The Effect of Gain/Loss-Coupling on Mode Beatings in Weakly Coupled Two-Section DFB Lasers

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Introduction

- DFB Self-pulsating devices reported in the literature –

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

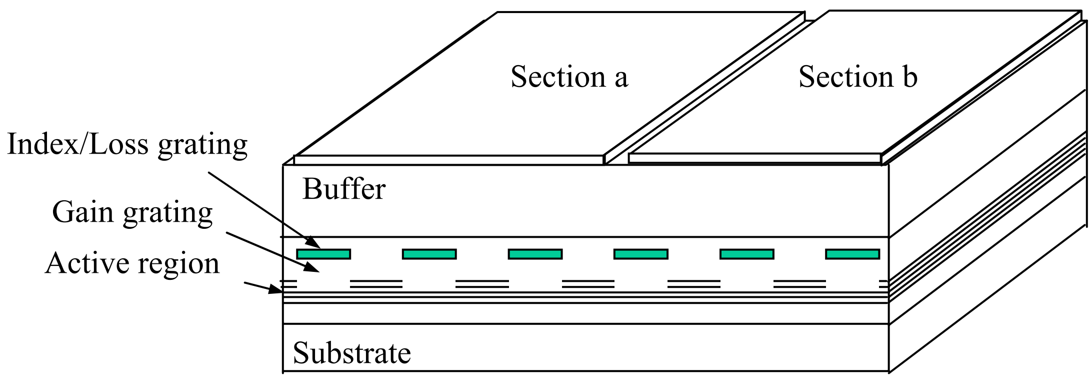
  Three Section: Three DFB sections, Two DFB sections and a center phase section.
- Application include –
- All-optical clock recovery, Wireless Fiber Links, Terahertz generation.
- Motivation –

  Having Predicted Symmetrical and Asymmetrical mode-beating in partially gain-coupled DFB lasers

  – In the symmetrical mode beating case, does the modal dynamics differ from that of Index-coupled DFB lasers?

  – What about Loss-coupled DFB lasers?

Complex-Coupled Two-Section DFB Lasers

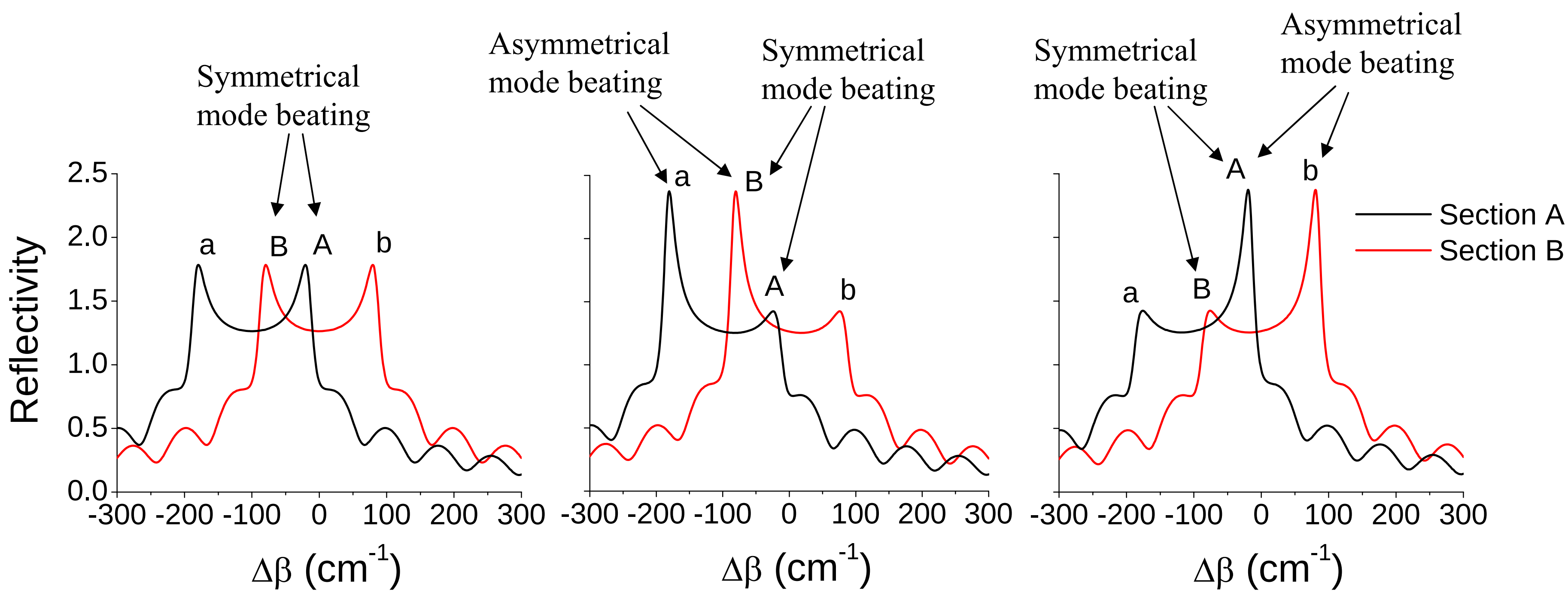


- Index-coupling $n(z) = n_{eff,0} + \Delta n_{eff} A_n \cos(2\pi z/\lambda + \varphi_g)$
- Loss-coupling $\alpha(z) = \alpha_0 + \Delta \alpha_0 A_L \cos(2\pi z/\lambda + \varphi_g)$
- Gain-coupling $g(z) = g_0 + \Delta g_0 A_g \cos(2\pi z/\lambda + \varphi_g)$

$$\kappa = \frac{\pi}{\lambda} A_n \Delta n_{eff} + \frac{j}{4}\left(A_g \Delta g_0 - A_L \Delta \alpha_0\right)$$

Björn et al. "Instabilities and Nonlinear L-I Characteristics in Complex-Coupled DFB Lasers with Anti-Phase Gain and Index Grating", J. Quant. Elect. Vol. 32 no. 5 May 1996

Reflectivity Spectra



Index-coupled Loss-coupled Gain-coupled

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

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

Only gain-coupled

The inclusion of Wavelength Tuning

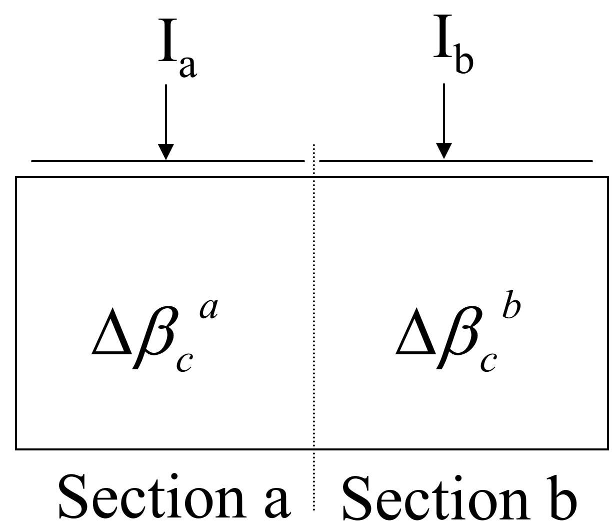
$$G(z,t) = \Gamma_x g_n \left(N(z,t) - N_0\right)\left[\frac{1}{1+\varepsilon P(z,t)} - i\alpha\right] - \Gamma + i\Delta\beta(z),$$

$$\delta = \delta_s + \delta_I + \delta_c,$$

$$\delta_s = \beta_B(A) - \beta_A(B) = \frac{\pi}{\Lambda_A} - \frac{\pi}{\Lambda_B},$$

$$\delta_I = \frac{\delta\beta_B}{\delta I}\Delta I,$$

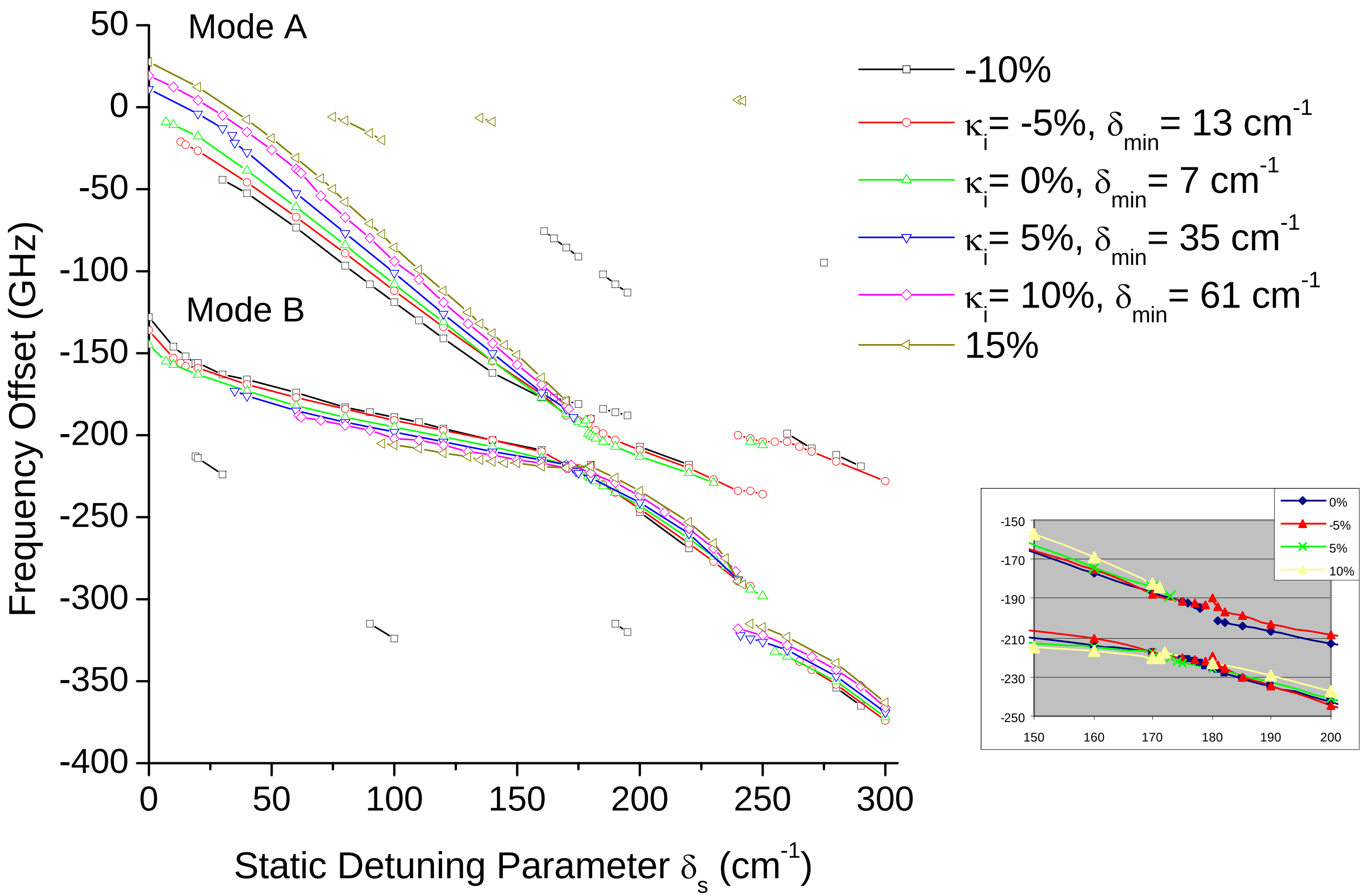
$$\delta_c = \frac{2\pi}{\lambda}\left(\overline{n}_{eff}(A) - \overline{n}_{eff}(B)\right) = \alpha\Gamma g_n\left(\overline{N}_A - \overline{N}_B\right),$$



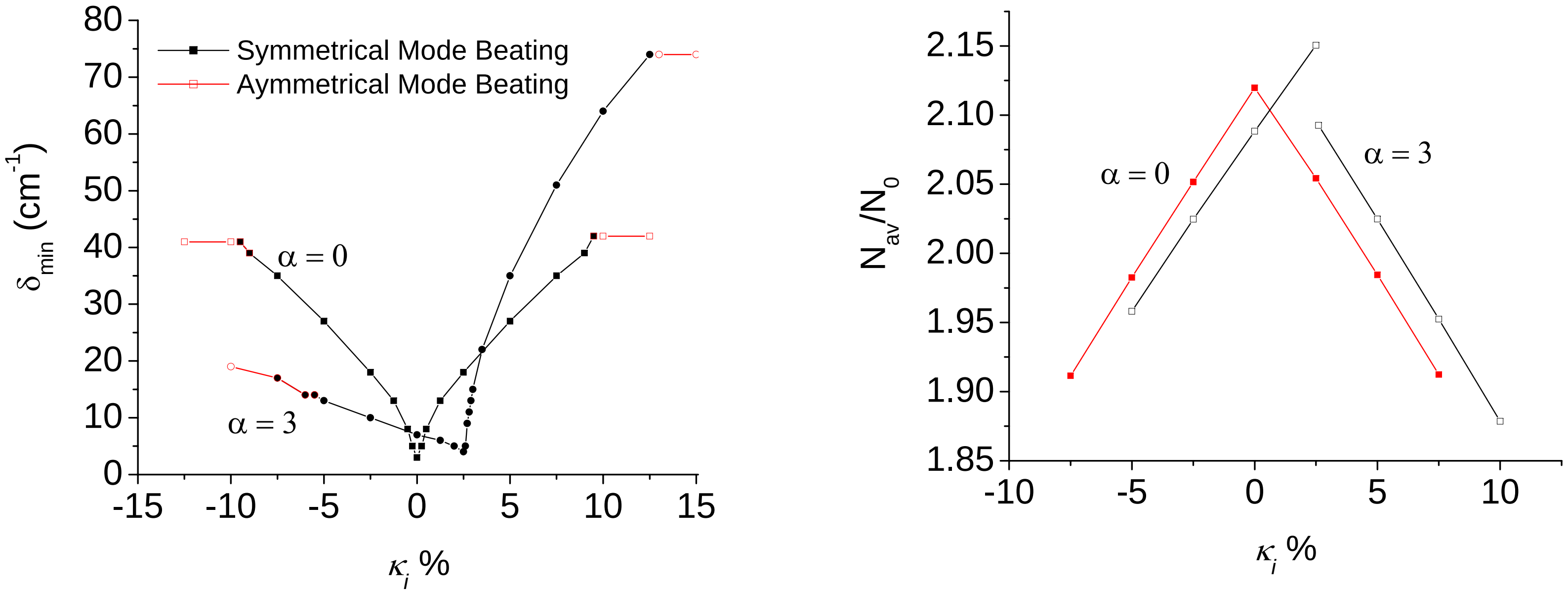
Device Parameter

Symbol	Description	Quantity
L	Section Length	400 μm
κ_r	Coupling Constant	50 cm^{-1}
N_0	Carrier density at transparency	1.5×10^{18} cm^{-3}
g_n	Differential gain	3×10^{-16} cm^2
Γ_x	Confinement factor	0.068
λ_B	Free space wavelength	1.55×10^{-4} cm
Γ	Cavity loss	20 cm^{-1}
α	linewidth enhancement factor	3
τ	Carrier lifetime	1.25 ns
ε	Nonlinear gain coefficient	1×10^{-17} cm^3
n_{sp}	Spontaneous emission factor	2
n_{eff}	Effective refractive index	3.7
n_g	Group refractive index	3.55
$\delta\beta/\delta(I/I_{tr})$	Temperature induced shift in Bragg condition	-30 cm^{-1}

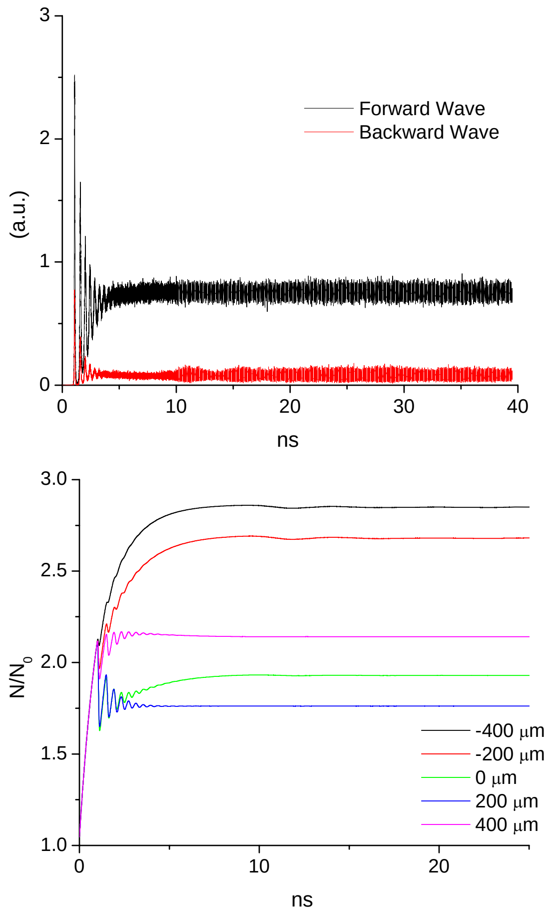
Predicted Modes vs Static Detuning



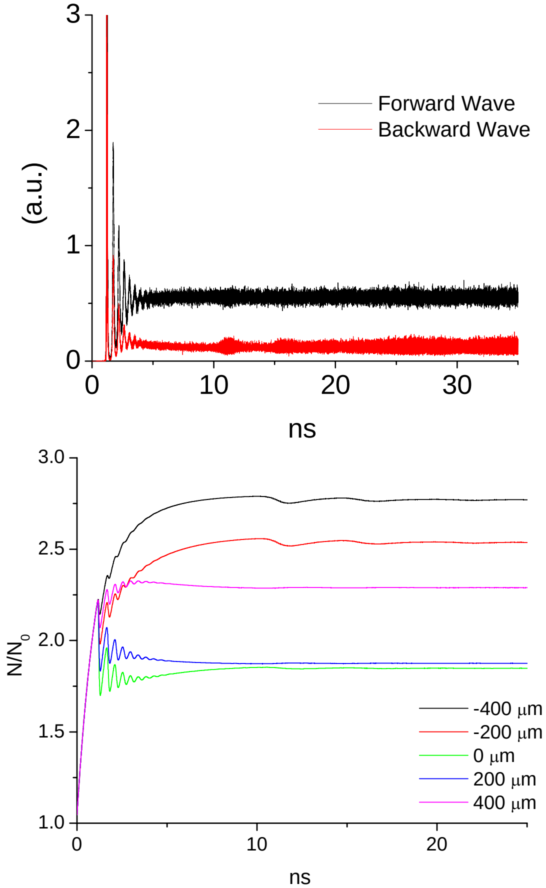
Minimum Static Detuning vs.κ_i %



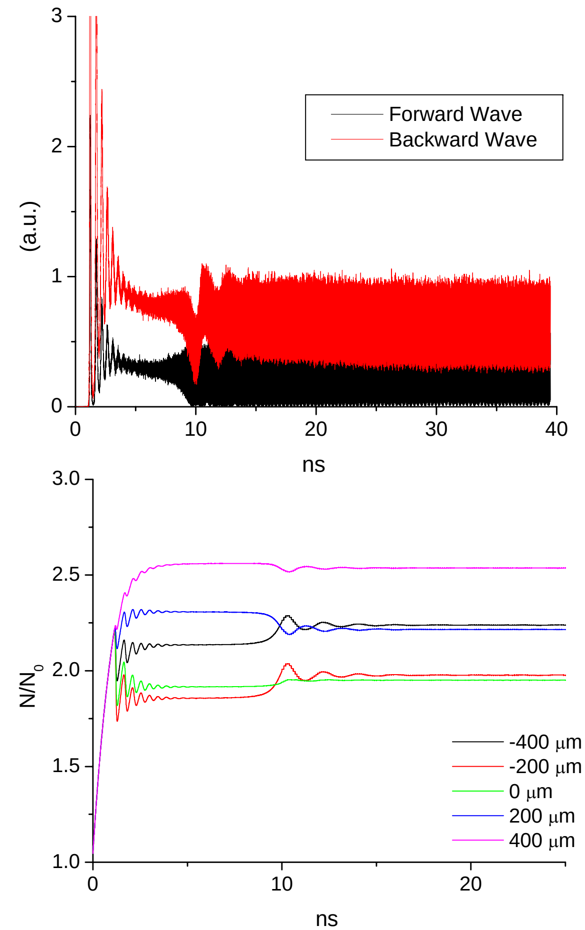
Minimum Static Detuning LC, IC and GC



κ_i =-5% δs = 13 cm^{-1}

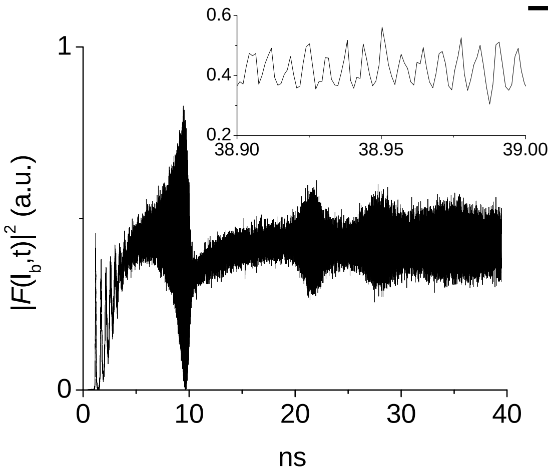


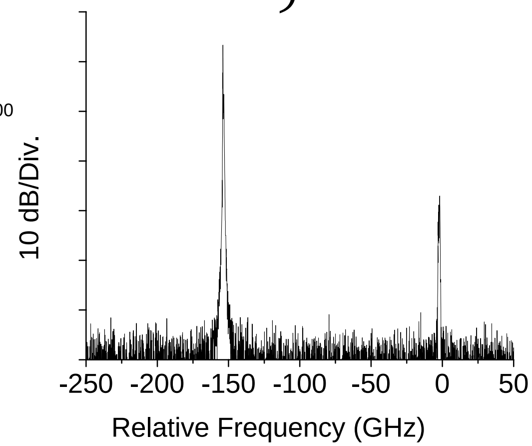
κ_i = 0% δs = 7 cm^{-1}

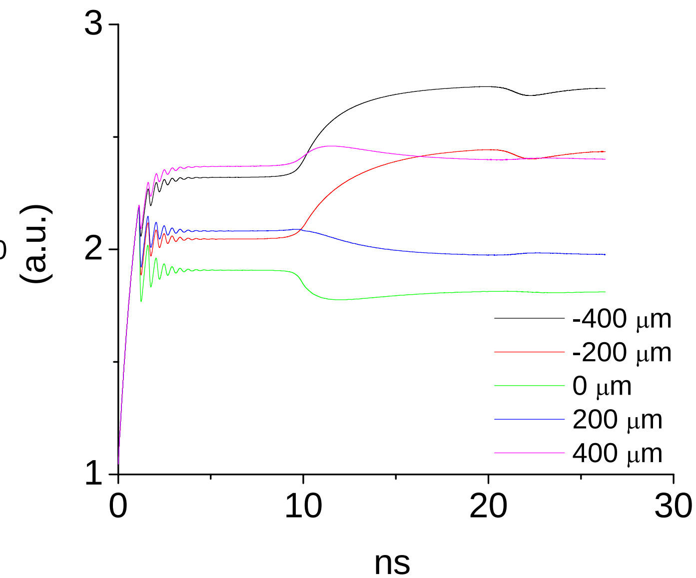


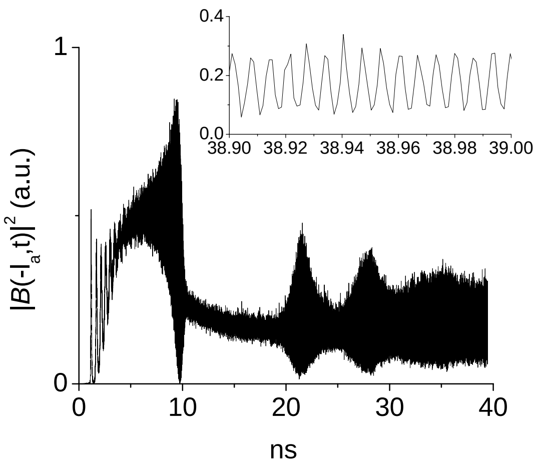
κ_i = 5% δs = 35 cm^{-1}

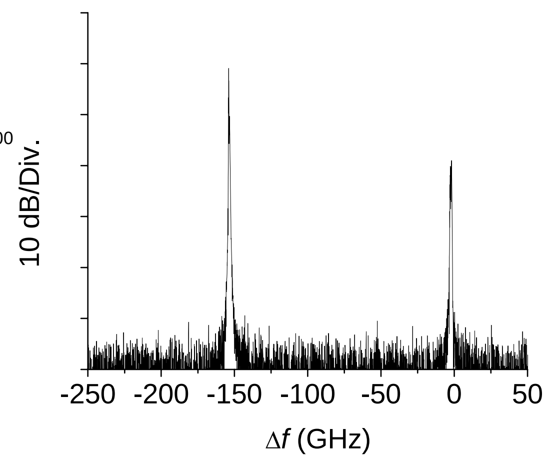
Minimum Static Detuning at κ_i =2.5%, δs = 4 cm^{-1}



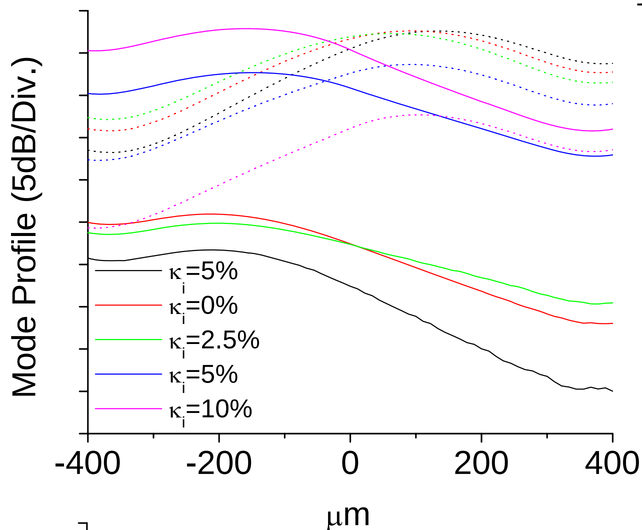


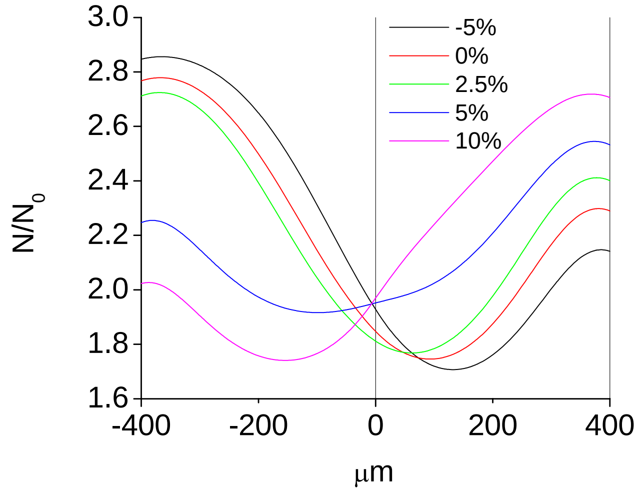




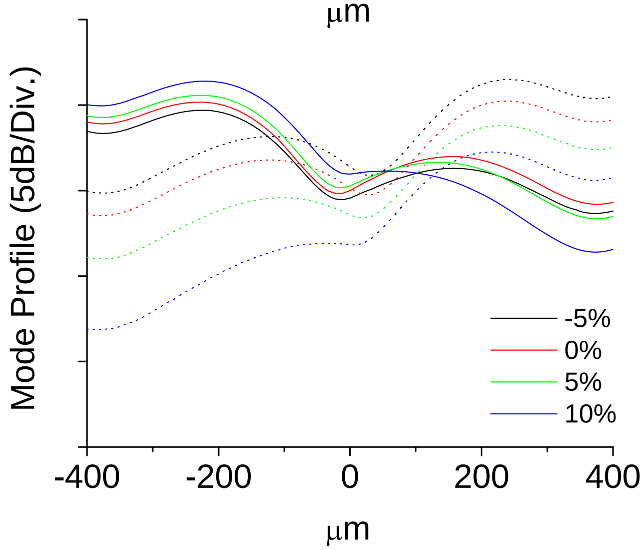


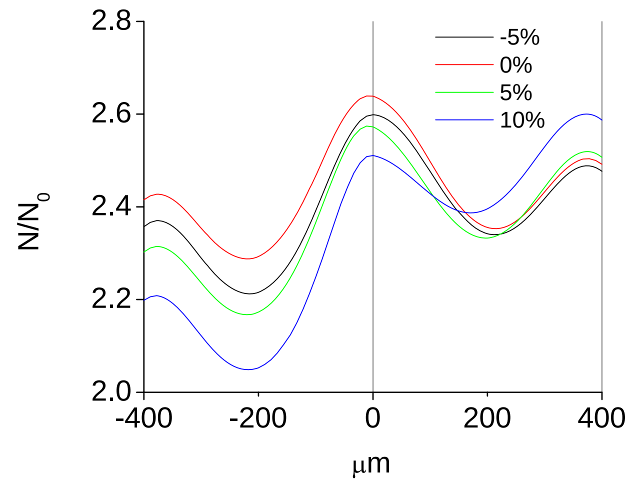
Mode Profiles and Carrier Distribution





Minimum detuning range.





Minimum self-pulsation frequency

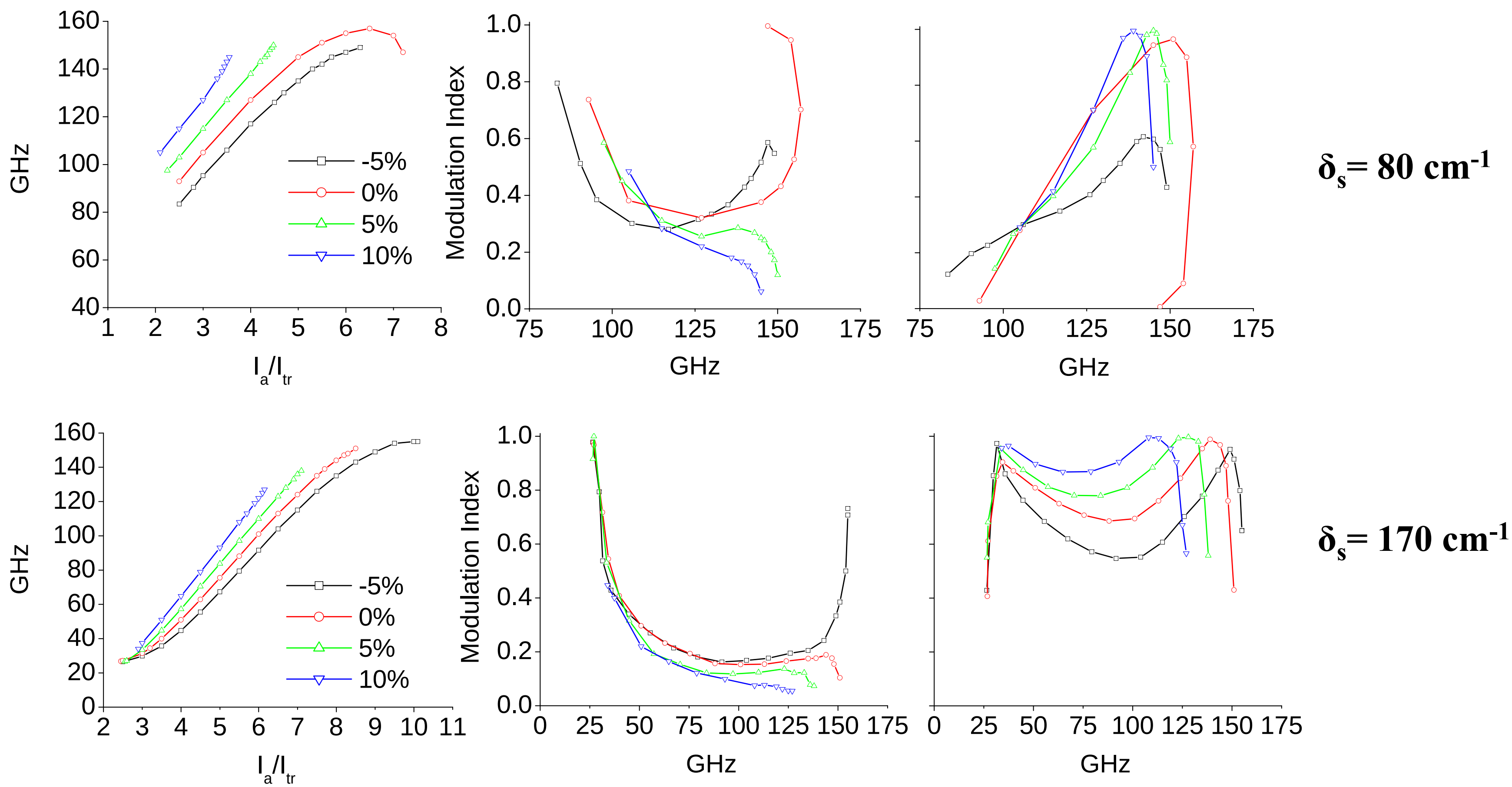
κ_i=-5% δ_s= 175 cm^{-1}

κi= 0% δs= 175 cm^{-1}

κi= 5% δs= 173 cm^{-1}

κi=10% δs= 171 cm^{-1}

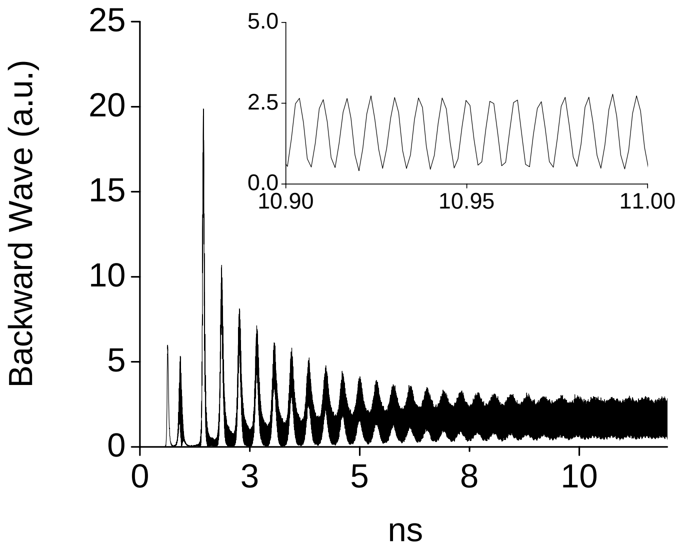
Tuning Range and Modulation Index

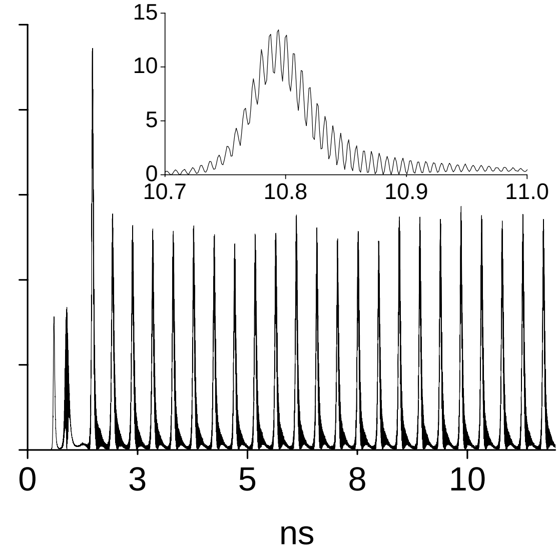


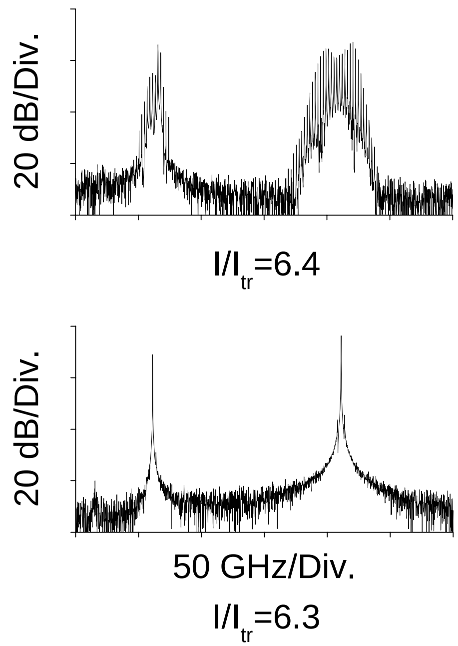
Self-pulsation frequency as a function of Ia with Ib=3Itr, (b) index of the forward wave at the facet of section B, (c) Modulation and the modulation index of the backward wave at the facet of section A (Top - δs=80 cm^{-1}, Bottom δs=170 cm^{-1}).

Temporal Response Loss-Coupled

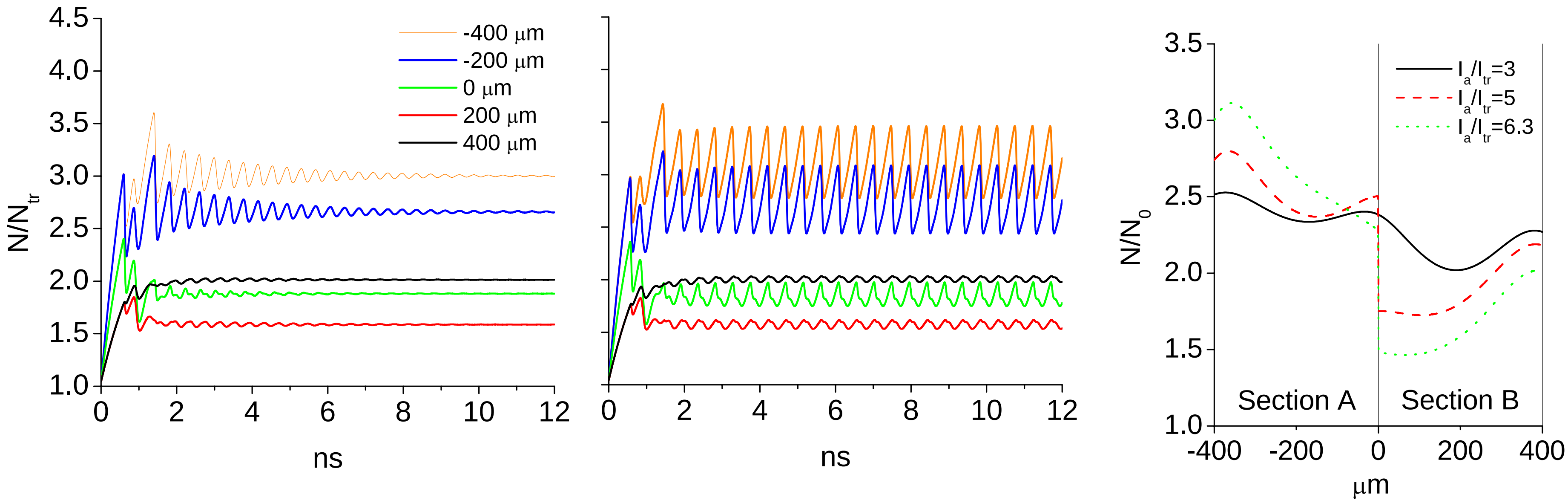
2.12 GHz mode spacing





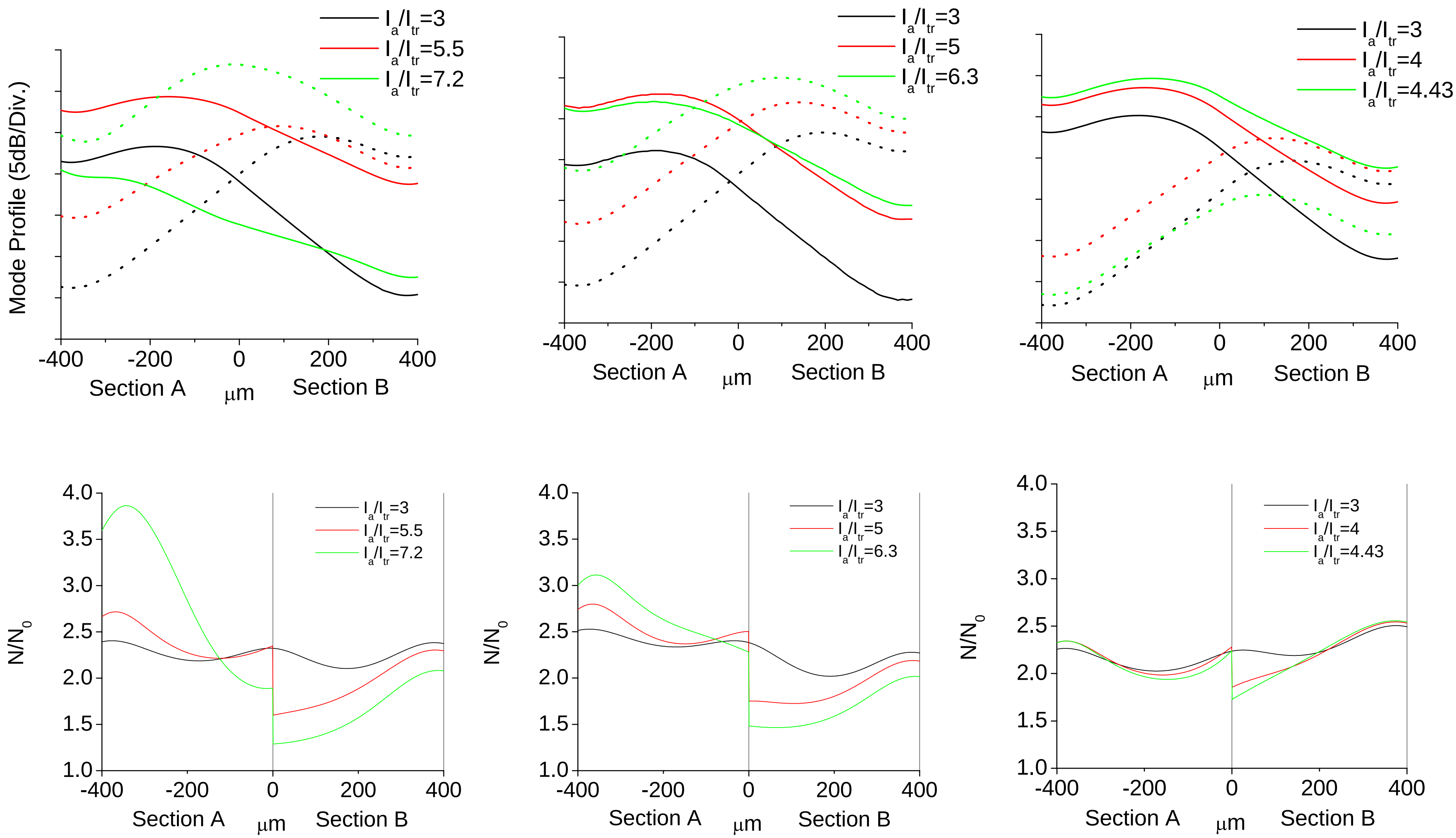


Carrier Response Loss-Coupled



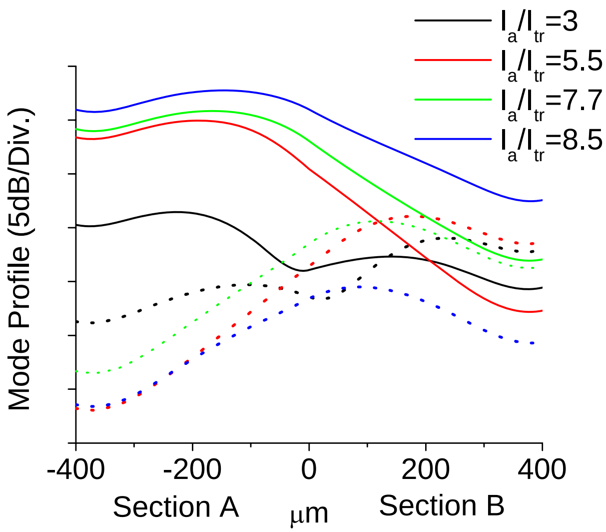
Modes Profiles (δ_s=80 cm^{-1})

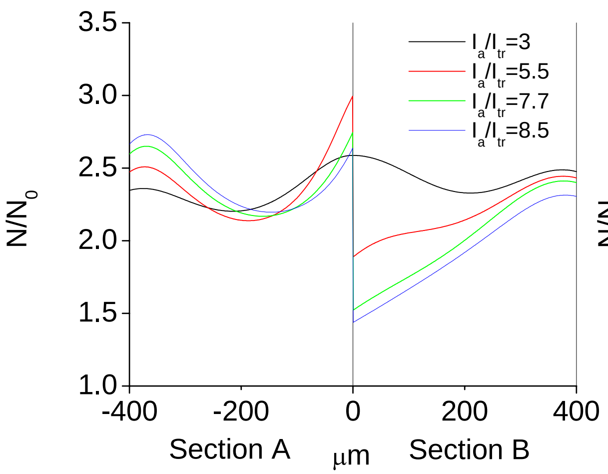
IC LC GC



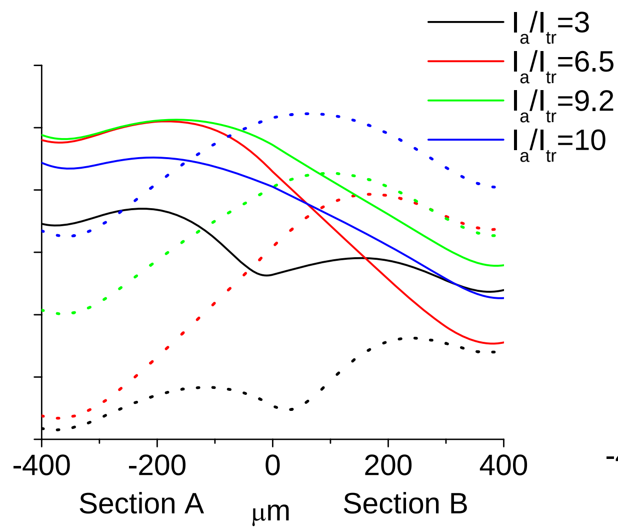
Modes Profiles (δ_s=170 cm^{-1})

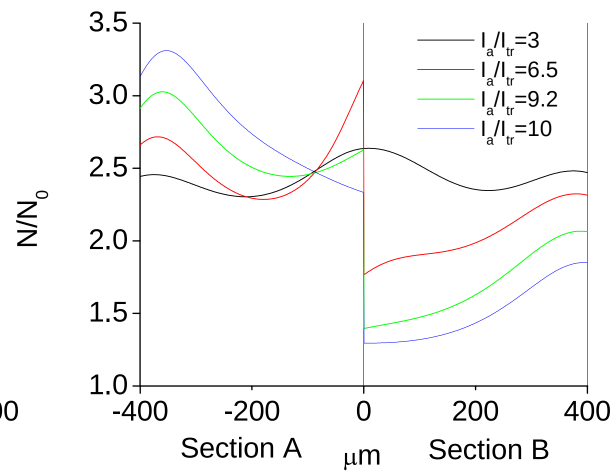
IC



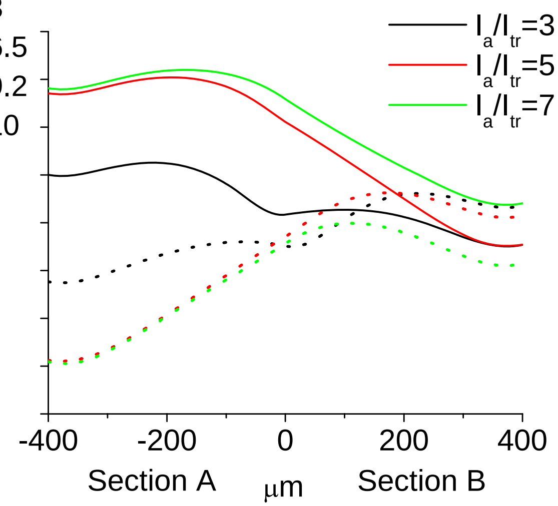


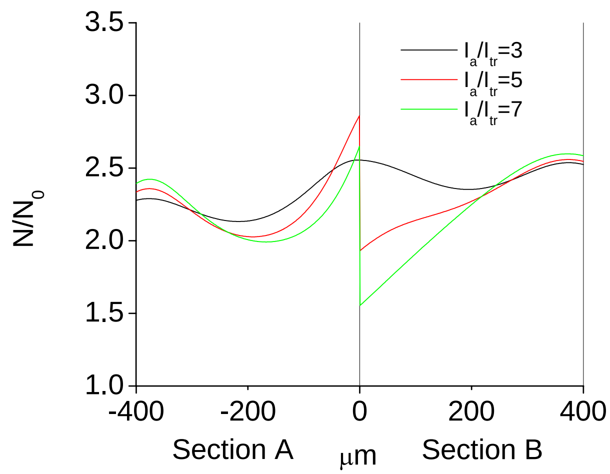
LC



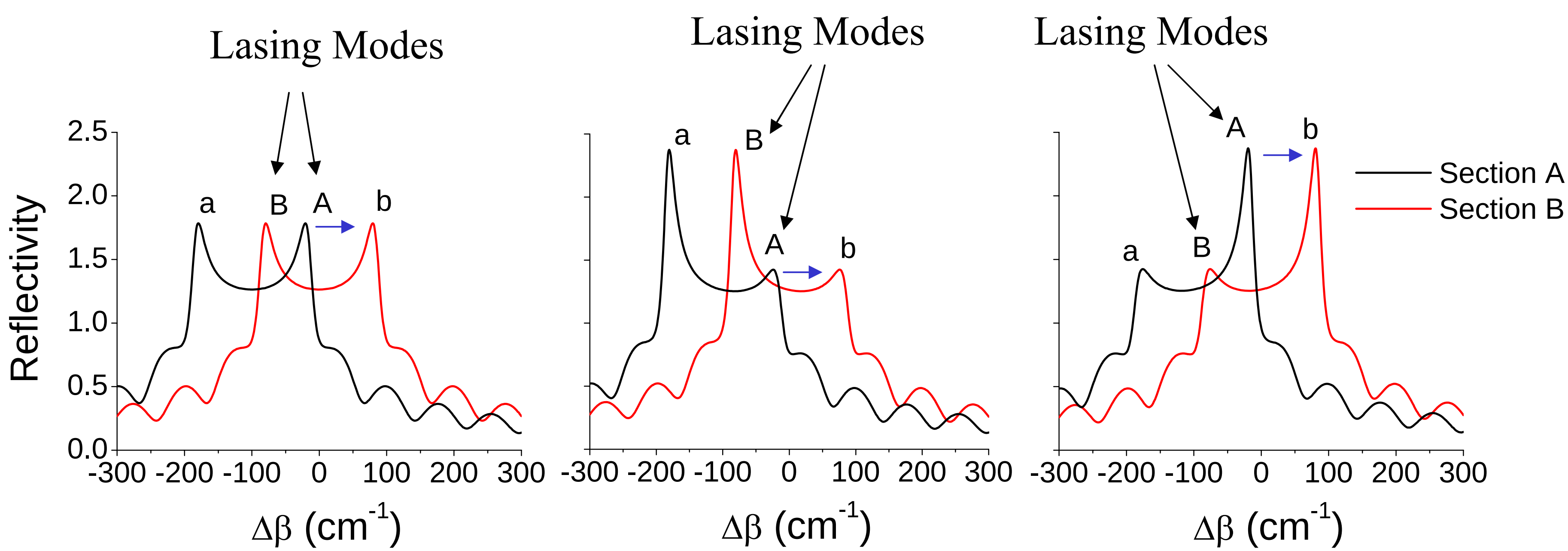


GC





Reflectivity Spectra



Index-coupled Loss-coupled Gain-coupled

Modal Dynamics

- Loss-coupled DFB lasers – When the current of section A is increased, mode B is also increased – Mode B is the dominant mode.
- Index-coupled DFB lasers – The dominant mode depends on the static detuning parameter.
- Gain-coupled DFB lasers –Mode A is the dominant mode.

Conclusion

- For 10% gain-coupled DFB laser - above 90% modulation index is predicted for self-pulsations between 34 and 123 GHz.
- For 5% loss-coupled DFB laser - above 50% modulation index is predicted for self-pulsations between 27 and 155 GHz.
- When the difference in current levels is large the self-pulsation become pulsed for loss-coupled DFB lasers
- The carrier levels are least sensitive to current levels in the case of gain-coupled DFB lasers.