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Linewidth Enhancement Factor Effects and Modulation Response Improvement Mechanism in Injection-Locked Semiconductor Lasers

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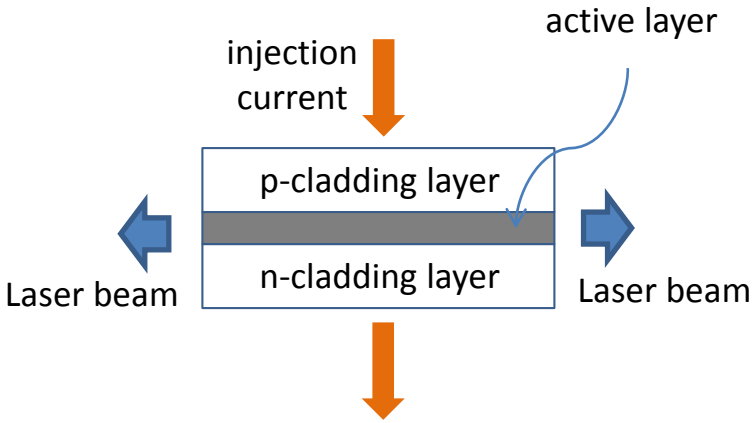
Introduction

Semiconductor Lasers

p-n junction

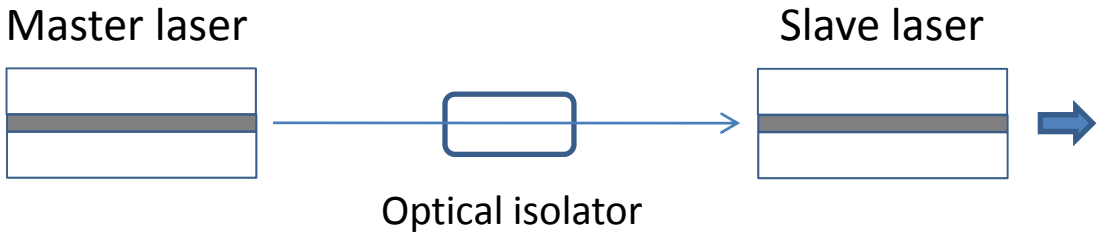
electron-hole recombination



Modulation of Injection Currents – applications in telecommunications

Modulation Response – how to achieve high speed

Injection-Locking – increasing the MR bandwidth



Removing the optical isolator simplifies experimental setups,
but complicates theoretical analysis: coupled-laser system

Coupled-Laser System

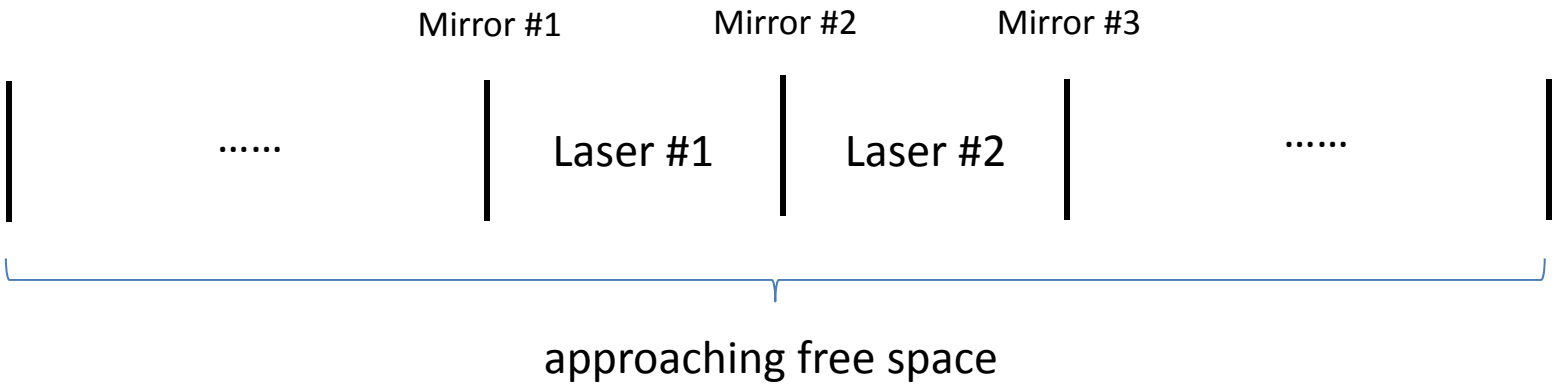
Schematic:

Laser cavities
DFB mirrors
Free space

Treated as a Combined System

Simplified Model:

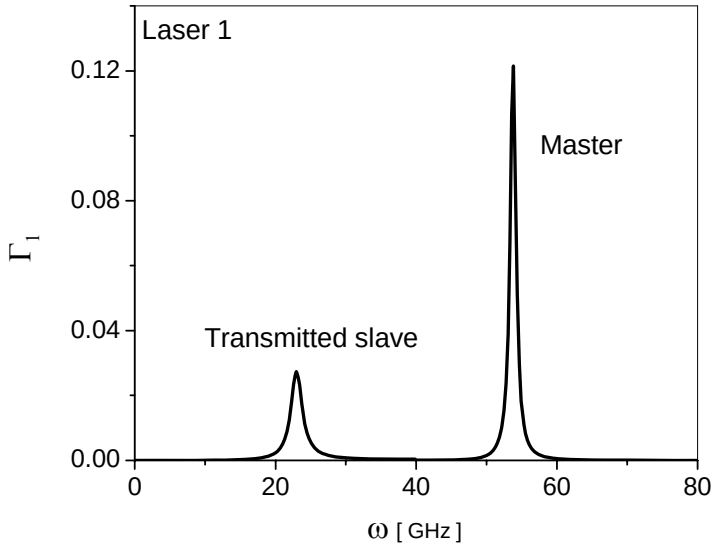
Cavities with effective lengths
Infinitely-thin mirrors
Free space modeled by a very large cavity

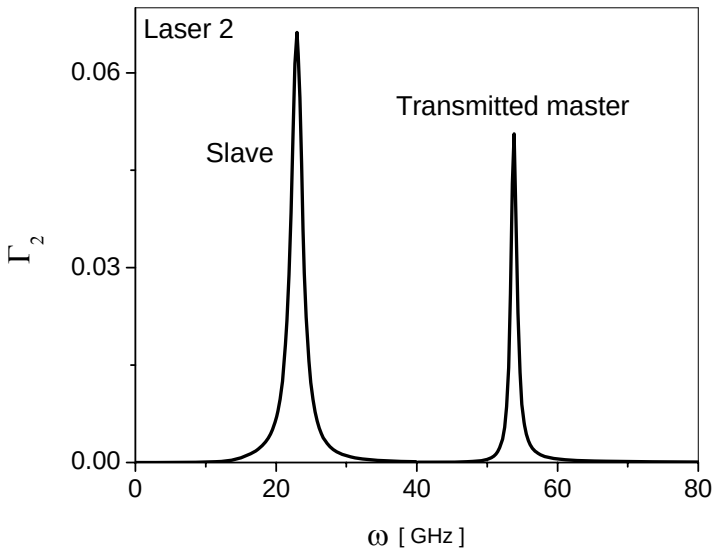


Coupled-Laser System

Passive-Cavity Composite-Mode Resonances

- Master and slave lasers
- Master and slave resonances





Theory and Simulations

Dynamical Equations:

$$\frac{dE_m}{dt} = \sum_n \left(\sum_r g_{mn}^{(r)} - \gamma_{mn} \right) e^{i2\pi(\omega_m - \omega_n)t} E_n$$

$$\frac{dN_r}{dt} = \frac{J_r}{ed} - \gamma N_r - \frac{\epsilon_b}{\hbar\omega_0} \sum_{mn} \mathrm{Re}\left[g_{mn}^{(r)} e^{i2\pi(\omega_m - \omega_n)t} E_m^{\star} E_n \right]$$

$$g_{mn}^{(r)} = (1 - i\alpha) A \int_r dz\, u_m(z)\, u_n(z) \left[N_r - N_{tr} \right]$$

$$\gamma_{mn} = (\mu_0 \epsilon_b)^{-1/2} \int_{\text{large}} dz\, u_m(z)\, u_n(z)\, \alpha_{abs}(z)$$

g_{mn}^{r} : Gain γ_{mn} : Loss

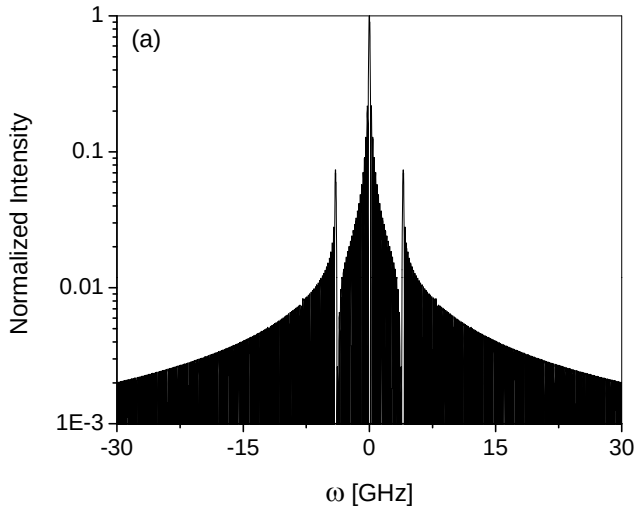
α : Linewidth Enhancement Factor

considerable influence on semiconductor laser behavior

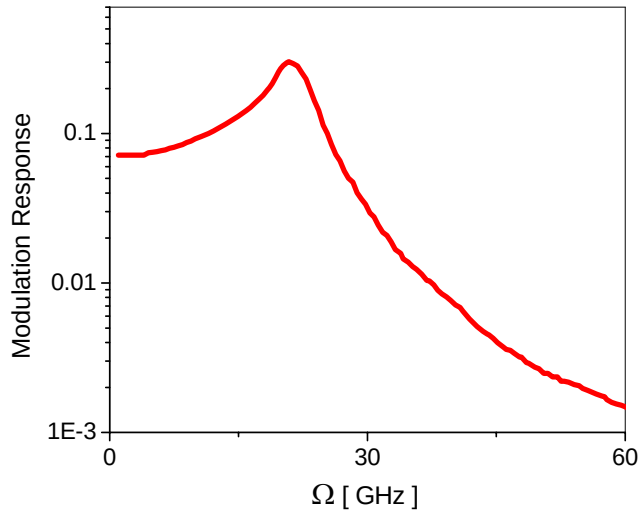
Theory and Simulations

Simulations: description of algorithm

Intensity Spectrum:



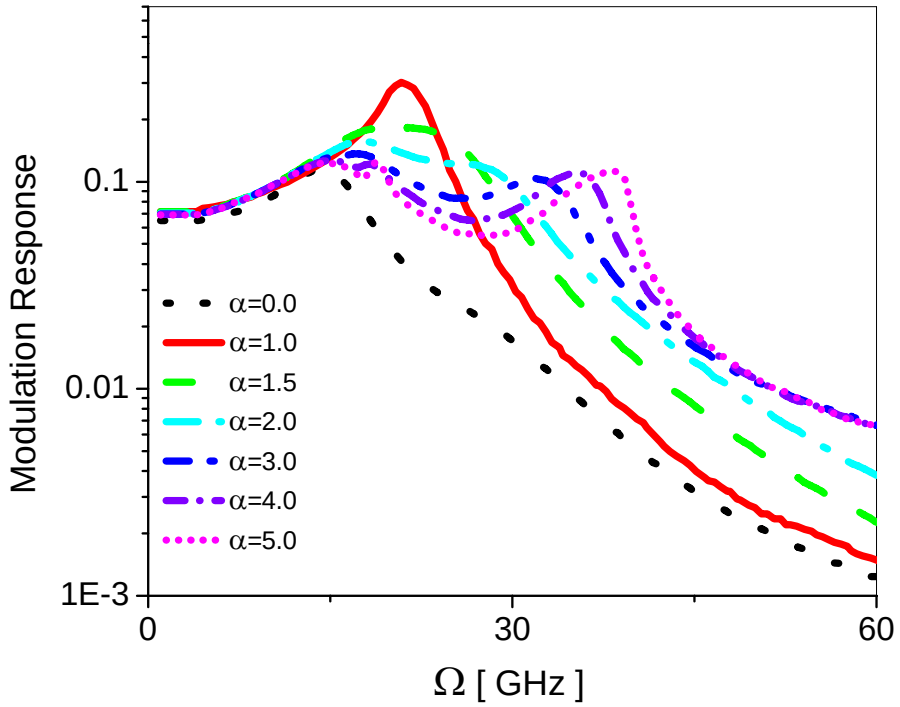
Modulation Response:



Theory and Simulations

Simulation Results:

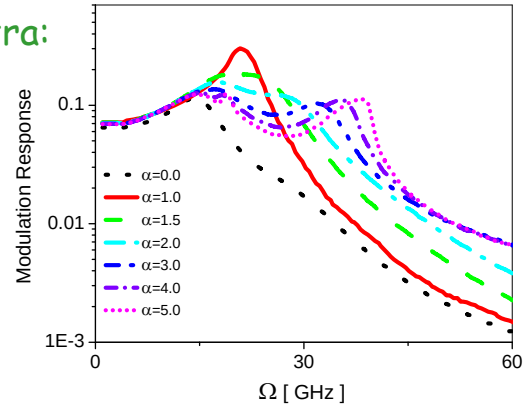
I. Modulation response spectra



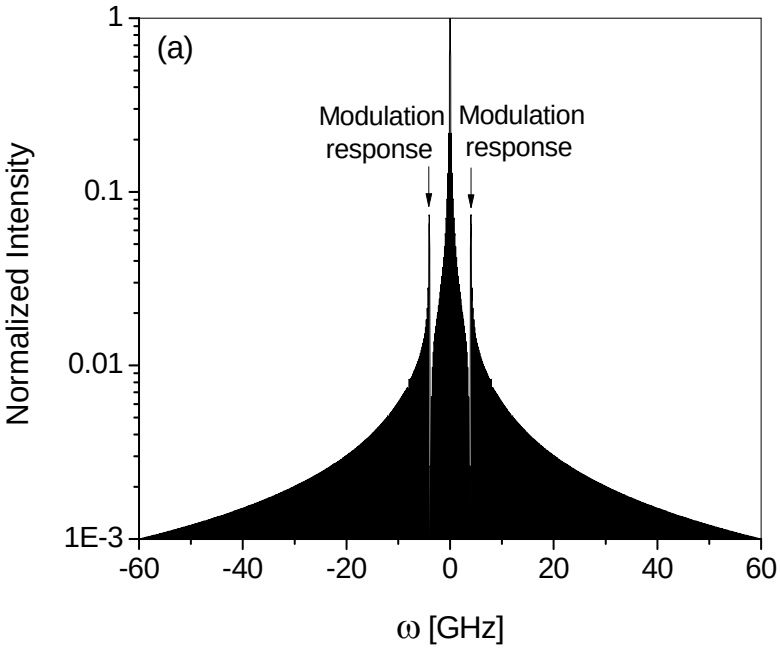
Theory and Simulations

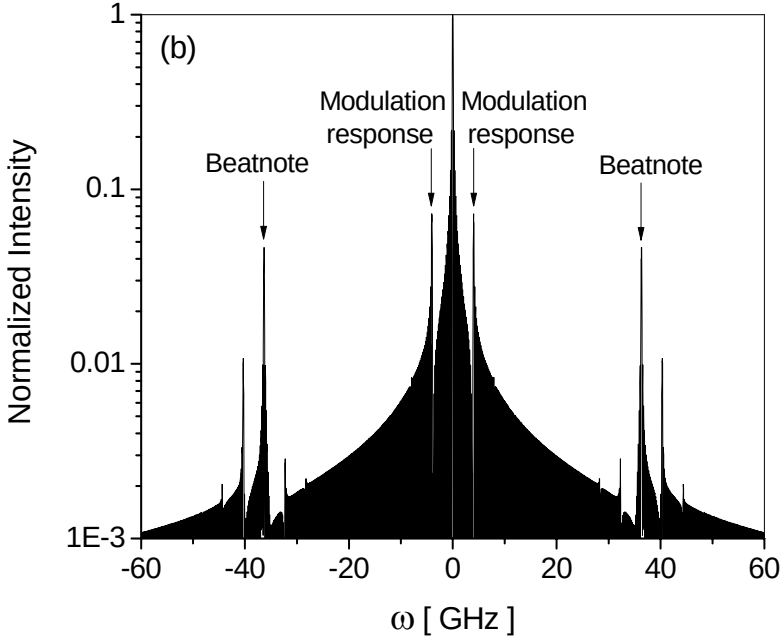
Simulation Results:

I. MR spectra:



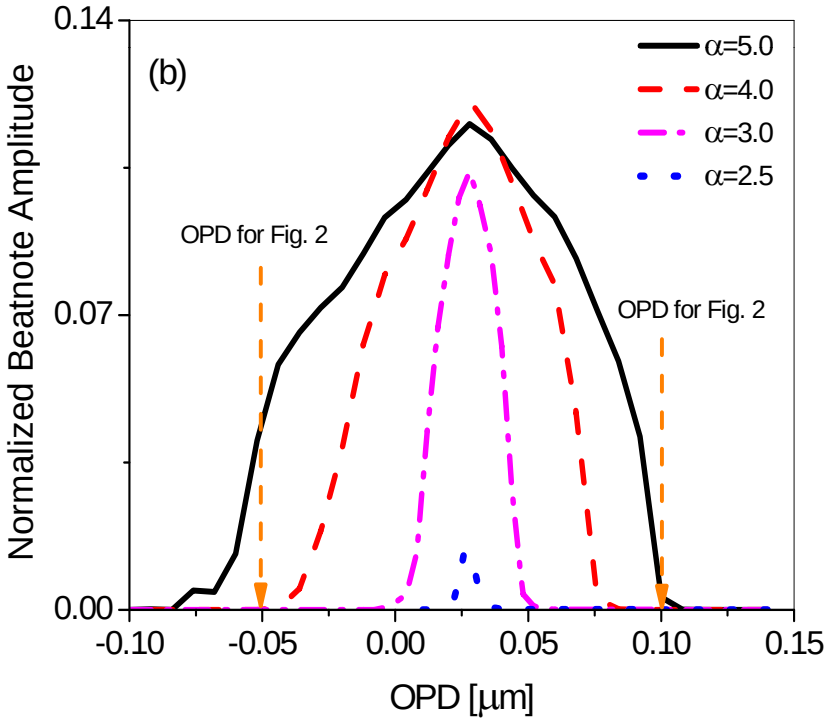
II. Intensity Spectra

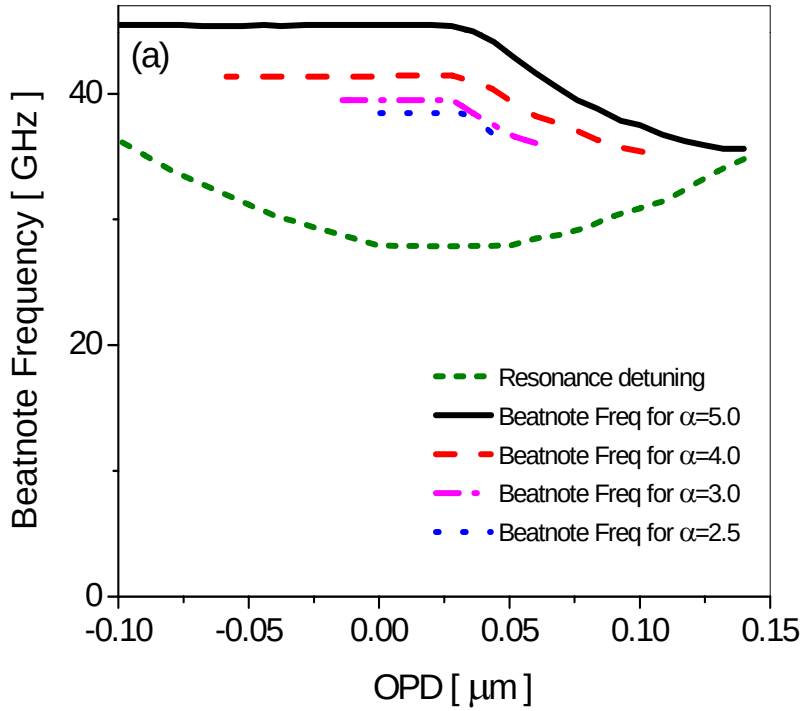




Modulation Enhancement Mechanism

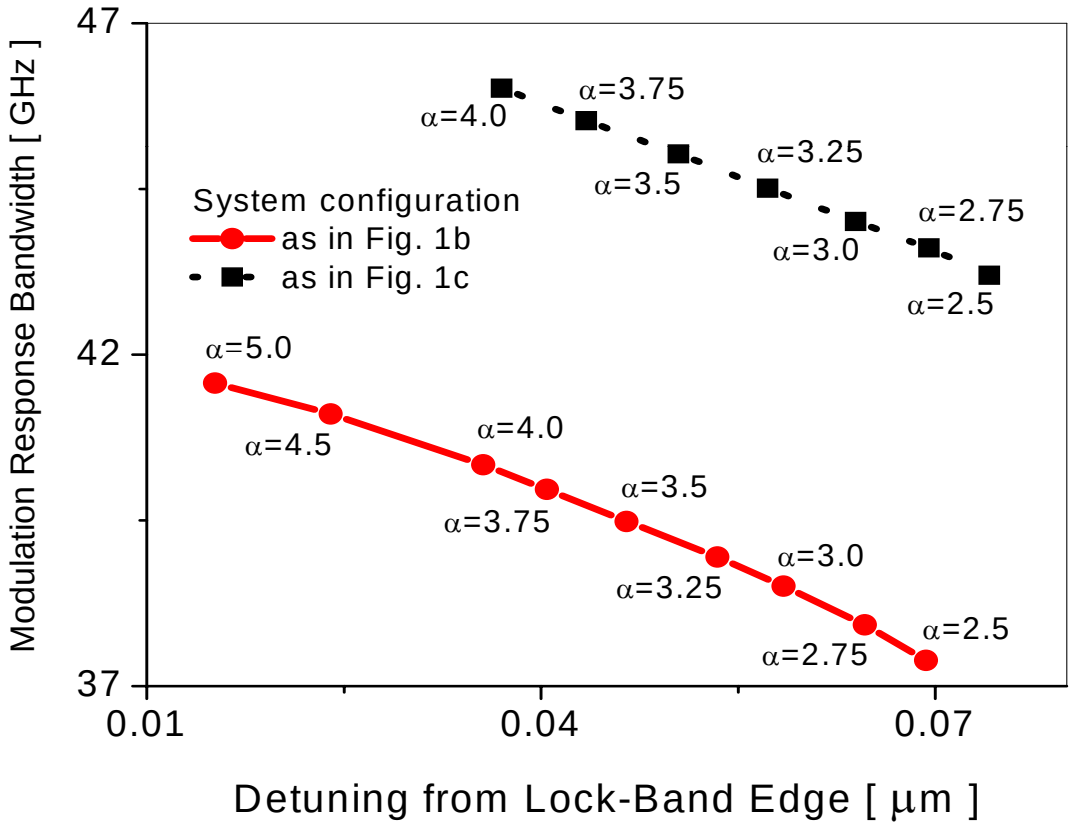
Un-Locked (Beat-Note Region) and Locked Regions





Modulation Enhancement Mechanism

Modulation Response Bandwidth and Lock-band Edge



Modulation Enhancement Mechanism

Conclusion:

Within the lock-band, the system is most sensitive to the modulation when it is operated close to the lock-band boundary.

Interpretation:

Modulation-induced transition between locked and unlocked operations of the laser system.

Summary

Modulation Response and Injection-Locking

Composite-Mode Theory of Coupled Lasers

Effects of Line-width Enhancement Factor

Modulation Enhancement Mechanism