Laser Diodes for (3D) Sensing

Swiss Photonics Meeting, Industrial 3D Vision

June 21, 2018

Dr. Julien Boucart
Overview

- Deployment of 3D sensing in consumer devices
- Derived requirements of 3D sensing technologies on light sources
- Comparison of laser vs LED illumination for Time Of Flight
- Lasers for 3D sensing at II-VI Laser Enterprise
Motivation

- Deployment of 3D cameras in consumer space
  - Microsoft Kinect
  - Intel RealSense
  - iPhone X
  - LG G3 Auto Focus Assist

- Why Semiconductor Laser Diodes?
  - High volume
  - Low cost
  - High reliability
  - Compactness
  - Low power consumption
Searching for the Killer App

Smartphones
- gesture control
- smarter touch interfaces
- face recognition

Tablets
- people detection
- 3D scanning
- full body tracking

Virtual reality
- indoor navigation

Smart home / IoT
- TVs

Automotive & Drones
- Gaming

PCs & Notebooks
Basic 3D Sensing Methodologies

- Time based: Time of Flight
  - Direct TOF (1cm=67ps)
    - Fast modulation
    - Fast detectors
  - Indirect (CW TOF)
    - E.g. Sine Modulation

- Two methods to retrieve phase
  - Pros / Cons
    - Simple SW
    - No parallax required (compact)
    - Noise increases linearly with depth
    - Dedicated pixel technology
    - Lower spatial resolution

- Triangulation: Structured light / Stereo
  - Parallax transforms depth difference into lateral image displacement
  - Two methods
    - Stereoscopic
    - Structured Light

- Pros / Cons
  - “Standard” CMOS image sensors
  - Good depth resolution
  - Computation intensive
  - Complicated optics
  - Requires robust mechanical platform
  - Stringent reliability requirements
  - Depth noise increases with distance^2
## Requirements for Illumination Sources

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Stereoscopic with IR</th>
<th>Direct TOF</th>
<th>Indirect TOF</th>
<th>Structured Light / Active Stereo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fast Modulation</td>
<td>![Exclamation Mark]</td>
<td>![Exclamation Mark]</td>
<td>![Exclamation Mark]</td>
<td>![Exclamation Mark]</td>
</tr>
<tr>
<td>Narrow Spectrum</td>
<td>![Exclamation Mark]</td>
<td>![Exclamation Mark]</td>
<td>![Exclamation Mark]</td>
<td>![Exclamation Mark]</td>
</tr>
<tr>
<td>Small Spectral Shift with $T^\circ$</td>
<td>![Exclamation Mark]</td>
<td>![Exclamation Mark]</td>
<td>![Exclamation Mark]</td>
<td>![Exclamation Mark]</td>
</tr>
<tr>
<td>Eye Safety</td>
<td>![Exclamation Mark]</td>
<td>![Exclamation Mark]</td>
<td>![Exclamation Mark]</td>
<td>![Exclamation Mark]</td>
</tr>
<tr>
<td>Collimation Requirements</td>
<td></td>
<td>![Exclamation Mark]</td>
<td>![Exclamation Mark]</td>
<td>![Exclamation Mark]</td>
</tr>
<tr>
<td>Individual Emitters Reliability</td>
<td></td>
<td>![Exclamation Mark]</td>
<td>![Exclamation Mark]</td>
<td>![Exclamation Mark]</td>
</tr>
<tr>
<td>Spatial Mode Control</td>
<td></td>
<td>![Exclamation Mark]</td>
<td>![Exclamation Mark]</td>
<td>![Exclamation Mark]</td>
</tr>
<tr>
<td>Power Overdrive</td>
<td>![Exclamation Mark]</td>
<td>![Exclamation Mark]</td>
<td>![Exclamation Mark]</td>
<td>![Exclamation Mark]</td>
</tr>
</tbody>
</table>

**Illustration**

- Lit2
- Lit3
- Lit4
- Lit5
Laser Diode Technology and Products

Semiconductor Laser Technology

High Power Laser Wafer
- HPL Bars & Chips
- HPL Bars on Cooler
- HPL Water Cooled Stack
- HPL Fiber Coupled Chips

Vertical Cavity Surface Emitting Laser Wafer
- VCSEL Chip
- VCSEL Array

TECHNOLOGY & PRODUCTS
Types of Semiconductor Laser Diodes

VCSELs
- Pros / Cons
- Power Scalable
- Fast Modulation
- Stabilized Wavelength
- Easy Packaging
- Emitter Redundancy
- Beam Shaping
- Fill-Factor
- Brightness
- Single Mode Power

Single Mode Fabry Pérot
- Pros / Cons
- Single Mode Transverse
- Assembly Costs
- Manufacturing Costs
- Speckle
- Wavelength shift with T°
- Beam Shaping

Single Mode DFBs
- Pros / Cons
- Single Mode Transverse
- Stabilized Wavelength
- Assembly Costs
- Manufacturing Costs
- Speckle
- Beam Shaping
More on Specifics of VCSELs vs LED

VCSELs Narrower spectrum and low shift with temperature: narrower bandpass filter

VCSELs: Fast modulation >30MHz ~200ps rise and fall times

VCSELs lower divergence: smaller optics / more efficient beam shaping

In short pulse and low duty cycle can be overdriven
Here 250mW CW yields 5W pulsed
What Illumination Wavelength?

- **940nm essential for outdoor operation**
- **Advantages for 850nm**
  - 850nm are commercially available Si-based CMOS sensors
  - 940nm sensors are less common (e.g. black Si, Quantum Dots)
- **Advantages for 940nm**
  - Large spectral content from the sun at 850nm (degraded SNR)
  - 850nm illumination is visible to human eye (red glow)
- **Alternative: 15xx nm**
  - Attractive from ambient sunlight and eye safety point of view
  - Light sources and detectors not ready for consumer applications
Comparison LED vs VCSEL: A ToF case study

- Optical train for a generic Time Of Flight system

- Ambient parasitic light

- CMOS TOF Sensor

- Electrical pulse

- Diffuser

- VCSEL or LED

- Binary data

- Optical train for a generic Time Of Flight system
Laser-based System: 3x More Efficient

- Assuming ideal diffusor to yield FOI 78° with 90% uniformity
- Assuming 20nm optical notch filter
- For the same efficiency light source, Laser-based system is 3x more efficient

<table>
<thead>
<tr>
<th>Loss mechanism</th>
<th>Assumptions</th>
<th>LED</th>
<th>VCSEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency of light source ($\eta_{\text{EO}}$)</td>
<td></td>
<td>35%</td>
<td>35%</td>
</tr>
<tr>
<td>Transmission through diffusor ($\eta_{\text{abs}}$)</td>
<td></td>
<td>90%</td>
<td>90%</td>
</tr>
<tr>
<td>Critical angle loss through diffusor ($\eta_q$)</td>
<td>$n=1.5$</td>
<td>95%</td>
<td>100%</td>
</tr>
<tr>
<td>Roll off after diffusor ($\eta_{\text{diff}}$)</td>
<td>FOI defined with 90% uniformity</td>
<td>58%</td>
<td>78%</td>
</tr>
<tr>
<td>Reflection on object</td>
<td>Ignored here</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Transmission through notch filter ($T_{\text{filt}}$)</td>
<td>20nm filter</td>
<td>41%</td>
<td>95%</td>
</tr>
<tr>
<td>TOF sensor efficiency</td>
<td>Ignored here</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Efficiency of electrical modulation</td>
<td>$&lt;30\text{MHz}$</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>$&gt;30\text{MHz}$</td>
<td>0%</td>
<td>100%</td>
</tr>
<tr>
<td>Total</td>
<td>$&lt;30\text{MHz}$</td>
<td>7.1%</td>
<td>23.3%</td>
</tr>
<tr>
<td></td>
<td>$&gt;30\text{MHz}$</td>
<td>0%</td>
<td>23.3%</td>
</tr>
</tbody>
</table>
Laser Array for Time of Flight and Flood Illumination

- 280 emitters
- Suitable for Time of Flight application
- 2.5W at 3.25A operation
- Single longitudinal mode
- Multimode transverse
- 940nm

10% D.C. 2.2ms, 18-58°C

FarField intensity

Power (mW) vs. Current (mA)

PCE (%) vs. Angle (°)
Example of Product: 940nm DFB

- Tailored for high volume 3D camera structured light applications

- Principle of operation
  - Embedded grating stabilizes emission wavelength

- Characteristics
  - Single-mode power (longitudinal and transverse)
  - Emission wavelength: 940nm
  - Wavelength stabilized over operating temperature range
  - High Wallplug Efficiency
Conclusions

- Various technologies for 3D sensing drive different requirements on illumination sources

- Semiconductor laser diodes are well suited to address the consumer 3D sensing market

- VCSELS and DFBs are appropriate light sources for Structured Light, Active Stereo and Time Of Flight systems

- Comparing the benefits of light sources needs to be done together with the systems they enable
References / Sources

[Lit1]:

[Lit2]:
• https://www.researchgate.net/figure/Stereo-vision-principle-two-cameras-which-view-the-same-scene-detect-a-common-3D-point_fig1_221908788

[Lit3]:
• https://www.researchgate.net/figure/Principle-of-distance-determination-using-direct-time-of-flight_fig3_226367459

[Lit4]:
• http://image-sensors-world.blogspot.com/2014/08/mantis-vision-reviews-3d-camera.html

[Lit5]:

[Lit6]:
• http://commons.wikimedia.org/wiki/File:Solar_spectrum_ita.svg
• https://commons.wikimedia.org/w/index.php?curid=11362653

[Lit7]: