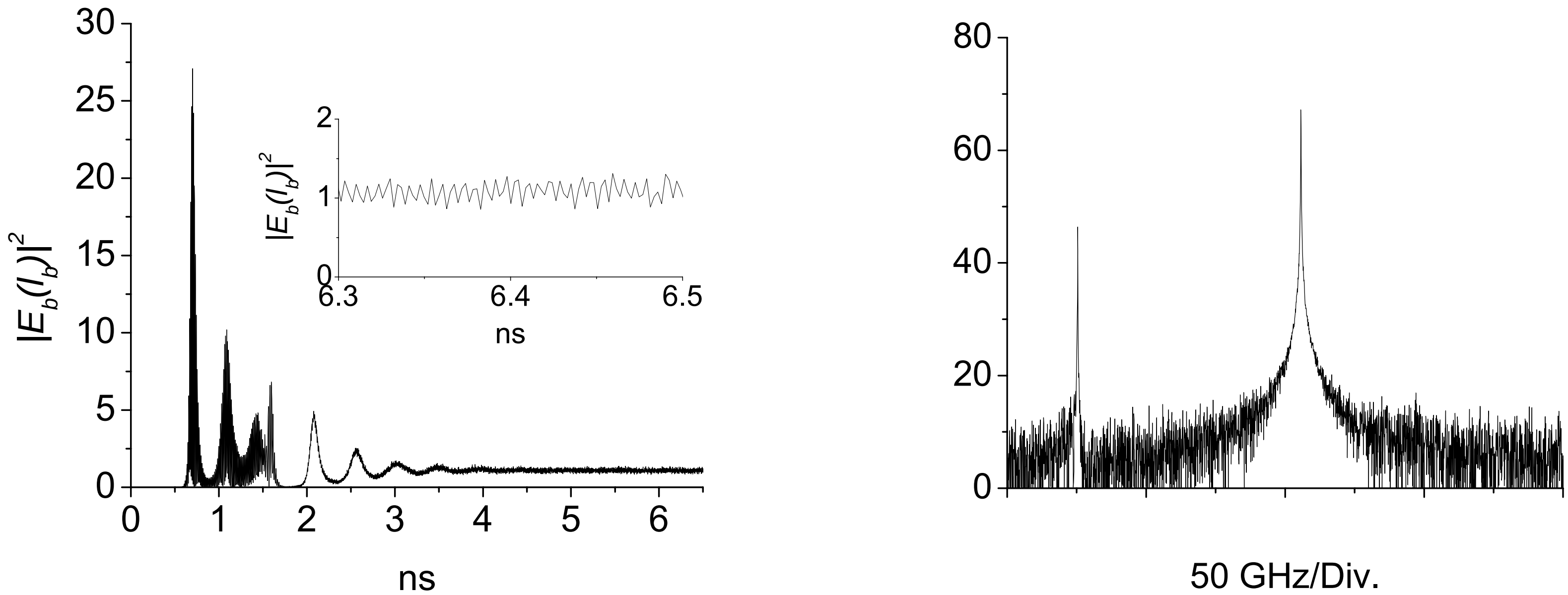
1^{st} SSP Regime





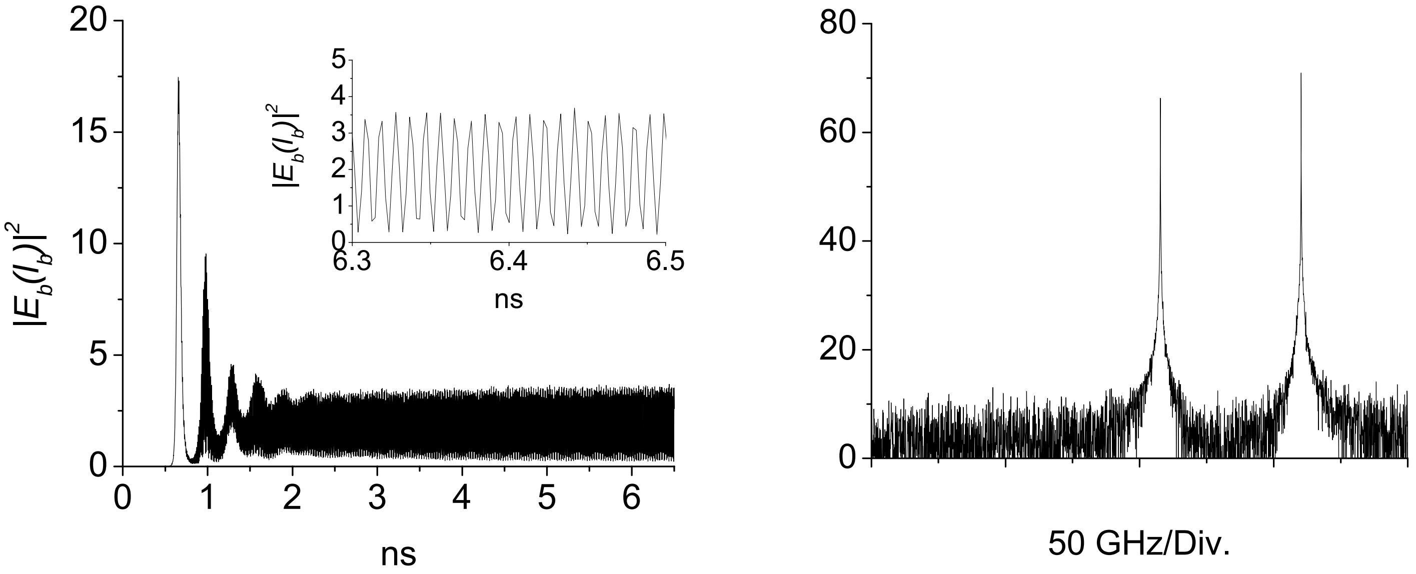
The transient response and the optical power spectrum at the facet of section A for $I_a = 3I_{tr}$ and $I_b = 3I_{tr}$.

Transitional Regime



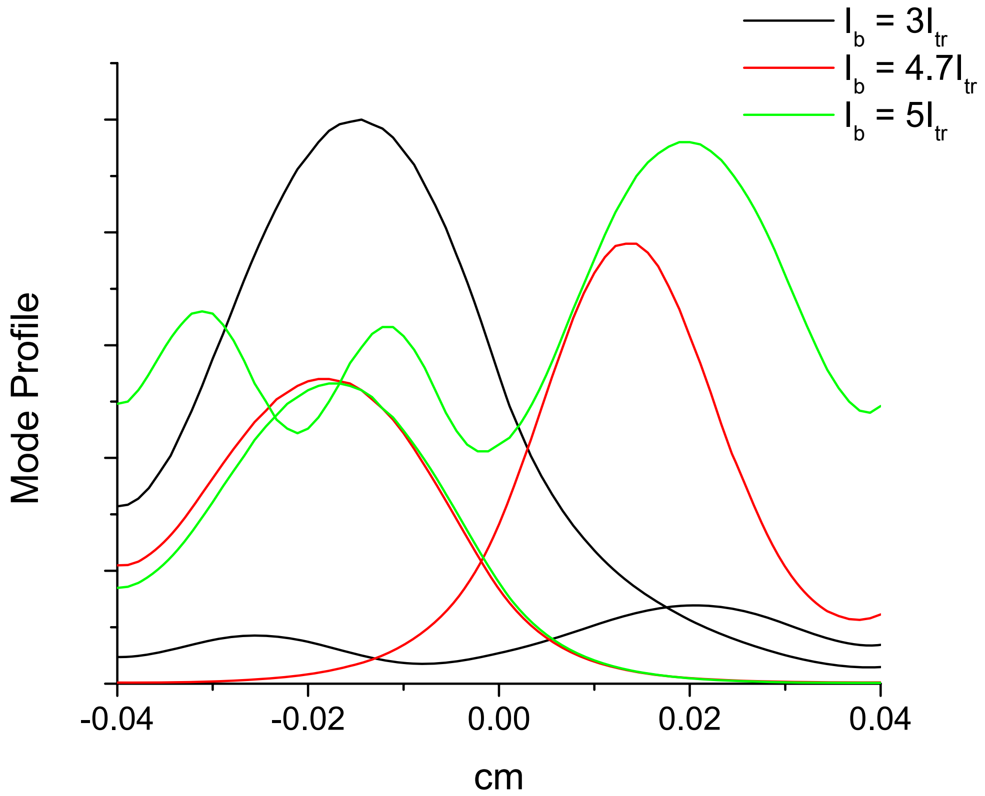
The transient response and the optical power spectrum at the facet of section A for $I_a = 3I_{tr}$ and $I_b = 4.7I_{tr}$.

2^{nd} SSP regime

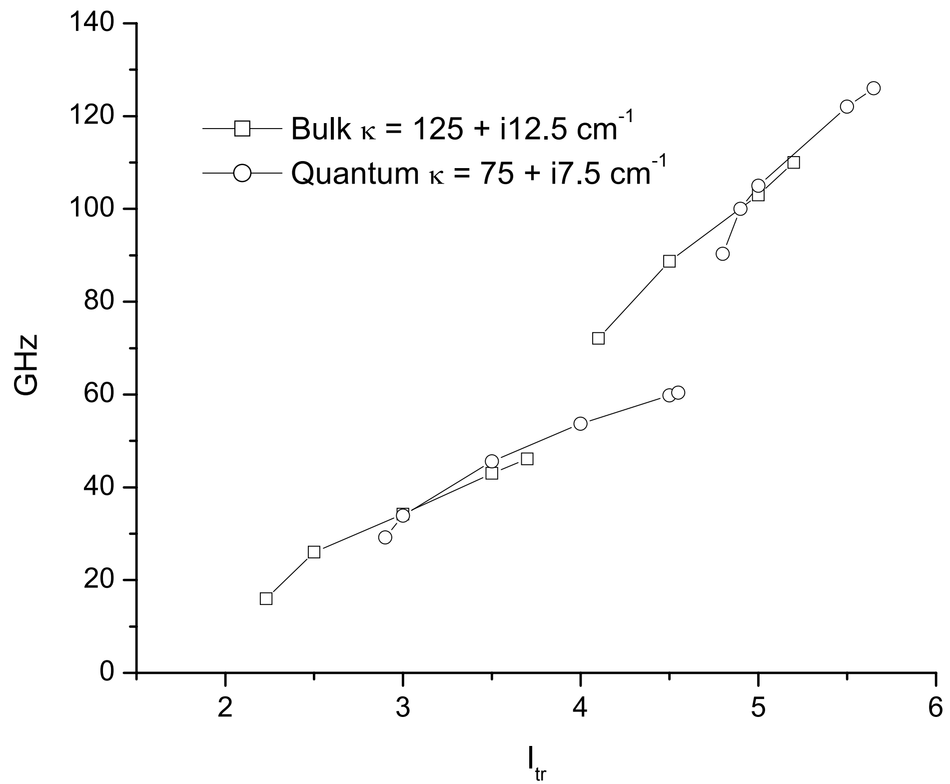


The transient response and the optical power spectrum at the facet of section A for $I_a = 3I_{tr}$ and $I_b = 5I_{tr}$.

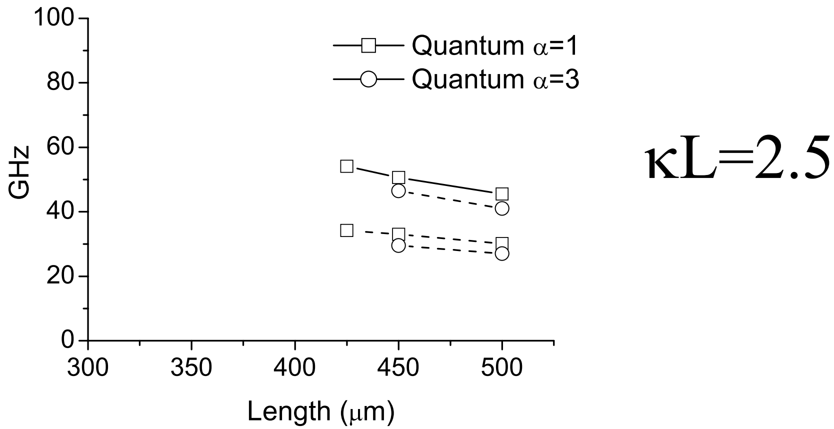
Modal Profile

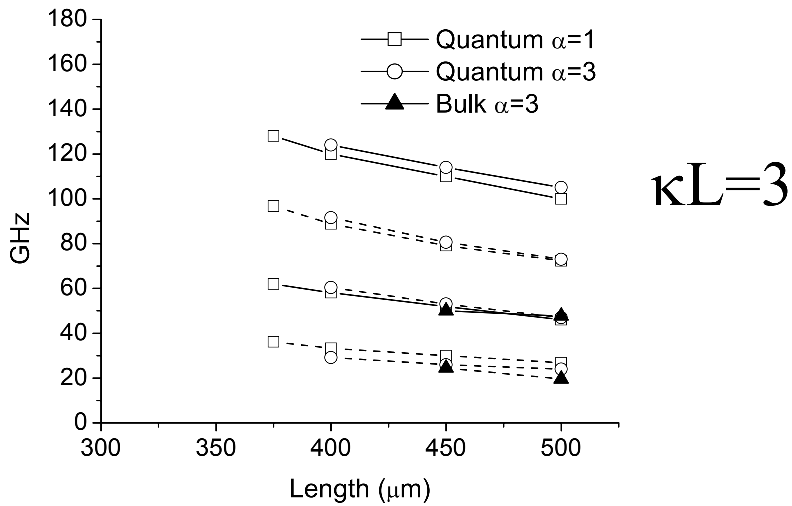


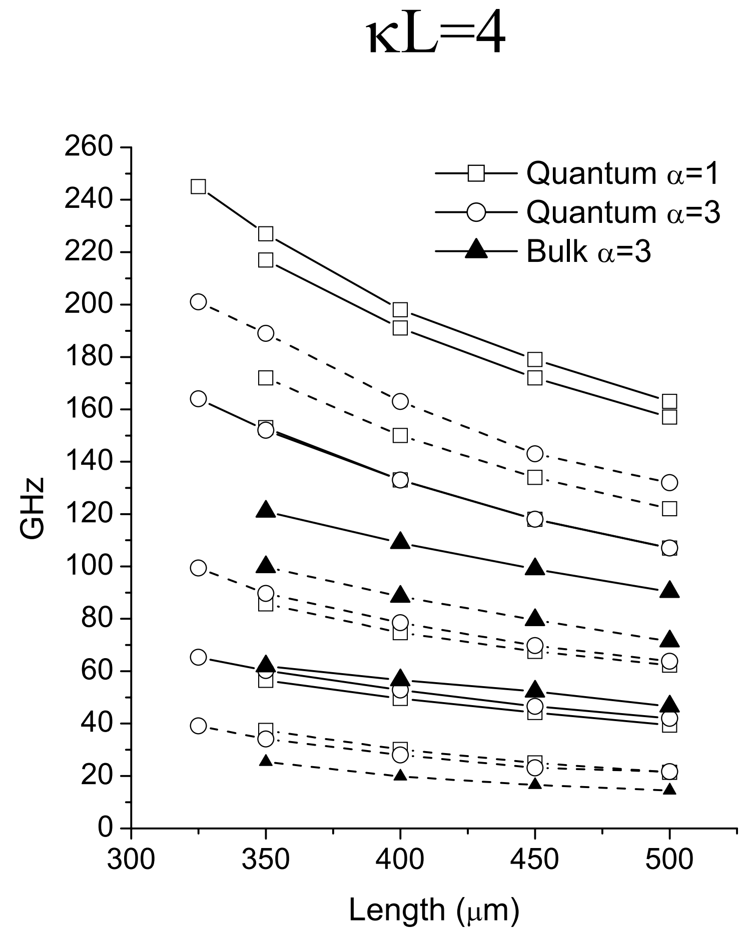
Two SSP regimes



SSP range vs. Coupling Strength







Summary

- A self-consistent model is able to predicted the general characteristics of two-section gain-coupled DFB lasers.
- Applying Quantum-Well parameters instead of Bulk parameter to the model allows the prediction of SSP behavior at a lower coupling strength.
- Degenerate and non degenerate mode beating is possible in partially two-section gain-coupled DFB lasers.

Acknowledgment

- Thanks to Wenzel H., Bandelow U., Wünsche H-J., Rehberg J., Radziunas M., Bauer S., Brox O., and Sartorius B. for the excellent work on Index-coupled two and multi-section self-pulsating DFB lasers.
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