Thoughts on PMD baseline proposal for automobile based on Si-Photonics

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Jan. 2021

IEEE P802.3cz Multi-Gigabit Optical
Automotive Ethernet Task Force
Introduction

Nov. 2019 Hawaii “Introduction of Si Photonics transceiver technology with High temperature operation capability and MMF transmission” by I. Ogura and K. Kurata

Jan. 2020 Geneva “A study for highly-reliable optical transceiver based on Si Photonics technology” by I. Ogura and K. Kurata

Si Photonics for Automobile applications

- High speed: 25Gbps and higher
- 40m reach through OM3@25G

- High temperature:
  Quantum Dot (QD) Laser Source operates over 105°C

- Reliability:
  QD-LD lifetime expected over 20 years @105°C
  Redundancy of light sources is possible for higher reliability

This Presentation

Thoughts on baseline proposal based on Si-photonics for possible implementation to meet the OMEGA objectives.
Contents

Si-photonics to meet OMEGA objectives

1. 40m reach at 25Gbps
   - For a reference to develop OMEGA specifications
     25Gbps/ch Si-photonics transceiver sub-assembly with MMF
     standardized in IEC SC86C (Optical systems and active devices)
   - Results with conventional OM2,OM3 MMF and 1310nm-optimized MMF

2. 15m reach at 50Gbps
   50Gbps operation by 25Gbaud-PAM4 and 50Gbps-NRZ

3. Reliability assessment

4. Eye-safety
Si photonics technology commercially available for short reach interconnect

**Chip-scale package of silicon photonics transceiver**

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throughput</td>
<td>100G: 25Gx4ch Tx + Rx 300G: 25G × 12ch Tx/Rx</td>
</tr>
<tr>
<td>Footprint</td>
<td>5mm × 5mm</td>
</tr>
<tr>
<td>Power consumption</td>
<td>5mW/Gbps</td>
</tr>
<tr>
<td>Wavelength</td>
<td>1.3μm (O-band)</td>
</tr>
<tr>
<td>Media</td>
<td>MMF up to 300m*</td>
</tr>
</tbody>
</table>

* 1310nm-optimized MMF

- High density
- Low power consumption
- Low cost solution through the combination of Si-Photonics and multimode optics with wide alignment margin
Si photonics with QD-laser and MMF optics for short reach interconnects incl. automobile

Si photonics one-chip transceiver

Quantum dot laser light source: wide temperature range

Diagram of Si photonics one-chip transceiver with labels: Receiver, Transmitter, Optical pins, Electrical output, Electrical input, Grating coupler, Wave guide, Modulator, Receiver IC, Driver IC, LD, MMF.
Integrated Si photonics transceiver

Transmitter

- Drv. IC
- Integrated LD
- Modulator

Receiver

- Rec. IC
- PD

Si wafer

One chip integration
Mass-producible

Butt coupling to MMF
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Raw characteristics of Si-photonics transceiver sub-assembly
- operating at 25Gbps/ch with 1310nm MMF
- without CDR and FEC
Building block for short reach pluggable or embedded optics
Up to 300m at 28Gbps with 1310nm-optimized MMF (2000MHz·km)

Reference for OMEGA specifications at 25Gbps;
Single channel configuration,
Target BER with FEC, Reach, Power budget with 4 inline connectors
Part 11: Multiple channel transmitter/receiver chip scale package with multimode fibre interface

Raw characteristics of Si-photonics transceiver sub-assembly
- operating at 25Gbps/ch with 1310nm MMF
- without CDR and FEC

### Transmitter optical characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average output optical power (each channel)</td>
<td>$P_o$</td>
<td>-3</td>
<td></td>
<td>2.0</td>
<td>dBm</td>
<td></td>
</tr>
<tr>
<td>Average output optical power - disabled (each channel)</td>
<td>$P_o$</td>
<td></td>
<td>-15</td>
<td></td>
<td>dBm</td>
<td></td>
</tr>
<tr>
<td>Extinction ratio</td>
<td>$E_x$</td>
<td>2.0</td>
<td>3.5</td>
<td></td>
<td>dB</td>
<td></td>
</tr>
<tr>
<td>Centre wavelength</td>
<td>$\lambda_c$</td>
<td>1 280</td>
<td></td>
<td>1 320</td>
<td>nm</td>
<td></td>
</tr>
<tr>
<td>Spectral width - rms</td>
<td>$\Delta \lambda$</td>
<td>3</td>
<td></td>
<td>5</td>
<td>nm</td>
<td></td>
</tr>
</tbody>
</table>

### Receiver optical characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input optical power sensitivity (^a) (each channel)</td>
<td>$S$</td>
<td></td>
<td></td>
<td>-9.0</td>
<td>dBm</td>
<td></td>
</tr>
<tr>
<td>Overload optical power (OMA) (^a) (each channel)</td>
<td></td>
<td>-2.0</td>
<td></td>
<td></td>
<td>dBm</td>
<td></td>
</tr>
<tr>
<td>Operating centre wavelength</td>
<td>$\lambda_c$</td>
<td>1 280</td>
<td></td>
<td>1 320</td>
<td>nm</td>
<td></td>
</tr>
<tr>
<td>Return loss</td>
<td></td>
<td>10</td>
<td></td>
<td></td>
<td>dB</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Bit-error ratio = $10^{-12}$

Reference for OMEGA specifications at 25Gbps;
Target BER with FEC, Reach, Power budget with 4 inline connectors
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   50Gbps operation by 25Gbaud-PAM4 and 50Gbps-NRZ

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4. Eye-safety
MMF transmission results at 25Gbps

**OM2** (500MHz·km@1310nm) and **OM3**

If 40m is enough, OM2 can be a low cost solution

1310nm-optimized (2000MHz·km) :300m-500m

Longer reach is feasible
4 inline connectors

Comply Encircled flux launch for stable connection

- EF evaluated by using near field pattern at output plane
- The light from TX optical pin met the standard TIA/EIA-455-203 (FOTP-203) (less than 30% at $R = 4.5 \, \mu m$ and larger than 86% at $R = 19 \, \mu m$)
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50Gbps (25Gbaud-PAM4) operation demonstrated
Same Si-photonics chip is used

25Gband PAM4 optical output
for 0.87\(V_{pp}\) modulation
50Gbps-NRZ operation under development (future 100G-PAM4)

Tx waveform in each operation speed

Clear eye opening was observed up to 32Gbps (32Gbps:PPG limitation)

Next 56G(NRZ)

Optimization of segment number

Improvement of Modulation efficiency

Higher operation of CMOS
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High temperature operation of Quantum Dot LD light source

(Temp. range limited by equipment)

25Gbs Tx waveform

-5°C
85°C

105°C (W/O LD bias control)

General Operation current
**LD lifetime test results** (tentative up to 105°C)

**Acceleration test (Po=31mW)**
for QD laser Results in
Ea=0.746eV

Arrhenius equation
\[ \kappa = A \cdot \exp\left( -\frac{E_a}{k_B T} \right) \]
where \( \kappa \) : rate constant
Ea: Activation energy 0.746eV
kB: Boltzmann Constant (=8.617*10^{-5} eV/K)
T : Absolute temperature (in kelvins)

MTTF in actual use at Po=20mW for Ea=0.746eV
Expected to be **20 years at 105°C**

\[ k = k_0 \cdot \exp\left\{ \frac{E_a}{k_B} \cdot \left( \frac{1}{T} - \frac{1}{T_0} \right) \right\} \cdot \left( \frac{I}{I_0} \right)^{-n} \cdot \left( \frac{P}{P_0} \right)^{-m} \]
assumed n=2 & m=1

**Actual use condition (20mW@100mA, TO CAN)**

<table>
<thead>
<tr>
<th>Environment Temp.</th>
<th>Junction Temp. Tj(°C)</th>
<th>MTTF of 4 Channels (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60°C</td>
<td>68.1</td>
<td>642</td>
</tr>
<tr>
<td>85°C</td>
<td>95.0</td>
<td>87.5</td>
</tr>
<tr>
<td>105°C</td>
<td>116.8</td>
<td>20.9</td>
</tr>
</tbody>
</table>
Mission profile study (after Ruben)

<table>
<thead>
<tr>
<th>Temperature, °C</th>
<th>Percentage, %</th>
<th>Operating hours, H</th>
</tr>
</thead>
<tbody>
<tr>
<td>T0 -40</td>
<td>6</td>
<td>1920</td>
</tr>
<tr>
<td>T1 23</td>
<td>20</td>
<td>6400</td>
</tr>
<tr>
<td>T2 50</td>
<td>65</td>
<td>20800</td>
</tr>
<tr>
<td>T3 100</td>
<td>8</td>
<td>2560</td>
</tr>
<tr>
<td>T4 105</td>
<td>1</td>
<td>320</td>
</tr>
<tr>
<td>total</td>
<td>100</td>
<td>32000</td>
</tr>
</tbody>
</table>

Estimated lifetime of QD light source
20 years at 105°C (vs. 320H)
- Si-photonics may commit to reliable automobile network
- CW light source has no constraint for higher speed operation of 100Gbps or over
Si-photonics to meet OMEGA objectives

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Class1 eye safety level for 850nm (VCSEL) and 1310nm (Si-photonics)

Eye-safety constraints (power, handling) are relaxed at 1310 nm
Summary

Si-photonics to meet OMEGA objectives

1. 25Gbps transmission
   IEC standard of 25Gbps/ch Si-photonics transceiver sub-assembly with MMF as a reference, working on OMEGA specifications for single channel configuration, target BER with FEC, reach, power budget with 4 inline connectors

40m with OM2,OM3 MMF and 300m with 1310nm-optimized MMF are feasible

2. 15m reach at 50Gbps
   25Gbaud-PAM4 is feasible and
   50Gbps-NRZ is under development (for future 100G-PAM4)

3. Reliability assessment
   Estimated lifetime of QD laser light source (20 years at 105°C)
   may commit to reliable automobile network
   Si-photonics using CW laser light source

4. Approx. 20 times higher eye-safety power level for Si-photonics at 1310nm than 850nm-VCSEL may relax constraints of power and handling

Appreciate your feedback for baseline proposal