# 850 and 910nm VCSELs for POF Automotive Links

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# Background

- **GI-POF applicable between 800 and 1000nm [1]**
  - 20GHz BW over 15m with <85dB/km attenuation achievable

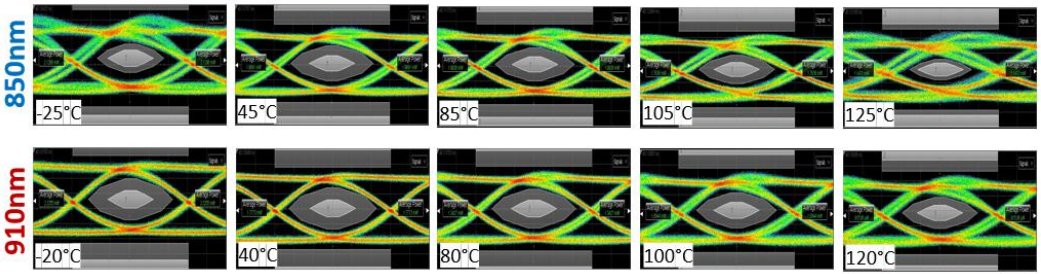
- **Automotive GI-POF link specification in IEEE 802.3dh**
  - ⇒ broad wavelength range for a high number of potential component suppliers beneficial

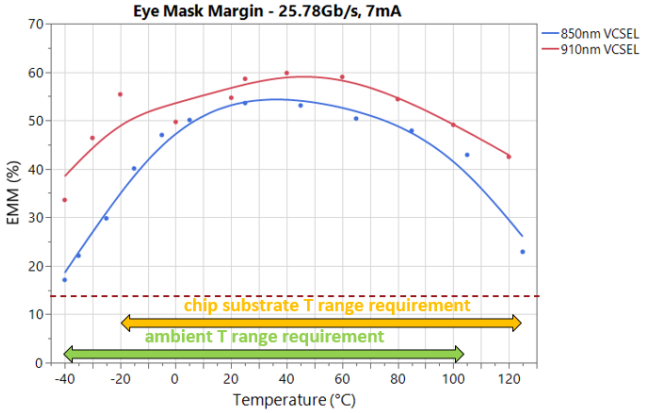
- **850nm to 940nm VCSELs mature and well-established on Datacom market [2]**
  - 25Gbps NRZ since more than 8 years
  - now up to 106 Gb/s PAM-4 available

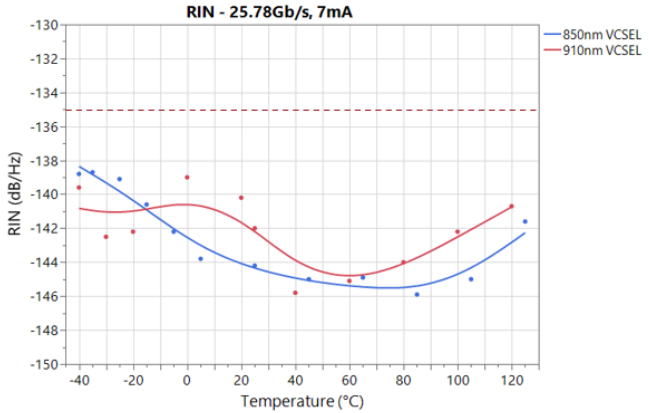
- **Automotive requirements differ from Datacom requirements [3]:**
  - -40 to 105°C ambient temperature operation (ΔT to substrate T ca. -20°C)
  - automotive ambient T mission profile:
    - 6% at -40°C, 20% at 23°C, 65% at 50°C, 8% at 100 °C, 1% at 105°C

# 850/910 nm VCSEL – Large Signal Performance

- **850 and 910nm 28G NRZ VCSELs tested**
- **Test setup:**
  - BPG -> Bias-Tee -> Probe -> VCSEL -> OE module
  - no DSP, no impedance matching etc.
  - 25.78 Gb/s, 7mA
- **good RF Performance over whole automotive temperature range demonstrated:**
  - EMM > 20%
  - RIN < -138 dB/Hz



# 850nm VCSELs - Field Reliability Experience

- **>70M VCSELs 850nm VCSELs channels with ≥25Gb/s in the field for Datacom applications (Transceivers, AOCs, …)**

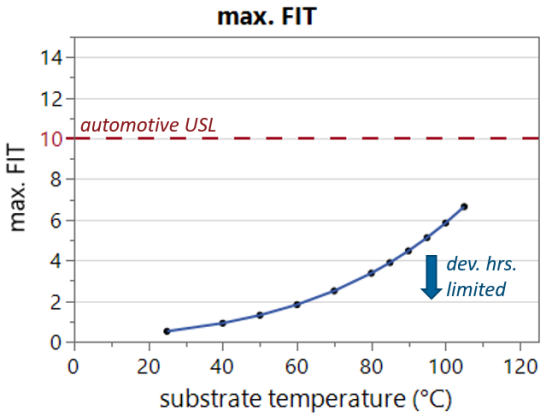
- **Random failure rate in the field:**
  - << 1 FIT <= automotive requirement of <10 FIT demonstrated
  - << 1 dppm

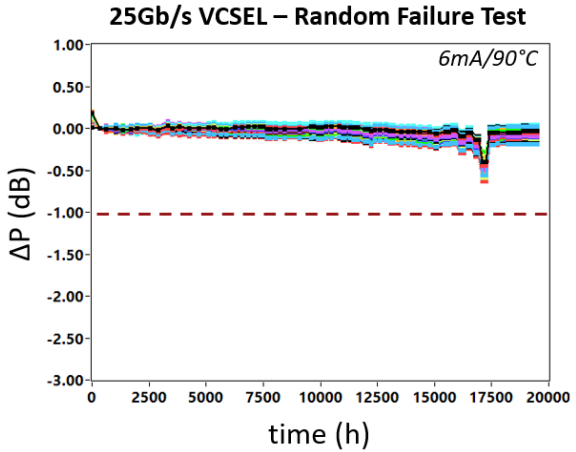
- **Wear out in the field:**
  - Wear out failure mode not observed in the field
  - prior ALT test for each wafer for ensuring TT1%F >10years at 70°C/8mA operation

# 850nm VCSEL – Internal Random Failure Rate Tests

- **~0.3B device hours from >80k chips from >2k wafers accumulated**
- **Test:**
  - Failure criterion: >1dB power drop
  - no current acceleration (n=0) and low activation energy (Ea= 0.35eV) according to Telcordia GR 468
- **FIT rates limited by accumulated device hours, not by failures**
  - shown FIT values correspond to upper limits as test are ongoing
  - further decrease over time expected
- **< 1 FIT at 40°C and <7 FIT at 105°C substrate T**

⇒ **automotive requirement of <10 FIT demonstrated**



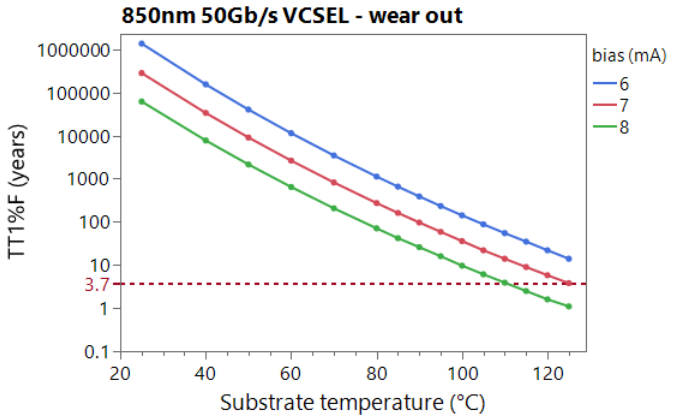
# 850nm VCSEL – Wear-Out Lifetime

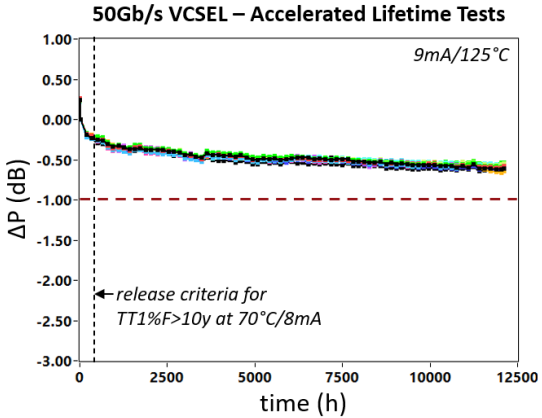
- **Accelerated Lifetime Tests at 9mA and 125°C**
  - conservative MFT >9khrs
  - >340h TTFF release criteria for Datacom (TT1%F>10years at 70°C/8mA)

- **TT1%F at different operation conditions calculated by aging model (Ea=1.3eV)**
  - TT1%F > 3.7 years or 1.1 years until 1ppm cumulated failures at 7mA and 105°C ambient T (ΔT=20°C)
  - 1 ppm cumulated failures after 28.8 years at 7mA and 70°C ambient T

⇒ **automotive requirement of > 3.7 years operation demonstrated**

| ambient T (°C) | substrate T (°C) | time to 1ppm cumulated failures at 7mA |
|---|---|---|
| -40 | -20 | >>1k years |
| 23 | 43 | >>1k years |
| 70 | 90 | 28.8 |
| 100 | 120 | 1.7 |
| 105 | 125 | 1.1 |



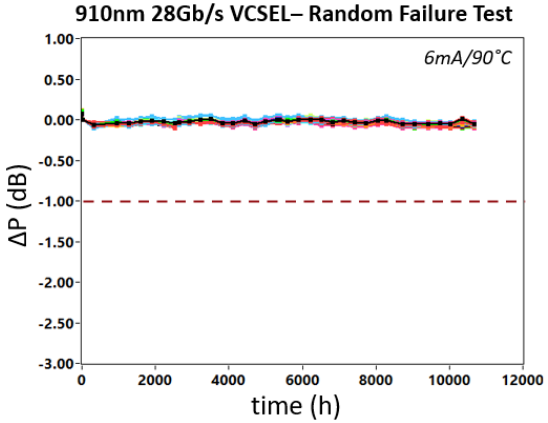



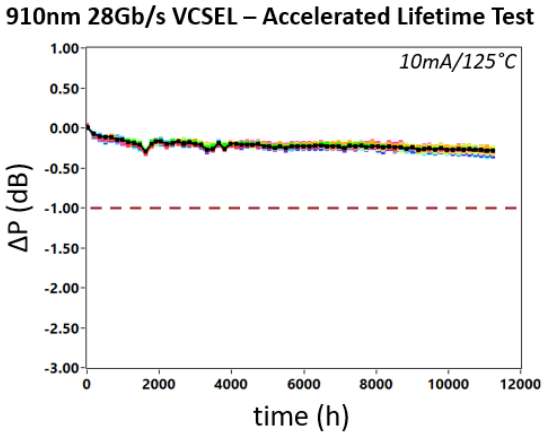
# 910nm VCSEL Reliability

- **field:**
  - ~1M VCSELs 910nm VCSELs channels with ≥25Gb/s in the field
    - no field returns
  - <10 FIT, <1 dppm
  - no wear-out observed

- **internal tests:**
  - FIT rate test:
    - no failures
    - 2.5M device hours
    - current upper limit: <208 FIT
  - wear-out lifetime at 10mA/125°C:
    - conservative MFT >7khrs
    - TT1%F >6.4 years at 7mA and 105°C ambient T (MFT >21years)
    - 1 ppm cumulated failures after 17.5 years at 7mA and 70°C ambient T

⇒ **no indications for worse reliability and FIT than 850nm VCSELs**



# Summary

- **Extended automotive temperature range operation demonstrated for 805nm and 910nm VCSELs**
  - no RF performance limitations at 25Gbps

- **Automotive reliability requirements demonstrated for 850nm VCSELs**
  - FIT: field FIT<1, internal tests FIT<1
  - wear-out LT: TT1%F > 3.7 years/ 1.1 years until 1ppm cumulated failures at max. ambient T

- **Automotive wear-out lifetime requirements demonstrated for 910nm VCSELs**
  - 1 ppm cumulated failures after 17.5 years at 7mA and 70°C ambient T

# Links


[1] Y. Watanabe, https://www.ieee802.org/3/dh/public/July_2022/Watanabe_3dh_02_2207.pdf

[2] R. Murty, https://www.ieee802.org/3/dh/public/July_2022/Murty_3dh_01_2207.pdf

[3] R. King, https://www.ieee802.org/3/cz/public/nov_2020/king_3cz_01_1120.pdf

Thanks.

# Appendix: Lifetime Calculations

- **Acceleration model (n, Ea) derived from wear-out matrix test with ~16 different stress cells**
- **Acceleration factor between aging and usual operating conditions :**

$$(I_2 / I_1)^n \cdot \exp\left\{ E_a / k \left(\frac{1}{T_1} - \frac{1}{T_2}\right) \right\}$$

$I_1$ …operating current
$I_2$ … test current
n … current acceleration factor
$E_a$ … activation energy
k … Boltzmann constant
$T_1$ … operation junction temperature
$T_2$ … test junction temperature

- **MFT (Median Failure Time) for different operation conditions calculation based on MFT in accelerated aging test**
- **Typical wear-out estimates calculated from the mean of minimum MFT values of production wafers**
  - test stopped before reaching MFTs (not enough failures after 7k-9k hours)
- **TTx%F calculated based on conservative values taken for MFT and lognormal width σ (0.5)**

# Appendix: 850nm VCSEL – Wear-Out Lifetime

- **Lognormal extrapolation for 7mA and different ambient T**