OUTLINE

• Fiber-to-the-Home PONs
• Semiconductor Optical Amplifiers in Access Networks
• Reflective ONUs configurations
• Summary
• Questions
Fiber-to-the-Home PONs
INTRODUCTION

- Music
- Photo Sharing
- Research & Learning
- Video Conferencing
- Gaming
- Movies
- Sports
- Work at Home

PASSIVE OPTICAL NETWORKS

- Fiber To The Home
- Cost effective solutions
- Future broadband connections
- Passive Optical Components avoid
  - Power sources
  - Control equipment

HOME NETWORK

Optical Fiber

OLT

Optical Network Unit

BACKBONE NETWORK

Optical Line Termination

MUSE Workshop on Optical Access Networks - Berlin, Germany
Architecture 1: Cascaded AWGs


Main results:
- 512 users (16x32)
- x 100 MBit/s & triple play
- 2.5Gb x 16 tunable lasers
- Geographical-DBA (+30%)
- 30 Km + 10dB x2
- Security
- Scalable
- Cost effective (in between TDM and WDM)
Architecture 2: Hybrid WDM + TDM

- MxNxK users
- Scalable WDMA/TDMA (ONUs and Lasers)
- + Multicast using 2nd FSR


Architecture 3: Bidirectional single-fiber double ring

- Double protection
- Passive network
- Single fiber
ONU DESIGN

• Key element in Access Network
  ➔ Direct impact cost/customer
• Optical Access Network Success
  ➔ Robust
  ➔ Inexpensive
• Technical design requirements
  ➔ One single fiber ➔ reduce network size
  ➔ Wavelength independent ➔ transparent for WDM operation
  ➔ No active light source ➔ prevent stabilization
# Remodulation at the ONU

- **Downlink Data**
- **Signal for Remodulation**

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## Downstream Modulation

<table>
<thead>
<tr>
<th>Amplitude Modulation</th>
<th>Frequency Modulation</th>
<th>Phase Modulation</th>
<th>Polarization Modulation</th>
</tr>
</thead>
</table>

## Downstream Data

| 1 | 1 | 0 | 1 |

## Upstream Remote IM Modulation

| 0 | 1 | 1 | 0 |

---

**Pol h**

**Pol v**
Semiconductor Optical Amplifiers in Access Networks
SOAs

- Bidirectional Single-Fiber Single-Wavelength
  - Cost-effective Access Network
- Single Light Source at the OLT + Wavelength Independence at the ONU
  - Optimize the design
General Characteristics of SOAs

- SOAs at the ONU
  - DETECTION, MODULATION, AMPLIFICATION
- Applications
  - Commutation
  - Wavelength Conversion
  - Signal Regeneration
- Low fabrication cost
- Small dimensions
- Easy integration
- Wide bandwidth
- Low insertion loss
- Fast time response
- Wavelength transparency
Physical Characteristics

- Input signal
- Input facet
- Active region and waveguide
- Output signal and noise
- Output facet
- Antireflection Faces
- High Reflection Face
- SOA
- RSOA
- Inducing photon
- Stimulated photon
- Stimulated Emission
- Hole
- Electron (carrier)
- Energy gap
- E2
- E1
Device Characterization

SOA Gain vs Input Power

RSOA Gain vs Input Power

$I_{BIAS}$ $\uparrow$ $\rightarrow$ Gain $\uparrow$ $G_{SAT} = \sim 15\text{dB}$

$P_{IN}$ $\uparrow$ $\rightarrow$ Gain $\downarrow$ $P_{IN}(\text{lin} \rightarrow \text{sat}) = \sim -10\text{dBm}$

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**Modulation & Detection**

Introducing modulated data at bias electrode

Sensing voltage differences at bias electrode

\[ \Delta V = \eta \left( \frac{kT}{q} \right) \ln \left( \frac{N + \Delta N}{N} \right) \]

![Graph showing gain vs. Pin with lines indicating lineal and saturation regions.](image)
Bias Current Selection

Lineal Region
Low Bias ➞ MODULATION
Saturated Region
High Bias ➞ DETECTION

Gain and Extinction Ratio vs. Bias Current

- SOA Gain
- RSOA Gain
- SOA Extinction Ratio
- RSOA Extinction Ratio

Ibias = 90 mA
I_{MOD} = +/- 40 mA
Gain = 12 dB

Pout (dBm) vs. Ibias (mA)
Pin = -10 dBm

Gain (dB) vs. Ibias (mA)
REFLECTIVE ONU CONFIGURATIONS
First reflective ONU

- Middle ’90s firsts works with reflective SOAs used for uplink modulation
- 2002 firsts works with data remodulation with SOAs
  ➔ Modulation and Detection
  ➔ Two fiber topology
- 2004 bidirectional single-fiber
Half Duplex ASK-ASK

- **Rx**: Receiver
- **Tx**: Transmitter
- **T_{switch}**: Switching Time
- **RSOA**: Rate-Sensitive Optical Amplifier
- **SOA**: Semiconductor Optical Amplifier
- **DOWNSTREAM SIGNAL FOR REMODULATION**: Signal for downstream data remodulation
Full Duplex ASK-ASK
Full-Duplex combined FSK-ASK
Full-Duplex Subcarrier Multiplexing

TX  
RX

LPF  

LPF  

f_{SCup}  

f_{SCdown}  

RSOA

LPF  

LPF  

f_{SCup}  

f_{SCdown}  

SOA
SCM RSOA&Photo detector

- SOA Electrical Bandwidth: 1.5 GHz
- TX
- LPF
- PD
- RSOA
- f_{SCdown}, f_{SCup}
- 3f_{SC}
- f_{SCdown}, f_{SCup}

(downlink, uplink)
# BER Measurements

<table>
<thead>
<tr>
<th></th>
<th>ASK-ASK (TDM)</th>
<th>FSK-ASK</th>
<th>SCM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sensitivity (dBm)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CW</td>
<td>CW</td>
<td>CW+FEC</td>
<td>-20</td>
</tr>
<tr>
<td>-15</td>
<td>-26.4</td>
<td></td>
<td>-30</td>
</tr>
<tr>
<td>PRBS</td>
<td>PRBS+FEC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-20</td>
<td>-28</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Bit rate (Gb/s)</strong></td>
<td>1.25</td>
<td>1.0</td>
<td>0.155</td>
</tr>
<tr>
<td><strong>ONU o/e devices</strong></td>
<td>RSOA</td>
<td>Optical filter PIN-PD RSOA</td>
<td>RSOA</td>
</tr>
<tr>
<td>Transmission</td>
<td>Half-duplex (TDM)</td>
<td>Full-duplex</td>
<td>Full-duplex</td>
</tr>
</tbody>
</table>
ONU RSOA Board
(February ’04)

Electrical INPUT

BIAS current

Electrical OUTPUT

RSOA Optical INPUT/OUT
ONU RSOA Board
(January ’05)
RSOA RF INPUT INTEGRATED (October ‘05)

SOA-RL-OEC-1550
SUMMARY

- Semiconductor Optical Amplifiers are potential devices to perform transceiver tasks at the ONU
- Capable of Detection & Modulation and Amplification
- Lower Bias Current ➔ Data Modulation
- Higher Bias Current ➔ Data Detection
- Cost-affordable, self-amplified, wavelength-independent ONU, suitable for Bidirectional Single-wavelength Single-fiber topology
Thank you

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