Design of a Widely Tunable Laser with a Chirped Ladder Filter

T. Kakitsuka, S. Matsuo, *S. –H. Jeong,
T. Segawa, H. Okamoto, Y. Kawaguchi,
Y. Kondo, Y. Yoshikuni, and H. Suzuki

NTT Photonics Laboratories, NTT Corporation

***National Institute of Advanced Industrial Science and Technology, Japan**

NTT

Outline

1. Background
2. Device structure
3. Design concept for wide tuning range
4. Numerical simulation of lasing spectra and tuning characteristics
5. Summary

Background

Widely tunable laser

- SG-DBR-LD
- SSG-DBR-LD
- GCSR-LD

→ Complex operation

- LD with AWG and SOAs (Digital wavelength tuning)

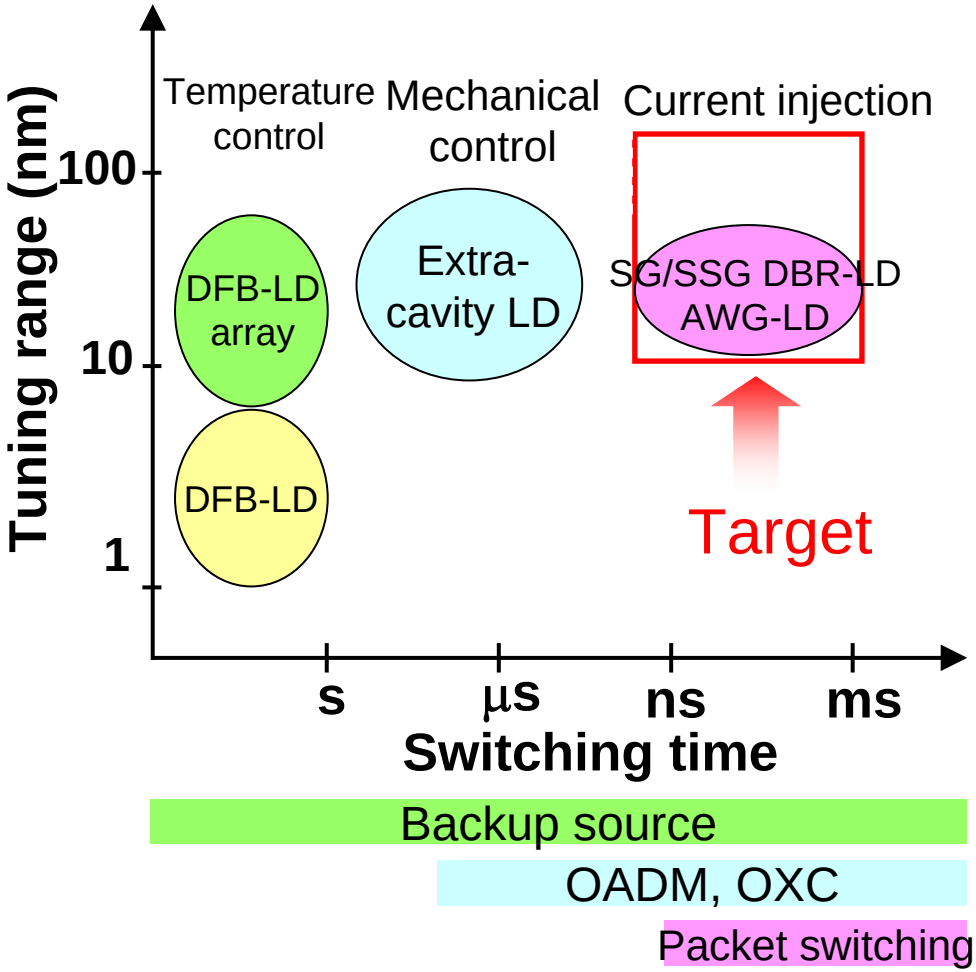
→ Large size

Our approach

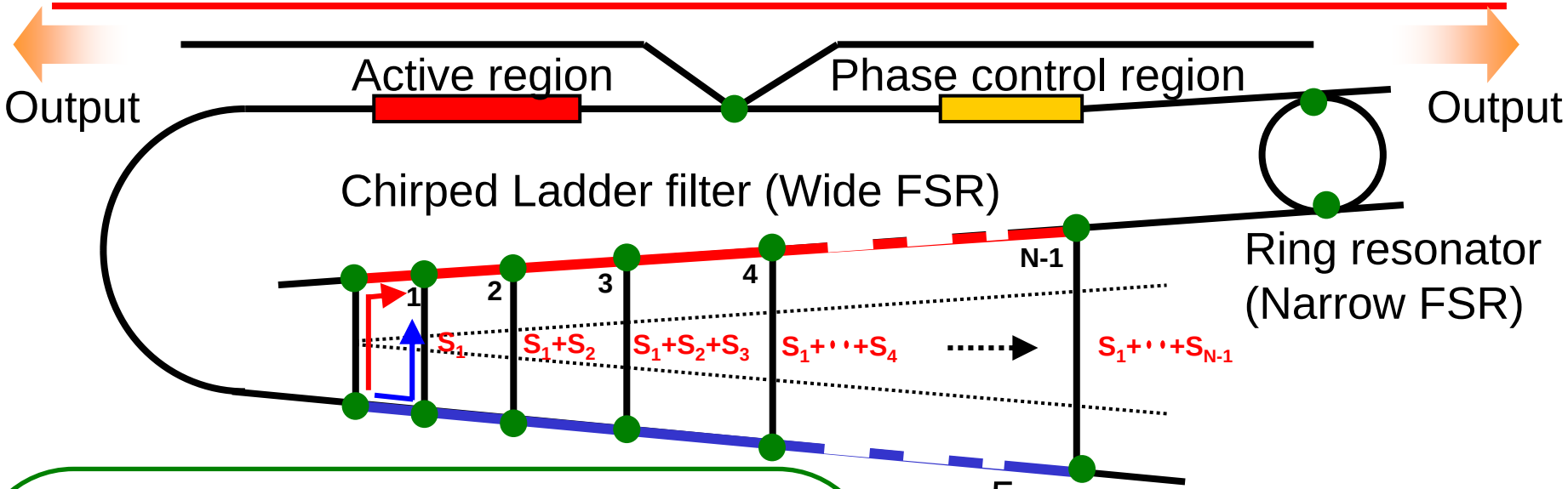
- Tunable ring laser with ladder filter and ring resonator

Goal

- Tuning range of over 40 nm



Device Structure

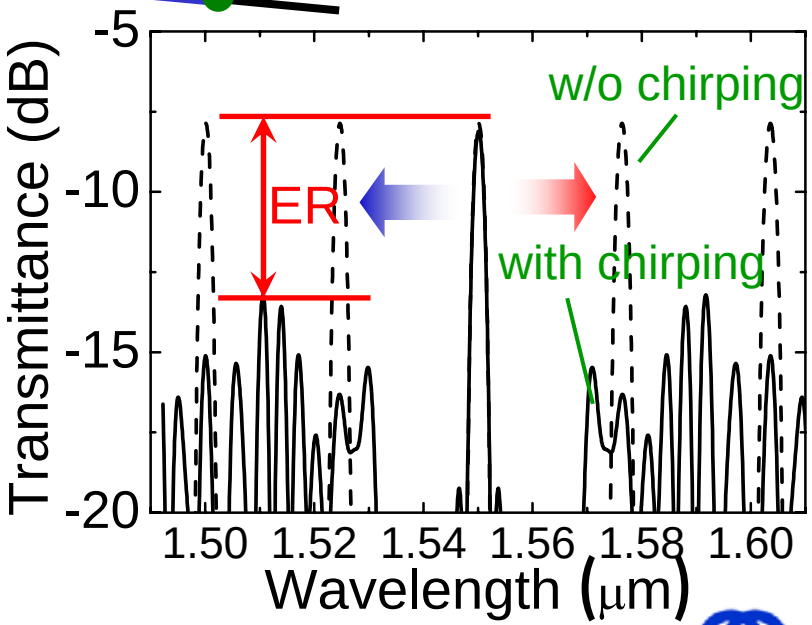


Feature

- Digital wavelength tuning $\Delta\lambda = \dfrac{\Delta n_{eff} L_i}{m}$
- Suppression of unnecessary modes by chirping

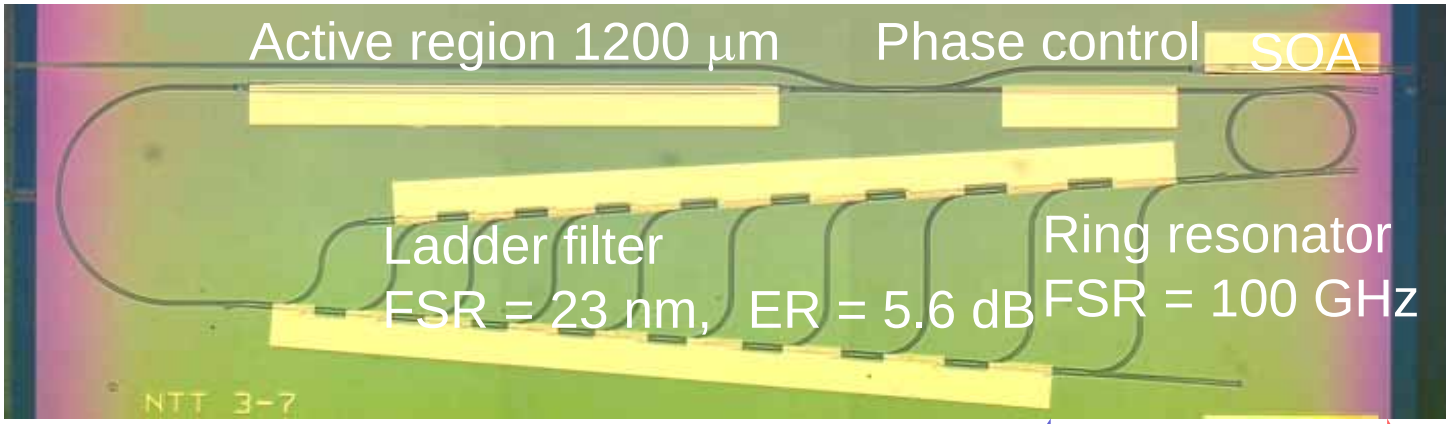
$$S_k = m_k \lambda_0 / n_{eq}, \quad m_k = m_0 + (k - \frac{N}{2})\gamma$$

L_i: Length of electrode n_{eff}: Effective index
m: Diffraction order γ: Chirping parameter



NTT

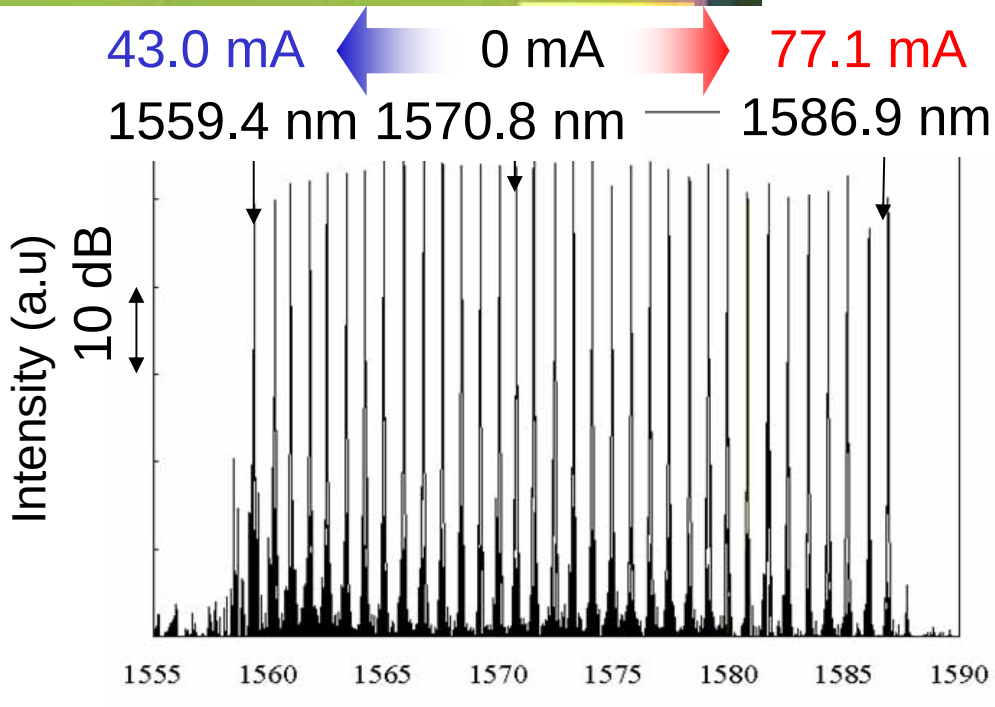
Fabricated Device



- Active region：MQW, ridge
  w = 1.6 μm, h = 1.8 μm
- Waveguide region：
  Deep ridge (1.4Q)
  w = 1.6 μm, h = 3.5 μm
- Size: 3.2 x 1.0 mm^2

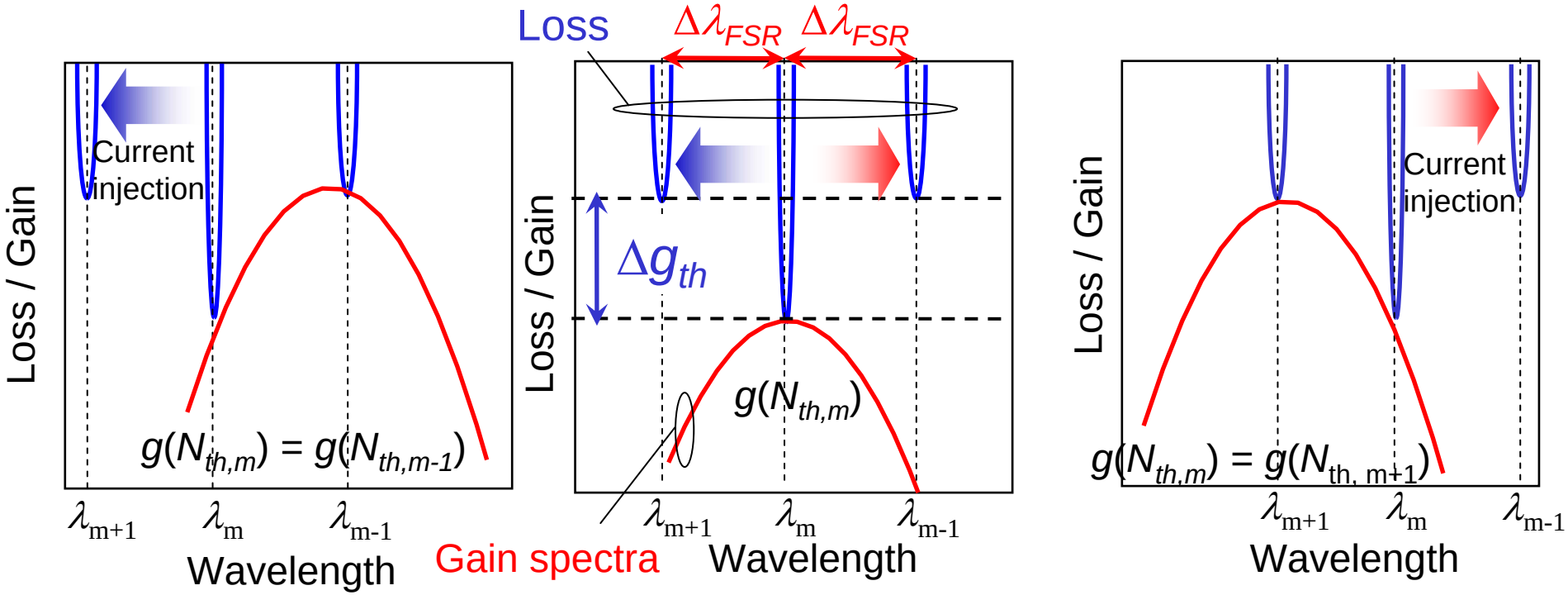
Tuning range ($\Delta\lambda_c$) 27 nm
spacing 100 GHz

Design for $\Delta\lambda_c$ > 40 nm?



Conditions for Lasing in Central Mode

$\lambda = \lambda_{cmin}$ $\lambda_{cmin} < \lambda < \lambda_{cmax}$ $\lambda = \lambda_{cmax}$



Lasing conditions for central mode

$$N_{th,m} < N_{th,m-1}$$
$$N_{th,m} < N_{th,m+1}$$

$N_{th,m}$:Threshold carrier density

Tuning range

$$\Delta\lambda_c = \lambda_{cmax} - \lambda_{cmin}$$

Analytical Expression for Tuning Range

Gain spectra

$$g = g'_N(N_c - N_0) - \frac{g''_\lambda}{2}\left(\lambda - \lambda_p\right)^2$$

Gain peak wavelength

$$\lambda_p = \lambda_{p0} - \lambda'_p N_c$$

Wavelength of transmittance peak

$$\lambda_{m+1} = \lambda_m - \Delta\lambda_{FSR}$$
$$\lambda_{m-1} = \lambda_m + \lambda_{FSR}$$

Threshold gain coefficient

$$g_{th,m+1} = g_{th,m-1} = g_{th,m} + \Delta g_{th}$$

g: Gain coefficient
N_c: Carrier density
N_0: Transparent carrier density
λ: Wavelength
λ_p: Gain peak wavelength
λ_{p0}: Bandgap wavelength
g_{th}: Threshold gain
m : Diffraction order

Δg_{th} : Difference in threshold gain due to chirped structure

Lasing conditions for central mode

$$N_{\mathrm{th,m}} < N_{\mathrm{th,m-1}}$$
$$N_{\mathrm{th,m}} < N_{\mathrm{th,m+1}}$$

Tuning range

$$\Delta\lambda_c = \Delta\lambda_{FSR} + \frac{2\Delta g_{th}}{g''_\lambda \Delta\lambda_{FSR}}$$

NTT

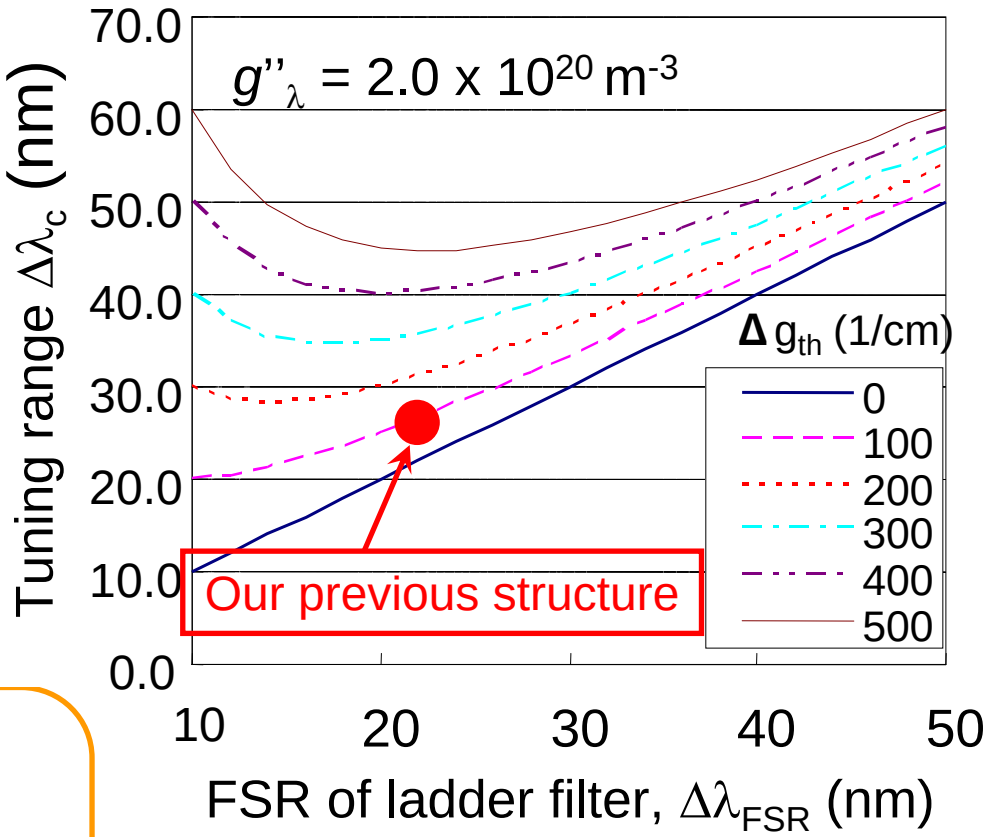
Requirements for Wide Tuning Range

Tuning range

$$\Delta\lambda_c = \Delta\lambda_{FSR} + \frac{2\Delta g_{th}}{g''_{\lambda}\Delta\lambda_{FSR}}$$

Effect of chirping

No chirping



Expansion of tuning range

- Large FSR of ladder filter
- Small g''_{λ} (Flat gain spectrum)
- Large Δg_{th} (Extinction ratio of ladder filter)

Is large FSR sufficient condition?

Design of Ladder Filter

FSR of ladder filter (no chirping)

$$\Delta\lambda_{FSR} = \frac{n_{eff}\Delta S}{m(m+1)} \approx \frac{\lambda_0}{m+1}$$

n_{eff}: Effective index
m: Diffraction order
ΔS: Difference of optical path
λ_0: Central wavelength
N: Number of ladders

3-dB bandwidth of ladder filter

$$\Delta\lambda_{3dB} \propto \frac{1}{mN}$$

Ref. S. -H. Jeong et al., Appl. Opt., 28, p6007, 2005.

Large FSR →
- Large 3-dB bandwidth
- Mode selectivity is degraded

Chirping is necessary to expand tuning range

NTT

Design of Laser Structure

Tunable region

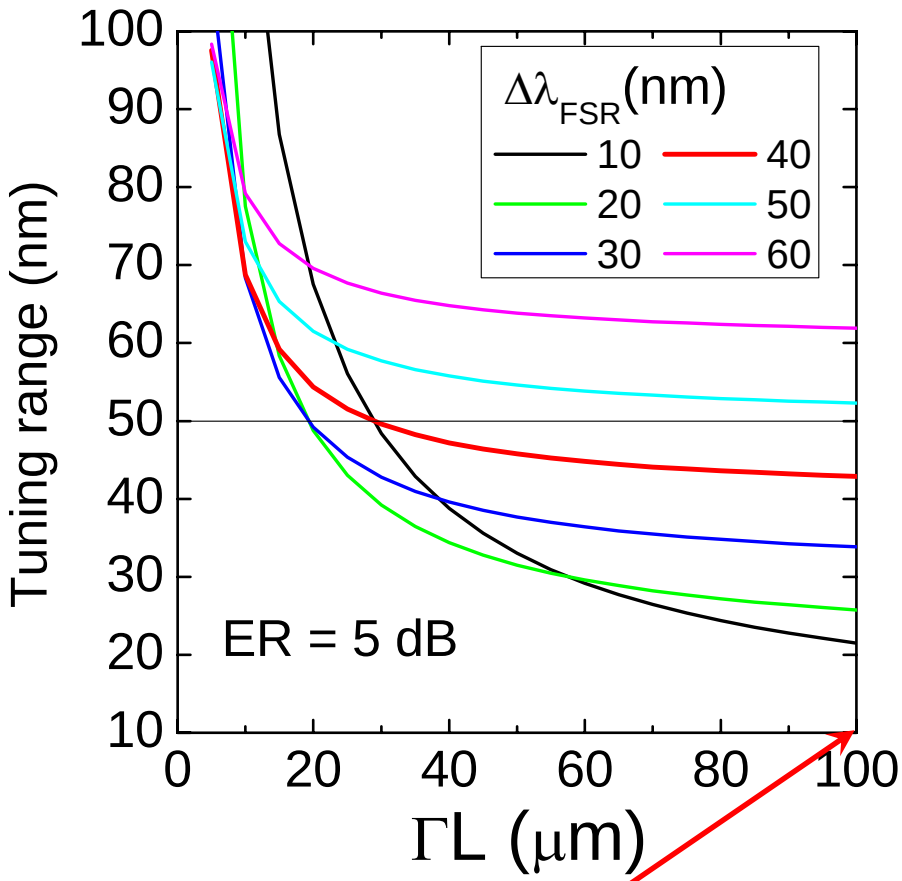
$$\Delta\lambda_c = \Delta\lambda_{FSR} + \frac{ER}{10\log_{10}(e)\Gamma L}\frac{2}{g''_{\lambda}\Delta\lambda_{FSR}}$$

Γ: Optical confinement
L: Length of active layer
ER: Extinction ratio of ladder filter (dB)

Approach

- Large extinction ratio of ladder filter (ER) induced by chirped structure
- Flat gain spectra (small ΓL)

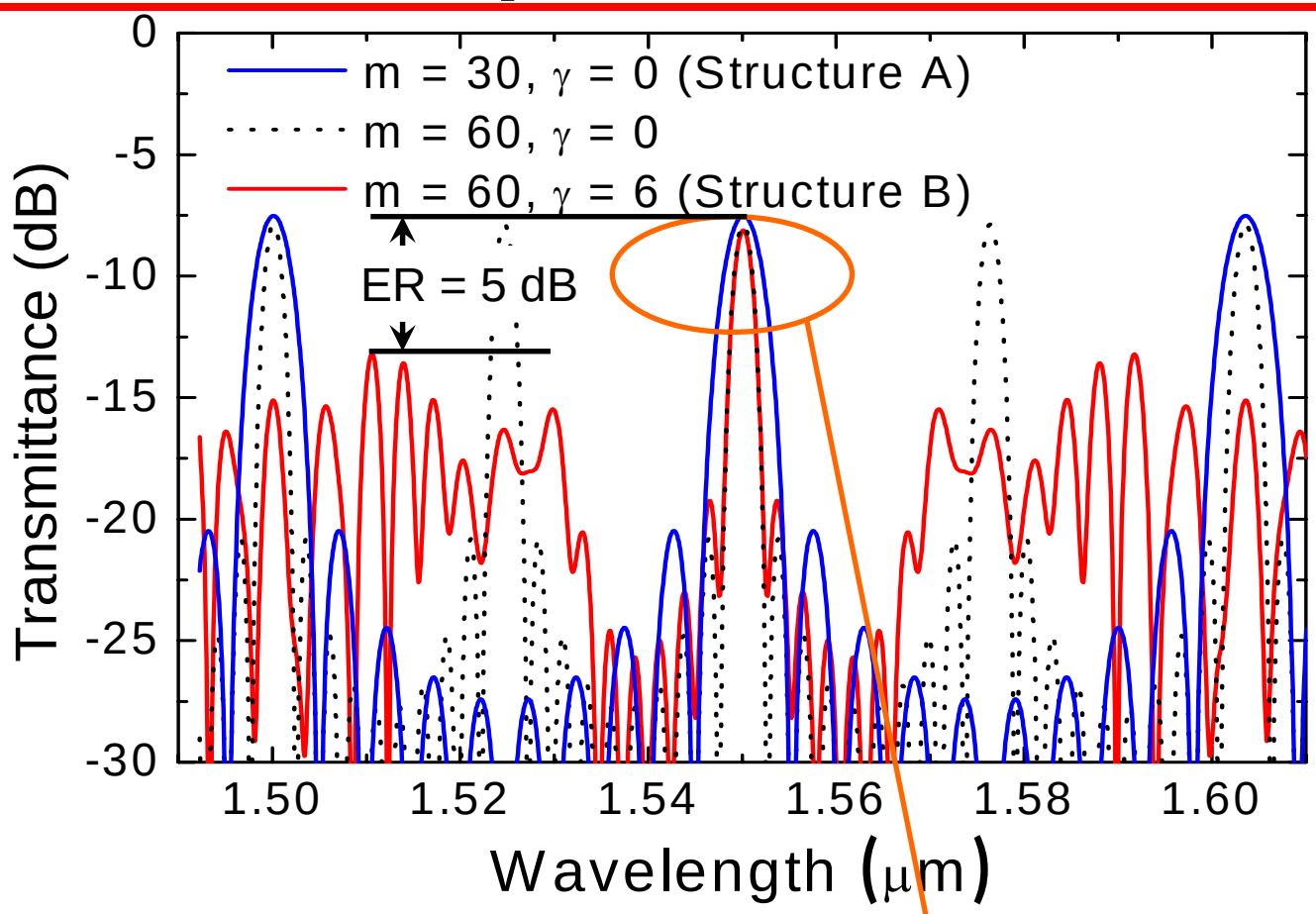
→ Full C, L-band (40 nm) operation



Our structure

Γ = 0.08
L = 1200 μm

Transmission Spectrum of Ladder Filter



Structure

A: Without chirping ($\Delta\lambda_{FSR}$ = 50 nm)

B: With chirping ($\Delta\lambda_{FSR}$ = 40 nm)

$\Delta\lambda_{3dB}(A) > \Delta\lambda_{3dB}(B)$

→ MSR(A) < MSR(B)

Multimode Rate Equation Model

Quantitative simulation

- Tuning range
- Lasing spectra
- Mode suppression ratio (MSR)

Multimode rate equation model

Including

- Gain spectrum
- Transmittance spectra (ring, ladder filter)

Rate equations

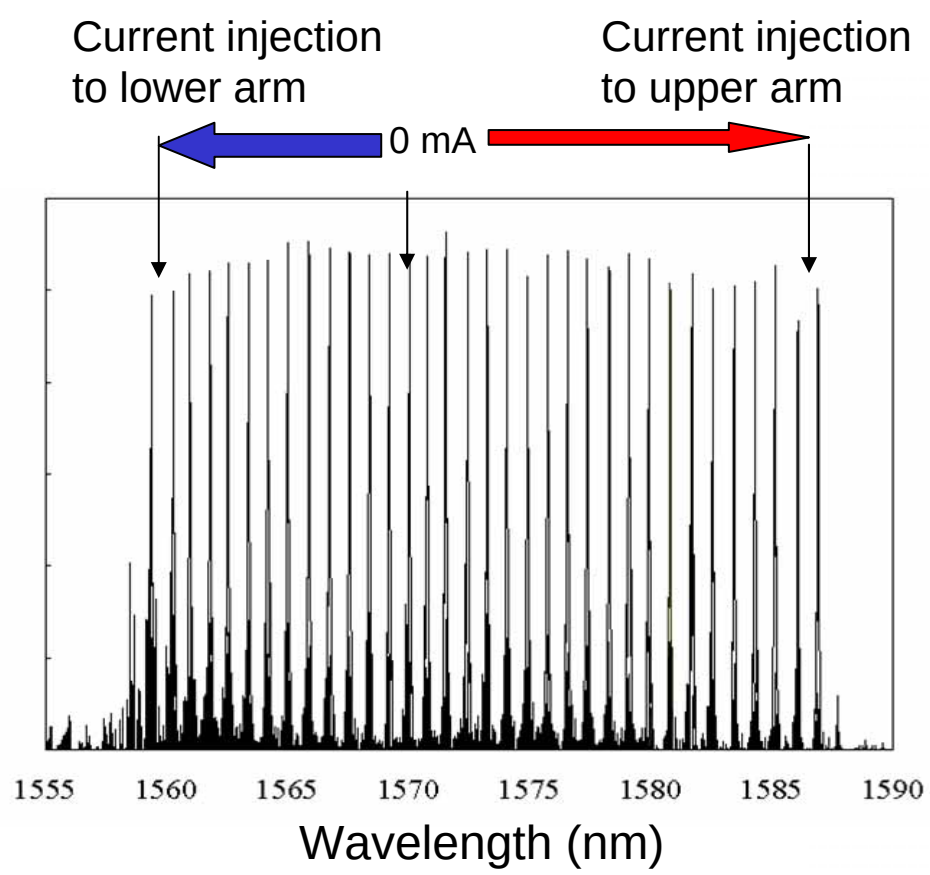
$$\frac{dS_i}{dt} = \left(G_i - \frac{1}{\tau_{pi}} \right) S_i + \frac{\beta}{\tau_r} N_c$$

$$\frac{dN_c}{dt} = \frac{I}{eV} - \sum_i G_i S_i - \frac{N_c}{\tau_r}$$

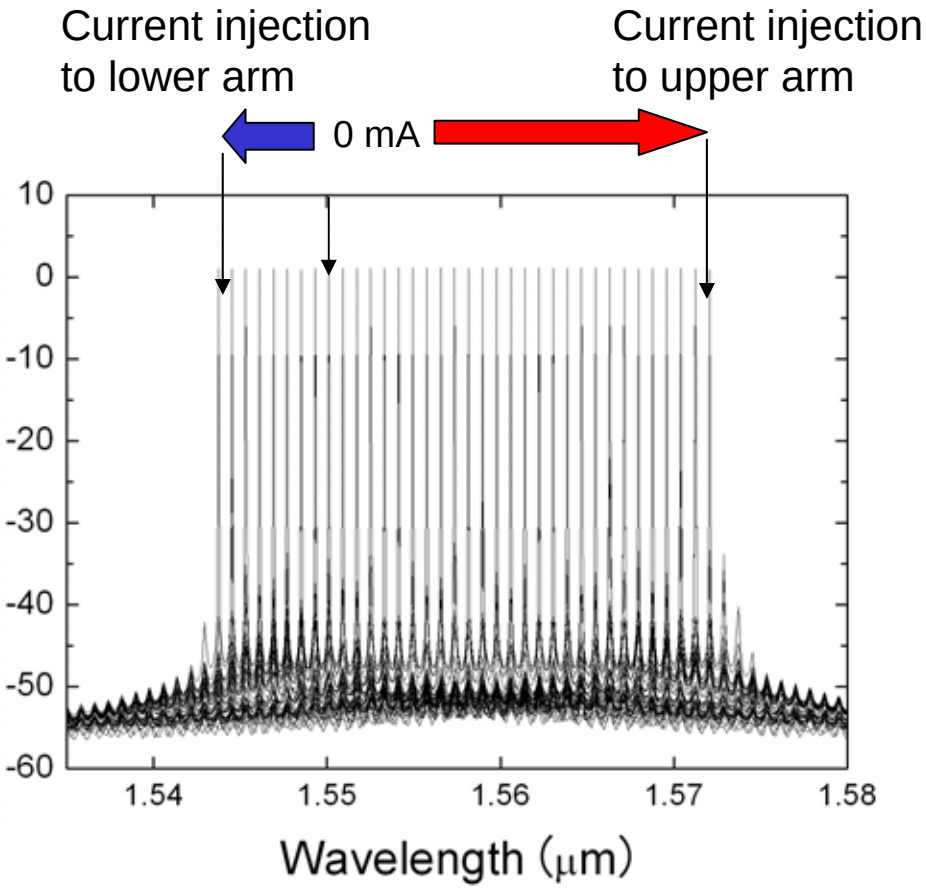
S_i: Photon density
τ_p: Photon lifetime
τ_r: Carrier lifetime
G: Optical gain
N_c: Carrier density
I : Current
V: Volume of active layer
i : Mode index

Lasing Spectra

Experiment



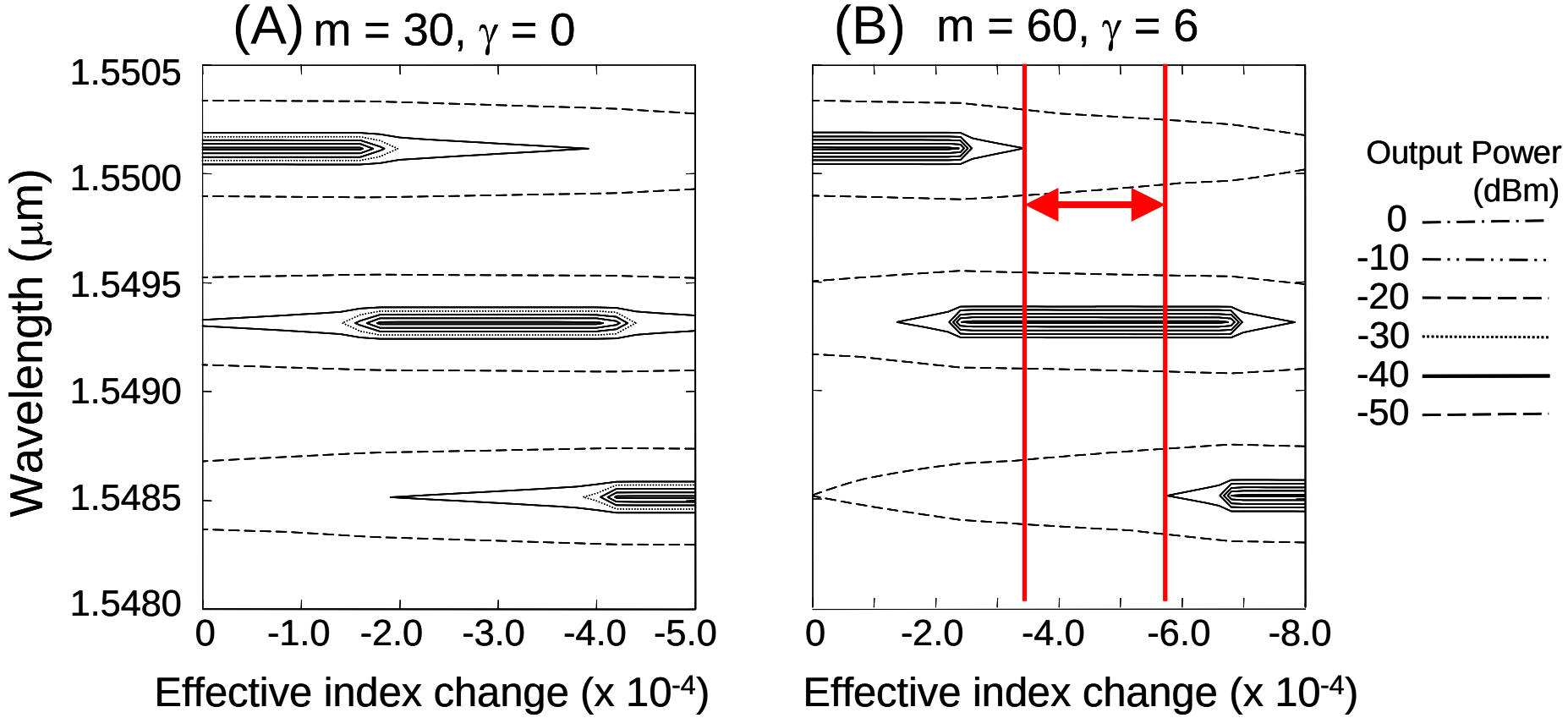
Simulation



- Digital tuning by current injection with spacing of 100 GHz
- Tuning range of 27 nm

NTT

Effect of Chirping – Improvement of MSR



Without chirping

- $\Delta\lambda_c$ = 50 nm
- MSR < 40 dB

With chirping

- $\Delta\lambda_c$ = 46 nm
- MSR > 40 dB

Summary

- Design of tunable laser with chirped ladder-type filter and ring resonator for wide tuning range
- Expansion of tuning range
  - Wide FSR of ladder filter
  - Chirped ladder structure
  - Flat gain spectrum
- Effect of chirped structure
  - Wide tuning range and stable lasing ($\Delta\lambda_c$ > 40 nm)
  - High mode suppression ratio (MSR > 40 dB)

NTT