# Laterally-corrugated ridge-waveguide distributed feedback lasers for 980 nm

***Antti Laakso**, Jukka Viheriälä, Mihail Dumitrescu, Juha Tommila, Kimmo Haring, Tomi Leinonen, Sanna Ranta and Markus Pessa*

**Optoelectronics Research Centre**

**Tampere University of Technology, Finland**

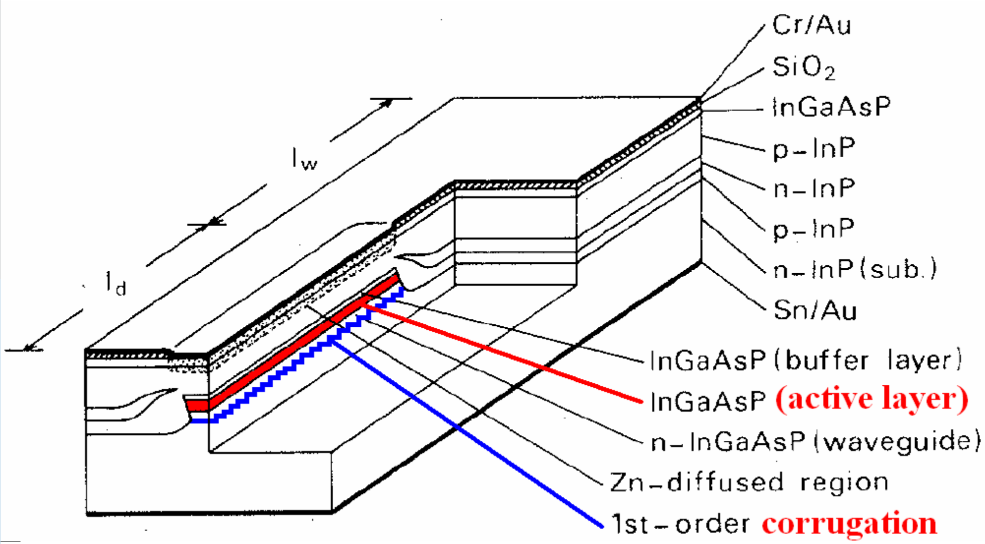
**e-mail: antti.i.laakso@tut.fi**

Optoelectronics Research Centre
Tampere University of Technology

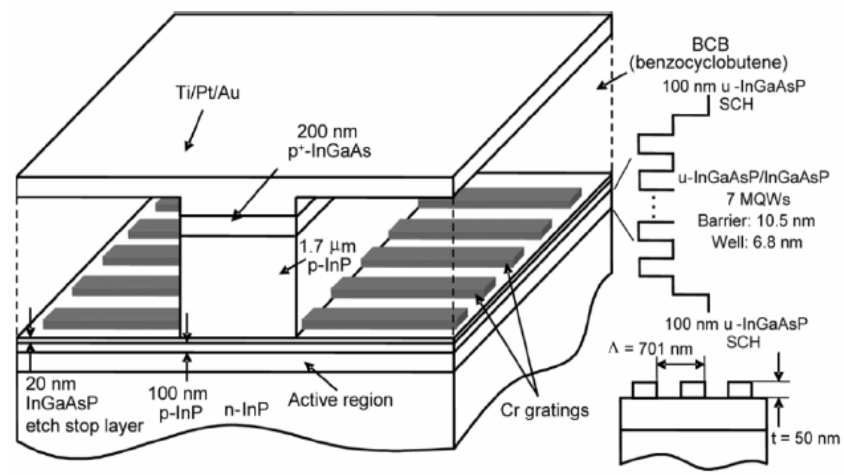
# Presentation outline

- Different DFB designs
- Coupling coefficient and κL
- Ridge geometry and different transverse modes
- PICS3D simulations
- Experimental results
- Summary

# "Traditional" DFB designs

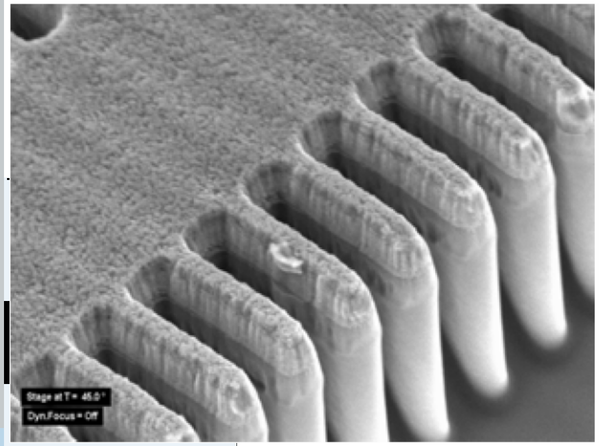


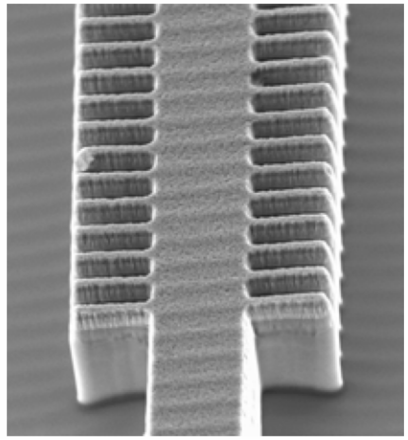

Akiba et al., *IEEE J. Quantum Electron.*, vol. 19, pp. 1052-1056, 1983




S. J. Jang et al., *IEEE Photon. Tech Lett.*, vol. 20, pp. 514-516, 2008

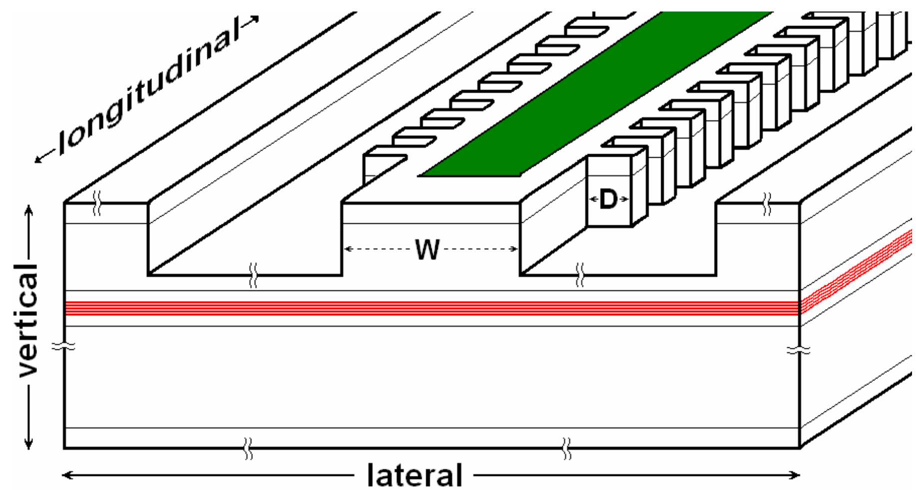
# Laterally-corrugated DFB structure



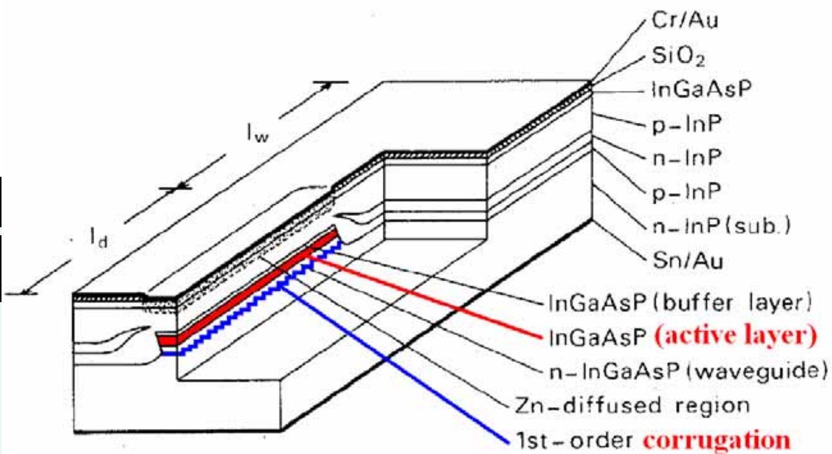


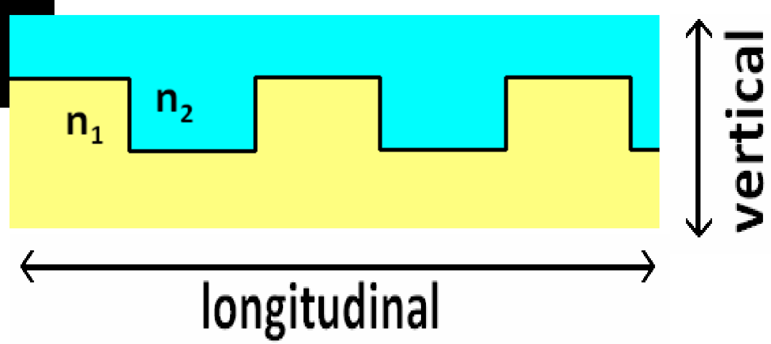
Fabricated using UV-based nano-imprint lithography (UV-NIL), which enables pattern resolutions beyond the limitations set by the diffraction and scattering for the conventional techniques

- si[illegible]rowth and processing sweep [illegible]r yield and lower cost
- limited interaction between the carriers and the grating structure → more stable devices



# Coupling coefficient




For conventional DFB laser $n_1 + n_2 \approx 2 \cdot n_{eff}$, and coupling coefficient can be written as:

$$\kappa = k_0 \cdot (n_2 - n_1) \cdot \Gamma_g \cdot \frac{\sin(\pi m \gamma)}{\pi m}$$

$k_0$ = vacuum wave number
$\Gamma_g$ = fraction of the mode energy inside the grating region
$m$ = grating order
$\gamma$ = *filling factor*

# Coupling coefficient

According to coupled-wave theory:

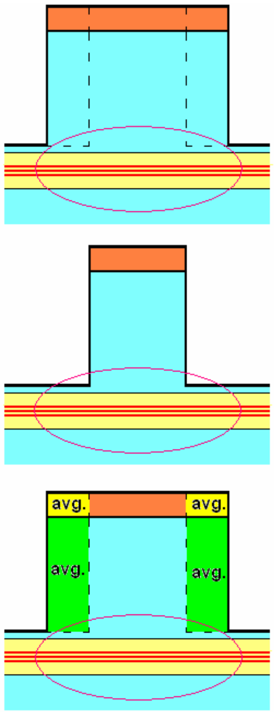
$$\kappa = \frac{k_0}{2n_{eff}} \cdot \frac{\int\limits_{-\infty}^{\infty}\int\limits_{-\infty}^{\infty} \Delta\varepsilon(x,y,z)\cdot\Psi^2(x,y)\,dxdy}{\int\limits_{-\infty}^{\infty}\int\limits_{-\infty}^{\infty}\Psi^2(x,y)\,dxdy}$$

Dielectric perturbation $\Delta\varepsilon_m(x,y,z)$ for m-th order rectangular-shaped grating:

$$\Delta\varepsilon_m(x,y,z) = \left[n_2(x,y)^2 - n_1(x,y)^2\right]\cdot\frac{\sin(\pi m\gamma)}{\pi m}$$

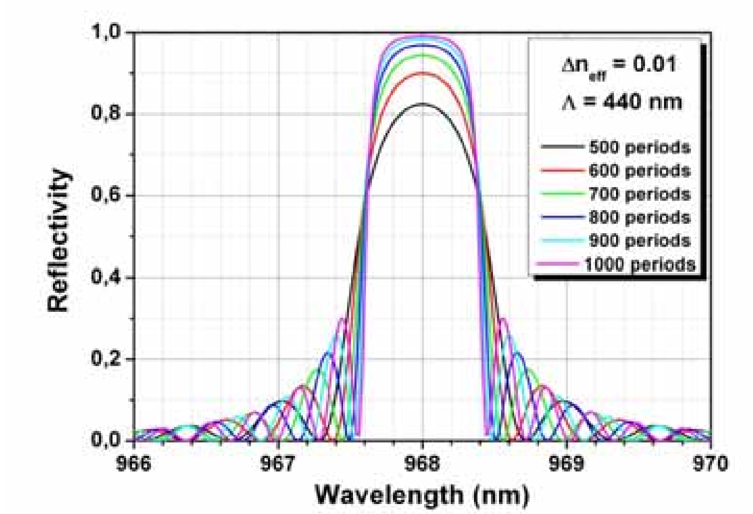
$$\kappa = \frac{k_0}{2n_{eff}} \cdot \frac{\sin(\pi m\gamma)}{\pi m} \cdot \left( \frac{\int\limits_{-\infty}^{\infty}\int\limits_{-\infty}^{\infty} n_2^2(x,y)\Psi^2(x,y)dxdy}{\int\limits_{-\infty}^{\infty}\int\limits_{-\infty}^{\infty}\Psi^2(x,y)dxdy} - \frac{\int\limits_{-\infty}^{\infty}\int\limits_{-\infty}^{\infty} n_1^2(x,y)\Psi^2(x,y)dxdy}{\int\limits_{-\infty}^{\infty}\int\limits_{-\infty}^{\infty}\Psi^2(x,y)dxdy} \right)$$

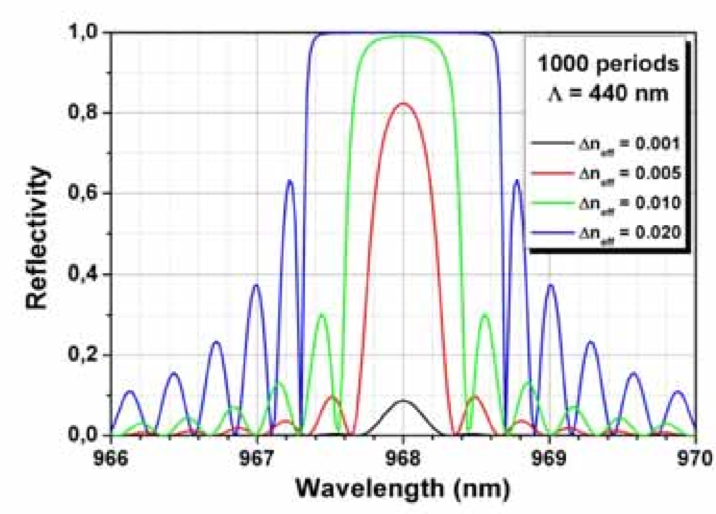
$$\kappa = \frac{k_0}{2n_{eff}} \cdot (n_{eff,2}{}^2 - n_{eff,1}{}^2) \cdot \frac{\sin(\pi m\gamma)}{\pi m} \approx k_0 \cdot (n_{eff,2} - n_{eff,1}) \cdot \frac{\sin(\pi m\gamma)}{\pi m}$$



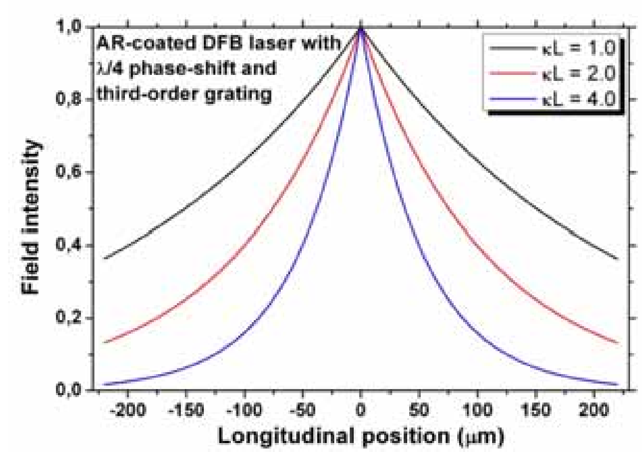

First order grating: $\kappa = \dfrac{2\cdot\Delta n_{eff}}{\lambda}$

# κL-value



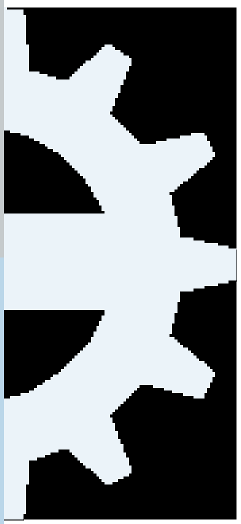

- s κL-value
  t enough selectivity for single-mode output
- high *κL*-value
  → spatial hole burning
    → multiple longitudinal modes
- *κL*-value should be around 1.0 – 2.0

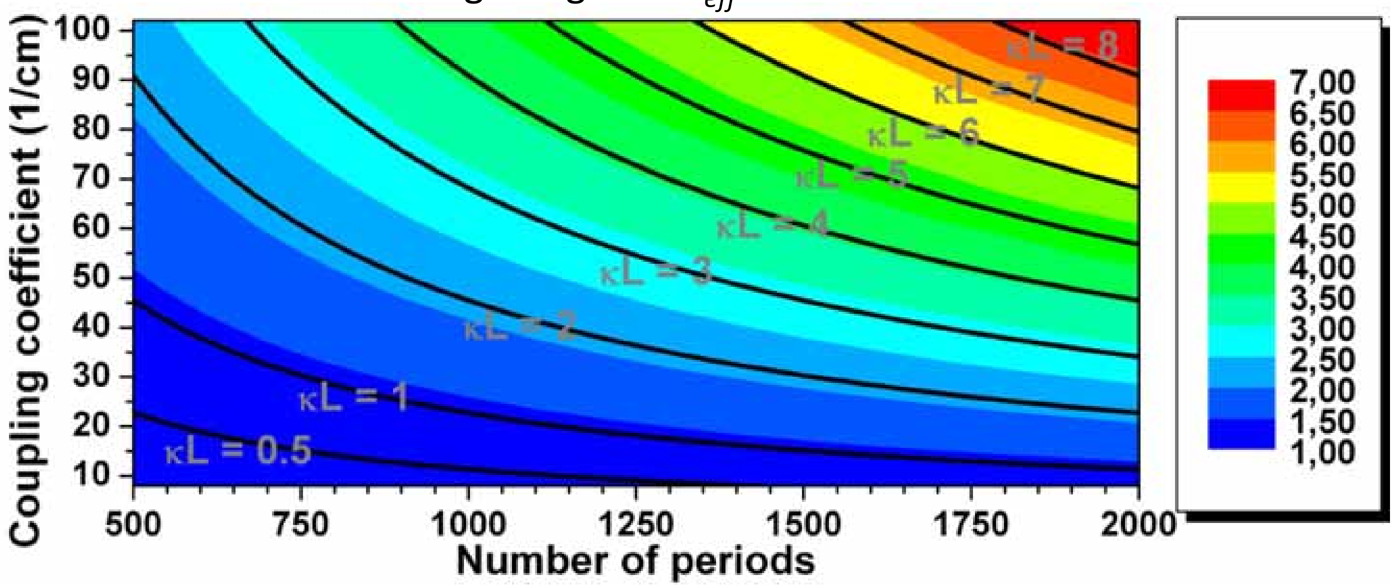


# κL-value

**Number of longitudinal modes than fall within the FWHM of the grating stopband**

Third-order grating with $n_{eff}$=3.3 and $\Lambda$=440 nm





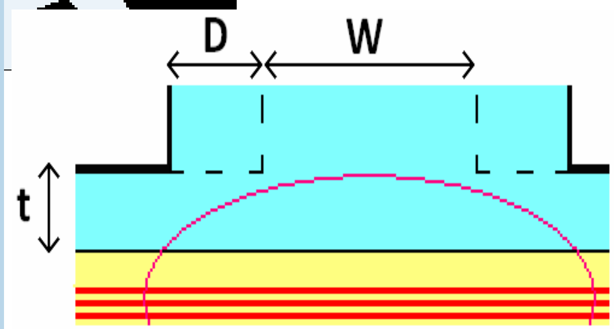

$$n_{l\text{-}modes} \approx \Delta\lambda_{sb} / \Delta\lambda_{ms}$$

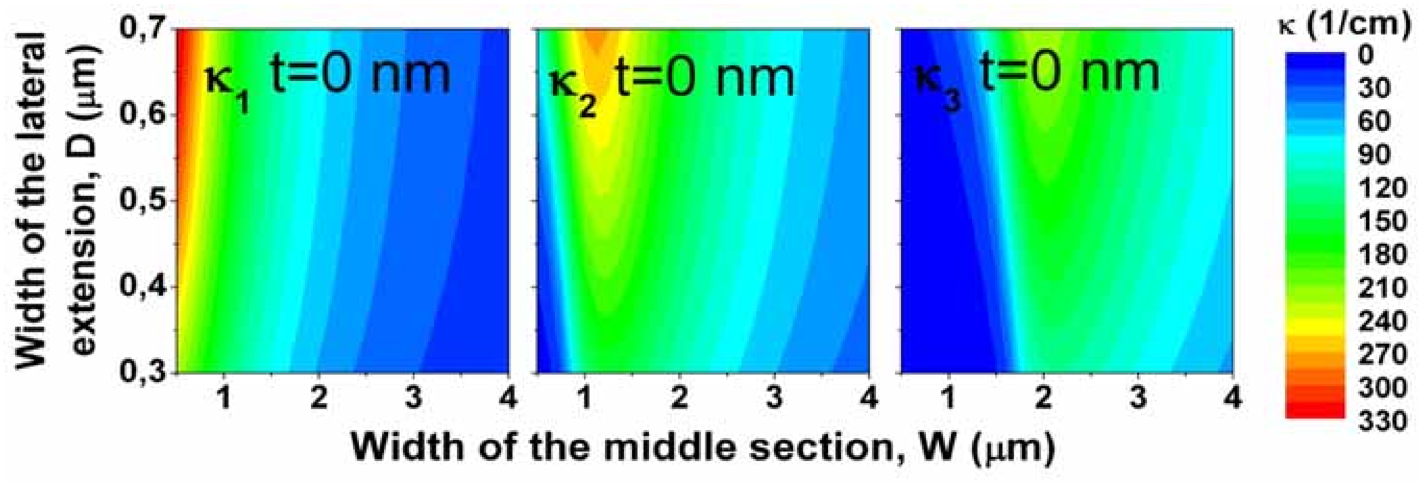
$$\Delta\lambda_{ms} = \frac{\lambda_0^2}{2 \cdot L \cdot n_G + \lambda_0}$$

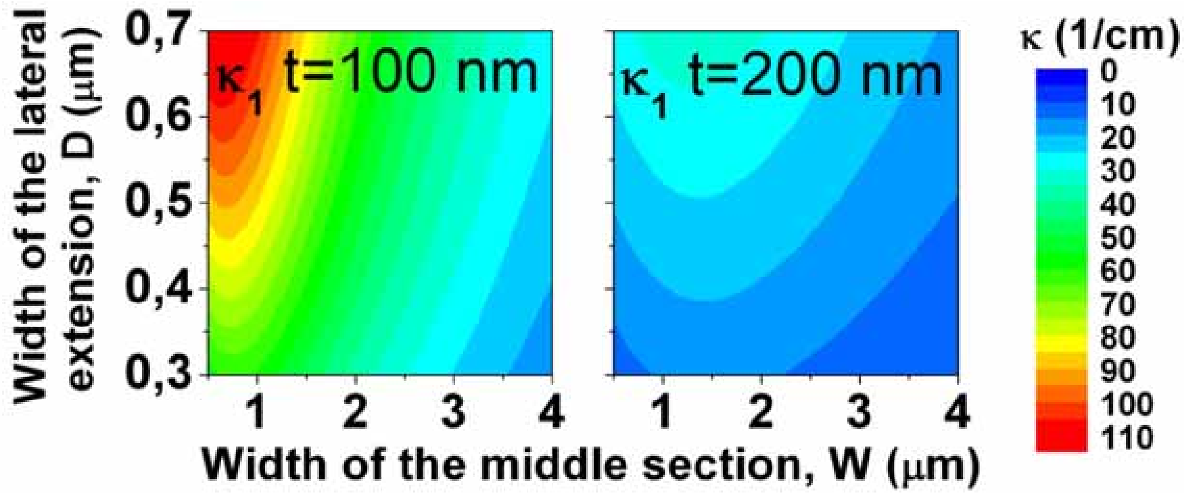
$\Delta\lambda_{ms}$ = mode spacing
$\Delta\lambda_{sb}$ = FWHM of the stopband
$n_g$ = group index

→ 1-2 longitudinal modes within the FWHM of the grating stopband in order to achieve a good yield of single-mode devices

# Ridge geometry and different transverse modes

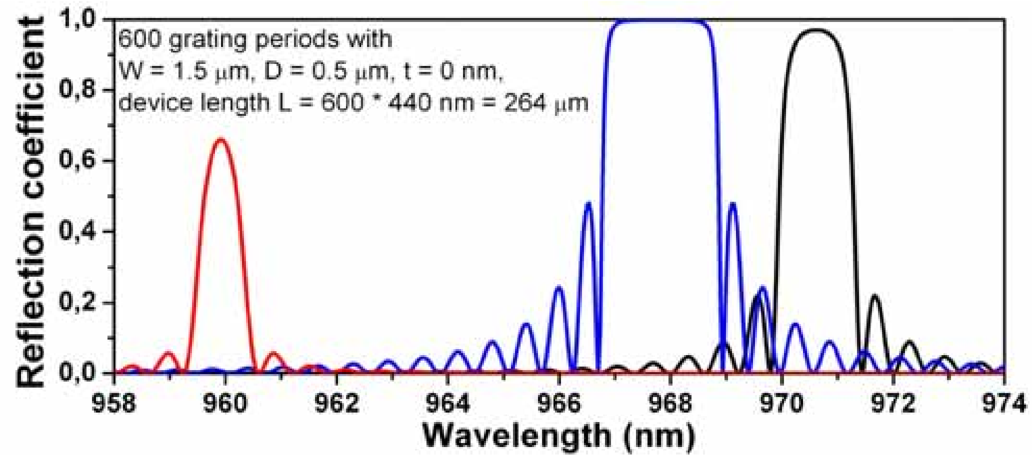


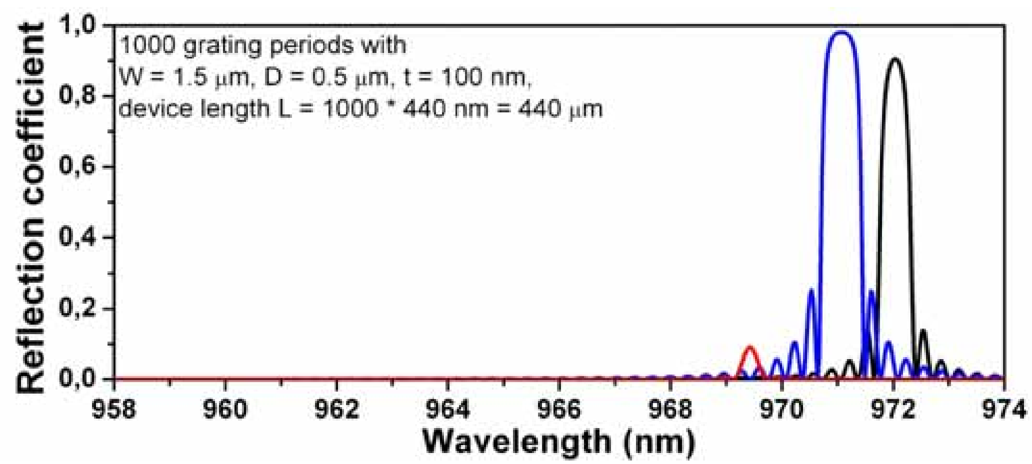



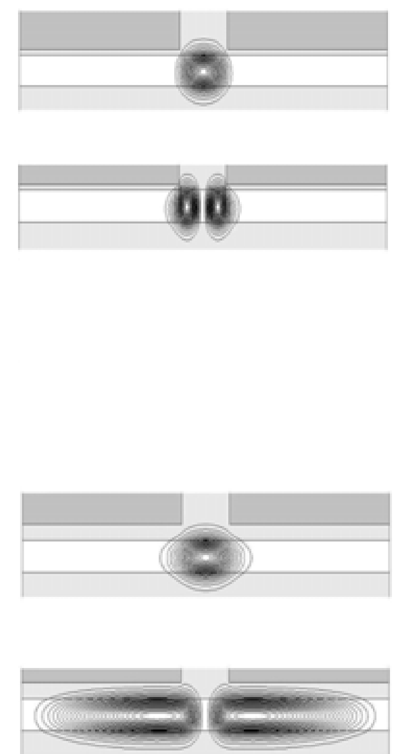




Optoelectronics Research Centre
Tampere University of Technology

# Ridge geometry and different transverse modes

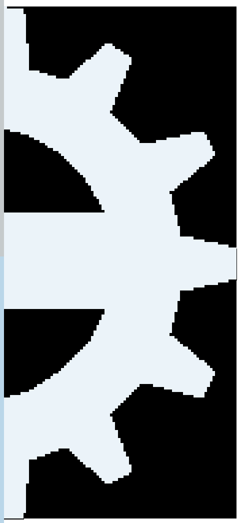


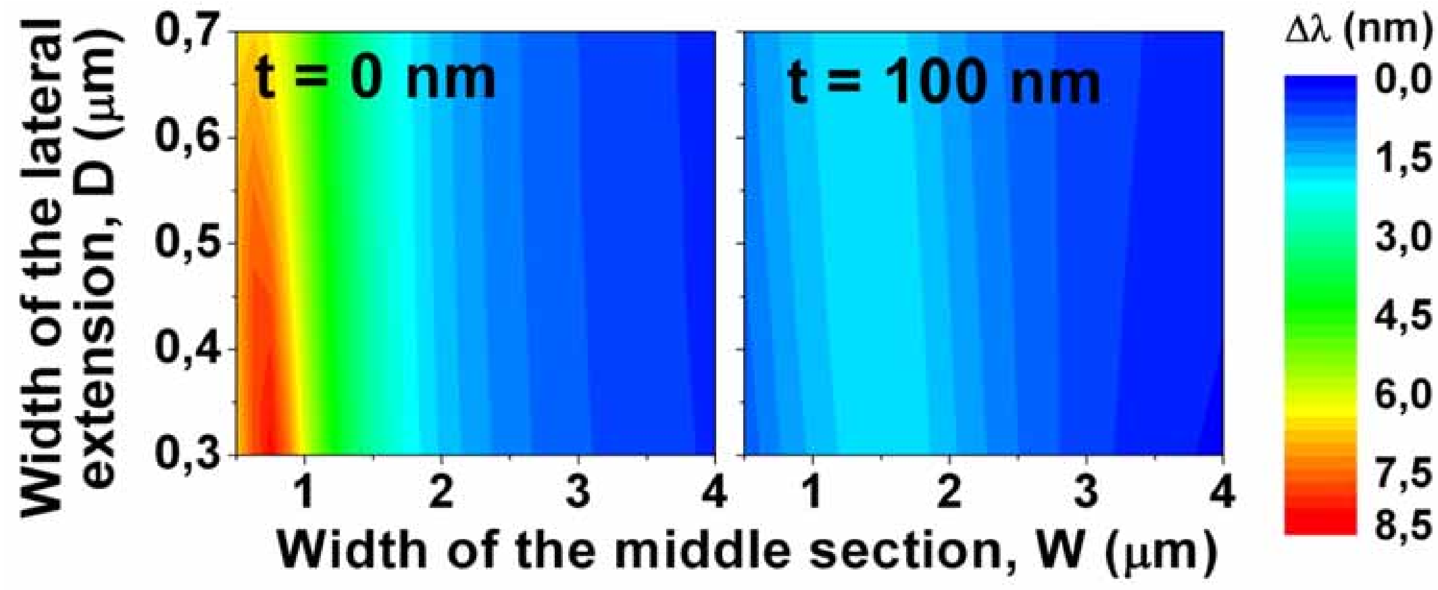



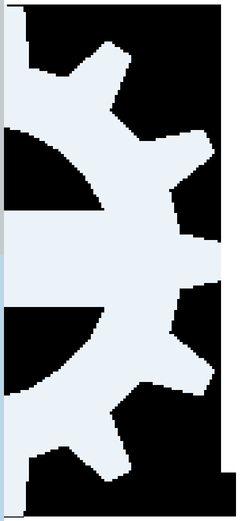
# Ridge geometry and different transverse modes

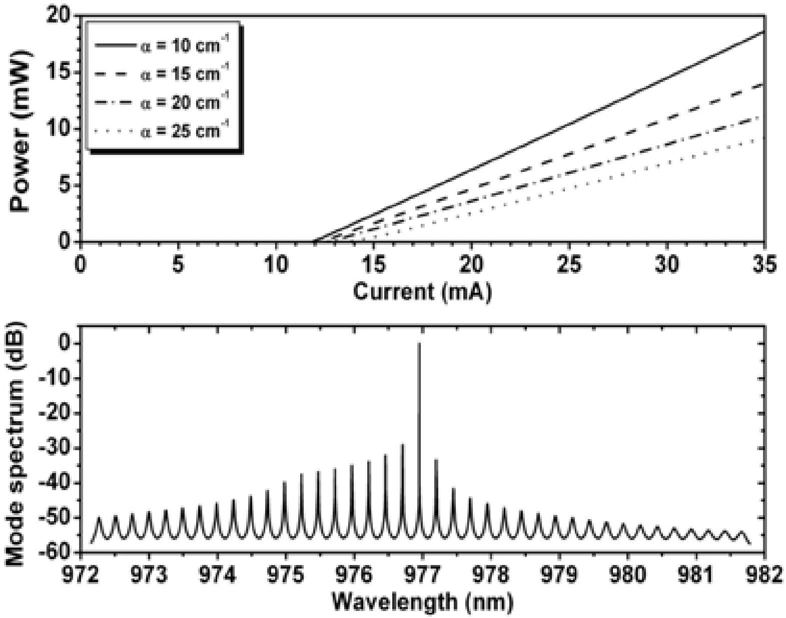
Bragg wavelength difference between first and second transverse mode

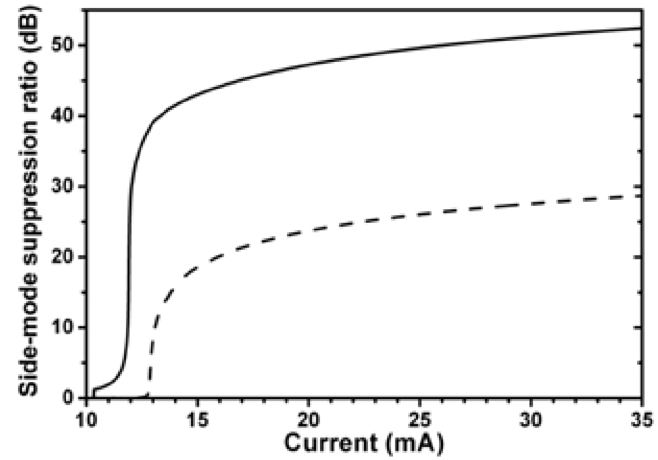


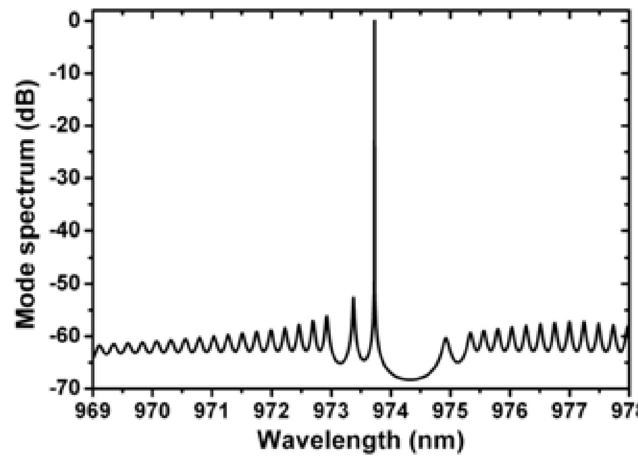


# PICS3D simulations





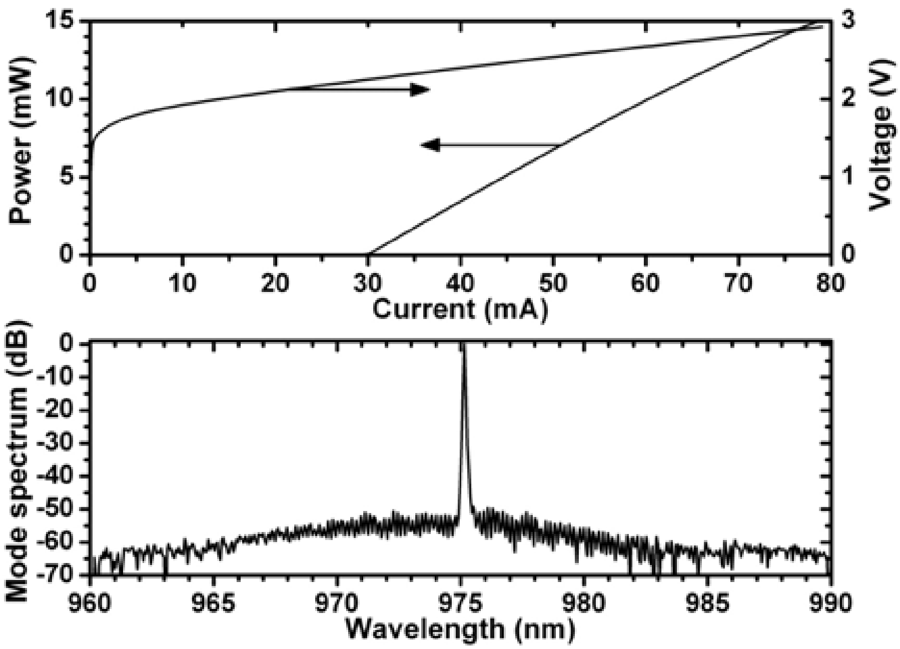

Normal fabricated un-coated RWG-EEL with same dimensions

- 10-15 mA threshold current
- 0.4-0.5 W/A slope efficiency

# Experimental results

A third-order grating with period $\Lambda \approx 440$ nm

W = 1.5 µm  D = 0.5 µm  t = ?  L = 570 µm




AR/HR –coated DFB structure without a phase shift region

- 30 mA threshold current
- 0.34 W/A slope efficiency
- 50 dB SMS-ratio at 10 mW

(operated at 10 °C)

# Conclusion

- κL-product is a key design parameter
- Output characteristics depend on the ridge geometry
- 50 dB SMS-ratio has been achieved, but there is room for optimization