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Simulation of Fourth-Order Laterally-Coupled Gratings

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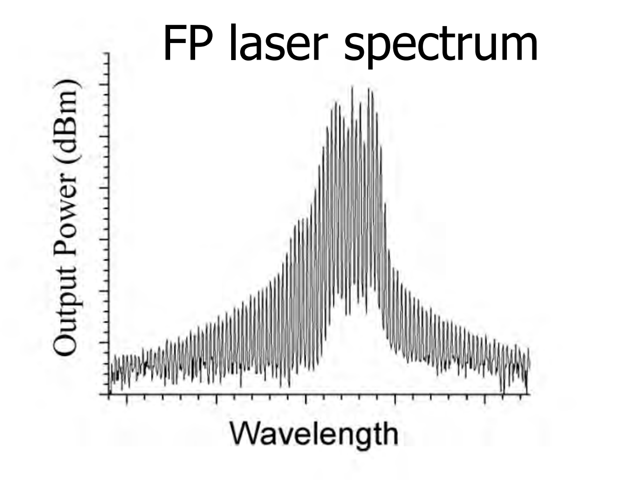
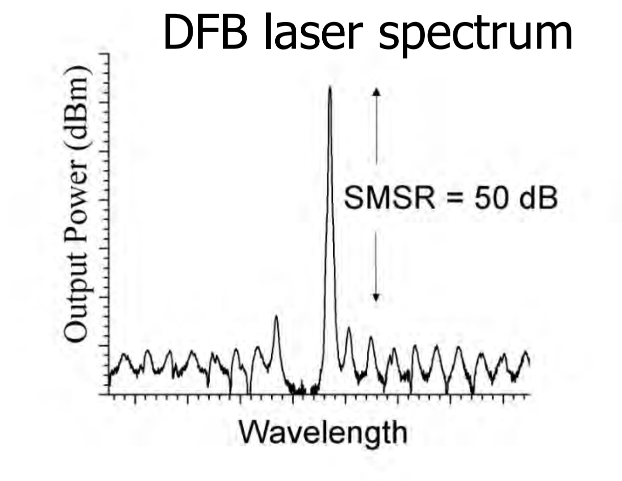
Outline

- Laterally-coupled distributed feedback (LC-DFB) laser introduction
- Modified coupled-mode theory
- Design parameters analysis (Comsol simulations)
- Conclusions

DFB laser introduction

- **Distributed feedback (DFB) lasers use a wavelength-selective grating for improved spectral purity**
- **Lower temperature and wavelength sensitivity than Fabry-Perot designs**
- **Better longitudinal mode selectivity; reduces multiple cavity modes of Fabry-Perot lasers**
- **Used for telecommunications, particularly DWDM, where there is a requirement for low linewidth and good stability**





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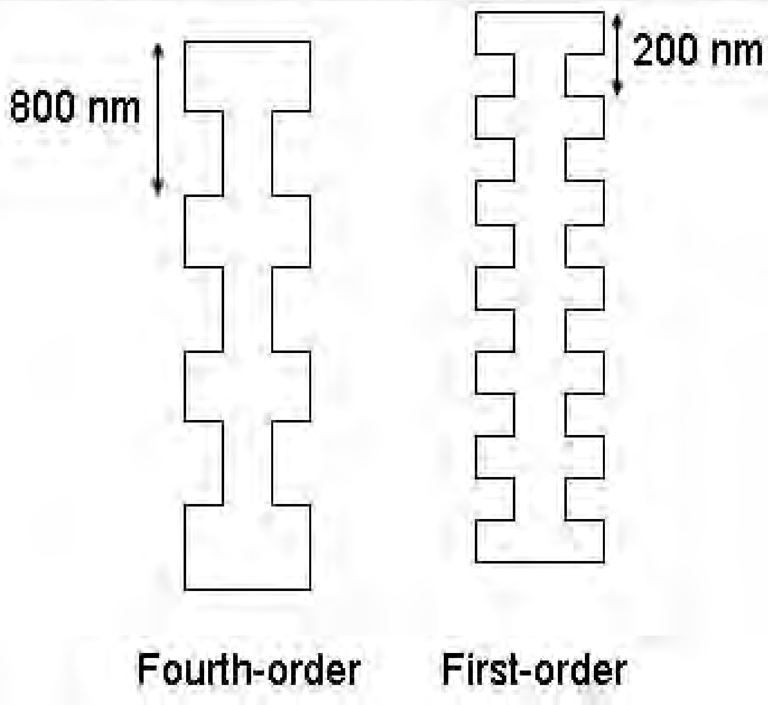
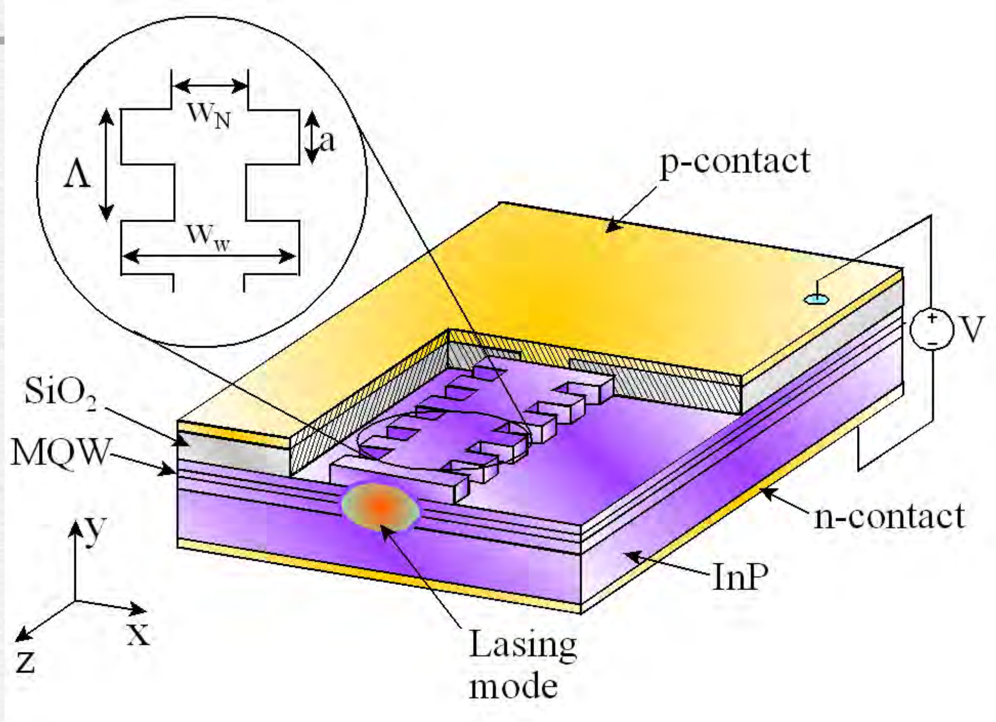
LC-DFB laser introduction

- Grating patterned out of upper ridge waveguide: No re-growth is needed
- Can be fabricated using stepper lithography or nano-imprinting – amenable to mass-manufacturing





- Some Higher-order gratings advantages:

- ease up the stringent fabrication limitations

- **allow better longitudinal mode discrimination**

Modified coupled-mode theory

In higher order gratings, additional terms are included to account for light radiating in transverse direction:

$$\frac{dA}{dz}+\left(-\alpha-i\delta-i\zeta_1\right)A=i\left(\kappa_p^*+\zeta_2\right)B$$

$$-\frac{dB}{dz}+\left(-\alpha-i\delta-i\zeta_3\right)B=i\left(\kappa_p+\zeta_4\right)A$$

A,B = longitudinal mode fields

κ_p = Coupling coefficient

α = modal gain

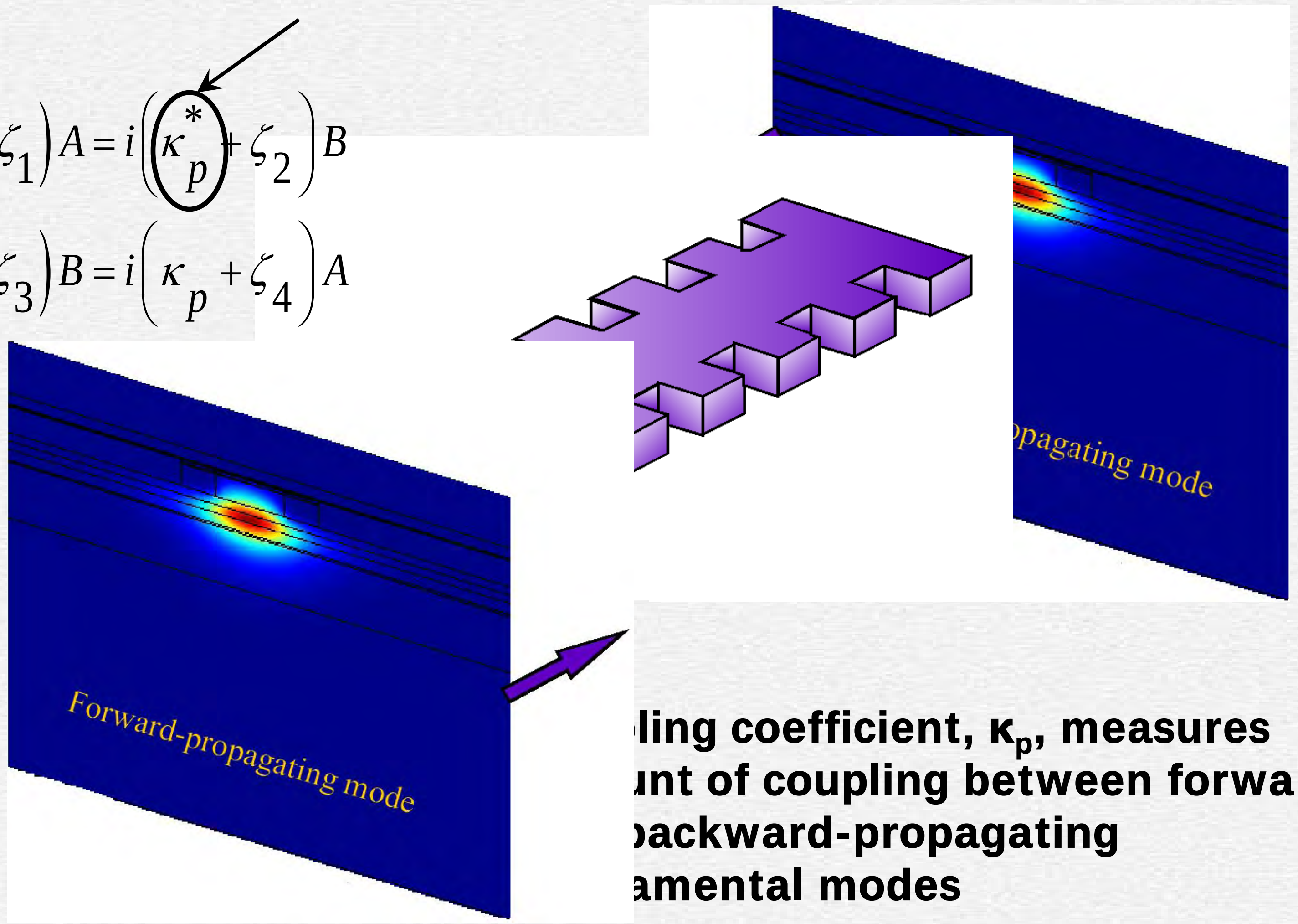
δ = Bragg frequency detuning

$\zeta_{1,\ldots,4}$ = Streifer correction terms

Coupling coefficient

$$\frac{dA}{dz}+\left(-\alpha-i\delta-i\zeta_1\right)A=i\left(\kappa_p^*+\zeta_2\right)B$$

$$-\frac{dB}{dz}+\left(-\alpha-i\delta-i\zeta_3\right)B=i\left(\kappa_p+\zeta_4\right)A$$

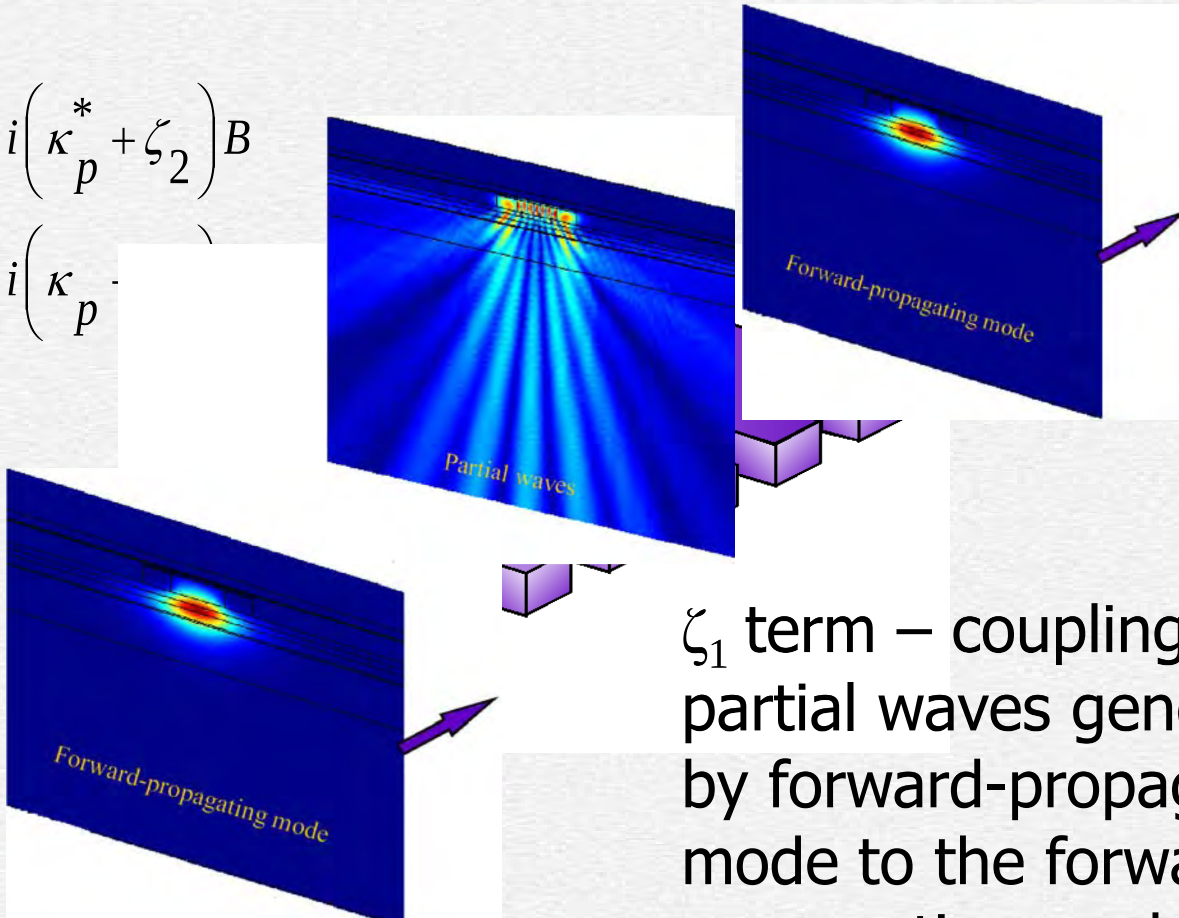


ling coefficient, κ_p, measures
unt of coupling between forward-
backward-propagating
amental modes

Streifer correction terms

$$\frac{dA}{dz}+\left(-\alpha-i\delta-i\zeta_1\right)A=i\left(\kappa_p^*+\zeta_2\right)B$$

$$-\frac{dB}{dz}+\left(-\alpha-i\delta-i\zeta_3\right)B=i\left(\kappa_p \ldots\right.$$



ζ_1 term – coupling of partial waves generated by forward-propagating mode to the forward-propagating mode

Streifer correction terms

$$\frac{dA}{dz}+\left(-\alpha-i\delta-i\zeta_1\right)A=i\left(\kappa_p^*+\zeta_2\right)B$$

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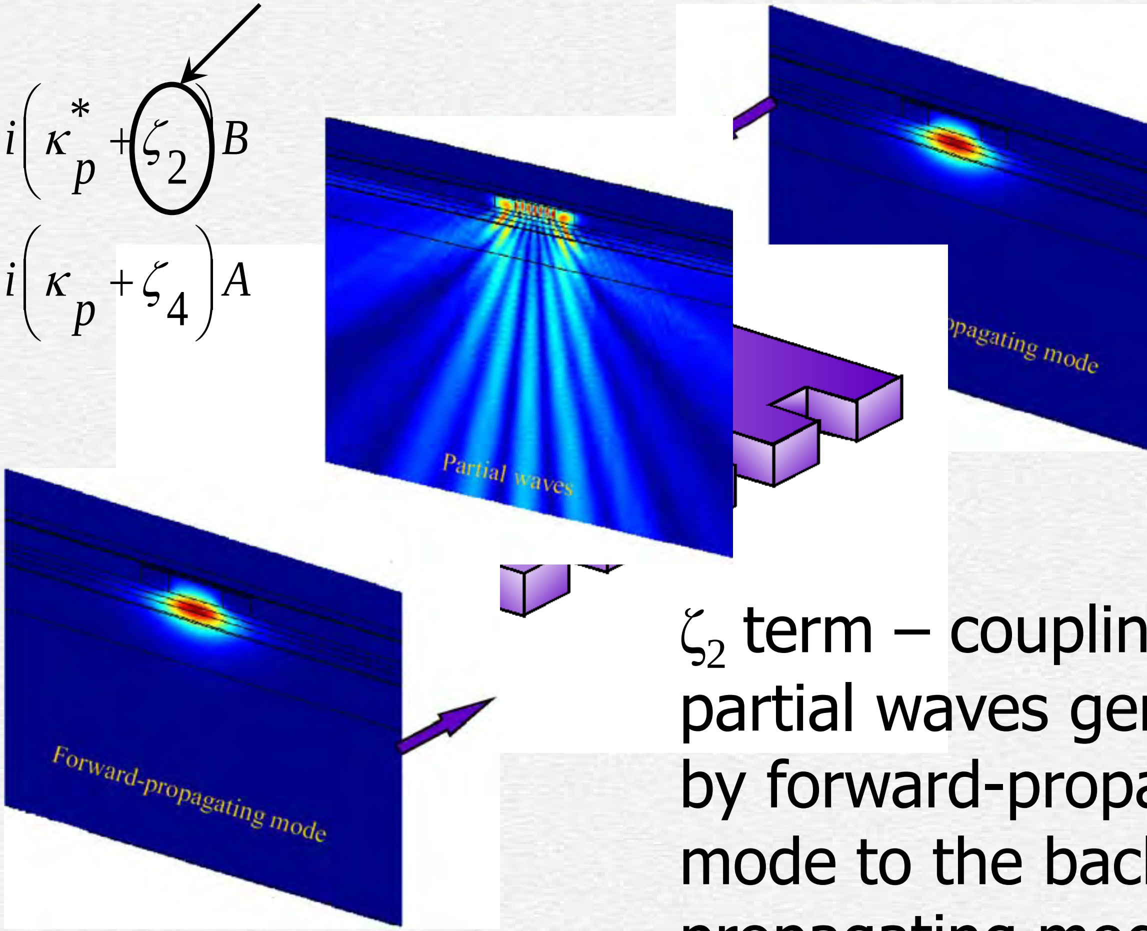
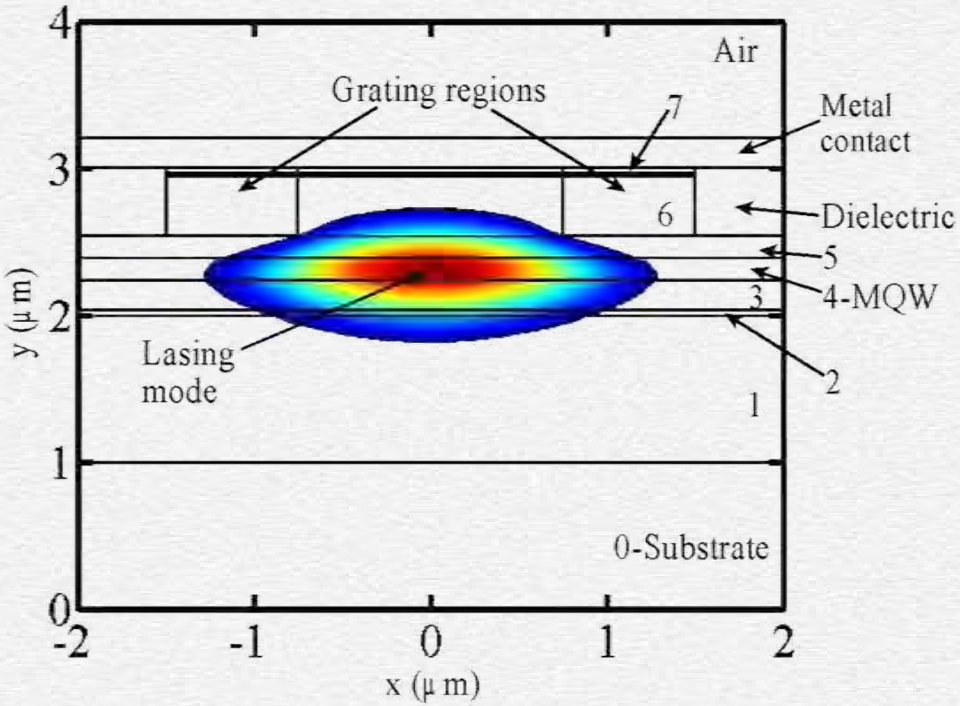


ζ_2 term – coupling of partial waves generated by forward-propagating mode to the backward-propagating mode

Modified coupled-mode theory

- **Quasi-TE fundamental mode $\varepsilon_0(x,y)$ is evanescently coupled to laterally-positioned grating region**
- **MQW active region**
- **Au/Pt/Ti contact with SiO_2 dielectric**



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Modified coupled-mode theory

Correction terms are determined through the solution of the driven wave equation having as a source the quasi-TE fundamental mode field $\varepsilon_0(x,y)$:

$$\frac{\partial^2 \varepsilon_m^{(i)}(x,y)}{\partial x^2} + \frac{\partial^2 \varepsilon_m^{(i)}(x,y)}{\partial y^2} + \left[k_0^2 n_0^2(x,y) - \beta_m^2 \right] \varepsilon_m^{(i)}(x,y)$$
$$= -k_0^2 A_{m-i}(x,y)\varepsilon_0(x,y), \qquad m \neq i, i = 0, p.$$

ε_m = partial wave field of order m

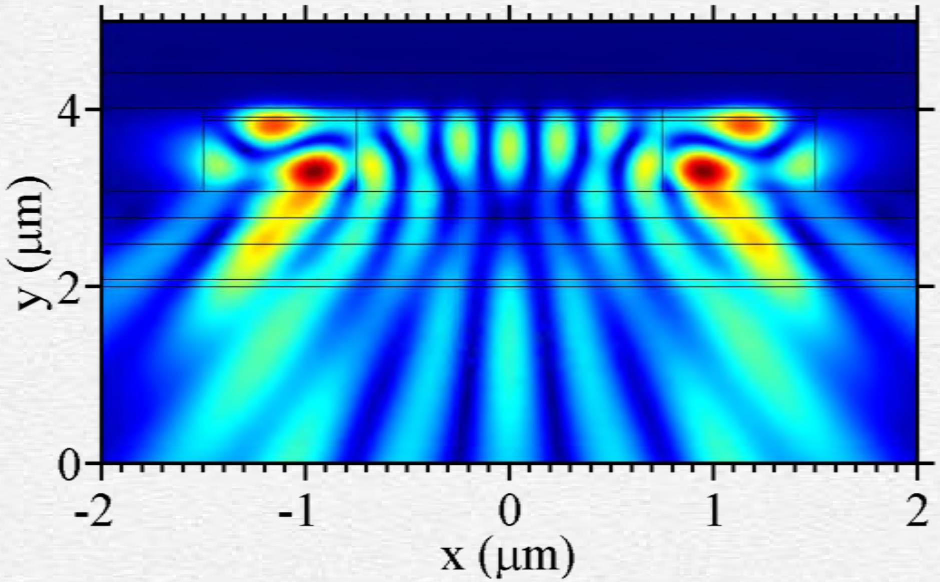
ε_0= fundamental TE mode field

k_0 = Vacuum wavenumber

β_m= partial wave propagation constant

A_q = q^{th} order Fourier coefficient

Radiating partial wave fields are calculated using the FEM with absorbing boundary conditions

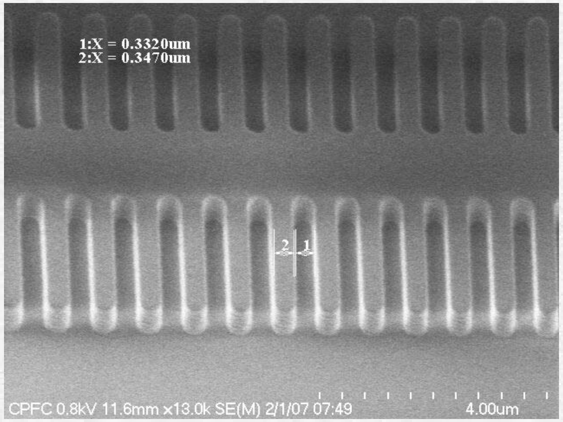


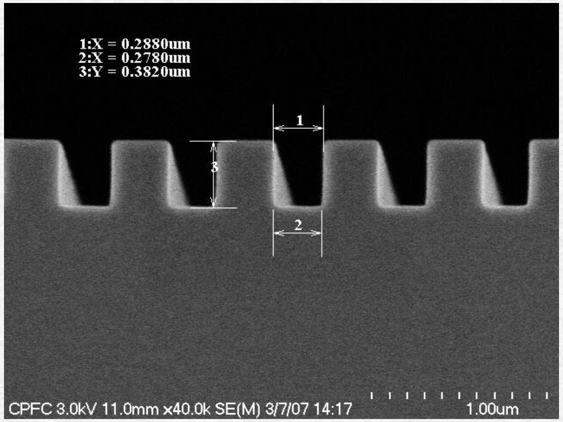
Grating strength

- A measure of grating strength in higher order gratings is the effective coupling coefficient:

$$\kappa_{eff} = \sqrt{\left(\kappa_p^* + \zeta_2\right)\left(\kappa_p + \zeta_4\right)} = \left|\kappa_{eff}\right| e^{j\phi\left(\kappa_{eff}\right)}$$

- Combination of all coupling terms between forward- to backward- propagating (and vice versa) waves
- Values of $\kappa L \approx 1.25$ (L=cavity length) are desirable for DFB lasers

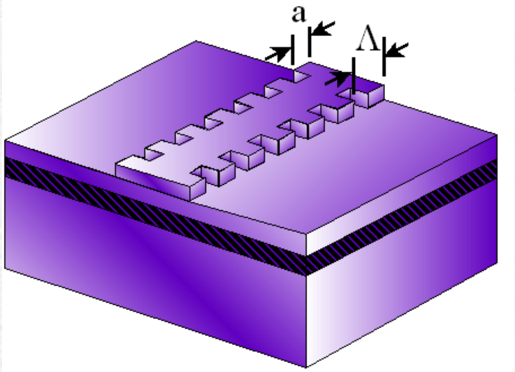


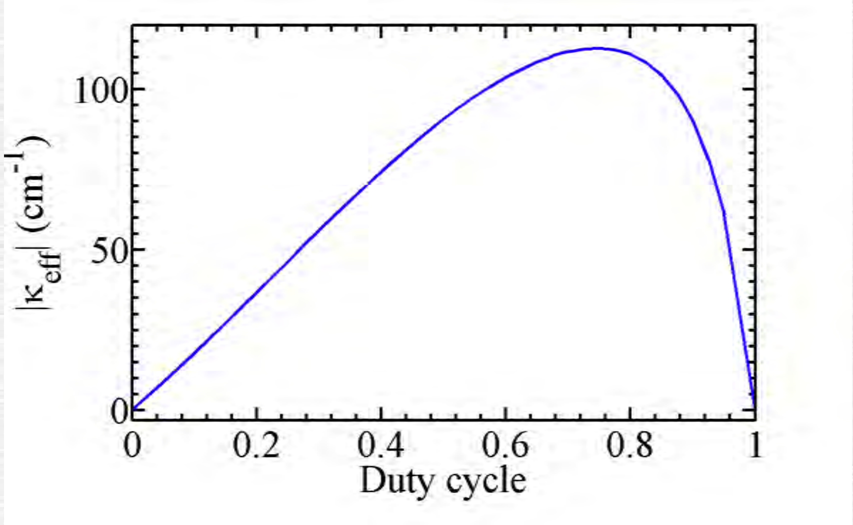


Fabricated at Canadian Photonics Fabrication Centre

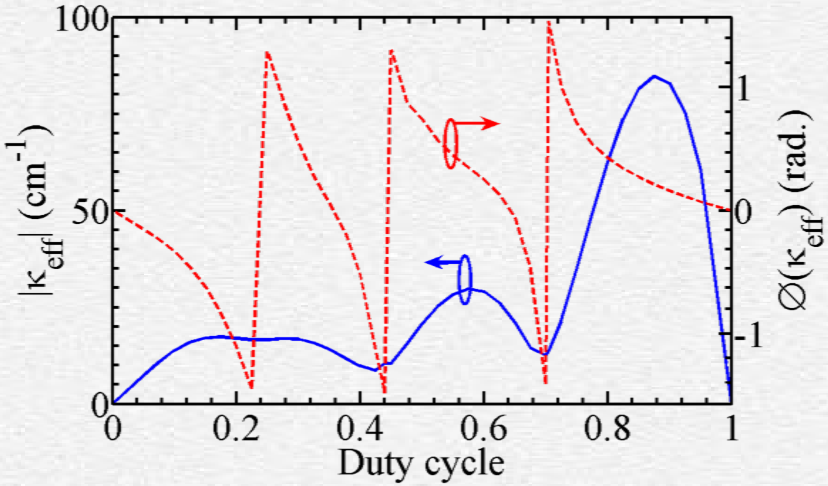
Duty cycle/Grating order

- Duty cycle = a/Λ
- LC-DFB performance is sensitive to duty cycle: larger values (> 0.5) are generally better



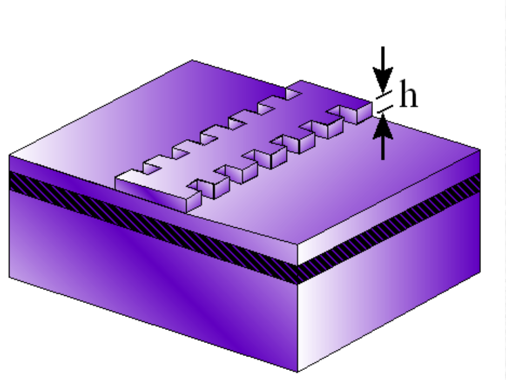


First-order



Fourth-order

Grating height: fixed duty cycle of 0.6

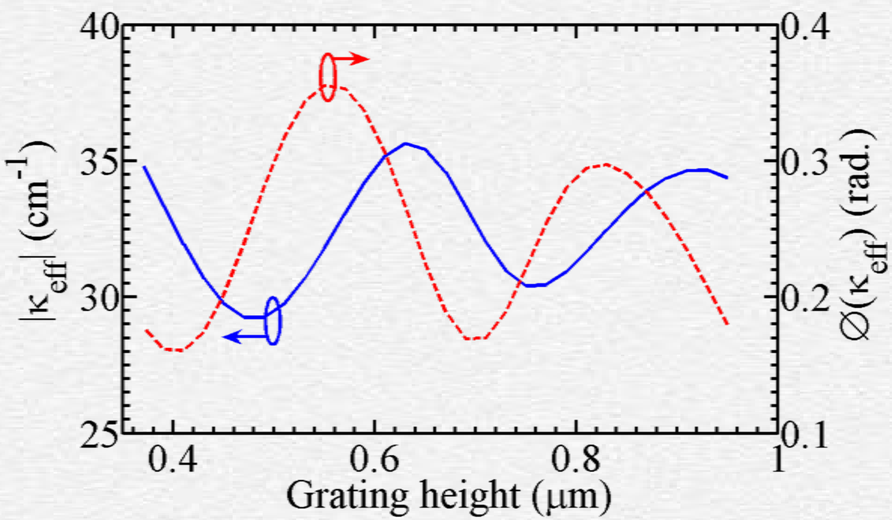


- Change in grating height produces a periodic change in effective coupling coefficient due to correction terms – resonance effects between upper metal contact and lower dielectric layers

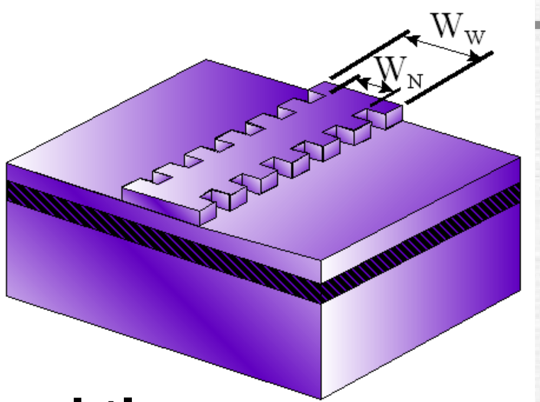
- Uncorrected κ_p at a grating height of 0.47 µm is 23.3 cm^{-1} ($|\kappa_{eff}|$~29cm^{-1}); this underscores the importance of including partial wave terms in the calculations

- First peak in $|\kappa_{eff}|$ at a height of ~0.64 µm represents a good stable fabrication point

$W_w / W_n = 3µm / 1.5µm$



Grating width: fixed duty cycle of 0.6

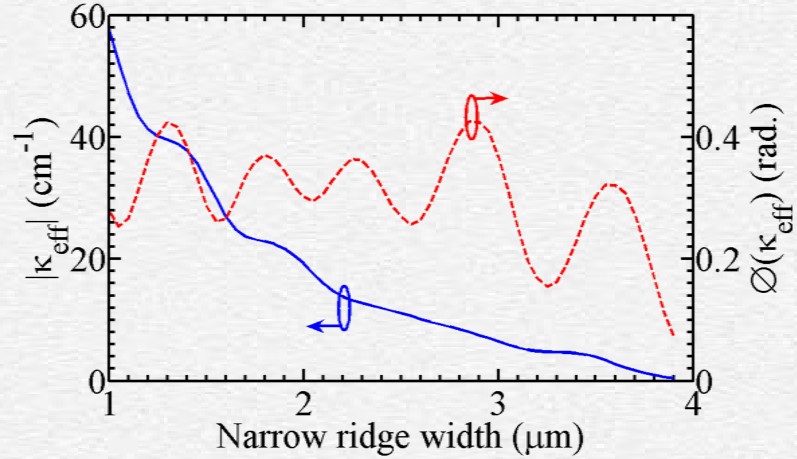


- **More subtle resonances are observed with grating width**

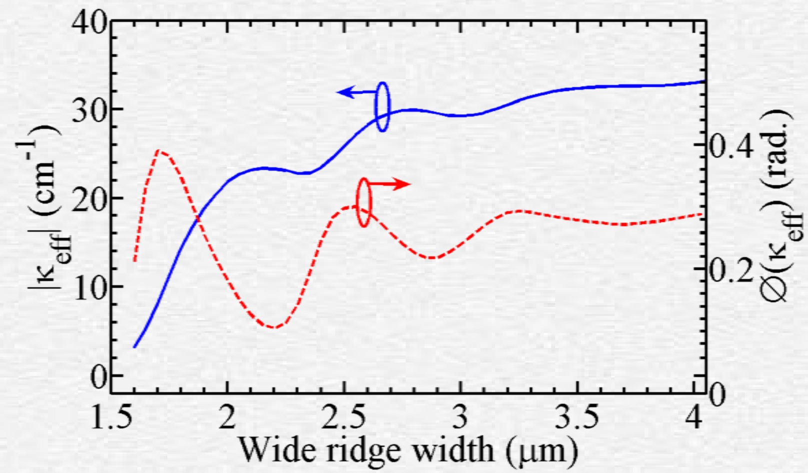
- **Less reflection from sidewalls of grating than at metal interface**

- **Coupling increases for a more pronounced grating (i.e. width ratio (W_W/W_N)>>1)**

- **Good target fabrication window: W_W> 3 µm WN <1.5 µm**



W_W=4µm



W_N=1.5µm

Conclusions

- LC-DFB lasers with higher order gratings can be effectively modeled using COMSOL Multiphysics
- Laser performance and tolerances are determined by grating geometry, including duty cycle, grating width and grating height
- Radiating partial wave effects should be included in the calculation of LC-DFB lasers with higher order gratings

Acknowledgments

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