GaAs 14G VCSEL characterization for automotive applications

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Introduction

• GaAs 14G VCSEL (TRUMPF VCSEL-ULM850-14G-Gen3-V0) has been characterized in wide range of temperatures, between —40 °C and +125 °C, to assess the suitability for automotive applications

• Different oxide aperture diameters have been tested to analyze the parametric deviation due to production process variations
  • Corners: 8.7 um (high I_TH, slower) and 6.5 um (low I_TH, faster)
  • Devices with different oxide aperture diameters will experience different current density, therefore different aging acceleration, under the same current driving condition

• Characterization of 3 samples per corner is reported

• Temperature is measured in the bottom side of the PCB where the VCSEL is connected, with low thermal resistance vias connected to the top GND plane where VCSEL is attached
  • Temperature reported is substrate temperature: -40, 0, +25, +85, +105, +125 °C
  • Junction temperature is expected to be higher due to (I·V - Po) and high thermal resistance of GaAs

• CPWG (co-planar waveguide with lower ground plane) high speed topology is used to connect coax cable 2.92 mm connector to VCSEL under test with good signal integrity
Equipment & Software

- **Marki Microwave BTN-0040 bias tee (40 kHz to 40 GHz)**
  - Used to combine bias current with RF signal from VNA or AWG

- **Minicircuits TMP40-3FT-KM+K+, temperature stable 2.92mm cable, 40.0 GHz**
  - Used to connect bias tee output to the DUT

- **Newport 1484-A-50 fiber-optic multimode receiver, 800-865nm GaAs detector, 22 GHz, FC/PC**
  - Used for S21 response measurement with VNA
  - Calibration provided for response de-embedding

- **Keysight E5071C ENA Vector Network Analyzer**
  - S21 magnitude response
  - Z11 real/imag reflect response
  - 2001 points linear sweep from 1 MHz to 20 GHz
  - Power -20 dBm

- **Keysight B2901A Precision Source/Measure Unit**
  - Bias current to VCSEL
  - Voltage drop measurement (V-I curve)

- **Optokon OFT-820**
  - Absolute optical power, calibrated for 850 nm
Equipment & Software

- Thorlabs FP1000URT 1 mm core multi-mode SI 0.50 NA glass fiber with Ø5.0 mm stainless steel tubing FT05SS
  - Used to collect full optical radiation from VCSEL (L-I curve)
- OFS C26133 2.2 mm simplex 62.5/200/230 GiHCS Cable, 3 meters
  - Used for AC and time-domain characterization
- Keysight M8195A 65 GSa/s, 25 GHz, Arbitrary Waveform Generator
  - Used to generate time-domain RF signal that drives the VCSEL
  - Capability of real-time digital signal processing with 8 bits DAC
  - Used to provide symbol clock to oscilloscope
- Keysight N1092C DCA-M Sampling Oscilloscope (one optical and two electrical channels)
  - Used to make the time-domain characterization with periodic arbitrary signal generated by VCSEL
- Keysight N1010A FlexDCA Sampling Oscilloscope Software, R&D package
- Matlab 2018a:
  - Test automation
  - Signal processing
  - Model extraction
  - User operator extensions for N1010A
Tests setups
DUT

TOP

CPWG

2.92 mm

VCSEL

BOTTOM

Thermo-couple attachment point

X-Y adjustable collimator with FC connector

Rogers dielectric
I-V characteristic

Vak characteristic per temperature (8.7 um)

-40 °C  
0 °C  
25 °C  
85 °C  
105 °C  
125 °C

Vak characteristic per temperature (6.5 um)

-40 °C  
0 °C  
25 °C  
85 °C  
105 °C  
125 °C
L-I characteristic

AOP characteristic per temperature (8.7 um)

AOP characteristic per temperature (6.5 um)
I threshold characteristic

I Threshold per temperature (8.7 um)

I Threshold per temperature (6.5 um)
Resonance frequency characteristic

Figure 2.2: Small signal electrical model of VCSEL with driving source [2]

\[
H(f) = C \cdot \frac{f_p^2}{f_p^2 - f^2 + j \frac{f}{2\pi} \gamma} \cdot \frac{1}{1 + j \frac{f}{f_p}}.
\]
Damping rate characteristic

\[ H(f) = C \cdot \frac{f_r^2}{f_r^2 - f^2 + j \frac{f}{2\pi} \gamma} \cdot \frac{1}{1 + j \frac{f}{f_p}}. \]
Extrinsic pole characteristic

\[
H(f) = C \cdot \frac{f_{r}^{2}}{f_{r}^{2} - f^{2} + j\frac{f}{2\pi} \gamma} \cdot \frac{1}{1 + j\frac{f}{f_{p}}}
\]

\[
H_{par}(f) = \frac{1}{1 + j\frac{f}{f_{p}}}
\]

This additional term is multiplied by the intrinsic transfer function of VCSEL \( H_i(f) \), producing the total electrical transfer function as \( H(f) = H_i(f) \cdot H_{par}(f) \).
-3 dB bandwidth characteristic

Bandwidth data per temperature (8.7 um)

Bandwidth data per temperature (6.5 um)
Eye diagram, 10 Gbps

• Signal type: NRZ

• Baud-rate: 10.625 GBd

• ER (current): 3 dB (expected worst case)

• AWG is configured with response correction calibrated from factory to avoid additional driving bandwidth limitations

• DCA receiver input filter: Bessel-Thomson 4th order BW-3dB = 21 GHz
  • Configured to observe VCSEL response entirely w/o bandwidth limitation and make possible time-domain simulation correlation

• It is observed that as higher is the current density, better is the performance
  • Increasing current will not be a reliability problem in low temperatures
  • In high temperature we need to demonstrate feasibility with low current densities
Eye diagram, -40 °C

8.7 um, sample ID #4

<table>
<thead>
<tr>
<th>I_{BIAS} = 3 mA</th>
<th>I_{BIAS} = 4 mA</th>
<th>I_{BIAS} = 5 mA</th>
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</thead>
</table>

6.5 um, sample ID #12

<table>
<thead>
<tr>
<th>I_{BIAS} = 3 mA</th>
<th>I_{BIAS} = 4 mA</th>
<th>I_{BIAS} = 5 mA</th>
</tr>
</thead>
</table>
Eye diagram, 25°C

8.7 um, sample ID #4

6.5 um, sample ID #12
Eye diagram, 125°C

8.7 um, sample ID #4

6.5 um, sample ID #12

Feasible!!
Is it possible to use this VCSEL for 25 Gbps?

8.7 um, sample ID #4

\[ T_{\text{SUB}} = 125^\circ C, I_{\text{BIAS}} = 6 \text{ mA}, \text{ER} = 3 \text{ dB} \]
26.88 GBd NRZ signal

• 25 Gbps can be transmitted by implementation of pre-emphasis in the driver and higher average current density in the VCSEL, at the cost of higher complexity and power consumption

• Lesson learned: pre-emphasis may be implemented in the driver to improve the VCSEL response, therefore the receiver sensitivity for the same \( I_{\text{BIAS}} \) driving
Thank you