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VCSEL design for automotive datacom
Experimental results for 980 nm versus 850 nm

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VCSEL design for 25/50 Gb/s automotive datacom

Today’s 850nm 25G VCSEL design is on the edge for automotive

Today’s 25/50 Gb/s VCSELs are operated at 18 kA/cm², 70°C

But operation with <15 kA/cm² at chip backside up to 125°C is required to support 15 years car service life
Improvement strategy “reduce wear out scale”
The “how” is not clear

“$\sigma \ln < 0.45$“ is already very challenging for today’s 850nm VCSEL

“$\sigma \ln < 0.25$“ is an unrealistic target for long term production
Improvement strategy “improve wear out location”

The how is clear: 980nm instead of 850nm VCSEL

“>3x of today’s t50%“ is a realistic design target

Wearout data 980nm → see pages 7,8,9
## VCSEL design options for 25/50 Gb/s automotive datacom

980nm is the preferred design from a pure VCSEL point of view

<table>
<thead>
<tr>
<th></th>
<th>850nm VCSEL</th>
<th>980nm VCSEL</th>
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<tbody>
<tr>
<td><strong>lower current, lower power dissipation, higher heat removal</strong></td>
<td></td>
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<tr>
<td>@ 25/50 Gbd, 125°C operation</td>
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<tr>
<td>compressive strain (for differential gain)</td>
<td>lower</td>
<td>higher</td>
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<tr>
<td>thermal conductivity of Bragg mirror</td>
<td>lower</td>
<td>higher</td>
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<tr>
<td>free carrier absorption</td>
<td>less</td>
<td>more</td>
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<tr>
<td>DBR layer stack</td>
<td>thinner</td>
<td>thicker</td>
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<tr>
<td>turn on voltage</td>
<td>higher</td>
<td>lower</td>
</tr>
<tr>
<td>thermal escape of carriers from quantum wells</td>
<td>more</td>
<td>less</td>
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<tr>
<td><strong>less variability in wearout</strong></td>
<td></td>
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<tr>
<td>quantum well growth window</td>
<td>tighter</td>
<td>wider</td>
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<tr>
<td>quantum well thickness</td>
<td>thinner</td>
<td>thicker</td>
</tr>
<tr>
<td>wafer quantities</td>
<td>low</td>
<td>high (at 940 nm)</td>
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<tr>
<td><strong>higher resistance to maverick defect propagation</strong></td>
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<tr>
<td>compressive strain (for dislocation pinning)</td>
<td>lower</td>
<td>higher</td>
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<tr>
<td><strong>better robustness</strong></td>
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<tr>
<td>flip-chip</td>
<td>top emission</td>
<td>top or bottom emission</td>
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</table>
Industrialization of 980nm VCSELs

The majority of VCSELs are 940nm. 850nm is the exception!

- Yole Développment 2020 report:
  - 2021 sensors VCSEL count: 1.6 billion units
  - 2021 datacom VCSEL count: 65 million units

- The majority of the ~50 VCSEL suppliers is active in 940nm and 850nm
  - Biggest hurdle at 850nm: epitaxial “alchemy”
    - Therefore, most VCSEL suppliers fail
    - “Reliable” QWs at 940nm are much easier

- 940nm .. 1065nm is very similar in terms of material composition, overall reliability and datacom performance

- No significant difference in cost between 850nm and 980nm VCSEL chips

- InGaAs PDs for 980nm are available

Datacom (850nm)

Sensing (940nm)
980nm versus 850nm 25G VCSEL design wear out reliability at 140°C, 10mA stress

850nm VCSEL
- Time to 50% fails = 853hrs @ 140°C, 10mA

Long wavelength VCSEL
- No wearout fails so far

850nm VCSEL

- No wearout fails so far

980nm endurance advantage already

>5x
980nm versus 850nm 25G VCSEL design wear out reliability at 155°C, 8mA stress

850nm VCSEL
- Time to 50% fails = 561hrs @ 155°C, 8mA

Long wavelength VCSEL
- No wearout fails so far

980nm endurance advantage already >9x

Stress condition: 155°C chip backside (substrate) temperature, 8mA continuous wave laser current
Every 24h the VCSEL is cooled down to ~40°C and the output power at 7mA drive current is recorded
980nm versus 850nm 25G VCSEL design wear out reliability at 170°C, 6mA stress

850nm VCSEL
- Time to 50% fails = 307hrs @ 170°C, 6mA

Long wavelength VCSEL
- No wearout fails so far

980nm endurance advantage already >>10x

Stress condition: 170°C chip backside (substrate) temperature, 6mA continuous wave laser current
Every 24h the VCSEL is cooled down to ~40°C and the output power at 7mA drive current is recorded
Summary

From a VCSEL point of view the 980nm design is the better choice for 25/50 Gb/s automotive applications

- 980nm VCSELs are far more robust than 850nm VCSELs
  - Use of aluminum-free quantum well barriers is the game-changer
- Automotive is not requiring backwards compatibility and offers the chance to take advantage of higher reliability at 980nm
  - Shorter link lengths (<40m) tolerate more dispersion in the optical fiber at 980nm
- There are plenty of suppliers capable of delivering 980nm VCSELs

Transferring the 980nm 25/50 Gb/s automotive VCSEL design to production is the next step

- Wearout test on 980 ..1040nm feasibility samples at TRUMPF will be concluded after 5000hrs → no fails observed so far
- Design for 980nm available at TRUMPF and likely at other vendors
- Manufacturing will be done on existing and released production equipment and processes
  - Automotive grade product prototypes for qualification testing are planned for Q3 2022
Thank you!

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