Silicon Photonics for Automotive
Response to Proposal Assumptions

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IEEE 802.3cz Multigigabit Optical Automotive Ethernet Interim Task Force
17th March 2021

Proposals under consideration — Proposal 3

- **FP QD laser + Si Photonics + OM3, 1310 nm**
- **Objectives: unknown**
  - Partial information:
    - One TX eye-diagram of 25 Gb/s at Ta = 105°C (see [21] , [22] and [23]).
    - AOP and ER only reported at range 0 ~ 70 °C (see [23])
    - RX characteristics fo 25 Gb/s reported w/ CDR and FEC at range 0 ~ 70°C, see [23]. Not reported fiber length.
    - TX and RX characteristics at 32 Gb/s, 20°C, see [23]. Not reported fiber length.
    - No reported data at -40°C.
  - Link budget: unknown, no contributions
- **Industry support (multi-source, automotive volume): unknown**
  - Fiber:
    - If standard OM3 is used (per DMD specification), the application will receive the biggest support.
    - If OM2 (per OFL specification) is required, the support will be smaller.
    - If 1310nm optimized OM3 is required the support will be small.
  - TX: FP QD edge-emitting laser. Industry support from other data-com applications. Unknown volume.
  - RX: Ge on Silicon substrate. Unknown support.
  - PHY technology: Si photonics for MZ-modulators, wave-guides, grating couplers, optical pins. Unknown support.
- **Technical characteristics: limited knowledge**
  - Only partial information.
  - Unknown detailed characteristics of every part of the system in full range of temperature
  - Link budget is unknown
- **Reliability: limited knowledge**
  - OM2 and OM3 are already used in harsh environments with extreme temperatures and mechanical requirements, e.g. avionics, militar, industrial automation, etc.
  - Reported reliability only focused on one element: FP QD laser
  - Big concern on reliability of Si Photonics elements (MZ mods, couplers, pins)
  - Ge on Si substrate PD: unknown
  - Si Photonics: are the foundries qualified for automotive?
- **Relative cost: big concerns**
  - It is well known that Si Photonics is expensive in single lane applications compared with VCSEL based solutions (reason behind many 802.3 projects)
  - Only laser is ~5x VCSEL and it is not the most expensive part
  - A relative cost comparison should be addressed

Broadly negative assumptions on silicon photonics deployment in automotive are misleading and incorrect

Objectives

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I. Ogura (PETRA) and K. Kurata (AIO Core) have made numerous contributions to IEEE 802.3cz with the requisite information:

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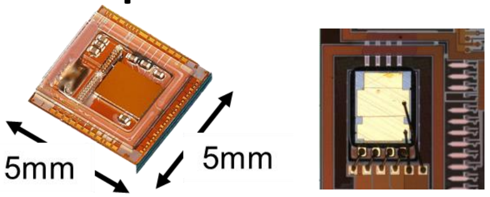
Footprint: 5mm x 5mm

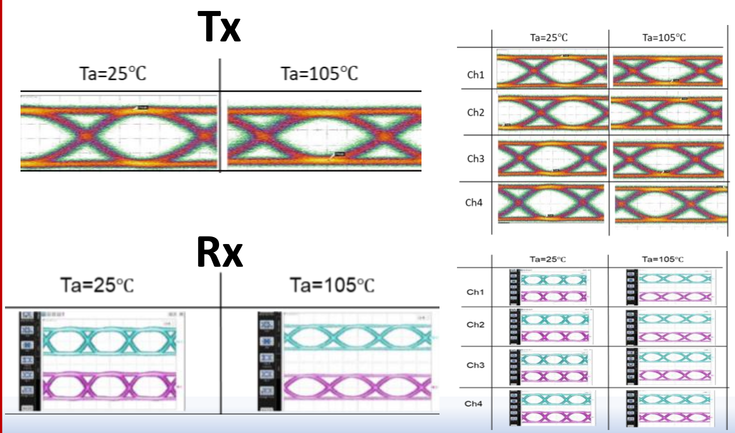


Junction temperature range: -40 °C - 125 °C

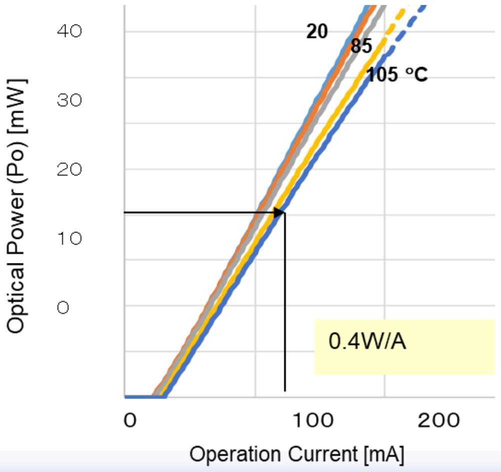
Power consumption: 5 pJ/bit

Bandwidth

4 Tx + 4 Rx @ 25 Gb/s



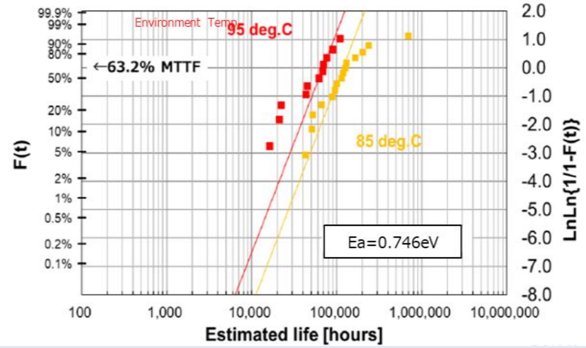
QD-LD performance



Reliability MTTF

20.9 years @ T_j 116.8 °C

	85°C	95°C
MTTF (Cumulative failure rate, F(t)=63.2%)	134,470 [hours]	63,682 [hours]
Median life (Cumulative failure rate, F(t)=50%)	112,450 [hours]	50,470 [hours]



Industry Support

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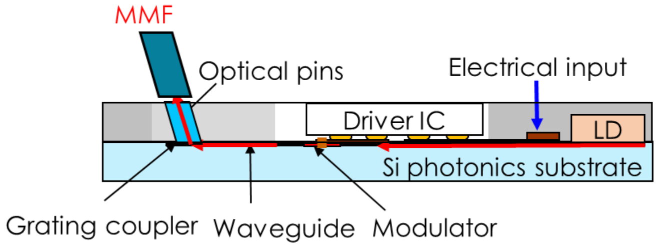

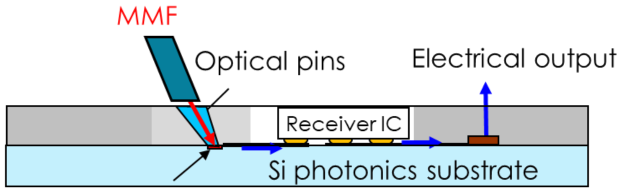

Photo detector

Fiber choice

- Standard OM3 is fine and verified for > 40m

Fabry Perot Quantum Dot laser

- Strong and increasing industry support due to superior performance, stability at high temperatures
- **Intel paper:** J. C. Norman et al., "A Review of High-Performance Quantum Dot Lasers on Silicon," in IEEE Journal of Quantum Electronics, vol. 55, no. 2, pp. 1-11, April 2019, Art no. 2000511, doi: 10.1109/JQE.2019.2901508

Ge on Silicon substrate

- Standard discrete Ge photodetector

Silicon photonics components (MZI, waveguides, MRRs, grating couplers)

- Widespread support for these components in PDKs of many mainstream CMOS foundries including Global Foundries, TSMC, Intel, ST, TowerJazz

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Multiple MSAs around silicon photonics including:
PSM4, CWDM4, 100GLambda, CW WDM

Silicon photonics is now a mature technology supported by major industrial organisations including:

- **Intel**
- **Cisco (Luxtera, Acacia)**
- **Iphi**
- **Neophotonics**
- **Fujitsu**
- **Juniper**
- **Hewlett Packard Enterprise**
- **Rockley**
- **SiFotonics**
- **II-VI (Finisar), Ranovus**

Silicon photonics stakeholders and competitive landscape

International silicon photonics supply chain is strong and growing

Industry Support

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Industry support for silicon photonics is growing exponentially with hyperscale data centres dominant

Hyperscale data centres will drive **95%** of the demand and supply for 1310 nm silicon photonic transceivers

Data centres will account for $3.6B by 2025

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1310 nm is the dominant wavelength for current and future data centre Ethernet standards and will drive communication laser demand

Speed	Ethernet Nomenclature	Lane no x Nominal rate	Link distance / medium	Wavelength	Standards group
100 GbE	100GBASE-SR10	10 x 10G NRZ	150m OM4 10 pair MMF	850 m	802.3ba
	100GBASE-SR4	4 x 25G NRZ	100m OM4 4 pair MMF	850 nm	802.3bm
	100G-PSM4		500m on 4 pair SMF	**1310 nm**	MSA
	100G-CWDM4		2km on duplex SMF	**CWDM (1271nm, 1291nm, 1311nm, 1331nm)**	MSA
	100GBASE LR4		10 km on duplex SMF	**LAN-WDM (1295 nm, 1300 nm, 1305nm, 1310 nm)**	802.3ba
200 GbE	200 GBASE-SR4	4 x 50G PAM4	100m on 4 pair OMF MMF	850 nm	802.3cd
	200 GBASE-DR4		500m on 4 pair parallel SMF	**1310 nm**	802.3cd
	200 GBASE-FR4		2km on duplex SMF	**CWDM (1271nm, 1291nm, 1311nm, 1331nm)**	802.3cd
	200 GBASE-LR4		10 km on duplex SMF	**LAN-WDM (1295 nm, 1300 nm, 1305nm, 1310 nm)**	802.3cd
400 GbE	400 GBASE-SR16	16 x 25G	100m on 16+16 parallel OM4 MMF	850 nm	802.3bs
	400 GBASE-FR8	8 x 50G PAM4	2km on duplex SMF	**4.36 nm WDM grid over 1310 nm**	802.3bs
	400 GBASE-LR8		10km on duplex SMF	**4.36 nm WDM grid over 1310 nm**	802.3bs
	400GBASE-DR4	4 x 100G PAM4	500m on 4 pair parallel SMF	**1310 nm**	802.3bs

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I. Ogura (PETRA) and K. Kurata (AIO Core) have published many scientific papers and made numerous contributions to IEEE 802.3cz on their devices alone (shown below)

Generally there is a vast body of technical publications on 1310 nm silicon photonics transceivers

Contributions to 802.3cz

- **March 2021**: A proposal of Si-photonics for automobile
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- **January 2020**: A study for highly-reliable optical transceiver based on Si Photonics technology
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Publications

1. Kurata, K. et al., "Short reach, low-cost silicon photonic micro-transceivers for embedded and co-packaged system integration," Proc. SPIE 11286, Optical Interconnects XX, 112860R (28 February 2020); https://doi.org/10.1117/12.2546626
2. Pitwon, R., O'Faolain, L., Kurata, K., Lee, B., Ninomiya, T., "Hyperscale Integrated Optical and Photonic Interconnect Platform," 2020 IEEE Photonics Conference (IPC), Vancouver, BC, Canada, 2020, pp. 1-2, doi: 10.1109/IPC47351.2020.9252246.
3. Nakamura, T. et al., "Fingertip-Size Optical Module, "Optical I/O Core", and Its Application in FPGA" IEICE TRANSACTIONS on Electronics, Vol.E102-C, No.4, pp.333-339
4. Mogami, T. et al., "1.2 Tbps/cm2 Enabling Silicon Photonics IC Technology Based on 40-nm Generation Platform," J. Lightwave Technol. 36, 4701-4712 (2018)
5. K. Kurata, I. Ogura, K. Yashiki and Y. Suzuki, "Chip-scale si-photonics optical transceiverfor a photonics-electronics convergence system (invited paper)," 2016 Tenth IEEE/ACM International Symposium on Networks-on-Chip (NOCS), Nara, Japan, 2016, pp. 1-6, doi: 10.1109/NOCS.2016.7579338.

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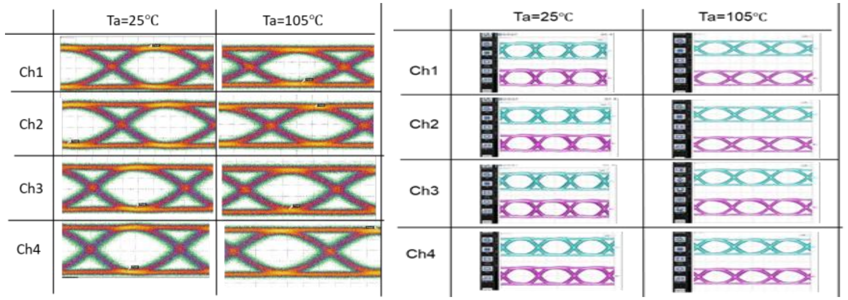
Refer to numerous IEEE 802.3cz contributions and publications

The laser diode (in all transceivers) represents greatest failure risk, therefore presented research has focussed on this component (see "A study for highly-reliable optical transceiver based on Si Photonics technology" – Jan 2020)

Entire silicon photonics devices have also been evaluated at 105 °C

Tx **Rx**



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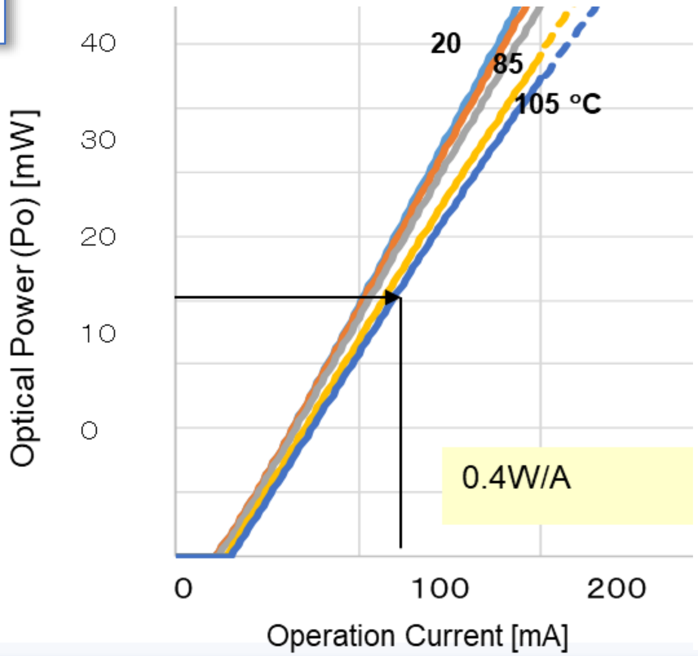

MTTF: 20.9 years @ T_j 116.8 °C

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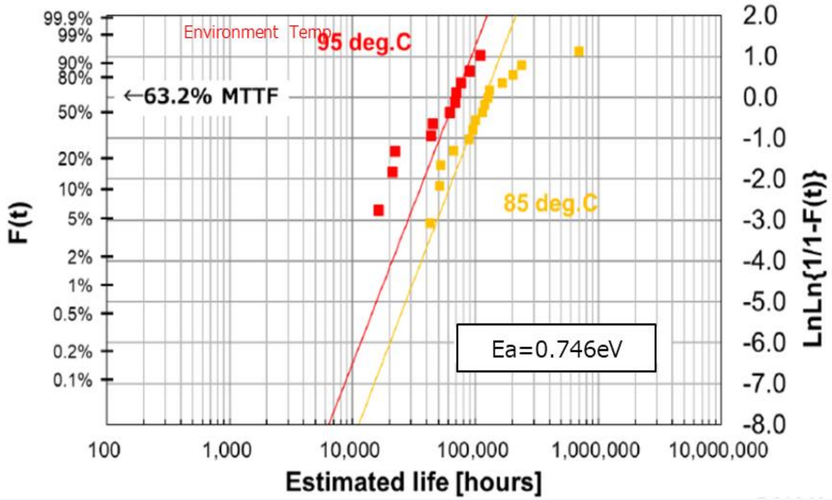

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105 °C Evaluation Result

Power budget specs on-going

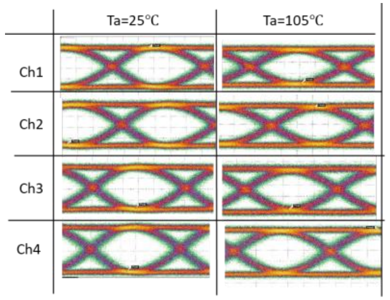
Test conditions

- Thermostatic chamber : Ambient temperature (Ta) 112 °C

IC Junction Temperature (Tj): 125 °C

- Data Rate : 25.781Gbps
- Test Pattern : PRBS^{-31}

Tx



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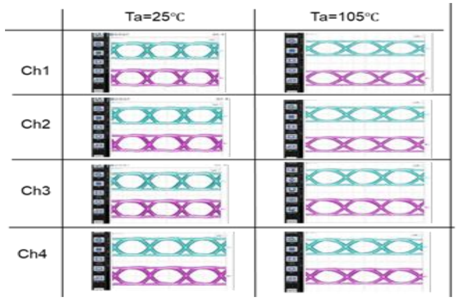
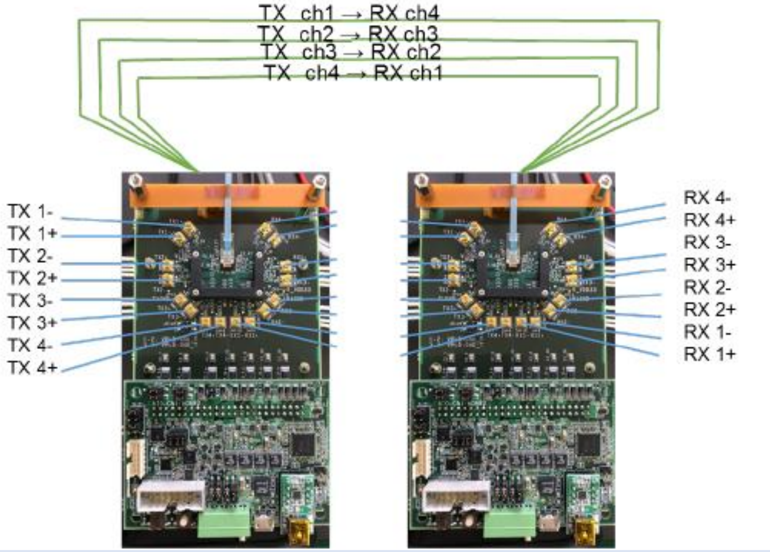
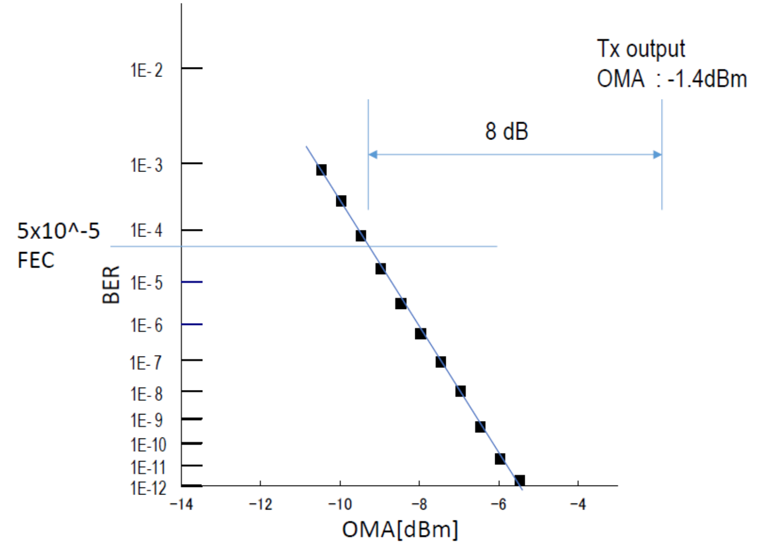




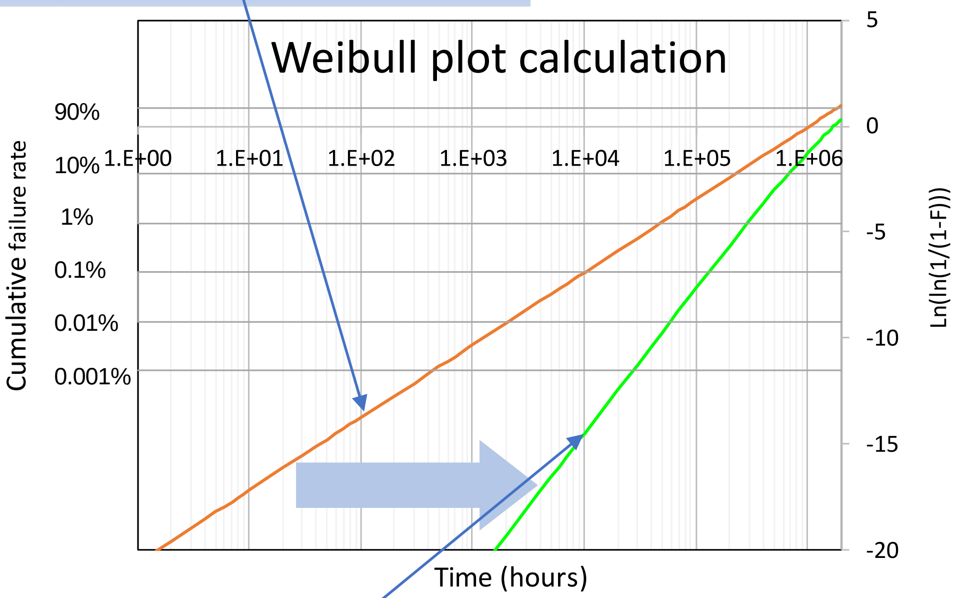


Reliability

Redundant optical circuit dramatically reduces failure rate

$Rs(t)=\{R(t)\}^n$ (Eq. 1)

Rs(t): Reliability per system (Survival rate)
R(t): Reliability per channel
n: Sequential LD-CH count (at current Tx topology, n = 4)



$Rs(t)=R(t)+\int_0^t f(u)\cdot R(t-u)du$ (Eq. 2)

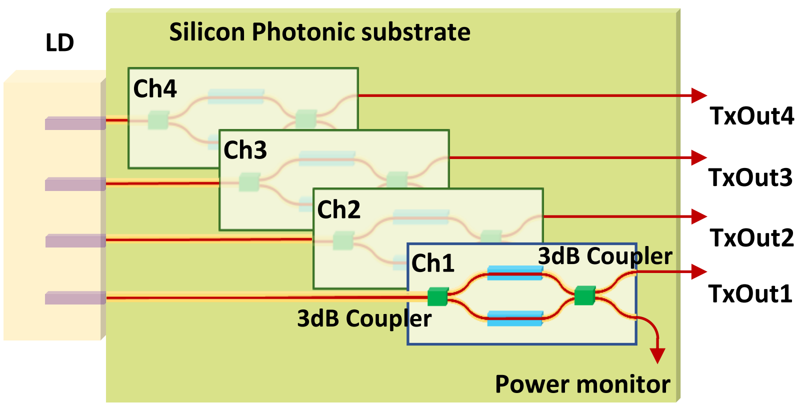
Rs(t): Reliability per system (Survival rate)
R(t): Reliability per channel
f(t): Probability density

R (t): Time until failure of common LD

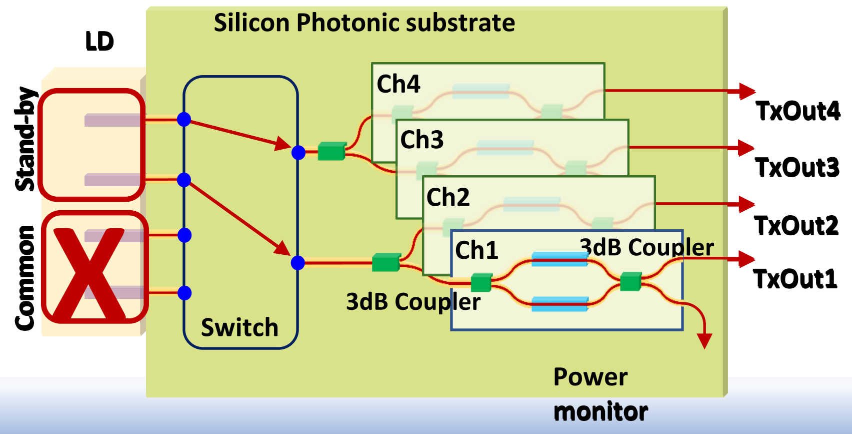
$\int_0^t f(u)\cdot R(t-u)du$:

Time from common LD failure to stand-by LD failure.

1st generation QD-LD and MZ configuration



2nd generation configuration with redundancy



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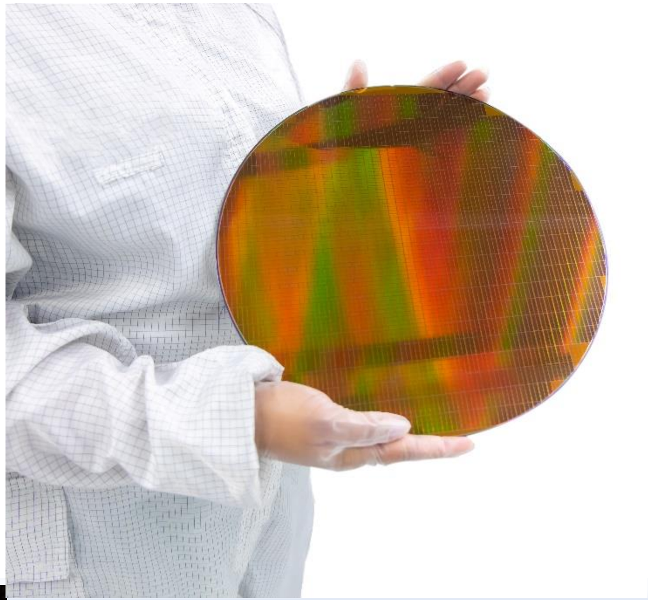


Mainstream international foundries manufacture silicon photonics

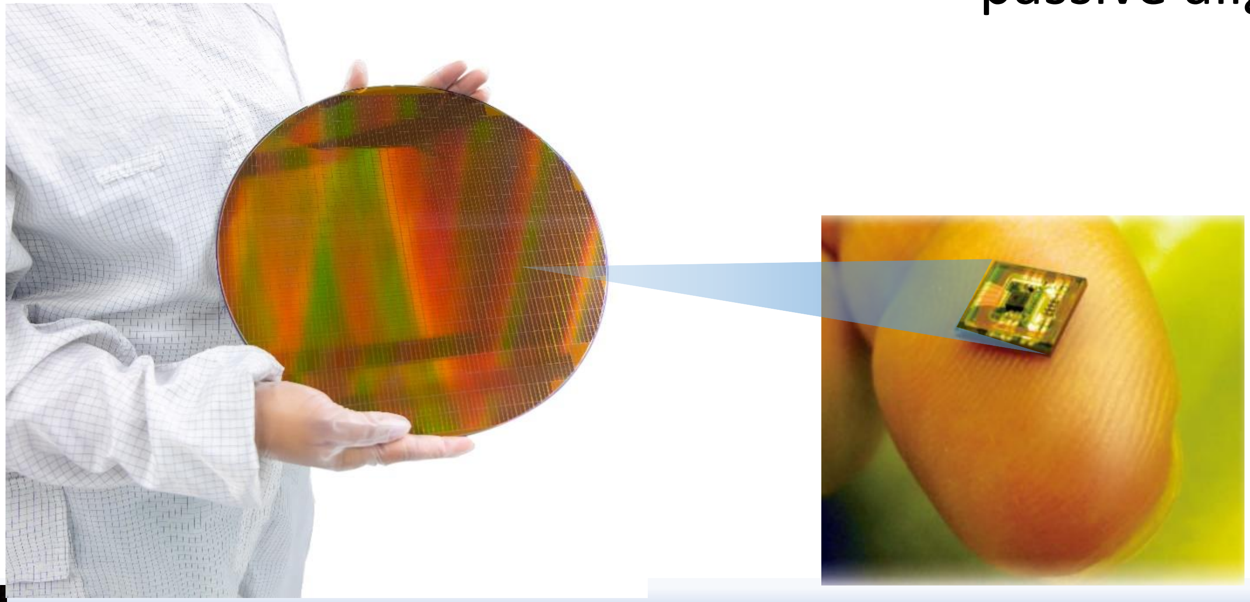
- Global Foundries
- TSMC
- ST Microelectronics
- Intel
- TowerJazz
- VTT
- Skorpios
- iHP
- CompoundTek
- Silex
- AIM Photonics
- APM
- CEA Leti
- IMEC
- AMF
- Skywater

Relative cost

- **Relative cost: big concerns**
  - It is well known that Si Photonics is expensive in single lane applications compared with VCSEL based solutions (reason behind many 802.3 projects)
  - Only laser is ~5x VCSEL and it is not the most expensive part
  - A relative cost comparison should be addressed

Cost depends on volume, chip size and assembly

- Silicon photonics benefits from mature CMOS process
- The cost of silicon photonics is determined by chip size. A 1-ch silicon photonics transceiver would be almost equal to a transceiver and receiver IC
- Coupling to GI-MMF (OM3) requires very low-cost passive alignment.



Multimode interface

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Cost of 1310 nm transceivers expected to continue to be driven down by economies of scale reductions through data centre demand

Proposal 1 Questions

OM3 is compatible

850 nm VCSELs have reliability issues at high temperature

980 nm is largely unknown and unproven for optical communication

In/GaAs PIN is responsive at 1310 nm

Silicon photonics leverages CMOS maturity

Proposals under consideration — Proposal 1

- **VCSEL + OM3**
- **Objectives: 100% fulfilled**
  - 2.5, 5, 10, 25 Gbps over 40 m + 4 inline connections
  - 50 Gbps over 15 m + 2 inline connections
  - Feasibility: [1], [2], [17], [18]
  - Link budget: [3], [4], [5], [6]
- **Industry support (multi-source, automotive volume): the biggest**
  - ✓ OM3: many suppliers, good knowledge, decades of experience of deployment
  - InGaAs VCSEL: even bigger than 850 nm if we move to 980nm
  - In/GaAs PIN PD: big
  - PHY technology: standard CMOS, the biggest volume technology
- **Technical characteristics: mature knowledge**
  - ✓ OM3: well established parameters and test methods, validated independently by many laboratories. See [7]
  - VCSELs: identified concern of performance in extreme temperatures, but well supported in 802.3cz TF. See [8], [9], [10], [11], [12], [13]
- **Reliability: long experience and deep analysis of identified concerns**
  - ✓ OM3 is already used in harsh environments with extreme temperatures and mechanical requirements, e.g. avionics, militar, industrial automation, etc.
  - ✓ CMOS: automotive quality management services in place in the biggest foundries
  - ✓ In/GaAs PIN PD: very low current densities, long experience, no concerns
  - InGaAs VCSELs: identified concern of reliability, but well supported in the TF. See [14], [15], [16]
  - TRUMPF is running extensive reliability testing of 850nm and 980nm VCSELs. TRUMPF will report in summer, and the TF should decide wavelength based on results
- **Relative cost: well known, technology leveraging**
  - CMOS, In/GaAs PIN PD, inGaAs VCSELs, and fiber are leveraged from datacenter and other markets

Direct modulation of any laser at high speed in a high temperature, vibrating environment will be inherently more damaging than operating a laser continuously

Data centres mostly specify 1310 nm and do not specify 980 nm

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THANK YOU