VCSEL-based solderable optical modules

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Contents

- Solderable optical modules for the front panel connection
- Simple and low-cost on-board optics assembly with polymer-waveguide embedded PCB
- >1.3 Tb/s on-board optical module
- Summary
Front panel applications using SFFs

◆ 12-channel optical modules
  - 14-Gb/s × 12-channel TX/RX
  - 28-Gb/s × 4-channel duplex

Temperature profile

- Sn-Bi solder reflow-capable
- Maximum temperature: 190°C
- QSFP+/QSFP28 CXP

◆ 4-channel optical modules
  - 14-Gbit/s × 4-channel TX/RX
  - 28-Gbit/s × 4-channel TX/RX

Temperature profile

- Sn-Ag-Cu solder reflow-capable
- Maximum temperature: 250°C
- QSFP+/QSFP28 MiniSAS SFP28

13.0mm × 14.7mm × 3.4mm

Temperature profile

- QSFP28 MPO-type transceiver

6.5mm × 10.7mm × 1.5mm

Plastic microlens

MIT (8.0mm × 7.0mm)

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QSFP28 SR solution

Loop-back test

Operated at 28.05 Gb/s PRBS $2^{31}-1$
Housing temperature: 71°C

Eye diagrams

TX output (Optical)

- Ch1
- Ch2
- Ch3
- Ch4

RX output (Electrical)

BER bathtub curves

- Housing temperature: 31°C
- Housing temperature: 55°C
- Housing temperature: 71°C
SM VCSEL-based optical modules

◆ Single mode 1300-nm 10-Gb/s x 4-channel engine for LR4

Driving conditions
- Vcc = 3.3 V
- Bias Current = 11 mA
- Modulation current = 10mA
- Ta = 25degC
- Input signal: 10.3125Gbps / PRBS_2^{31}-1 / Vamp_diff = 900mV

Ch1
Ch2
Ch3
Ch4

B to B

Pf = -2.7 dBm
Pf = -2.7 dBm
Pf = -2.1 dBm
Pf = -2.7 dBm

SM
10km

Pf = -6.3 dBm
Pf = -6.5 dBm
Pf = -5.8 dBm
Pf = -6.8 dBm
SM VCSEL-based optical modules

◆ BER characteristics

This approach keeps the sample packaging platform for both MM and SM optical modules
Long distance MMF transmission at 25.78 Gb/s

◆ 1060-nm VCSEL-based link
  ➢ OM4-like MMF for 1060 nm.

Encircled flux

Calculated fiber bandwidth

Error free at 1 km


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4th Symposium on Optical Interconnect for Data Centres
“On-board optics” is a promising solution for high-density optical interconnects

How do we mount on-board optics?

- Short electrical transmission lines to suppress degradation of high data rate signals.

Complicated board assembly
- Costly process
- Complex 3-D optical wiring
- Disturb air flow

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What is available with polymer-waveguides?

- **Polymer waveguide-embedded PCB**
  - Simple and smart optical wirings
  - 3-D optical wirings inside a PCB

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**Optical Wiring Board (PCB)**

- Chip to chip link: < 0.3 m
- Board to board link: 0.3 m ~ 1 m
- Connect to other devices
- Simpler assembly
- Better airflow
- Flexible design for optical wiring

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T. Ishigure, JIEP-OPT (2013)

Proposal for high-density board assembly

- Simple optical and electrical interfaces on polymer waveguide embedded PCB
  - Reducing piece parts
  - Reducing assembly cost
  - Minimizing footprint

- LOW COST
- HIGH DENSITY

Optical connector

- Optical fiber
- Screwed
- Heatsink / cover
- Screwed
- POM
- LSI
- PCB

Electrical socket
- PCB: Printed circuit board
- LSI: Large scale IC

- Sn-Ag-Cu solder-reflow

No electrical and optical connectors

Electrical and optical interfaces on the bottom surface

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Optical coupling interface

- No need an optical connector, but...a mechanical motion induced by a self-alignment effect of melted solder is concerned.

Coupling structure with two collimator lens arrays...

- Wide optical axis displacement tolerance
- Complexity and higher cost

A single lens array system

- Reducing piece parts
- Reducing assembly complexity and cost

Technical challenges

- A single lens coupling system
- Optical axis stabilization during the solder reflow
Concept of optical module mounting

- Schematic view

Front view

- Inner electrical wiring
- Optical module
- Guide-hole
- Lens-array
- Glass epoxy substrate
- Solder bump
- PCB
- Stud-pin
- Mirror
- Polymer waveguide

Side view

- Optical connection
- Electrical connection

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Fabrication of 12-channel modules

◆ Illustrations and photographs

14-Gb/s x 12-channel (TX/RX)
- 12-Ch VCSEL/PD
- 12-Ch VD/TIA
- LGA

25-Gb/s x 4-channel transceiver module
- 4-Ch PD
- 4-Ch VCSEL
- 4-Ch TIA
- 4-Ch VD
- LGA

Top surface
- Guide holes
- LGA

Bottom surface
- Dustproof cover
- Microlens array
- LGA

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Optical module mounting to Optical PCB

◆ Schematic illustration for module mounting

12-channel optical module

Top surface:
- Thermal dissipation
- The whole area of top surface can be used for thermal dissipation

Bottom surface:
- Electrical interface (land grid array)
- Optical interface

PCB

Polymer-waveguide
Optical axis displacement of lens array

◆ Measurement of axis displacement

Sample size: TX 6 pcs, RX 5 pcs

 Axis displacement $<$±5µm

Channel 12

\[
\Delta y [\mu m] \quad \pm 5\mu m
\]

\[
\Delta x [\mu m] 
\]

Channel 1

\[
\Delta y [\mu m] \quad \pm 5\mu m
\]

\[
\Delta x [\mu m] 
\]
Polymer waveguide-embedded PCB

Parallel-optical module

Differential transmission line

V-groove with mirror

Plastic stud-pin

Measured displacement: \( \Delta x, \Delta y < 3 \, \mu m \)

Total displacement: \( \pm 8 \, \mu m < \pm 12 \, \mu m \)

(Module: \( \pm 5 \, \mu m \), PWG: \( \pm 3 \, \mu m \))

Summary of PWG characteristics

<table>
<thead>
<tr>
<th>Material</th>
<th>Epoxy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>Photolithography</td>
</tr>
<tr>
<td>Propagation loss</td>
<td>0.17 dB/cm (1060 nm)</td>
</tr>
<tr>
<td>Refractive index in core/clad</td>
<td>1.581/1.541</td>
</tr>
<tr>
<td>Type of refractive index profile</td>
<td>Step index</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shape of core</th>
<th>Square (35 ( \mu m \times 35 , \mu m ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>42.45 mm</td>
</tr>
<tr>
<td>Core pitch</td>
<td>250 ( \mu m )</td>
</tr>
<tr>
<td>Numerical aperture</td>
<td>0.3</td>
</tr>
<tr>
<td>Optical bandwidth</td>
<td>6.6 MHz·km</td>
</tr>
</tbody>
</table>
Assembly process

◆ Optical PCB
Assembly process

◆ Masking for the optical interface

Masking tape
Assembly process

- SMT and solder-reflow process

![Solder-reflow graph](image)

Temperature (deg.C) vs. Time (sec)

- In compliant with JEDEC level 3
- The peak temperature is 235°C
Assembly process

♦ Removing the dustproof cover
Assembly process

◆ Removing the masking tape
Assembly process

- Dust cap and heatsink attachment

![Image of assembly process](image-url)
Assembly process

◆ Edge connector attachment

Edge connector
Assembly process

- Fiber cable connection

Ribbonized fiber
14.0-Gb/s x 12-channel modules

◆ Optical coupling loss

- Maximum coupling losses:
  - TX: 3.4 dB @ Ch2
  - RX: 2.4 dB @ Ch1

The worst total coupling loss < 6 dB

◆ Eye diagrams

TX output (optical)

RX output (electrical)

✓ Clearly opened eye diagrams for all channel at both TX and RX
14.0-Gb/s x 12-channel modules

◆ BER characteristics

➢ Link transmission: 14.0 Gb/s, NRZ PRBS $2^{31}-1$

BER bathtub curves

Error-free transmission achieved

✓ Averaged minimum sensitivity: -10 dBm
✓ Averaged jitter margin: ~0.3 U.I. (including test environment)
25.78-Gb/s x 4-channel transceiver

- Eye diagrams and BER characteristic
  - Loop back test without CDR

![Eye diagrams and BER characteristic](image)

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>1.3 Tb/s on-board optical module

- 28-Gb/s x 24-channel optical transceiver module

Top view

Bottom view

10-cent coin

Test system

Bundled RF connector

Copper plains

Heat dissipation

Copper filled vias

Organic substrate

VCSEL/PD

VD/TIA

Plastic microlens

Structure of optical module (cross section)
>1.3 Tb/s optical module

- Loop-back link performance

Eye diagrams

TX

BER bathtub curves

28.05 Gb/s, PRBS $2^{31}-1$

- Jitter margin:
  - ~0.35 U.I. (w/o CDR)
  - ~0.45 U.I. (w/ CDR)
Summary

◆ VCSEL-based solderable optical modules were developed for the Front Panel Optics and On-Board Optics.
  ➢ QSFP+
  ➢ CXP
  ➢ QSFP28
  ➢ SM VCSEL solution for a longer reach applications

◆ Simple and low-cost on-board optics assembly with polymer-waveguide embedded PCB was introduced.
  ➢ 14-Gb/s x 12-channel TX/RX
  ➢ 25-Gb/s x 4-channel transceiver

◆ >1.3 Tb/s on-board optical engine for high-density optical interconnects
Thank you!

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