Properties of planar lightwave circuit (PLC) devices fabricated by silica and polymer

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Outline

- Introduction
- Silica-based PLC
  - AWG
  - Thermo-optical PLC-SW
- Optical devices for FTTH
- Silicone polymer based PLC
  - Digital TOSW
  - TO wavelength tunable filter
- Summary
Photonic networks

Point-to-point WDM transmission

MUX/DEMUX: WDM multi/demultiplexer
OXC: Optical crossconnect
OADM: Optical add/drop multiplexer
Optical devices for photonic networks

Photonic Networks
- WDM
- TDM
- OXC
- OADM
- FTTH

Lower cost
Larger scale

Optical filters
- Micro-optics
- Fiber-type (gratings)
  - PLC-type

Optical switches
- Mechanical SW
- PLC TOSW
- Polymer TOSW
- Olive
- MEMS
- Semiconductor, LN
Silica-based PLC

- excellent physical and chemical stability
- good compatibility with optical fibers
- low-loss single-mode channel waveguide
- compact and economical devices

- AWG
- TO PLC-SW
- Filters for access networks
- Hybrid modules with PLC platform
Silica PLC fabrication

- SiO\textsubscript{2}-GeO\textsubscript{2} particles
- SiO\textsubscript{2} particles
- Si substrate
- Core
- Under cladding
- Over cladding
- FHD
- Consolidation
- RIE
- FHD + Consolidation

SiO\textsubscript{2} particles
Si substrate
Core
Under cladding
Over cladding
FHD
Consolidation
RIE
FHD + Consolidation
AWG configuration

Arrayed waveguides (Grating)

Input waveguides

Output waveguides

\( \lambda_1 \sim \lambda_n \)
Compact package AWG module

AWG chip

- ESize: 90 ~ 50 ~ 11 mm
- EPower: 4.0 W (2/3)

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Channel number increase in AWG

Channel Number

1000

100

10


Year

Research
Product

400ch

64ch

SHΔ
## Experimental performance of fabricated AWGs

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Experimental results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel spacing</td>
<td></td>
</tr>
<tr>
<td>15 nm</td>
<td>0.8 nm 0.4 nm 0.2 nm</td>
</tr>
<tr>
<td>2 nm</td>
<td>(100 GHz) (50 GHz)</td>
</tr>
<tr>
<td>Number of channels</td>
<td>8 8 32 64 128 256</td>
</tr>
<tr>
<td>Center wavelength</td>
<td>1.55 µm</td>
</tr>
<tr>
<td>Path difference</td>
<td>12.8 µm 50.3 µm 63.0 µm</td>
</tr>
<tr>
<td>Focal length</td>
<td>2.38 mm 5.68 mm 11.35 mm</td>
</tr>
<tr>
<td>Diffraction order</td>
<td>12 47 59 59 59 26</td>
</tr>
<tr>
<td>On-chip loss</td>
<td>2.4 dB 6.1 dB 2.1 dB</td>
</tr>
<tr>
<td>3-dB Bandwidth</td>
<td>6.3 nm 0.74 nm 40 GHz</td>
</tr>
<tr>
<td>(BPM simulation)</td>
<td>(6.3 nm) (0.75 nm)</td>
</tr>
<tr>
<td>(9.5 GHz) (12.5 GHz)</td>
<td>(37 GHz) (21 GHz)</td>
</tr>
<tr>
<td>Channel crosstalk</td>
<td>&lt;-28 dB &lt;-29 dB &lt;-28 dB</td>
</tr>
<tr>
<td></td>
<td>&lt;-27 dB &lt;-16 dB &lt;-33 dB</td>
</tr>
</tbody>
</table>
Spectra of 256 channel AWG

On-chip loss: 4.4 ~ 6.4 dB
PD-λ: <0.03 nm
3-dB bandwidth: 0.12 nm
Far-end crosstalk: < -33 dB
Center port spectra of 256 channel AWG

On-chip loss: ~ 4.4 dB
PD-\(\lambda\): <0.03 nm
3-dB bandwidth: 0.12 nm
Far-end crosstalk: < -33 dB
256 channel AWG module

- Slab waveguide
- Input port
- (1.5% $\Delta$ waveguide)
- AWG
- Fan-out PLC (0.75% $\Delta$)
- 128-fiber array
- Output ports
- 80 mm
Transmission spectra of athermal AWG

\[ \frac{dn_{\text{silicone}}}{dT} = -37 \times 10^{-5} (1/\degree C) \]

\[ \frac{dn_{\text{SiO2}}}{dT} = 1 \times 10^{-5} (1/\degree C) \]
Silica PLC TOSW

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16x16 TOSW configuration

Strictly Non-blocking Matrix Switch Arrangement

Switching Unit

Optical Signal

1st MZ unit 2nd MZ unit

16x16 TOSW layout

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16x16 TOSW module

Size: 165 x 160 x 23 mm
Characteristics of 16 x 16 TOSW

- Light Source: 1.55 µm
- Number of samples: n = 256
- Average Insertion Loss: 6.6 dB
- Standard Deviation: 0.3 dB

Insertion Loss (dB) | 16x16TOSW |
---|---|
< 8.1 (7.1) |
Extinction ratio (dB) | > 46.1 (59.7) |
Power (W) | ~ 13 (0.8 W x 16) |
Switching time (ms) | 4 |
Size (mm) | 165 x 160 x 23 |
Optical Devices for FTTH system

Requirements
- Low cost (High mass-productivity)
- Good reliability
- Inter-operability
- A large number WDM channels (= wavelengths)

Passive Device
- Optical Splitter/coupler
- Optical Filter

Signal Light Source
- Semiconductor Lasers (FP-LD, DFB-LD, SS-LD)
- Wavelength tunable laser

Optical transceiver module
- Hybrid integrated with a PLC platform
- Co-axial, Mini-DIL, Butterfly, SFP/SP, etc.
Optical devices in B-PON system

1.26-1.50 \( \mu m \): ATM-PON transport services
1.55-1.56 \( \mu m \): Video distribution services

Customer

NTT

- B-ONU
- V-ONU
- BOLT
- EMDX
- VOLT
- WDM filter
- Optical splitter
- Optical transceiver module
- Video distribution service (BS/CS/CATV)
- Ethernet (100Mbit/s)
- Coax
- Internet
- Video Tx
- Broadcasters

Future L Band

Enhancement Band

Optical fiber

Data

1.31 \( \mu m \) → 1.49 \( \mu m \)

Video

1.55 \( \mu m \)

Wavelength (\( \mu m \)) 1.26 1.36 1.48 1.50 1.55 1.56

1.26-1.50 \( \mu m \): ATM-PON transport services
1.55-1.56 \( \mu m \): Video distribution services

OPTICAL DEVICES IN B-PON SYSTEM
1x4/1x8 Optical Splitter

OLT ↔ ONU

PLC

Y-branch waveguide

Package

Substrate

Optical adhesive (Fiber-PLC joint)

Waveguide

Insertion Loss [dB]

1x4 Optical Coupler Spectral Loss

Supplier: NEL

Wavelength (nm)

Supplier: NEL

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WDM filter for video distribution service

Insertion loss

<table>
<thead>
<tr>
<th>Property</th>
<th>Port</th>
<th>Property (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Insertion loss</strong></td>
<td><img src="image" alt="Insertion loss graph" /></td>
<td>0.8 dB @1.31 &amp; 1.49 mm</td>
</tr>
<tr>
<td><strong>Isolation</strong></td>
<td><img src="image" alt="Isolation graph" /></td>
<td>61 dB @1.55 mm</td>
</tr>
<tr>
<td><strong>Return loss</strong></td>
<td><img src="image" alt="Return loss graph" /></td>
<td>44 dB @1.55 mm</td>
</tr>
</tbody>
</table>

- Thin-film filter
- Groove
8-ch CWDM filter

Gull wing type AWG with 20nm channel spacing
Compact and low loss (2.6dB ~ 3.3dB)

Size: 12 x 6.5 x 90 mm³
Cost reduction of optical transceiver module

- **Discrete Module**
- **PLC Hybrid Module**
  - **<PLC End-face Coupling>**
- **Micro-optics Module**
- **PLC Hybrid Module**
  - **<PLC Platform Integration>**

### Cost Reduction

**Fabrication time**
- Discrete Type: 1
- Hybrid Integration Type: < 1/20
- Monolithic Type: < 1/4

**Number of components**
- Discrete Type: 1
- Hybrid Integration Type: < 1/4
- Monolithic Type: < 1/4
Hybrid integrated optical transceiver module

Configuration

Module without cover

Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LD drive current (0dBm ave. output)</td>
<td>19.5 mA</td>
</tr>
<tr>
<td>Minimum sensitivity</td>
<td>-21 dBm</td>
</tr>
<tr>
<td>Optical crosstalk</td>
<td>-32.4 dB</td>
</tr>
</tbody>
</table>
Compact multi-wavelength laser module

Configuration

Total throughput: 40-Gb/s
(4-channel x 10 Gb/s)
Transmission: 10-km

Spectrum
Polymer based PLC

- variety of optical functions
- simple and cost effective fabrication process
- large TO coefficient
  (more than 10 times higher than SiO$_2$'s)

- Digital TOSW
- TO wavelength tunable filter
Schematic configuration of 1 x 8 digital TOSW

![Schematic diagram of 1 x 8 digital TOSW](image-url)
Electrical field in a Y-branching TO switch

Calculated by BPM
Heater power: 100 mW
Fiber-to-fiber transmission of 1 x 8 digital TOSW at 1550 nm
Transmission characteristics of 1 x 8 digital TOSW

<table>
<thead>
<tr>
<th></th>
<th>ON port</th>
<th>OFF ports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission</td>
<td>&gt; -3.0 dB</td>
<td>&lt; -43 dB</td>
</tr>
<tr>
<td>PDL</td>
<td>&lt; 0.1 dB</td>
<td>about 3 dB</td>
</tr>
</tbody>
</table>

Driving power: 450 mW
Transmission spectra of the 1 x 8 digital TOSW

driving power: 390 mW
Configuration of TO wavelength tunable filter

- **Input**: $\lambda_1, \lambda_2, \ldots, \lambda_{N-1}, \lambda_N$
- **Output**: $\lambda_1, \lambda_2, \ldots, \lambda_{N-1}, \lambda_N$

- **Arrayed waveguide**
- **Heater A**
- **Heater B**
- **Slab waveguide**
- **Straight waveguide**
Tunability of TO wavelength tunable filter
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PLC evolution

1st generation
- Y branches
- Directional couplers

2nd generation
- MZIs, TOSWs
- Ring resonators

3rd generation
- N x N stars
- AWGs

4th generation
- Transversal filters
- Lattice filters

Microwave filters

Phased antennas

Digital filters