Laser Diodes for (3D) Sensing

Swiss Photonics Meeting, Industrial 3D Vision

June 21, 2018

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Overview

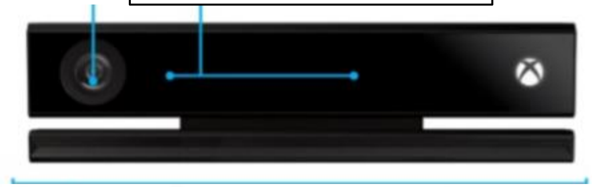
- **Deployment of 3D sensing in consumer devices**
- **Derived requirements of 3D sensing technologies on light sources**
- **Comparison of laser vs LED illumination for Time Of Flight**
- **Lasers for 3D sensing at II-VI Laser Enterprise**

Motivation

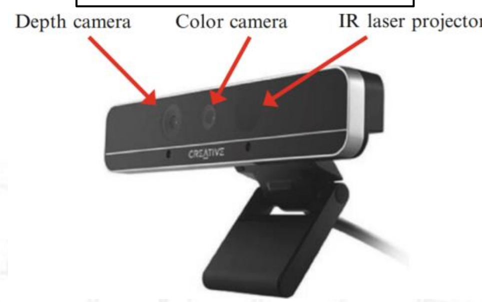
- **Deployment of 3D cameras in consumer space**
  - Microsoft Kinect
  - Intel RealSense
  - iPhone X
  - LG G3 Auto Focus Assist

- **Why Semiconductor Laser Diodes?**
  - High volume
  - Low cost
  - High reliability
  - Compactness
  - Low power consumption

Microsoft Kinect



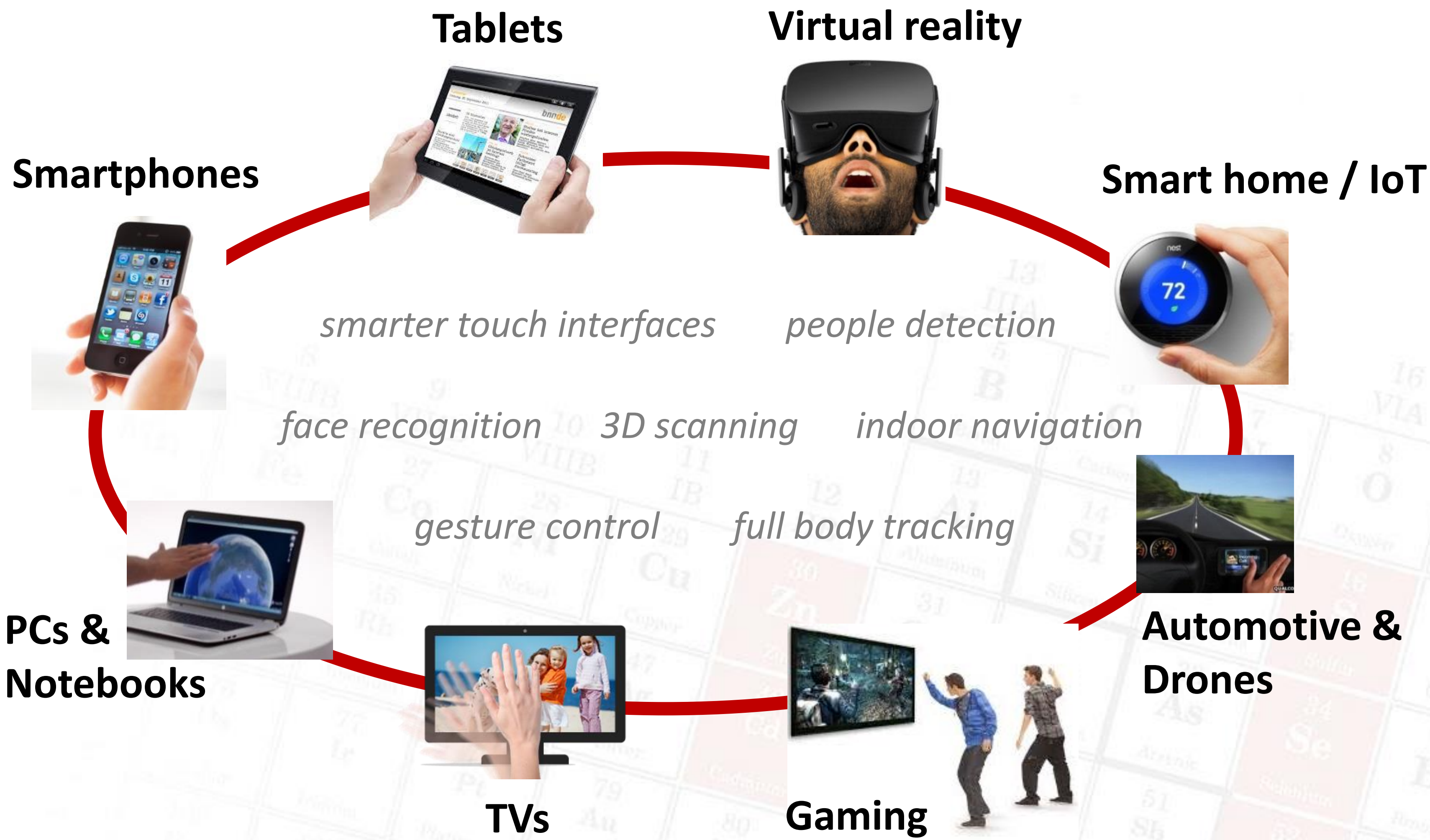
Intel RealSense



iPhone X

LG G3

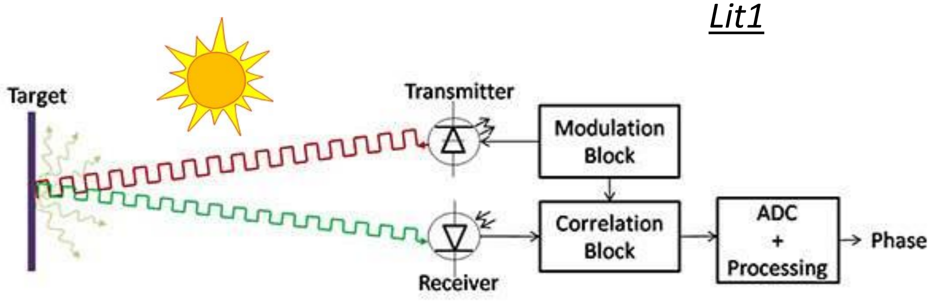
Searching for the Killer App



Basic 3D Sensing Methodologies

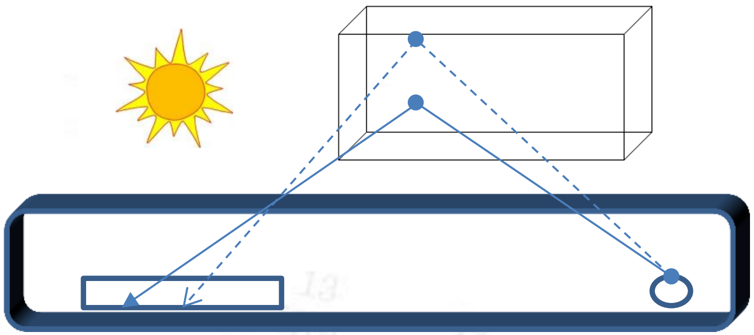
- **Time based: Time of Flight**

Lit1



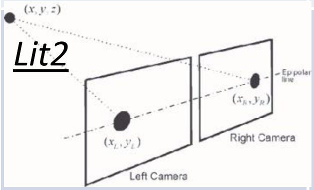
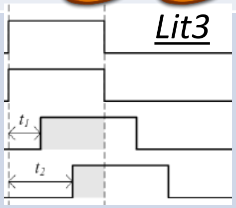
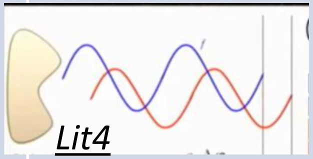
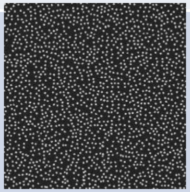
- **Two methods to retrieve phase**
  - Direct TOF (1cm=67ps)
    - Fast modulation
    - Fast detectors
  - Indirect (CW TOF)
    - E.g. Sine Modulation
- **Pros / Cons**
  - **Simple SW**
  - **No parallax required (compact)**
  - **Noise increases linearly with depth**
  - **Dedicated pixel technology**
  - **Lower spatial resolution**

- **Triangulation: Structured light / Stereo**

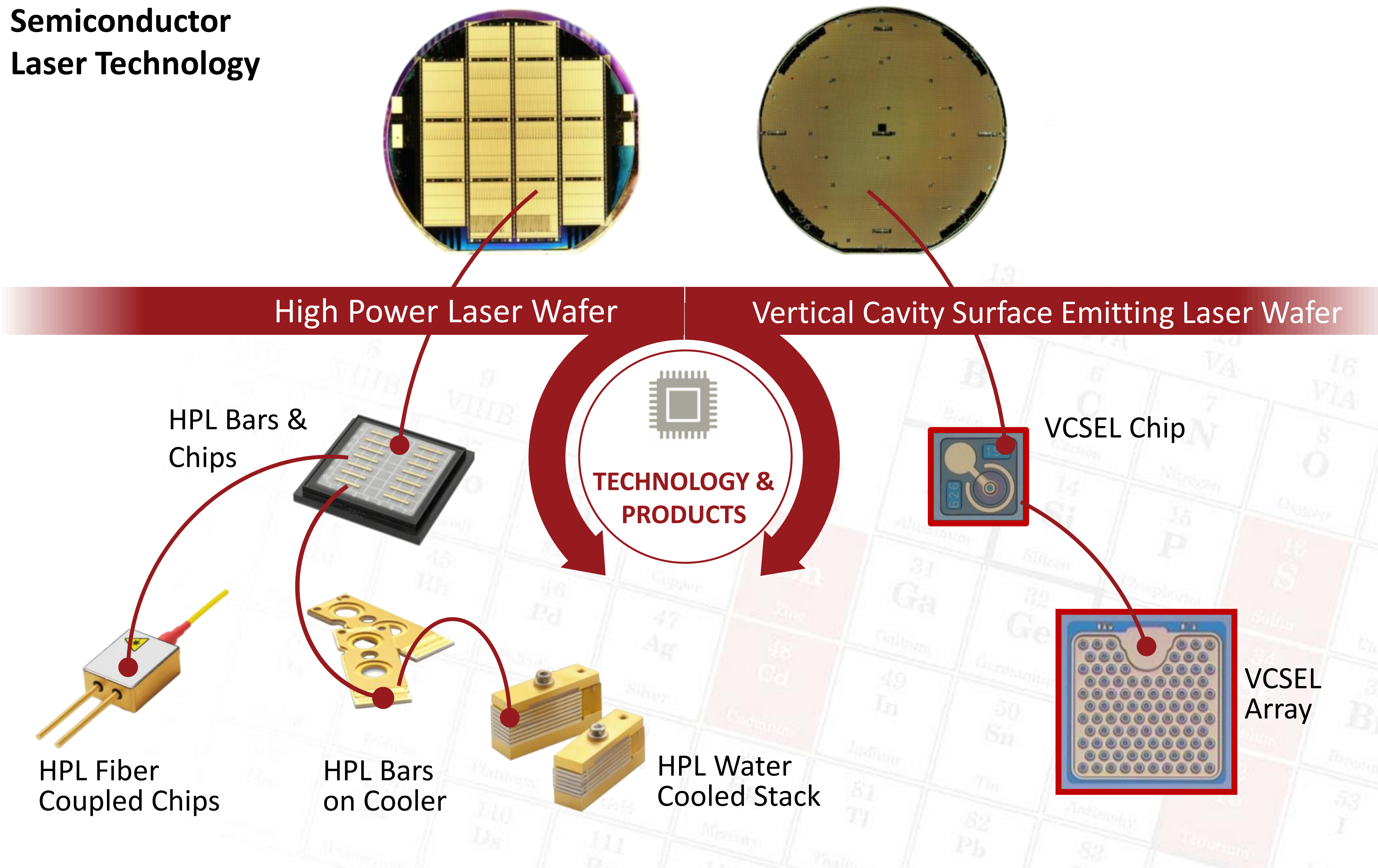


- **Parallax transforms depth difference into lateral image displacement**
- **Two methods**
  - Stereoscopic
  - Structured Light
- **Pros / Cons**
  - **"Standard" CMOS image sensors**
  - **Good depth resolution**
  - **Computation intensive**
  - **Complicated optics**
  - **Requires robust mechanical platform**
  - **Stringent reliability requirements**
  - **Depth noise increases with distance^2**

Requirements for Illumination Sources

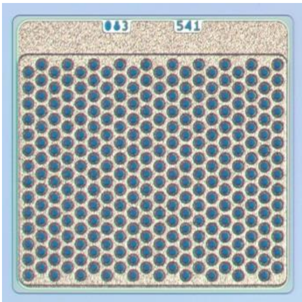
	Stereoscopic with IR	Direct TOF	Indirect TOF	Structured Light / Active Stereo
Fast Modulation		! !	!	
Narrow Spectrum	!	!	!	!
Small Spectral Shift with T°	!	!	!	!
Eye Safety	!	!	!	! !
Collimation Requirements				!
Individual Emitters Reliability				!
Spatial Mode Control				!
Power Overdrive		! !	!	
Illustration	 Lit2	 Lit3	 Lit4	 Lit5

Laser Diode Technology and Products



Types of Semiconductor Laser Diodes

VCSELs

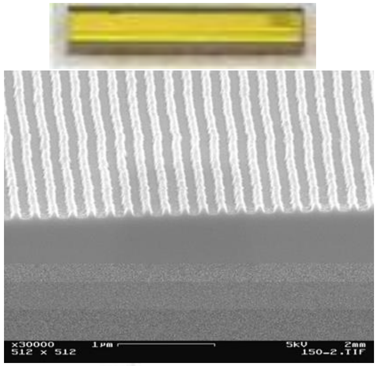


- Pros / Cons
- Power Scalable
- Fast Modulation
- Stabilized Wavelength
- Easy Packaging
- Emitter Redundancy
- Beam Shaping
- Fill-Factor
- Brightness
- Single Mode Power

Single Mode Fabry Pérot

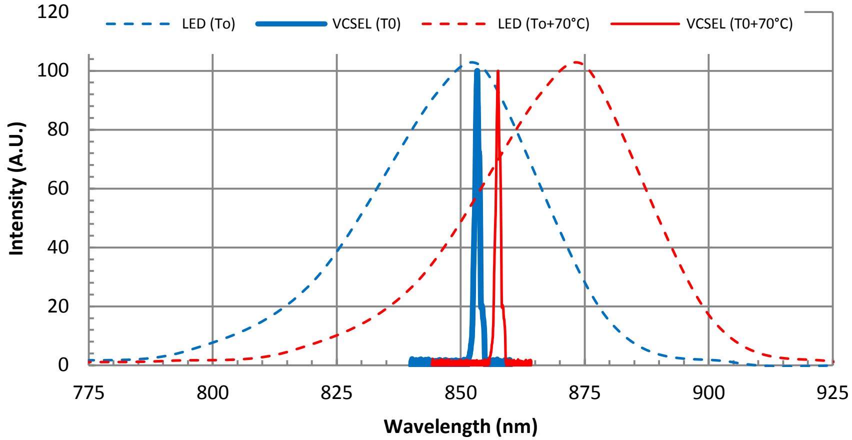
- Pros / Cons
- Single Mode Transverse
- Assembly Costs
- Manufacturing Costs
- Speckle
- Wavelength shift w T°
- Beam Shaping

Single Mode DFBs

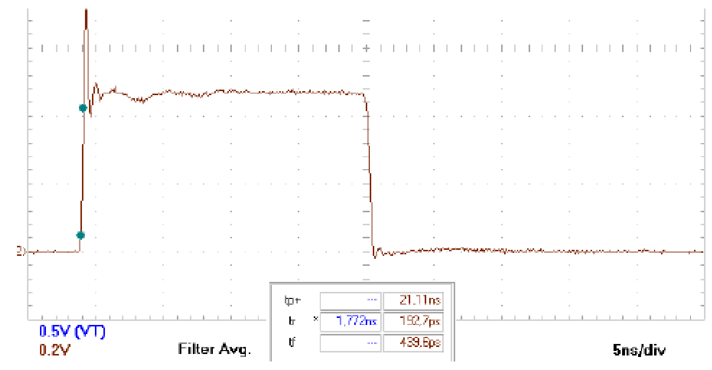


- Pros / Cons
- Single Mode Transverse
- Stabilized Wavelength
- Assembly Costs
- Manufacturing Costs
- Speckle
- Beam Shaping

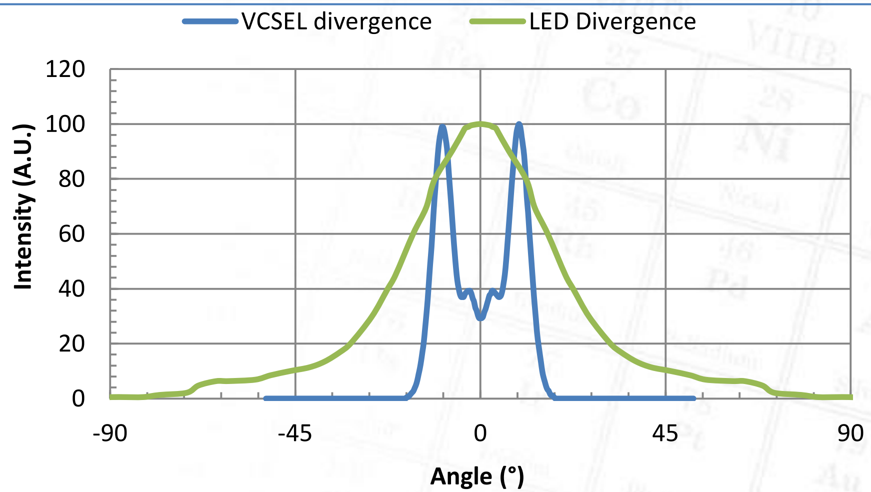
More on Specifics of VCSELs vs LED



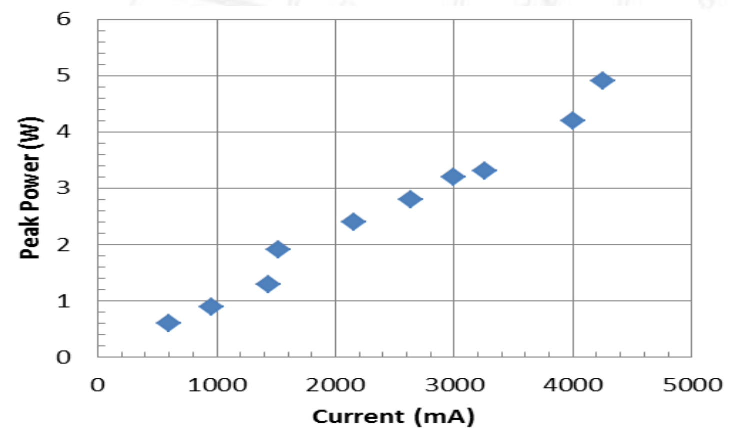
VCSELs Narrower spectrum and low shift with temperature: narrower bandpass filter



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



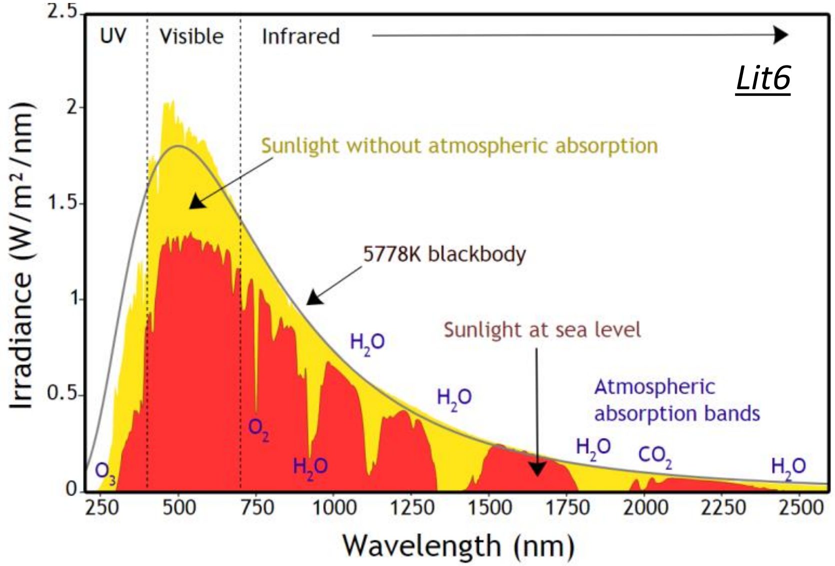
VCSELs lower divergence: smaller optics / more efficient beam shaping

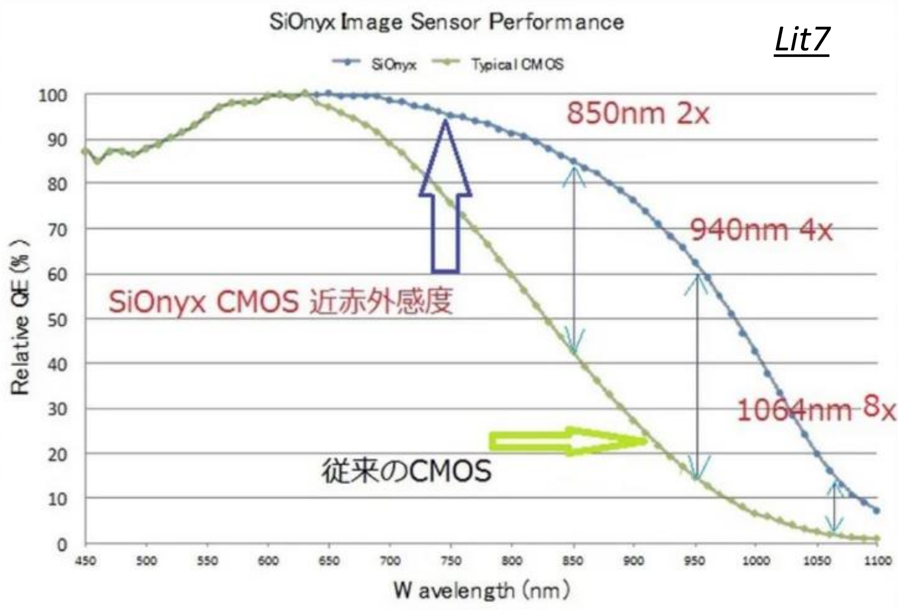


In short pulse and low duty cycle can be overdriven
Here 250mW CW yields 5W pulsed

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**

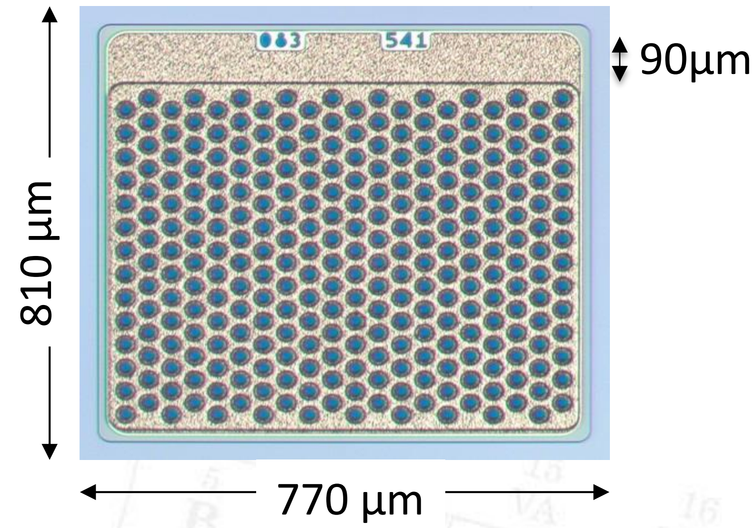
Laser-based System: 3x More Efficient

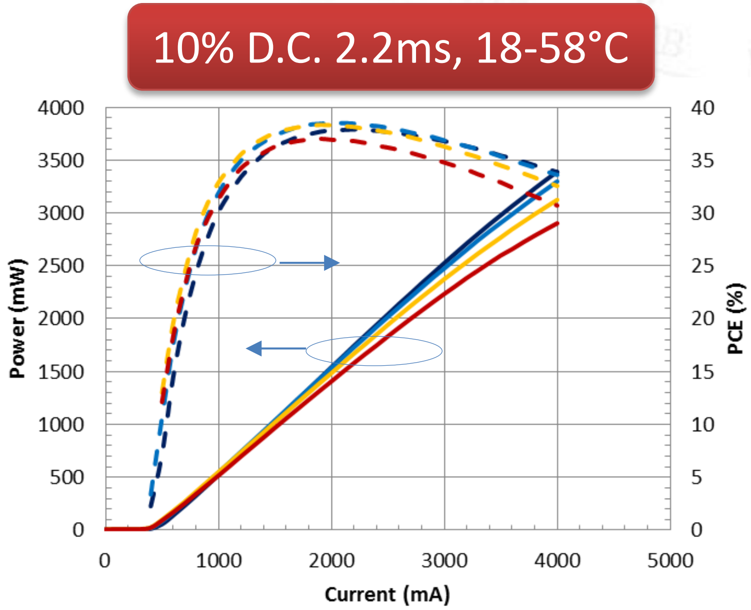
- **Assuming ideal diffusor to yield FOI 78° with 90% uniformity**
- **Assuming 20nm optical notch filter**
- **For the same efficiency light source, Laser-based system is 3x more efficient**

Loss mechanism	Assumptions	LED	VCSEL
Efficiency of light source (η_{EO})		35%	35%
Transmission through diffusor (η_{abs})		90%	90%
Critical angle loss through diffusor (η_q)	n=1.5	95%	100%
Roll off after diffusor (η_{diff})	FOI defined with 90% uniformity	58%	78%
Reflection on object	Ignored here	100%	100%
Transmission through notch filter (T_{filt})	20nm filter	41%	95%
TOF sensor efficiency	Ignored here	100%	100%
Efficiency of electrical modulation	<30MHz >30MHz	100% 0%	100% 100%
Total	<30MHz >30MHz	7.1% 0%	23.3% 23.3%

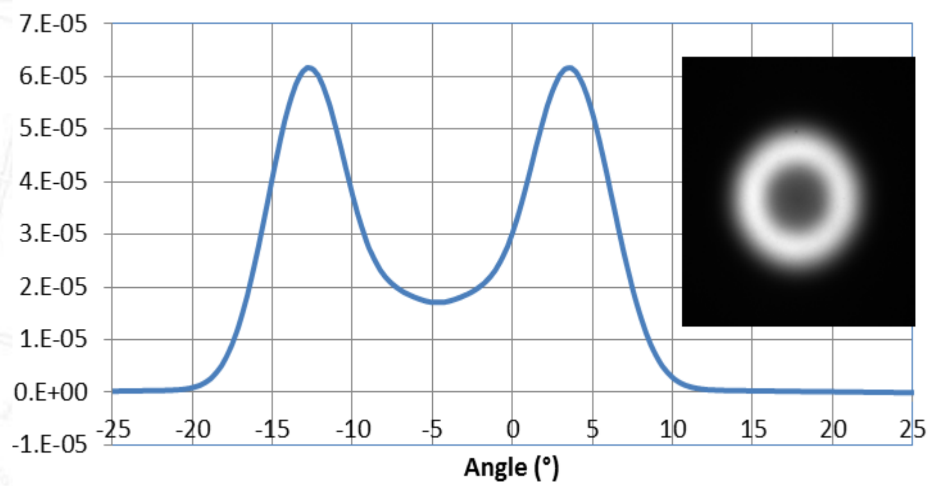
Laser Array for Time of Flight and Flood Illumination

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





FarField intensity

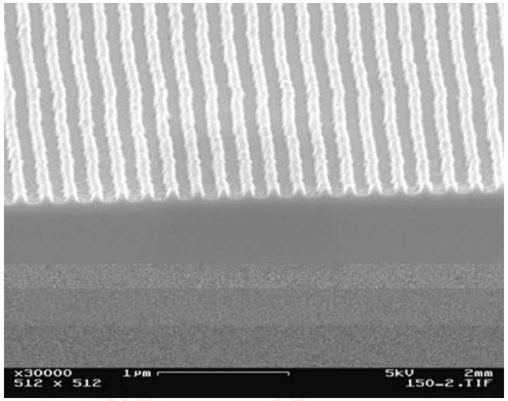


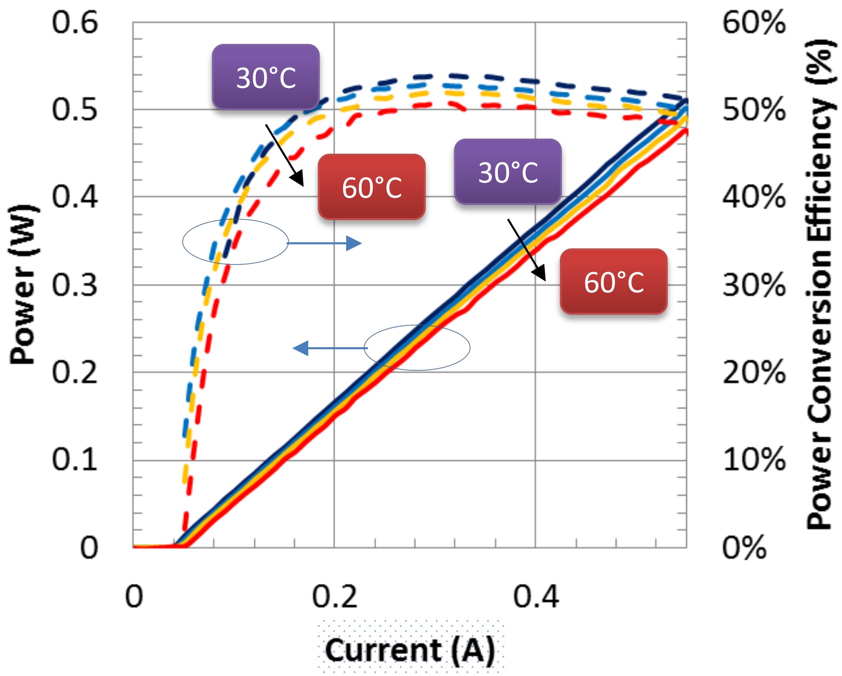
Example of Product: 940nm DFB

- **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]:
  - ttps://www.digikey.com/en/articles/techzone/2017/jan/simplifying-time-of-flight-distance-measurements
- [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]:
  - https://ch.mathworks.com/matlabcentral/answers/279911-i-want-to-be-able-to-numerically-create-a-speckle-pattern-circles-with-a-set-pixel-size-image-with
- [Lit6]:
  - http://commons.wikimedia.org/wiki/File:Solar_spectrum_ita.svg
  - https://commons.wikimedia.org/w/index.php?curid=11362653
- [Lit7:
  - http://image-sensors-world.blogspot.com/2017/09/cameras-with-black-silicon-sensors.html

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