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

Ci-Ling Pan (潘犀靈)

Department of Electrophysics, Institute of Electro-Optical Engineering

National Chiao Tung University,
1001 Ta Hsueh Road
Hsinchu, Taiwan 30010, ROC
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-\(\lambda\) co-axial output
- Spatial Mode Control

Grazing-incidence Grating
Objective Lens
Laser Diode

Si Substrate
Au

V-Shape Stripe Mirror
Single Stripe Mirror
m\lambda = a(\sin \theta_i + \sin \theta_r)

Where:
- \( m \): diffraction orders
- \( a \): groove spacing
- \( \theta_i \): incident angle
- \( \theta_r \): 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-\(\lambda\) - ECL w/LCPM
Liquid Crystal Pixel Mirror

- Au-coated silicon substrate (mirror)
- Polarizer
- Patterned ITO W/SA
- NLC
- Glass
- ITO W/SA
- Incident laser beam
Fabrication of the LCPM

1. ITO-coated glass
2. Photoresist
3. Patterning and Developing
4. Etching
5. LC Alignment layer (SA)
6. Packaging
   - ITO Glass
   - NLC
   - Patterned ITO Glass
   - Au-coated Si
7. External Circuit
8. 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

Transmittance (%) vs. $V_{\text{rms}}$ (Volt)

- Red dots: voltage up
- Yellow dots: voltage down
Digitally tuning the ECL (1550nm) in 100 GHz step (ITU grid)

Tuning range ~ 60 nm, SMSR > 30 dB
Max. Tuning Range \((l = 1.54 \, l_{th})\)

Linewidth < 20 MHz (Instrument-limited)
Multi-wavelength Operation

- 0.74nm
- 1.50nm
- 1.98nm
- 3.22nm
- 1.50nm
- 1.48nm
- 1.28nm
Multi-wavelengths Operation

- 0.76nm
- 0.72nm
- 2.00nm
- 3.30nm
- 0.76nm
- 3.98nm

Optical power (dBm)
Wavelength (nm)
Multi-wavelength Mode-locked MOPA w/intra-cavity dispersion compensation

Master Laser:
Up to 20 \( \lambda \) demonstrated

MOPA:
- \( P_{\text{avg}} > 150 \text{ mW} \)
- \( \tau = 25 \text{ ps} \)
MODE-HOP-FREE FINE TUNING OF AN EXTERNAL-CAVITY DIODE LASER WITH AN INTRACAVITY LIQUID CRYSTAL CELL

\[ \Delta I_{LD} = \frac{\lambda \cdot \Delta L_2}{\beta \cdot L_2} \]

\[ \beta = \Delta \lambda / \Delta I_{LD} \]

Application: High-Res. Spectroscopy

Mode-hop-free tuning range: 19.2 GHz
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 ($\lambda = 1550$ 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 $\sim 100$ ms.
Part (II):
Functional Liquid-Crystal-Based Devices for DWDM Applications
Vmux: Variable Optical Demultiplexer
Tunable Demultiplexer:
Channels Fixed to ITU grid (100 GHz)

<table>
<thead>
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<th>Channel</th>
<th>ITU Grid (nm)</th>
<th>Experiment (nm)</th>
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Tunable Vmux: Power Equalization

- Blue - pixel on
- Green - equalized
- Red - pixel off

Power equalized to < 0.5 dB
**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

\[ \lambda = 1534.26 \text{ nm} \]

\[ \lambda = 1536.66 \text{ nm} \]

Rise / Fall time = \( \approx 12 / 88 \) 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

θ_i = 46°

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)

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

Extinction ratio = 24.7 dB
Tunable Filter/Equalizer

power (dBm)

wavelength (nm)

-100
-90
-80
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100

1542.50 nm

1545.38 nm

\( \Delta P_{\text{peak}} = 17.9 \text{ dB} \)

\( \Delta P_{\text{peak}} = 0.3 \text{ dB} \)
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.
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