Tunable Lasers and Related Devices with Liquid Crystal Enabled Functionalities for DWDM Optical Communication

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Motivation and Objectives

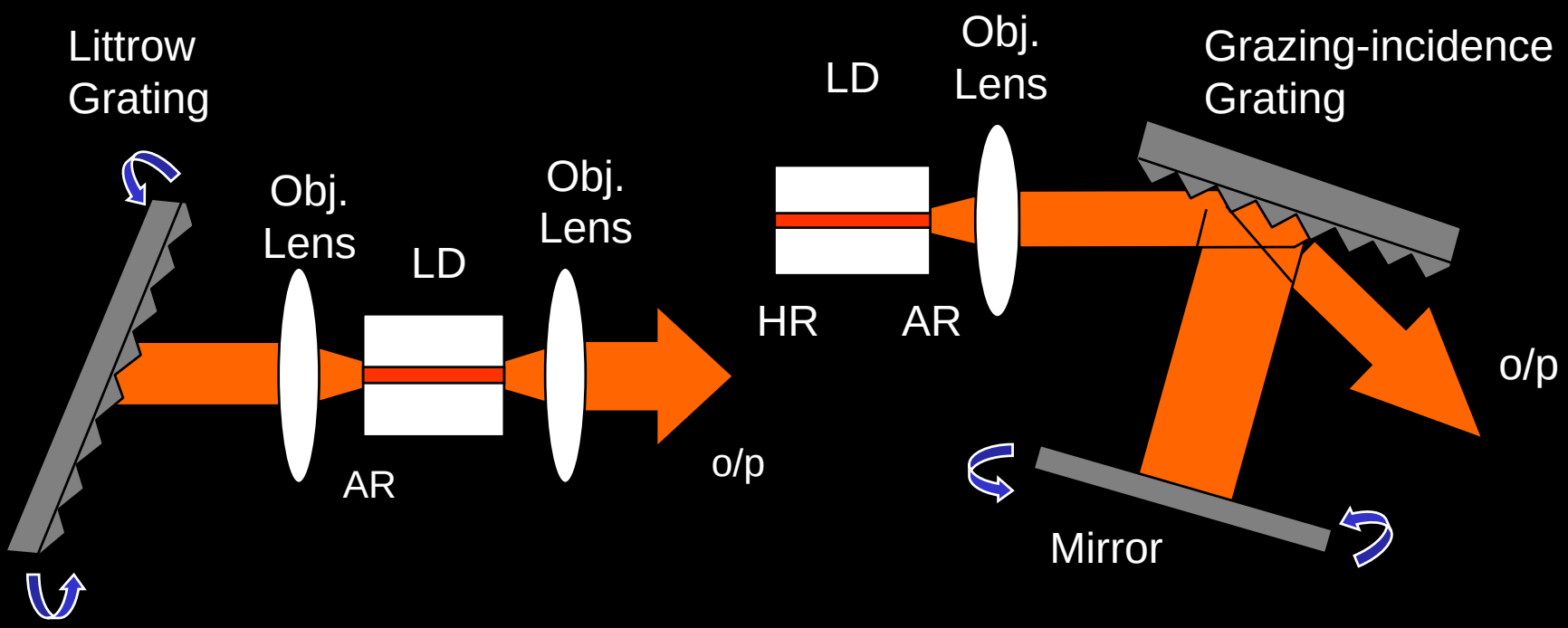
- Tunable Lasers for DWDM Optical Communication that are
    1. Compact
    2. Allow Channel switching
    3. Wavelength according to the ITU Grid
    4. Power equalization
    5. Multiple Wavelengths
- Other Generic Devices w/LC-enabled functionality:
    1. Demux
    2. Tunable Filter

Part (I):
Tunable Lasers
for DWDM Optical Communication

Basic Design Concept

- Patented Folded Telescopic Grating-loaded External Cavity (US 5,524,012 and pending)
- Use the LCPM (Liquid Crystal Pixel Mirror), a reflection-type liquid crystal spatial light modulator, for digital tuning and selection of the laser wavelength

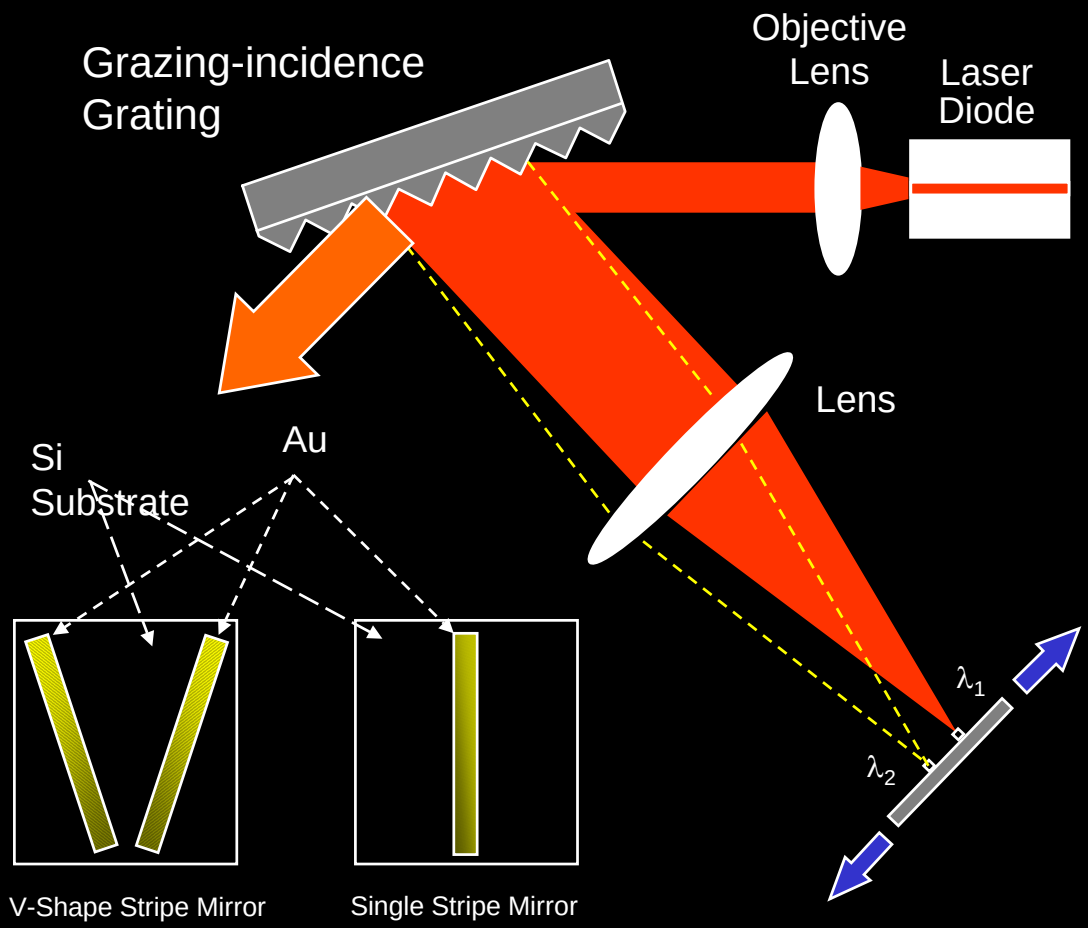
Conventional Grating-tuned External Cavity Laser Diode



Littrow -type ECL

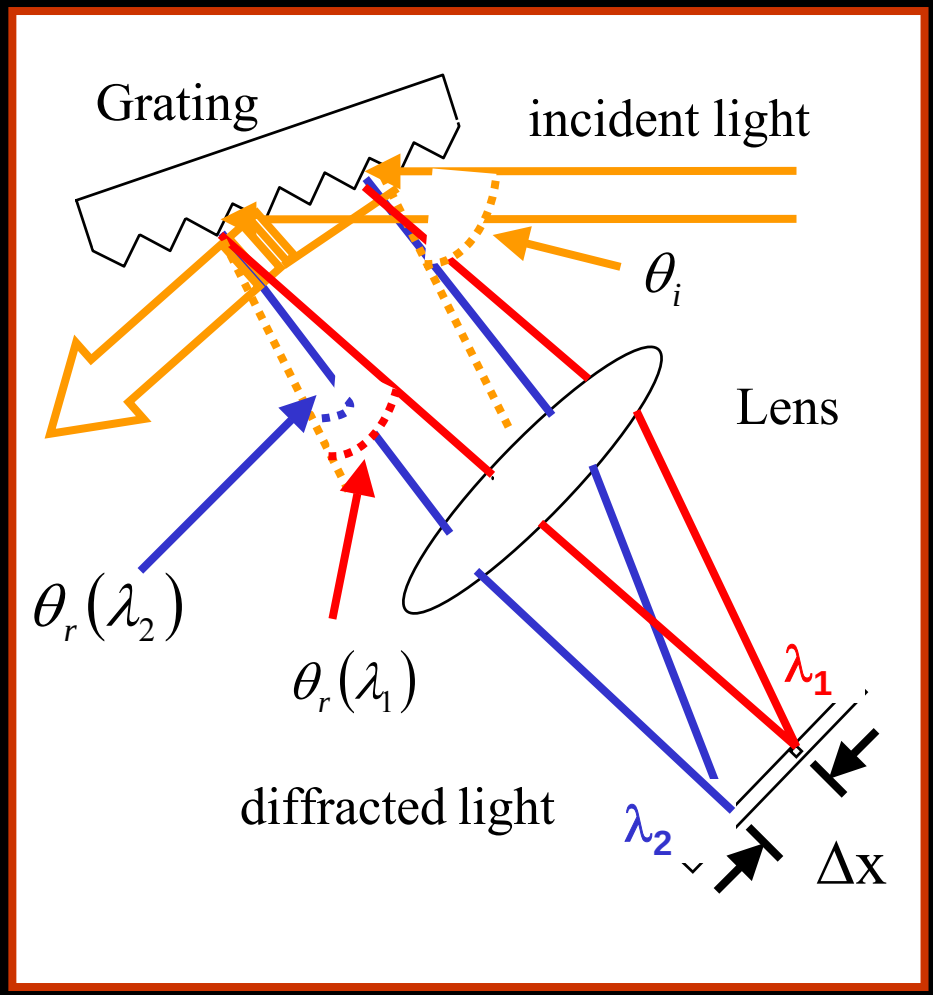
Littman-type ECL

Folded Grating-Lens-Stripe-Mirror External Cavity Laser Diode



- **Intra-cavity dispersion compensation**
- **Multi-λ co-axial output**
- **Spatial Mode Control**

λ - Tuning Mechanism



$$m\lambda = a(\sin\theta_i + \sin\theta_r)$$

Where m : diffraction orders

a : groove spacing

θi : incident angle

θr : diffractive angle

f : focus length

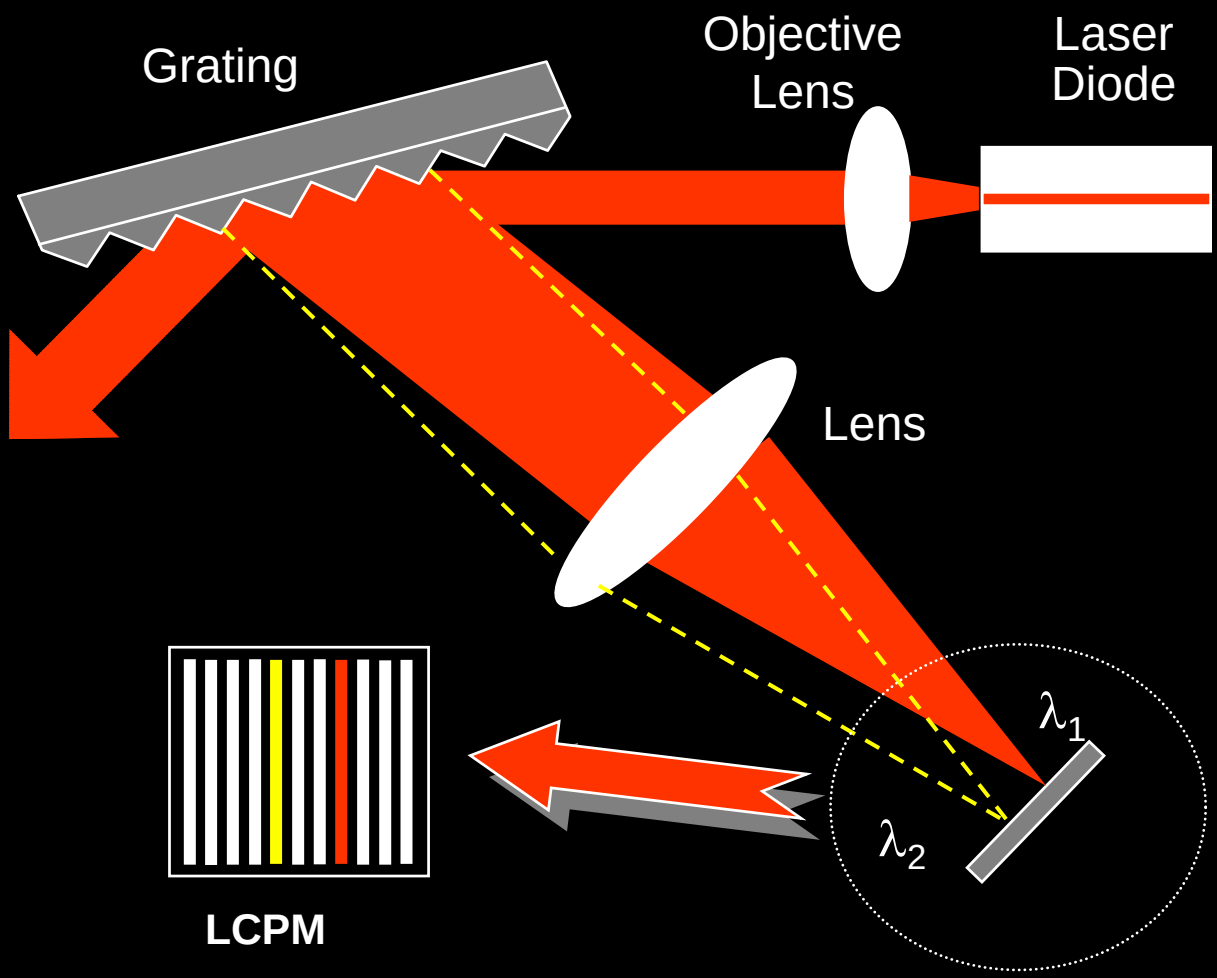
- For m=1,

$$\frac{d\lambda}{d\theta_r} = a\cos\theta_r$$

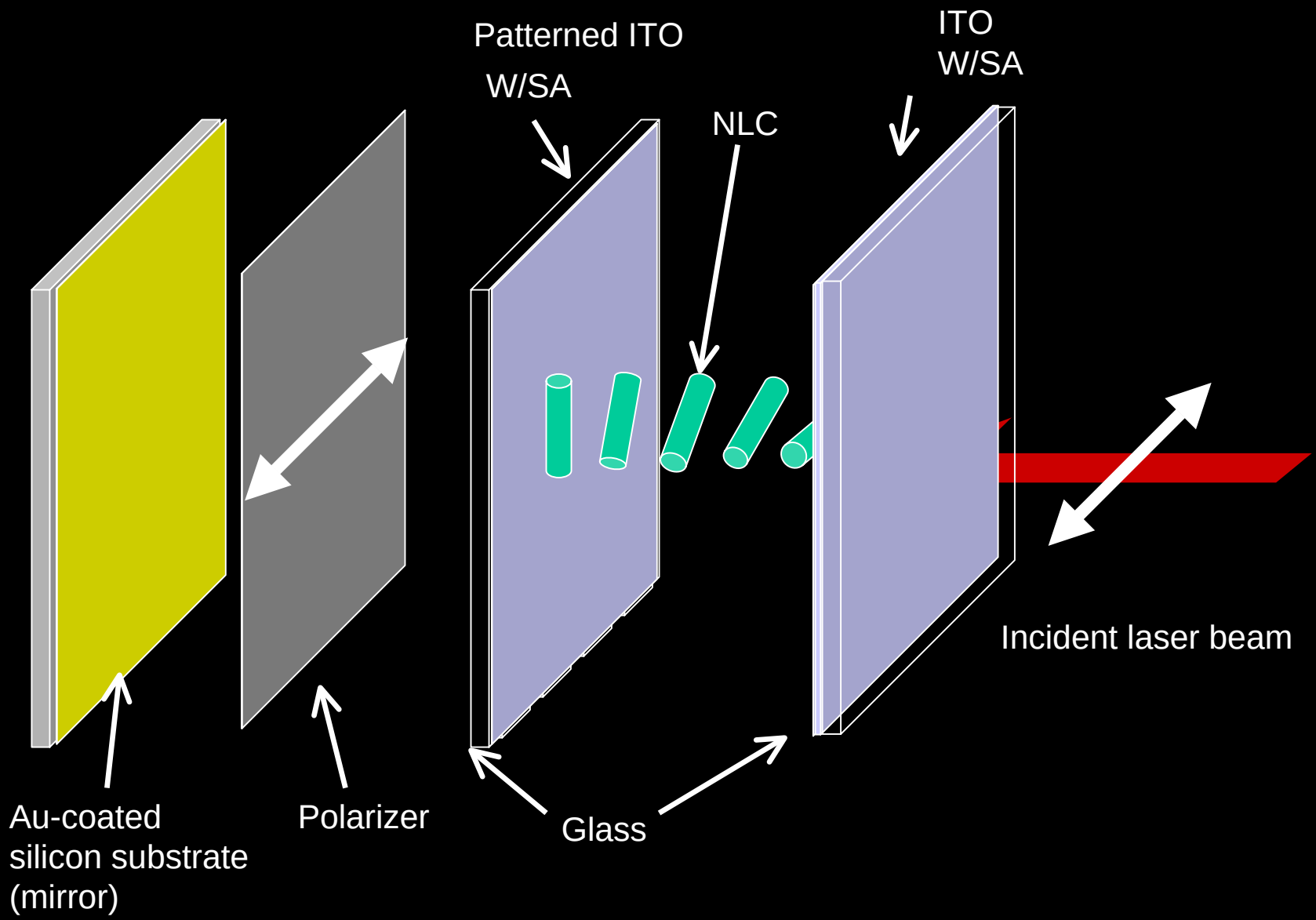
$$\Delta x = f\Delta\tan\theta_r \approx f\Delta\theta_r$$

$$\frac{\Delta\lambda}{\Delta x} = a\cos\theta_r\frac{1}{f}$$

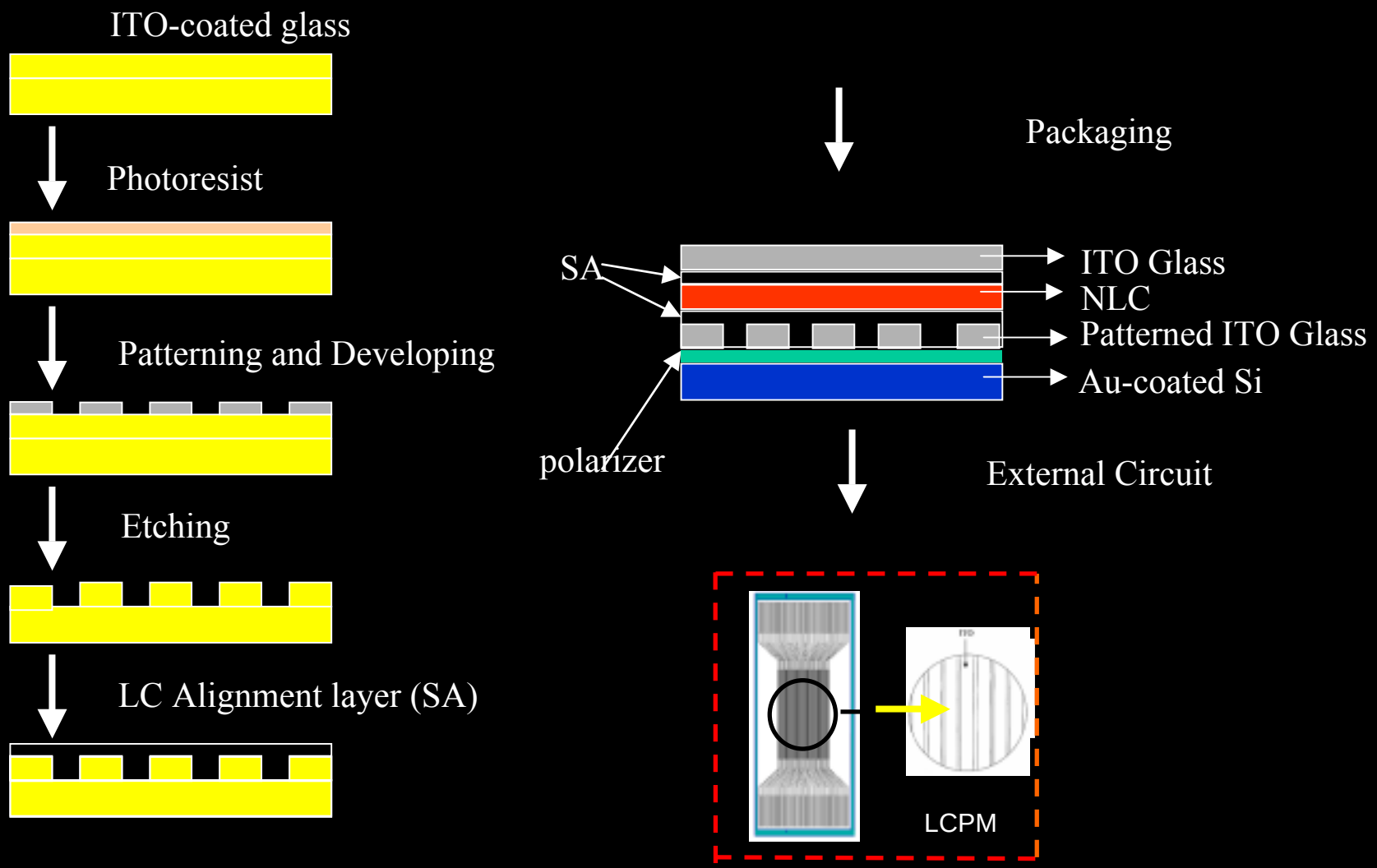
Multi-λ - ECL w/LCPM



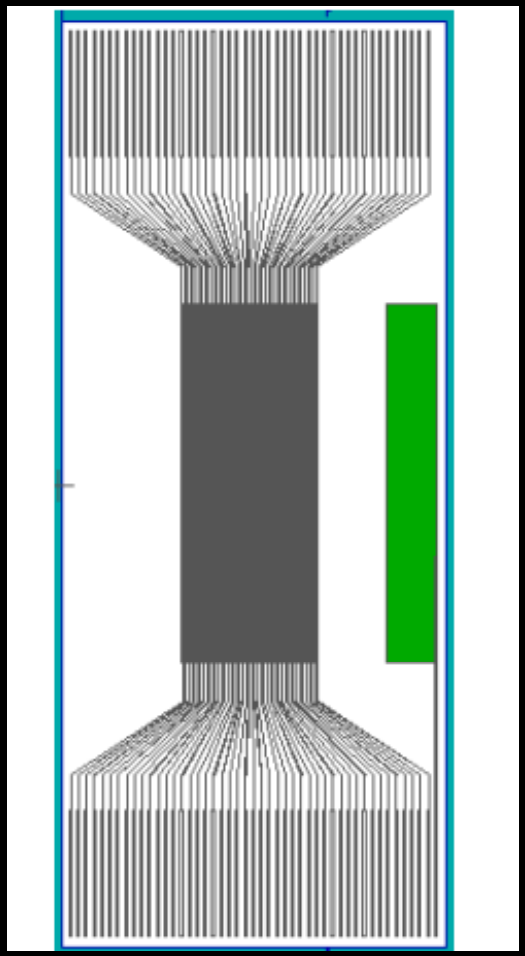
Liquid Crystal Pixel Mirror

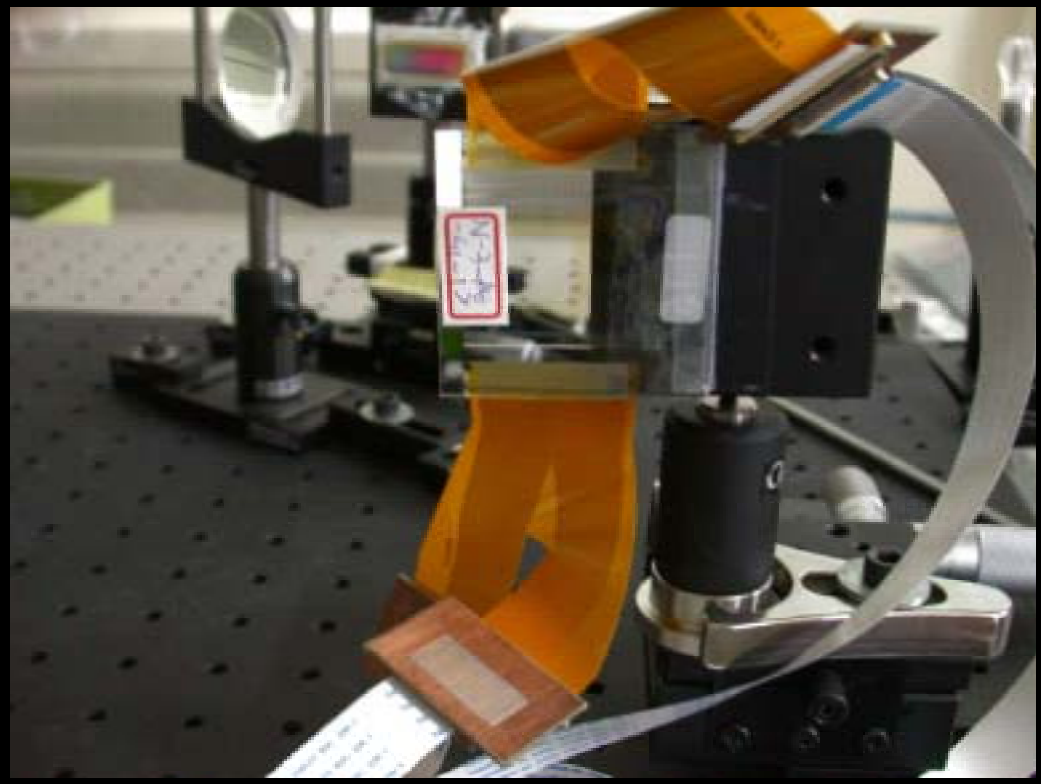


Fabrication of the LCPM



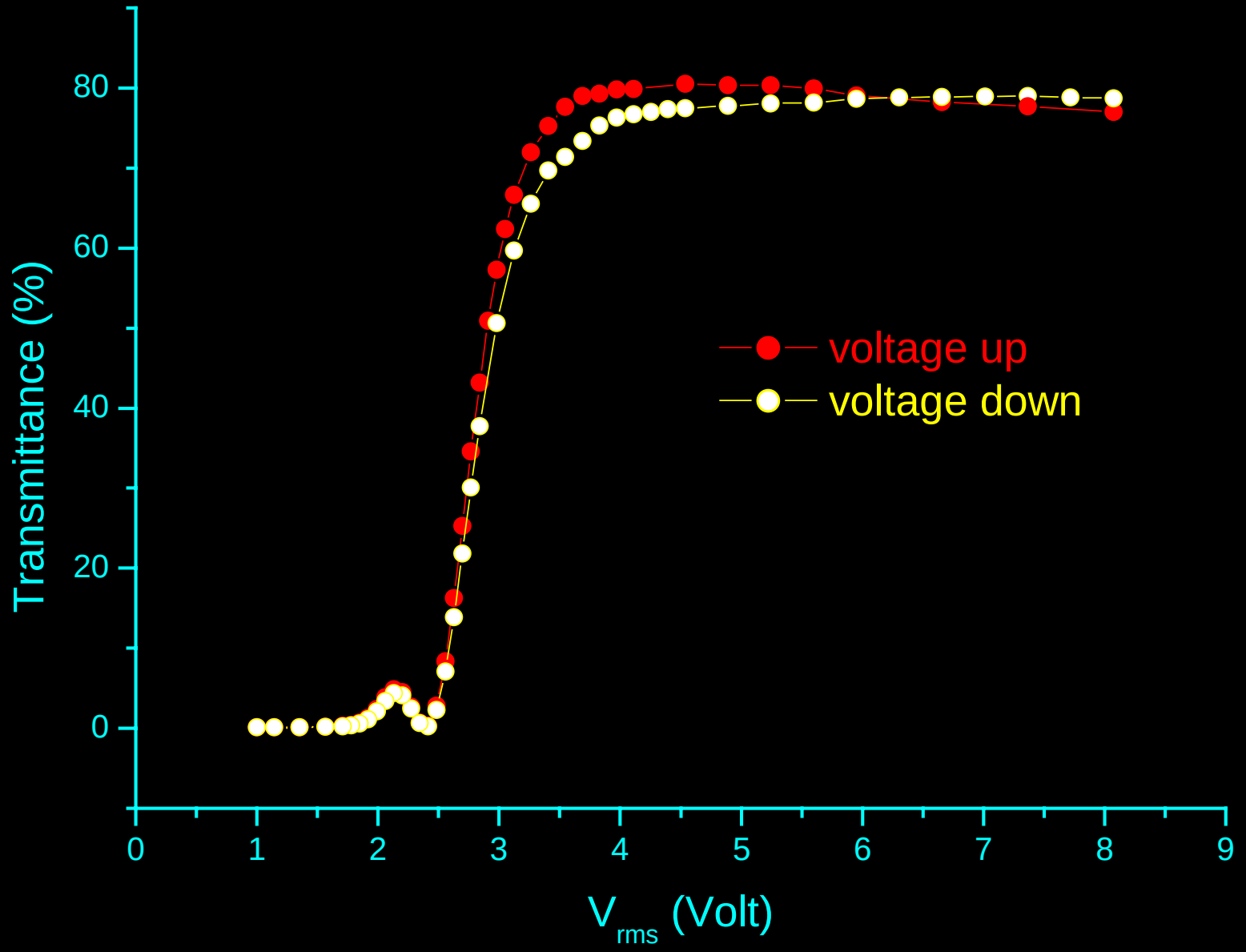
Liquid Crystal Pixel Mirror or Liquid Crystal Spatial Light Modulator



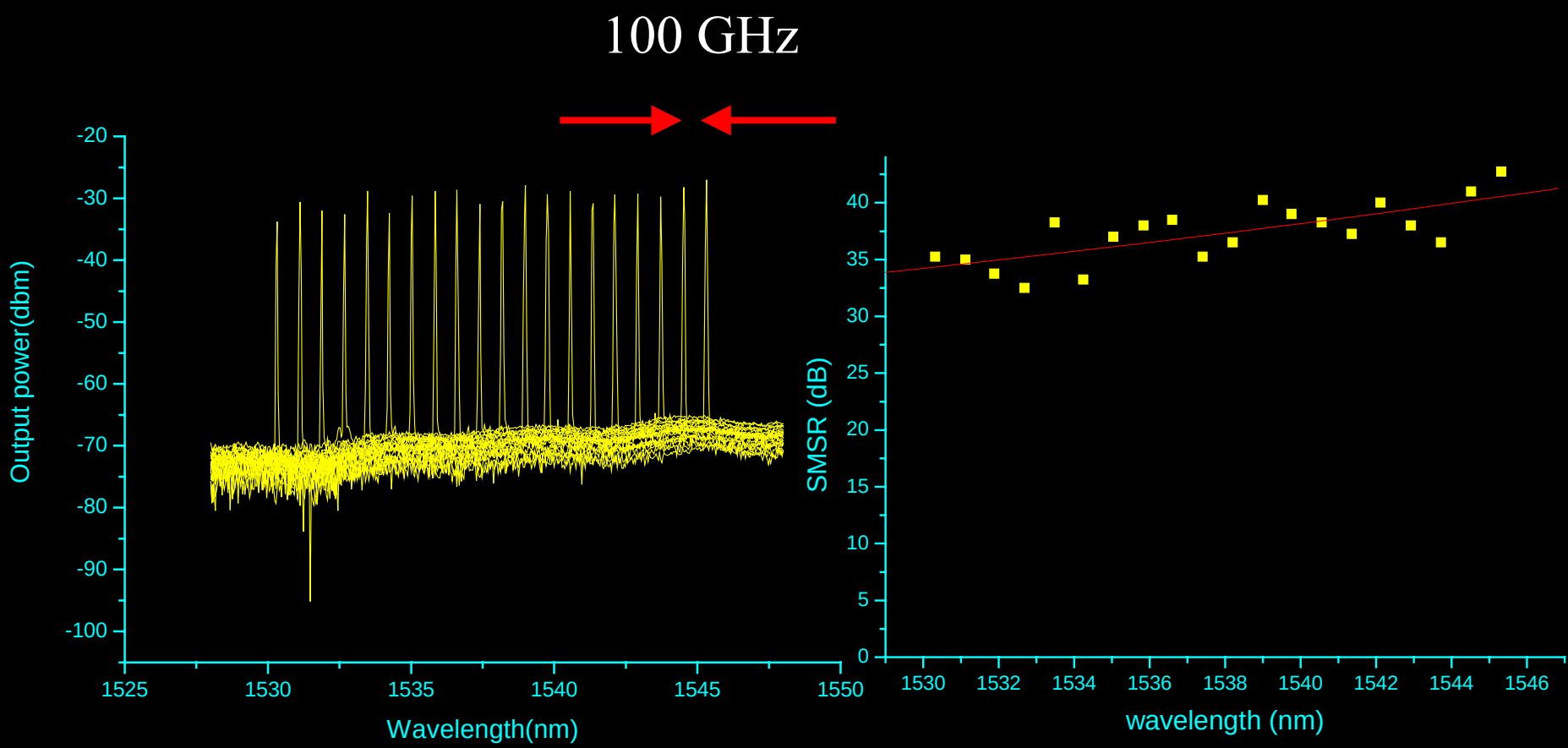


The LC-SLM pixel pitch/width
= 83.3/79.3 μm or 125/100 μm
Pixel number=96;The thickness~ 8 μm

Transmittance of the LCPM /w.o. Au Mirror

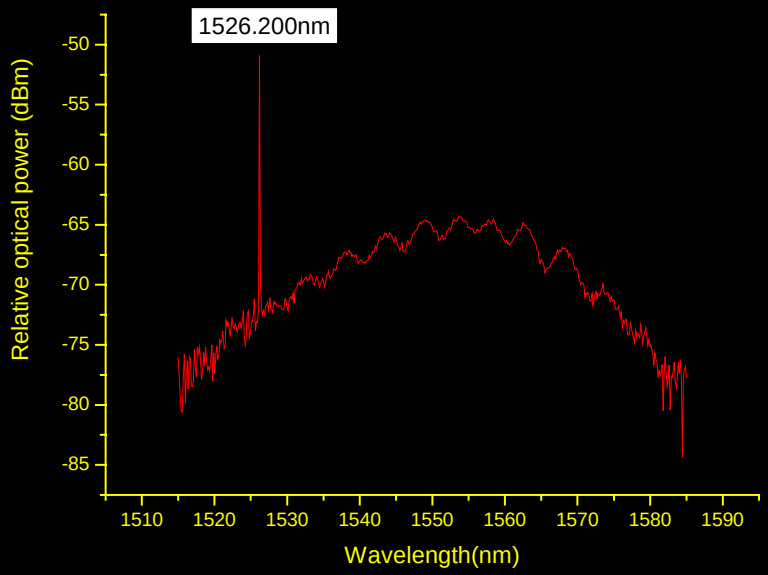


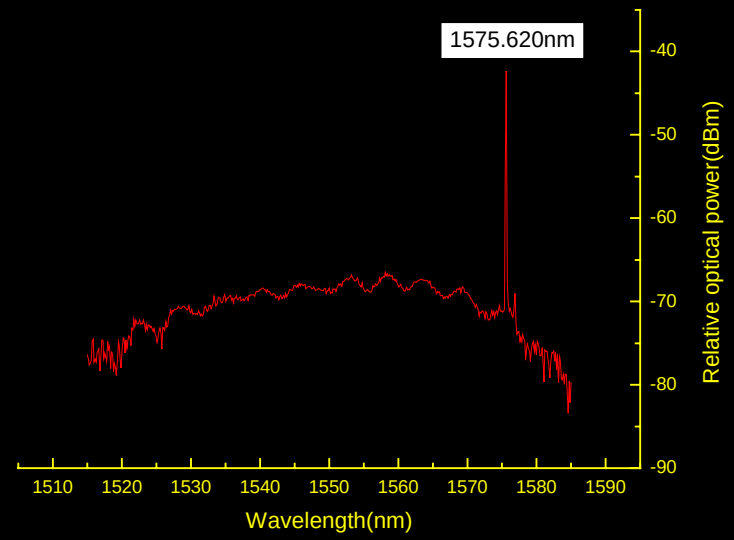
Digitally tuning the ECL (1550nm) in 100 GHz step (ITU grid)

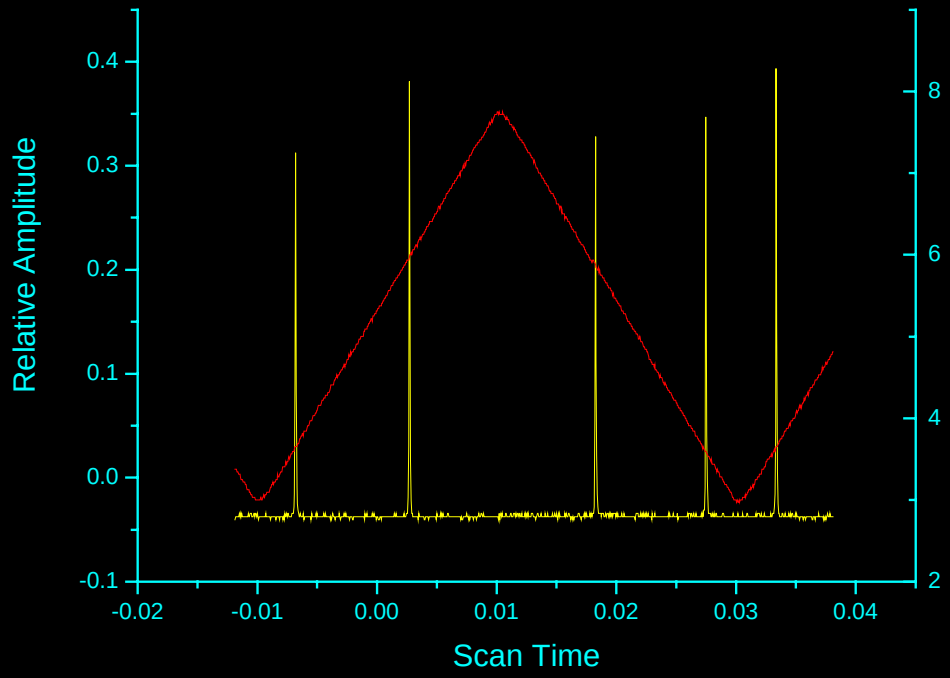


Tuning range ~ 60 nm, SMSR > 30 dB

Max. Tuning Range (I = 1.54 I_{th})

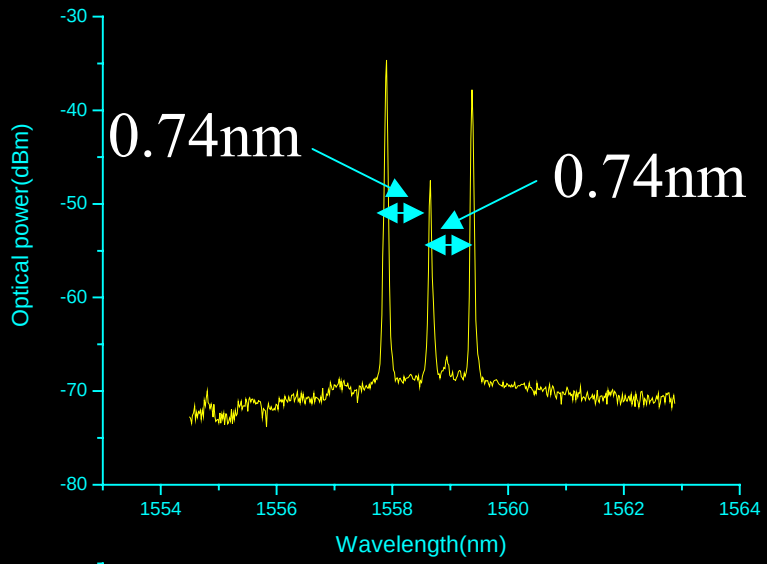


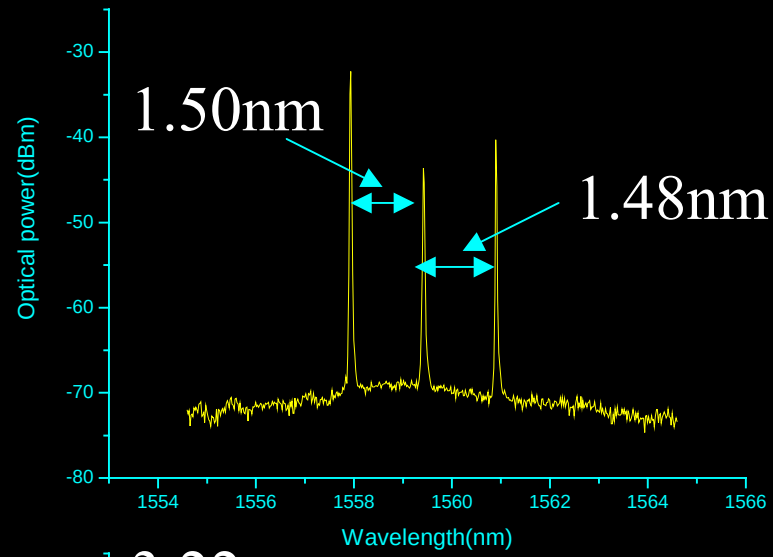


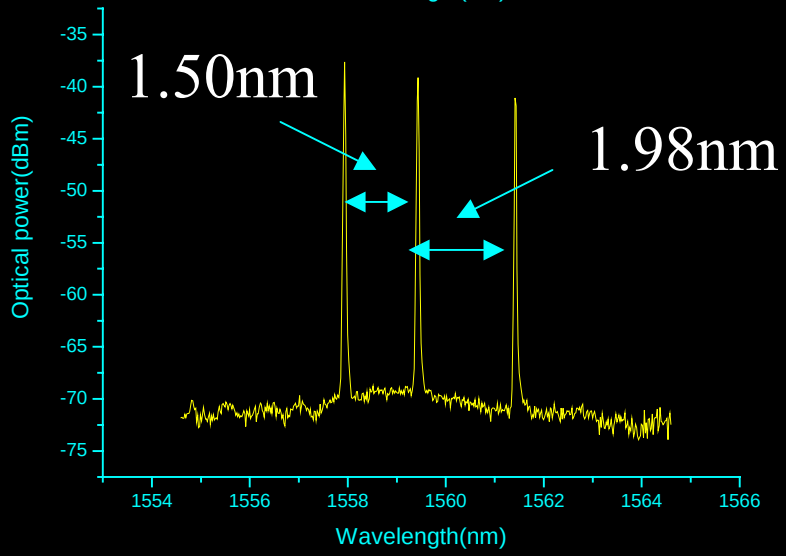


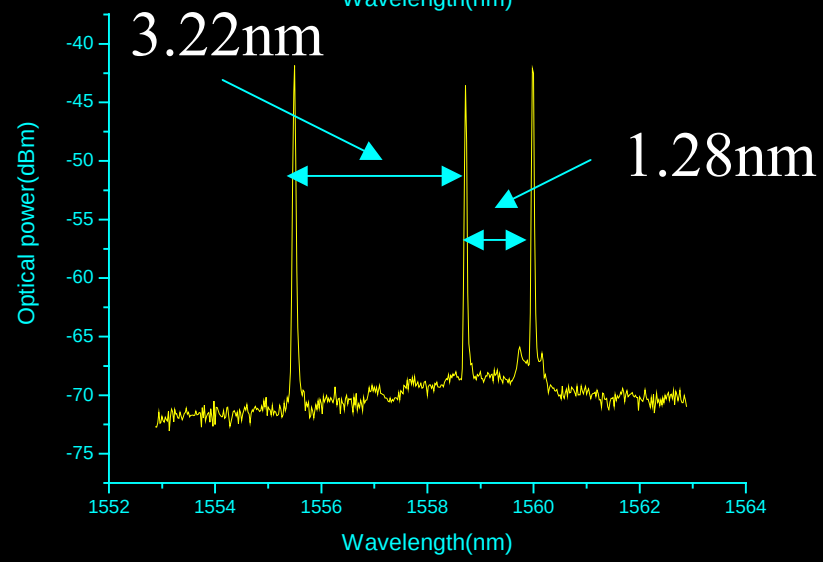
Linewidth < 20 MHz
(Instrument-limited)

Multi-wavelength Operation

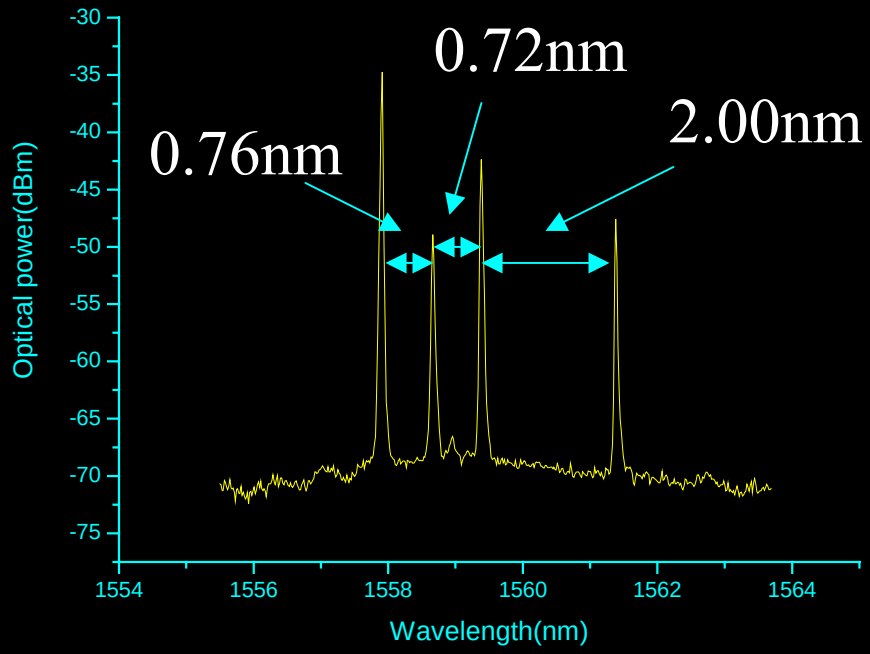


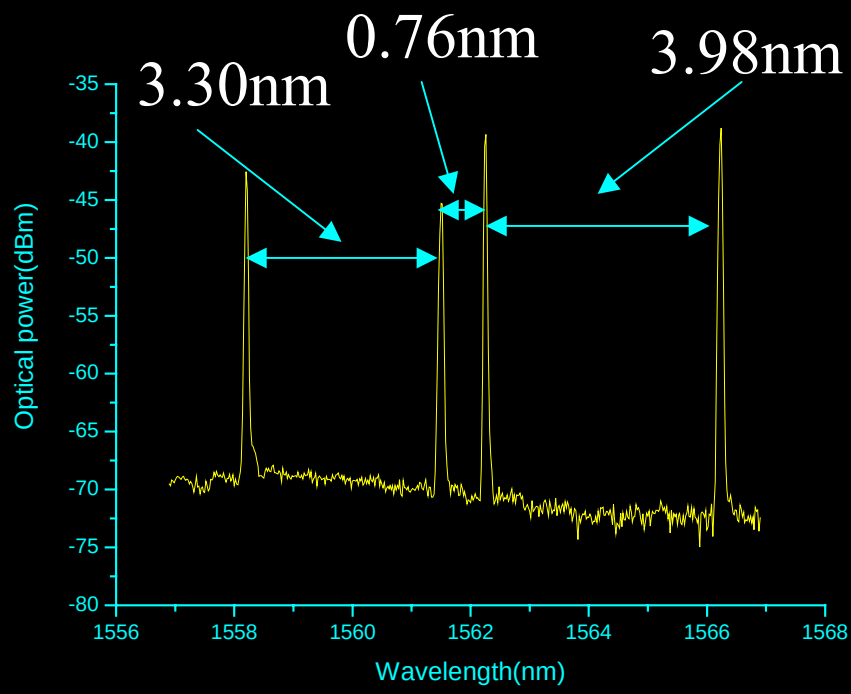




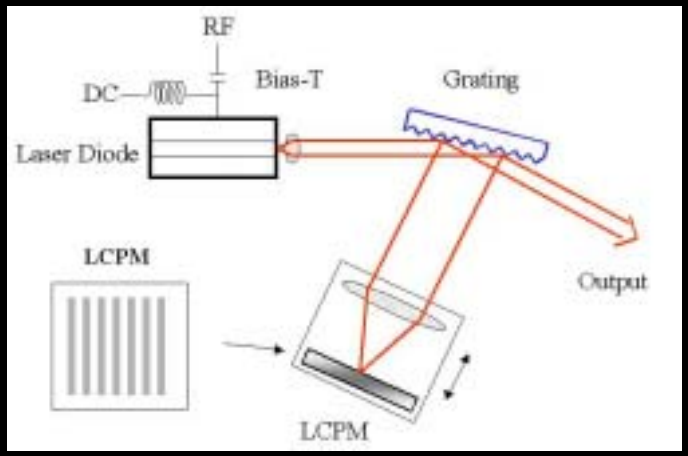


Multi-wavelengths Operation

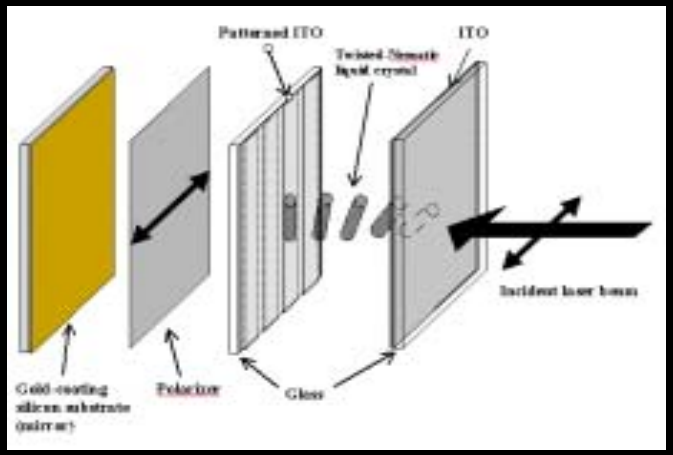




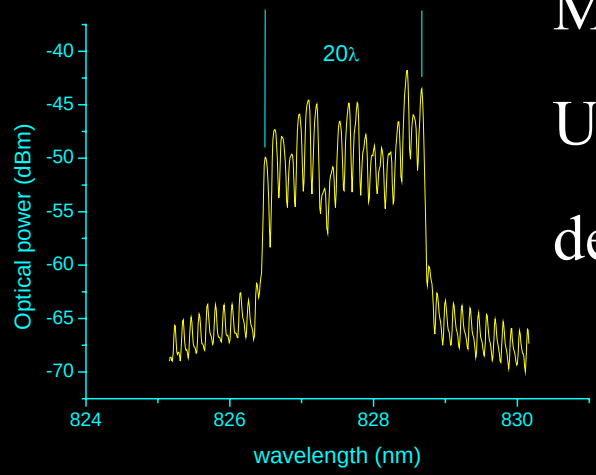
Multi-wavelength Mode-locked MOPA w/intra-cavity dispersion compensation



Master Laser



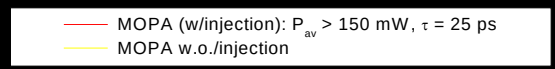
The LCPM

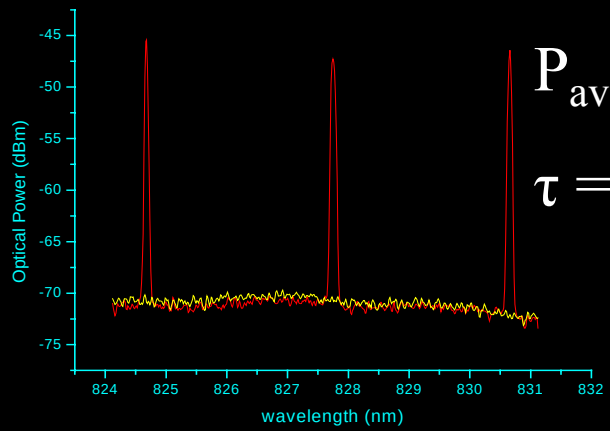


Master Laser:

Up to 20 λ

demonstrated



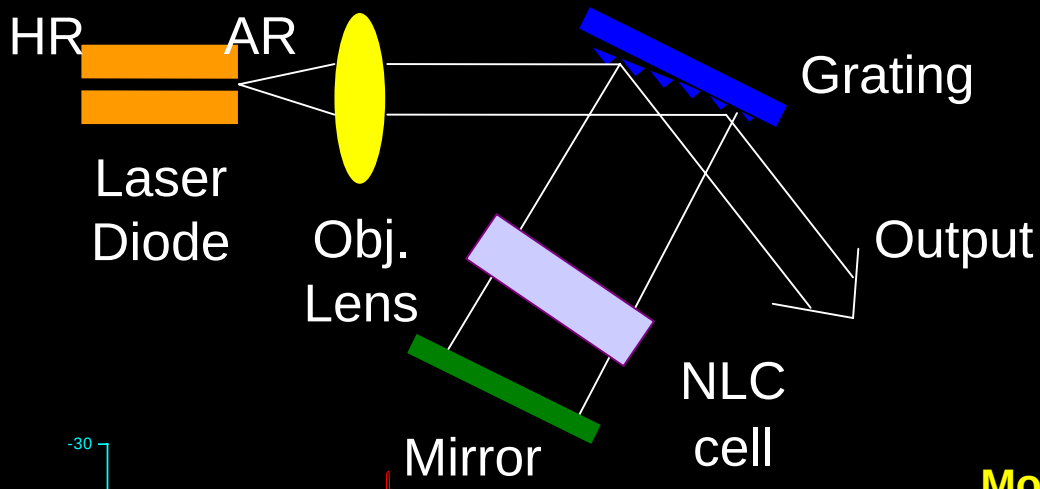


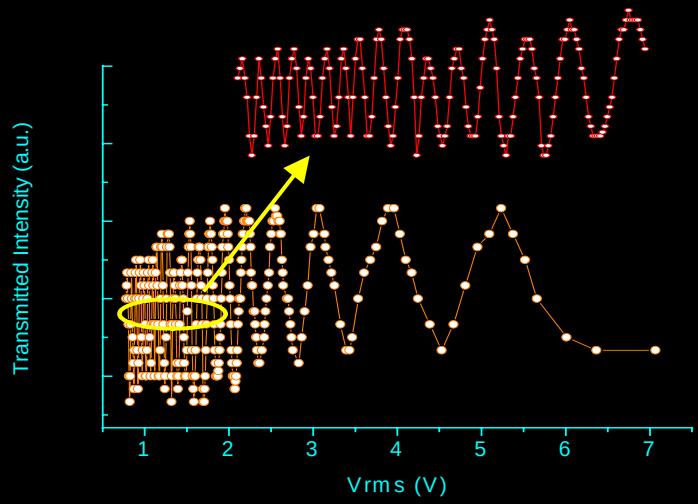
MOPA:

$P_{avg} > 150$ mW

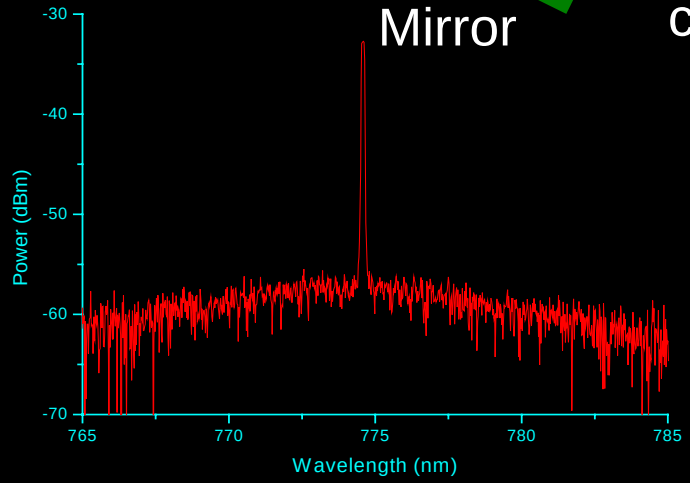
$\tau = 25$ ps

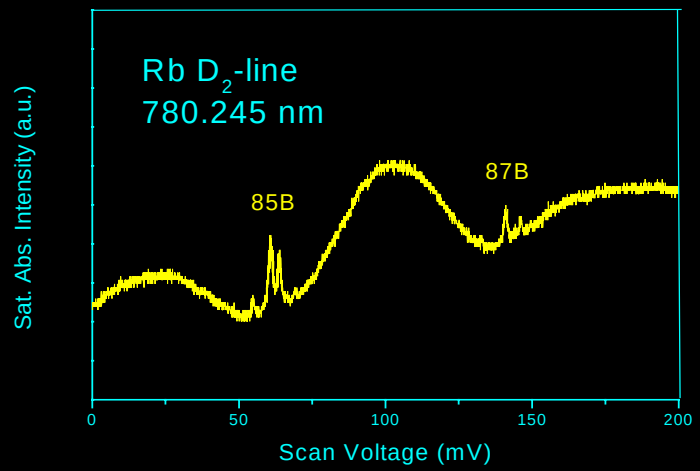
MODE-HOP-FREE FINE TUNING OF AN EXTERNAL-CAVITY DIODE LASER WITH AN INTRACAVITY LIQUID CRYSTAL CELL





Mode-hop-free tuning range : 19.2 GHz

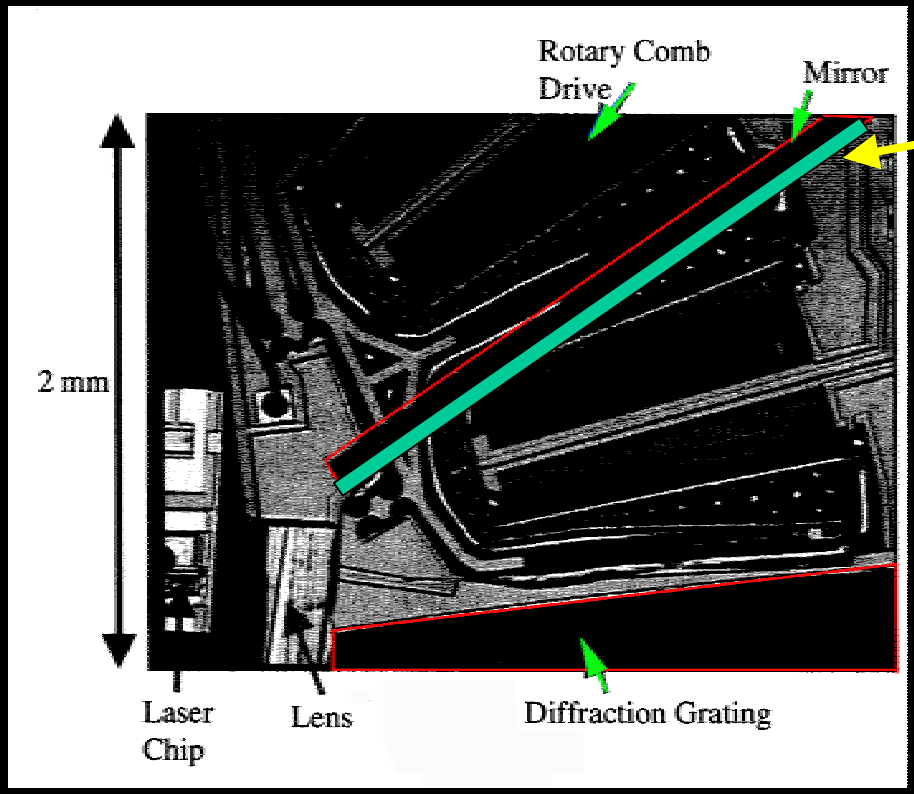




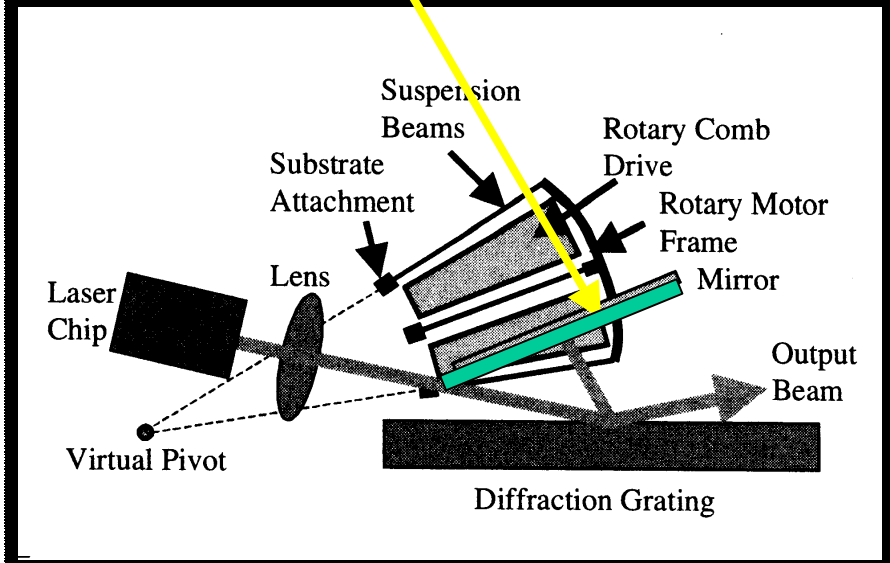
$$\Delta I_{LD} = \frac{\lambda \bullet \Delta L_2}{\beta \bullet L_2}; \quad \beta = \Delta\lambda / \Delta I_{LD}$$

Application:High-Res. Spectroscopy

Possible MOEM Implementation of the Laser

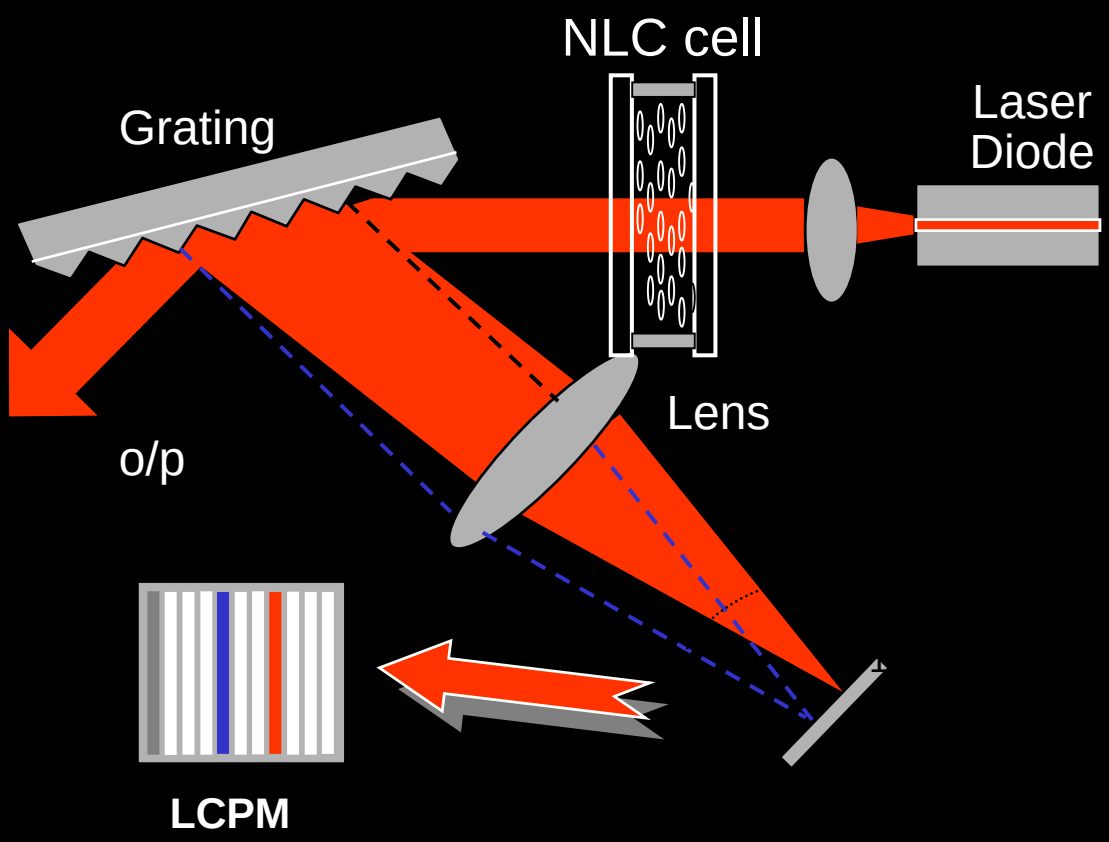


LC element for fine tuning



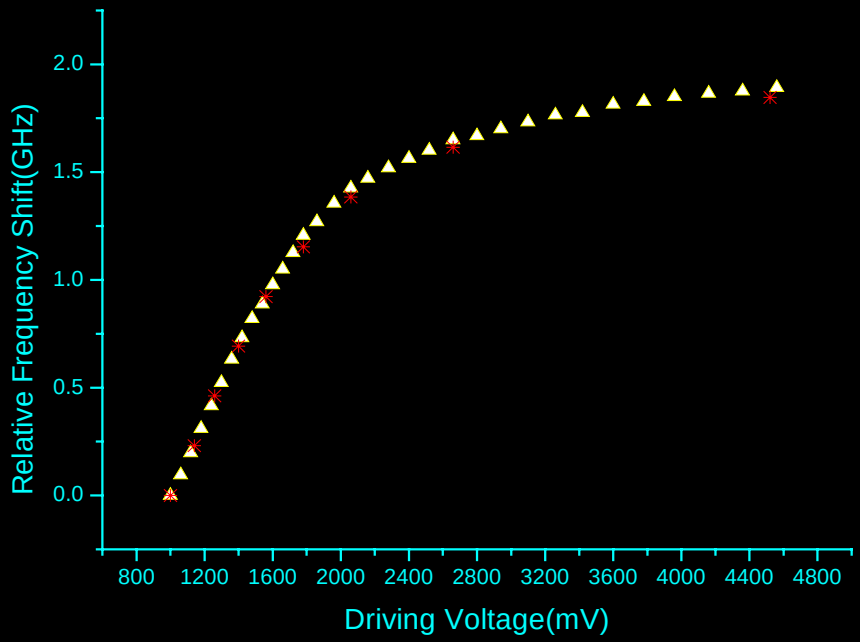
Berger et al, OFC2001,
Paper TuJ2 (Iolon)

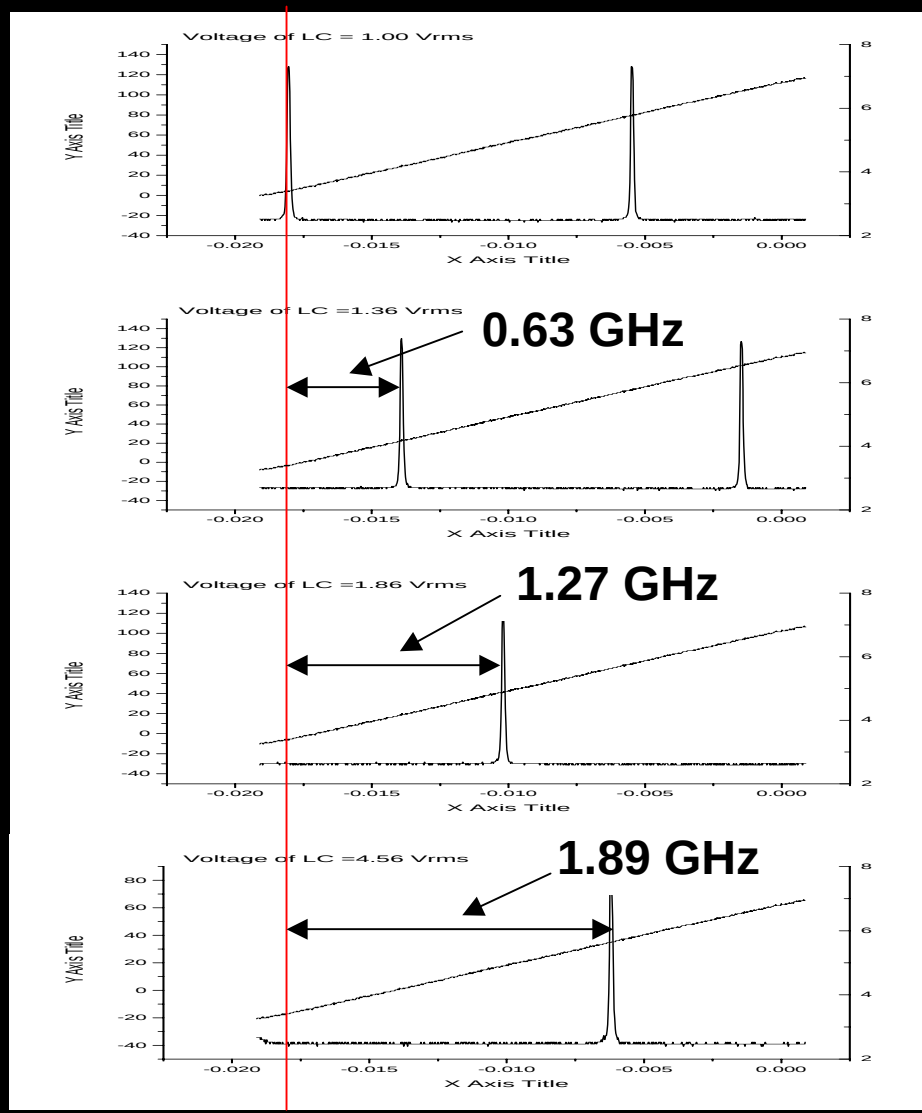
Tunable Laser with LC-enabled fine-tuning function



- AR-coated LD (Opto Speed RSOA1550CRI-R077)
- diffraction grating (Agilent 1100 lines/mm)
- Incident angle = 80˚
- lens (f = 25.7cm)
- Pixel width = 100μm
- ECDL cavity length=65 cm
- Thickness of NLC (E7) cell=52.3 μm

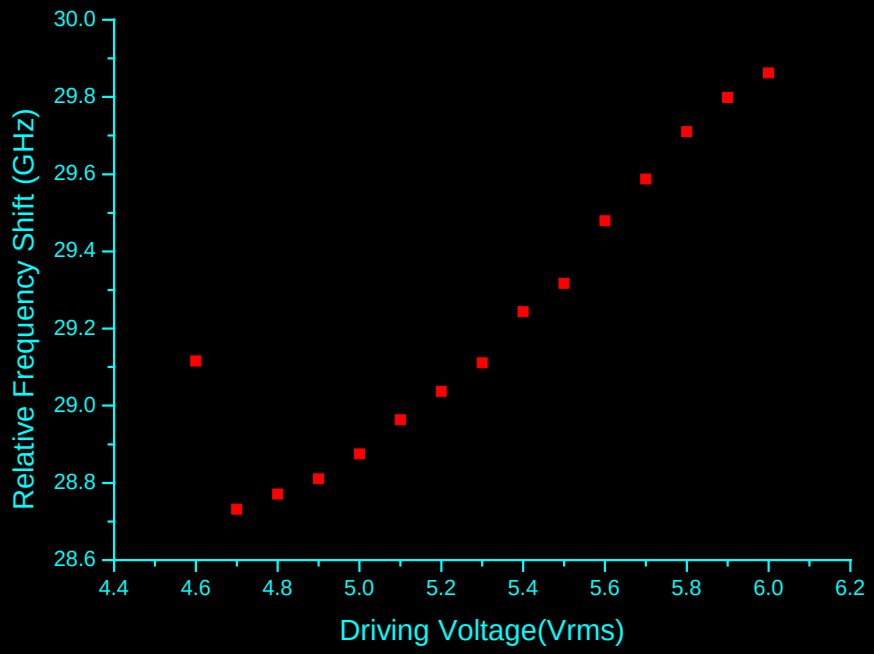
Mode-hop-free tuning of a tunable ECDL with an intracavity LC tuning element



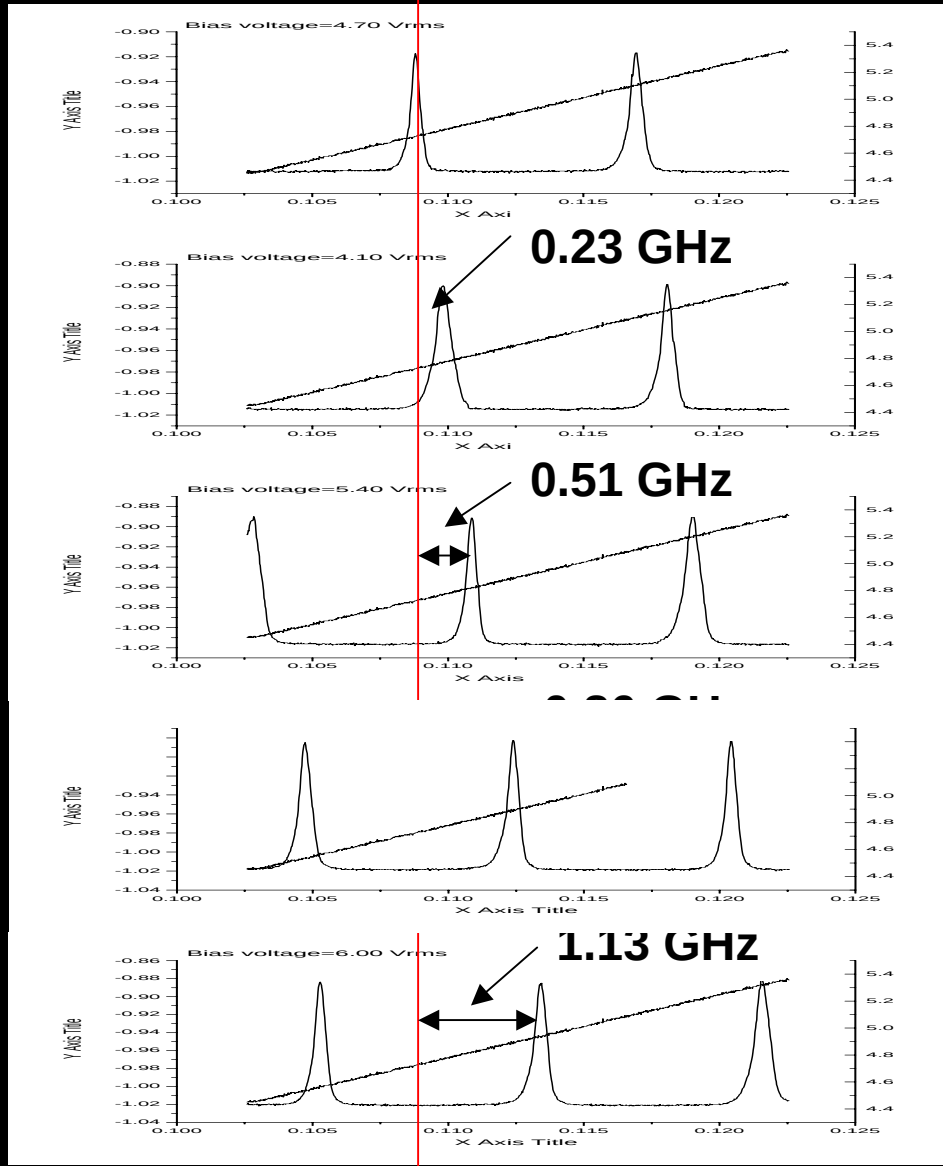


NLC voltage: (1.00 Vrms to 4.56 Vrms).
Theoretical predictions = 1.8464 GHz
Experimental tuning range ~ 1.89 GHz.

Mode-hop-free tuning using the LCPM



LCPM voltage: 4.70 Vrms to 6.00 Vrms
Tuning range ~ 1.13 GHz

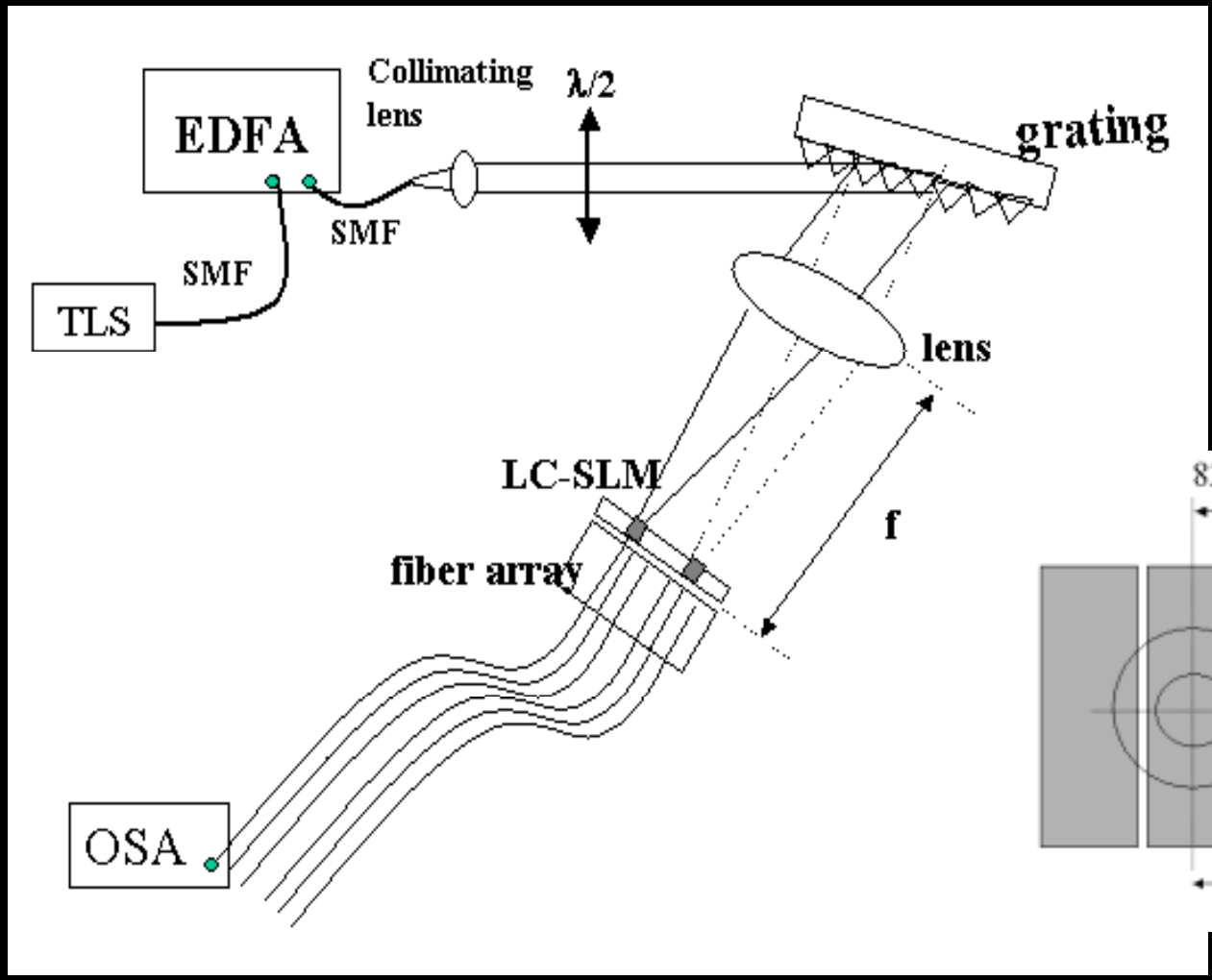


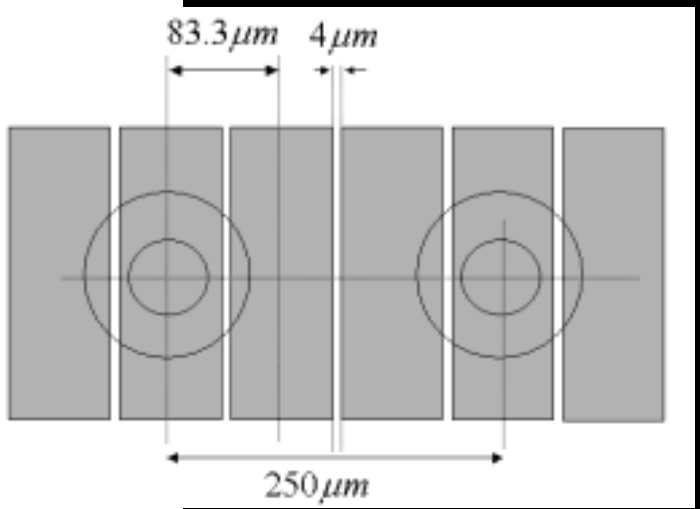
Summary (I)

- A novel digitally tunable laser diode (λ = 1550 nm) using liquid crystal technology is demonstrated.
- Laser wavelength can be locked to ITU grid.
- Multi-wavelength operation demonstrated
- Mode-hop-free fine tuning demonstrated.
- Wavelength switching response is ~ 100 ms

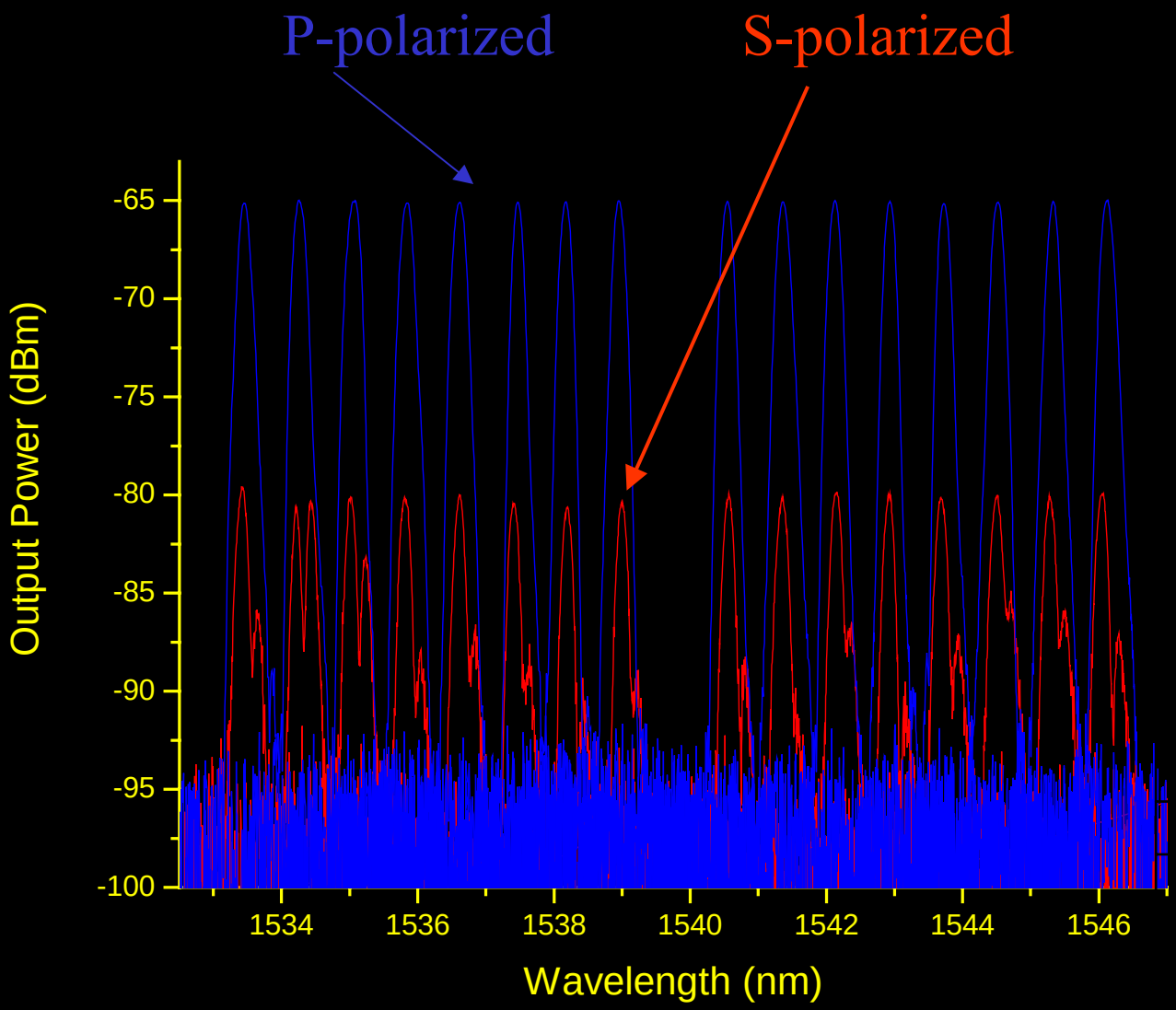
Part (II):
Functional Liquid-Crystal-Based Devices for DWDM Applications

Vmux: Variable Optical Demultiplexer



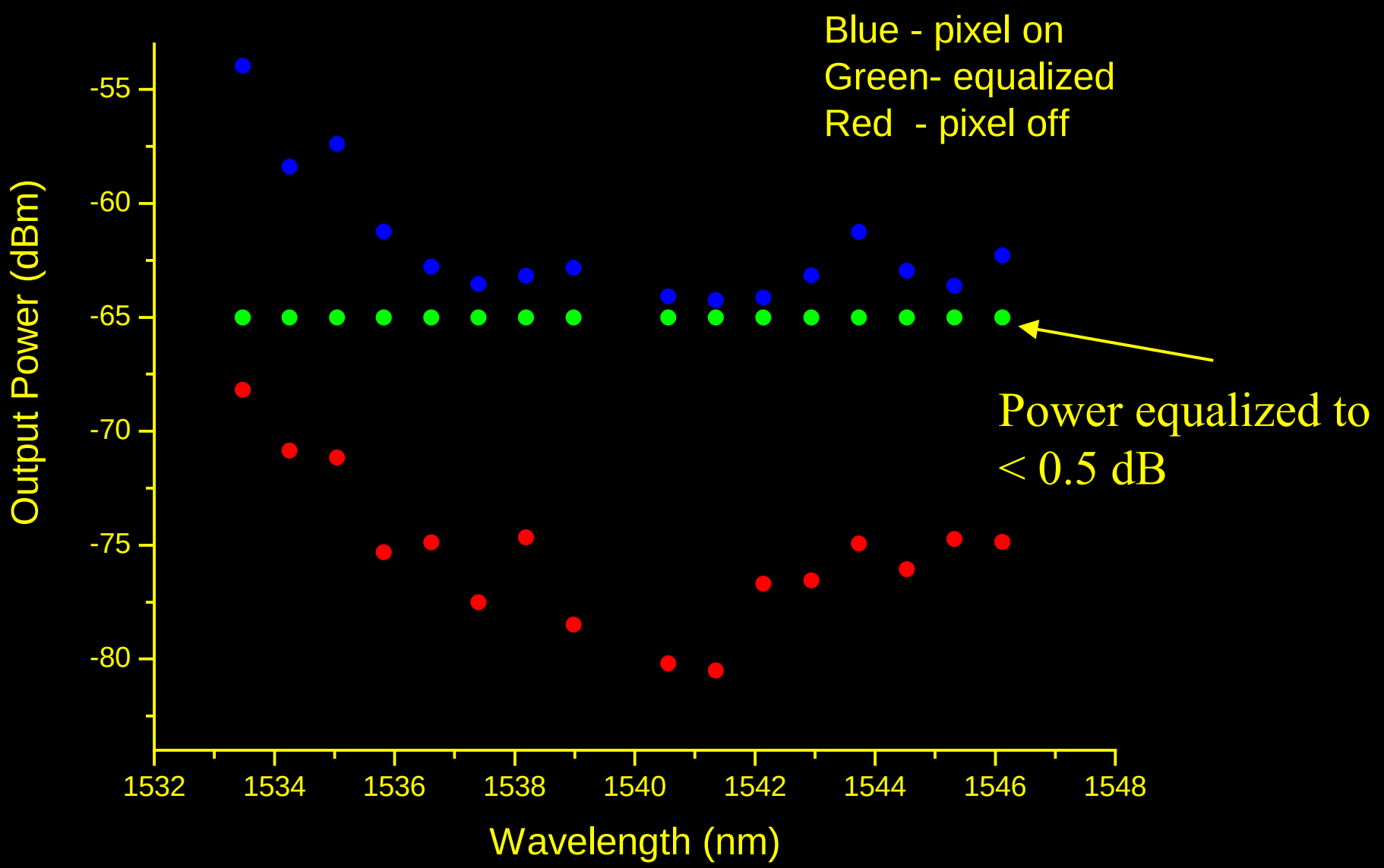


Tunable Demultiplexer : Channels Fixed to ITU grid (100 GHz)

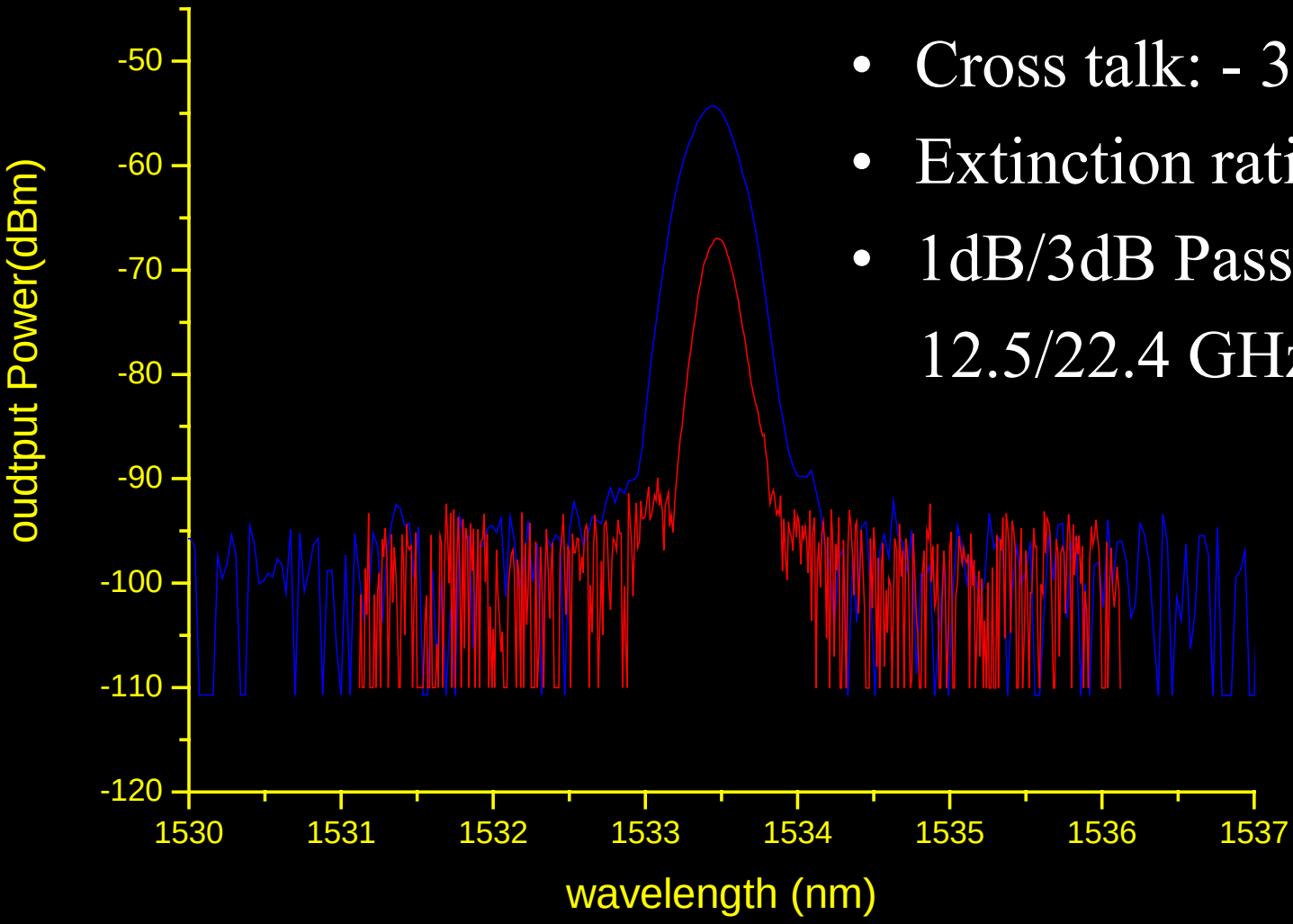


channel	ITU grid (nm)	Experiment (nm)	ITU-Experiment
1	1533.47	1533.48	-0.01
2	1534.25	1534.21	0.04
3	1535.04	1535.02	0.02
4	1535.82	1535.83	-0.01
5	1536.61	1536.59	0.02
6	1537.4	1537.4	0
7	1538.19	1538.2	-0.01
8	1538.98	1538.98	0
9	1540.56	1540.56	0
10	1541.35	1541.34	0.01
11	1542.14	1542.13	0.01
12	1542.94	1542.93	0.01
13	1543.73	1543.73	0
14	1544.53	1544.52	0.01
15	1545.32	1545.28	0.04
16	1546.12	1546.08	0.04

Tunable Vmux : Power Equalization

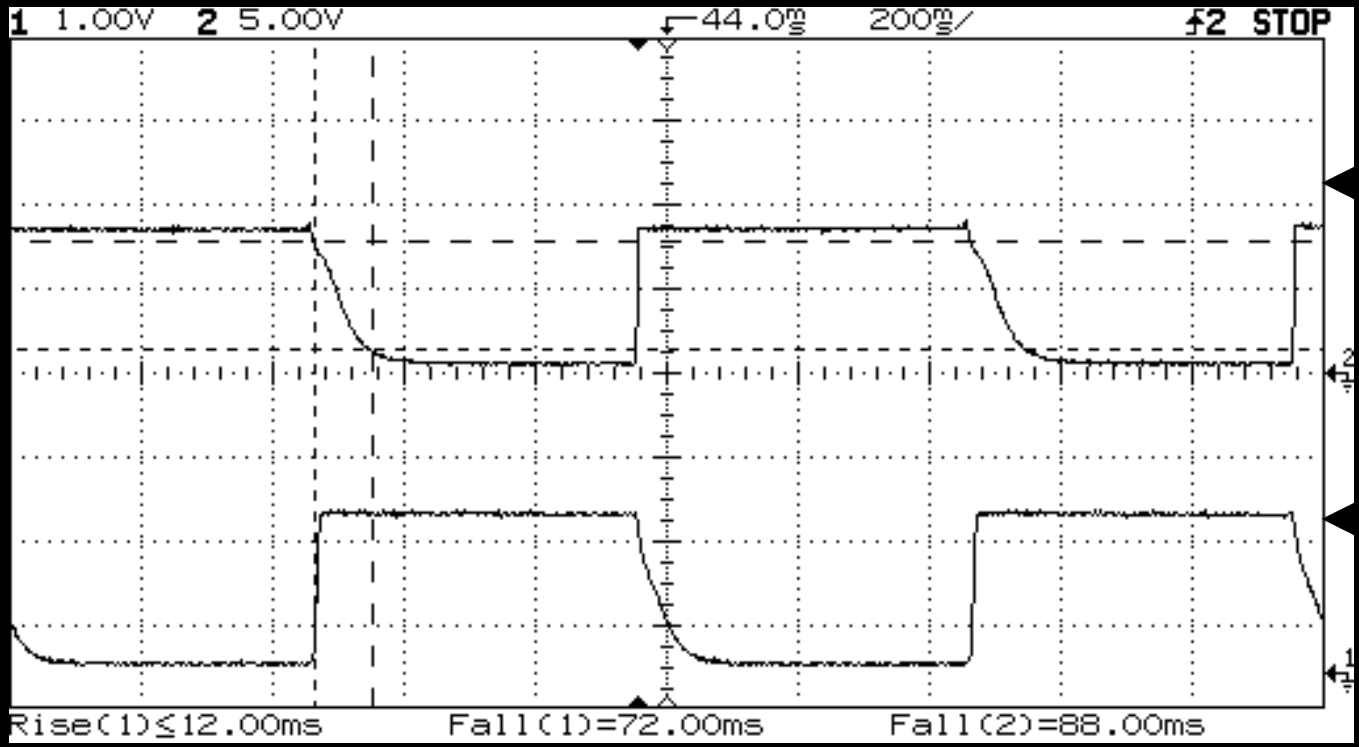


Tunable Vmux : Output characteristics



- Cross talk: - 30 dB
- Extinction ratio: 13.5 dB
- 1dB/3dB Passbands: 12.5/22.4 GHz

Dynamic Characteristics: Channel Switching Results



λ=1536.66 nm

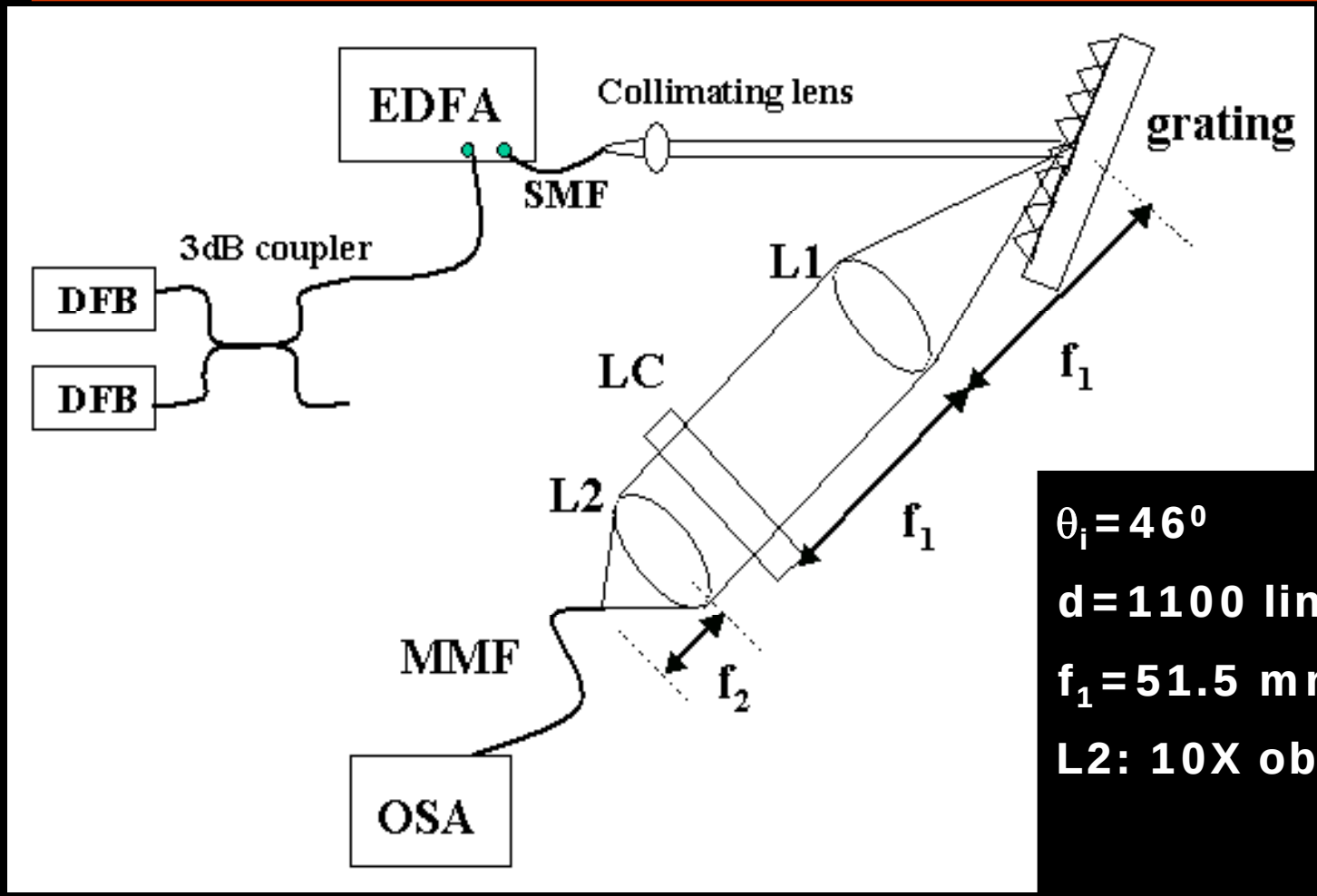
λ=1534.26 nm

Rise /Fall time=~12/88 ms

Summary (II)

- A 16-channel liquid-crystal-based tunable optical demultiplexer with channel spacing of 100 GHz is demonstrated.
- The channel crosstalk is less than –30 dB and the average 1dB and 3dB passbands of 12.5 and 22.5 GHz, respectively. Insertion Loss ~ 12 dB.
- The average extinction ratio is 13.5 dB (higher if laser source is used).
- Power equalized to within 0.5 dB.
- Different channels can be switched with a rise and fall time of tens of millisecond.

Liquid-Crystal-Based Tunable Optical Filter/Equalizer



$\theta_i = 46^0$

d = 1100 lines / mm

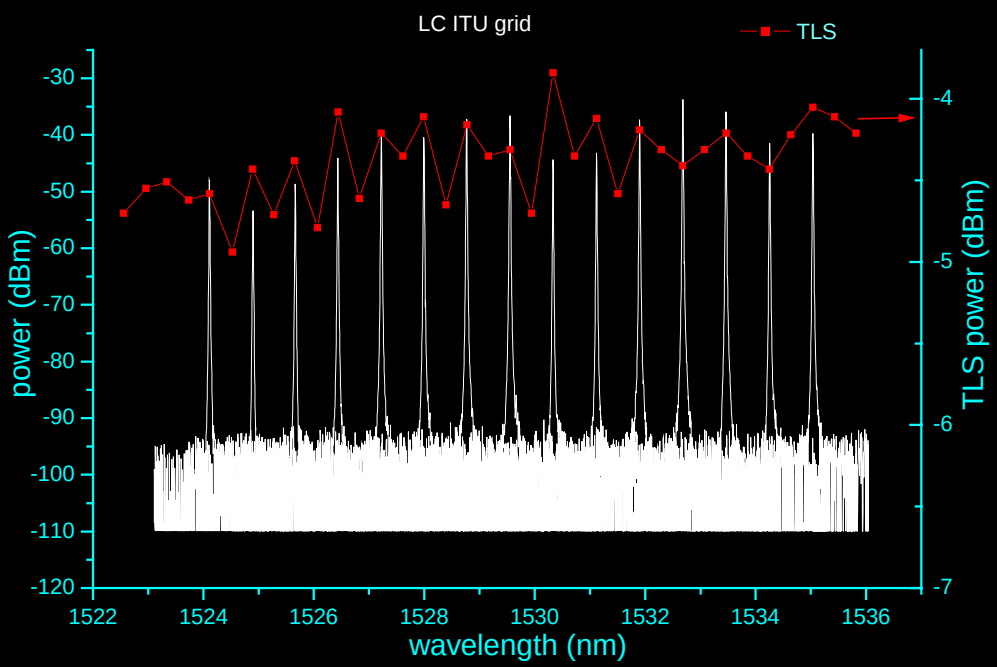
f_1 = 51.5 mm

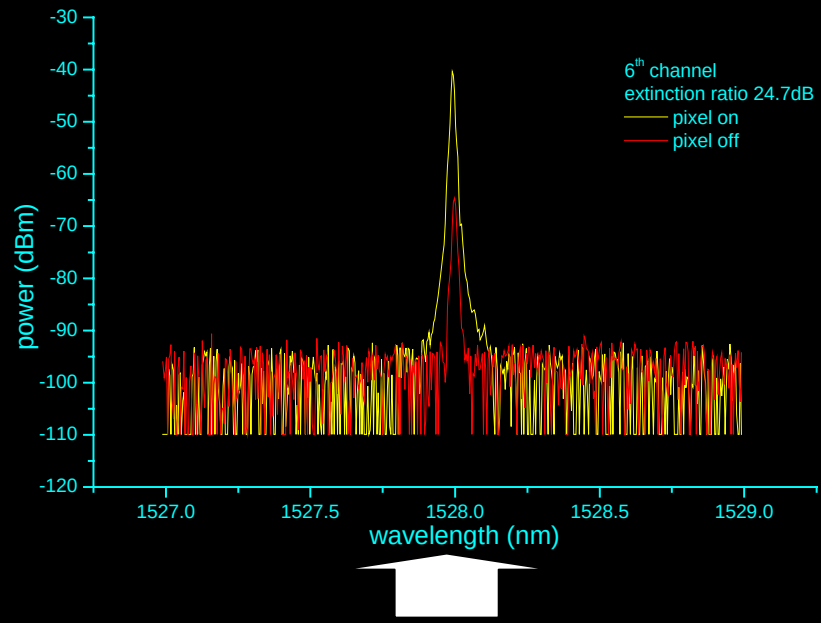
L2: 10X objective lens

Tunable Filter w/LC-SLM : Channels Fixed to ITU grid (100 GHz)

Light source : TLS

(Tunable laser source)

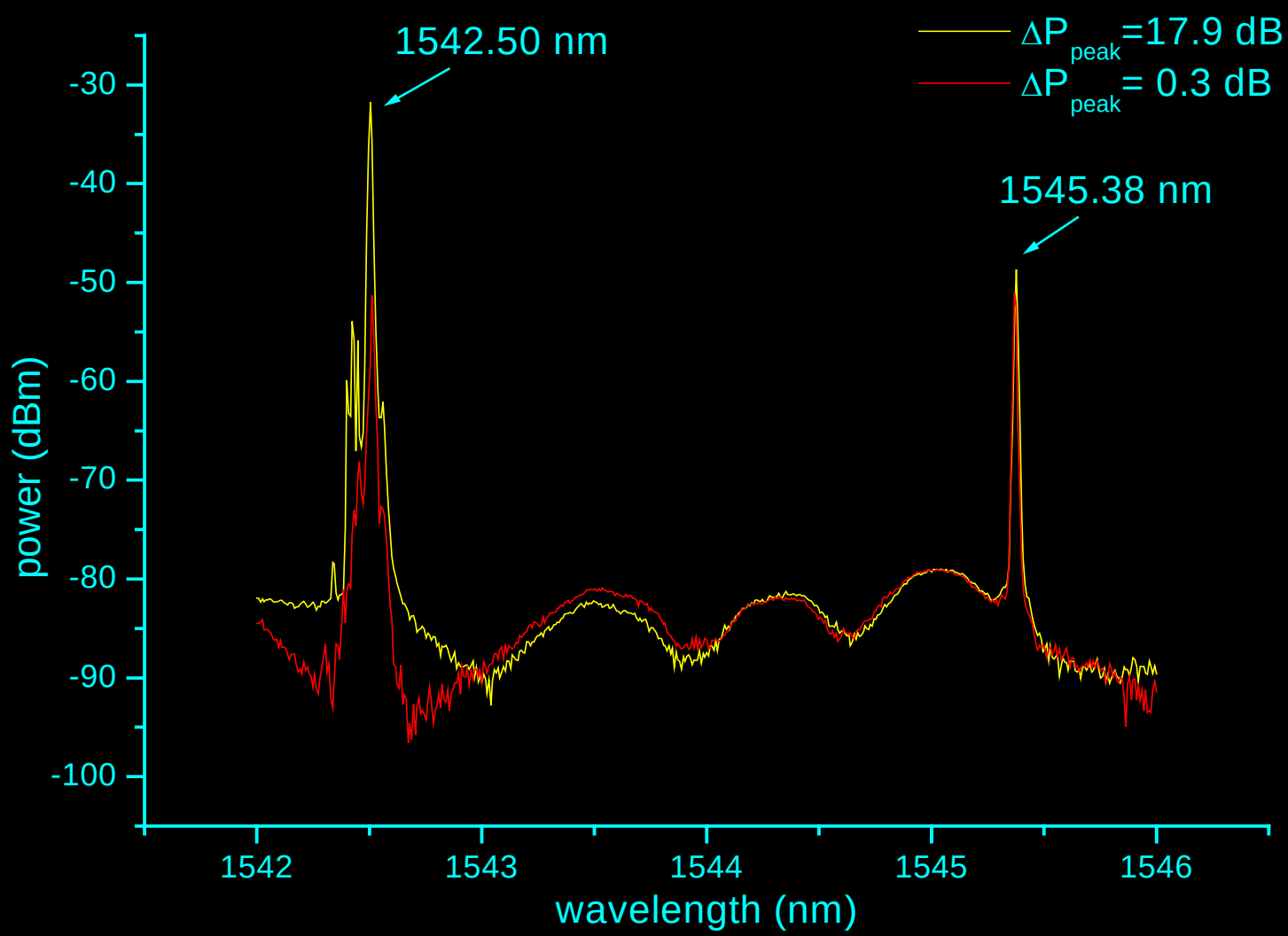




Extinction ratio=24.7 dB

Channel number = 15
Channel spacing = 0.79 nm
Average extinction ratio =18.2 dB

Tunable Filter/Equalizer



Summary (III)

- A new type of liquid-crystal-based tunable filter/demultiplexer has been developed.

- As a first demonstration, two channels (on 100 GHz ITU Grid) are selected with a peak-power difference of 17.9 dB are equalized to within 0.3 dB.

Acknowledgements

- Support by NSC, MOE, Lee-MTI Center/NCTU, and Radiatech Corp.

- Co-workers:.Prof. Ru-Pin Chao, Mingjay Huang, Yu-Ping Lan, Chia-Rong Sheu, and Iefan Lai