



# Technology Enhancements and New Applications for VCSELS

## EPIC Meeting on VCSEL Technology and Applications

Mary Hibbs-Brenner | October 17, 2019 |

Light is OSRAM

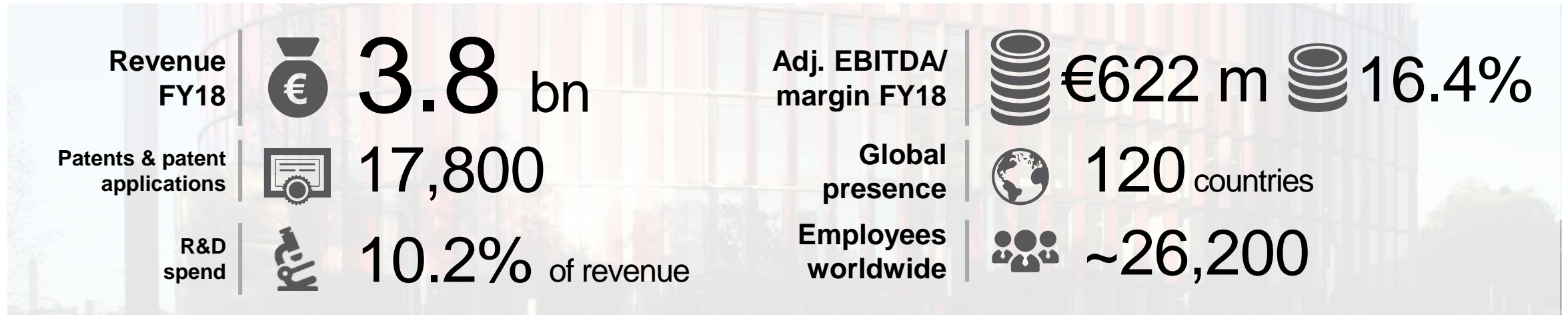
**Vixar**  
**OSRAM**  
Opto Semiconductors

# Agenda

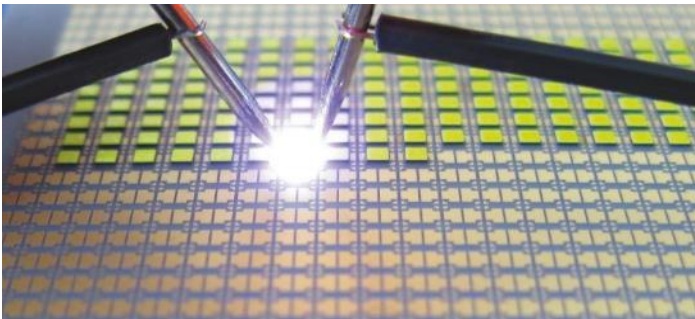
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- 1** Vixar Inc / OSRAM Company Overview
- 2 Vixar Product Overview
- 3 High Volume 940nm/850nm Applications
- 4 Alternate VCSEL Technology and Applications
- 5 Future challenges

## Key figures for financial year 2018



### Opto Semiconductors (OS)



### Automotive (AM)



### Digital (DI)



Figures for continued operations FY18 (per 09/30/2018), employee figure as FTE per 09/30/2018



# OSRAM OS at a glance



**Segment Automotive**  
~50% of revenue




No. 1 in Automotive<sup>2)</sup>

**Segment Industry and Mobile Devices**  
~35% of revenue



No. 2 in Industry and Mobile Devices<sup>1)</sup>

**Segment General Lighting**  
~15% of revenue

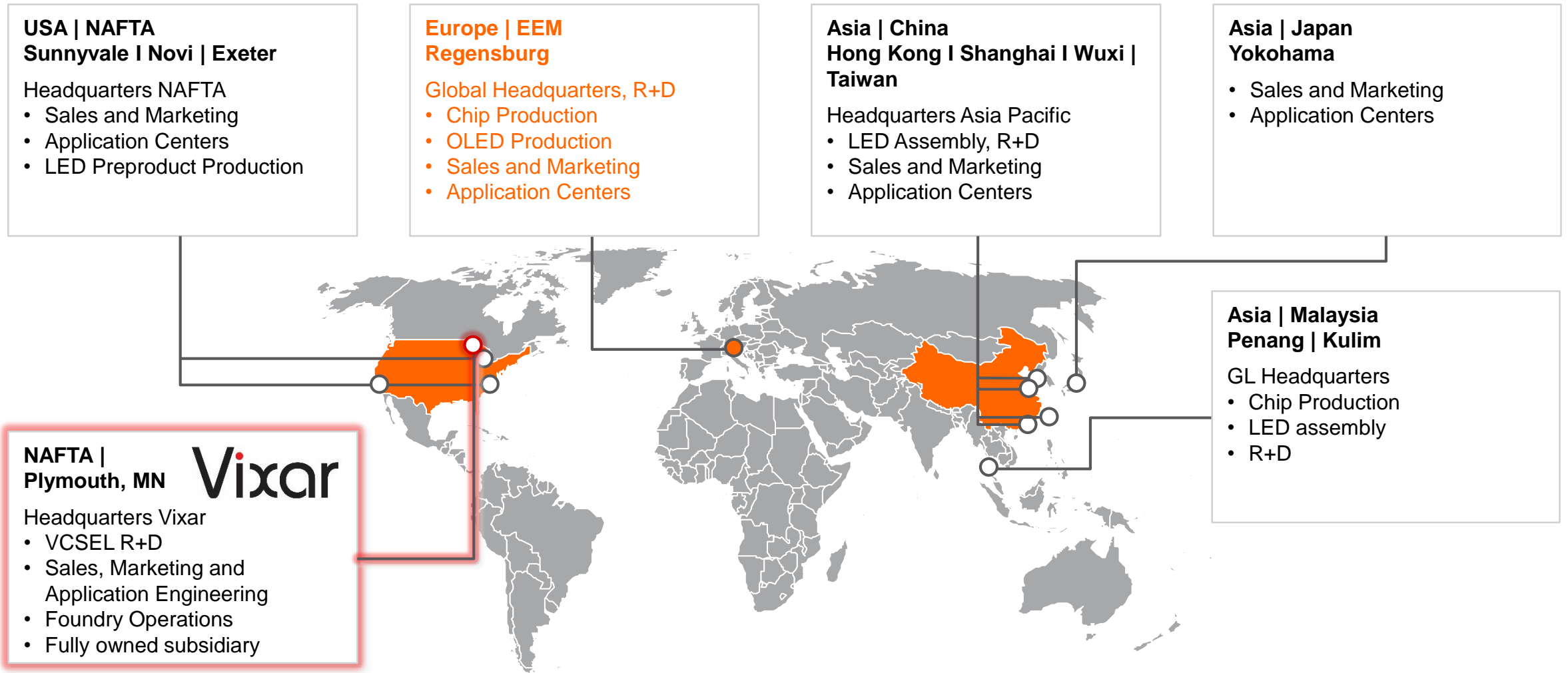


No. 3 in High Power<sup>2)</sup>

1) Packaged LED (Visible + IR); 2) Packaged LED (Visible); Source: IHS Markit, Technology Group, LED Intelligence Service 2018. Data is not an endorsement

# OSRAM Opto Semiconductors

## Key locations and key markets worldwide



# OSRAM Acquired Vixar in July 2018

## VIXAR INC.



- ✓ **VCSEL** Design expertise
- ✓ **Design** for reliability
- ✓ Dual outsourced **manufacturing partners**
- ✓ **Packaging** expertise

## Technology and Operational Excellence



- ✓ High performance, high volume VCSEL products
- ✓ High quality, high reliable VCSEL products
- ✓ Robust dual and triple sourced supply chain
- ✓ Best in class package options

## OSRAM OS



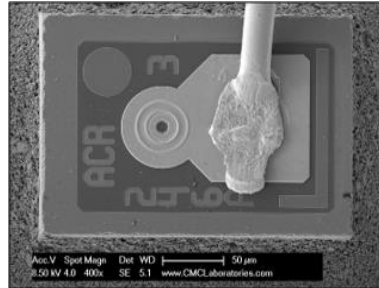
- ✓ **High volume** manufacturing expertise
- ✓ **Experienced** quality systems organization
- ✓ Internal Wafer and Packaging **production**
- ✓ **Packaging** expertise

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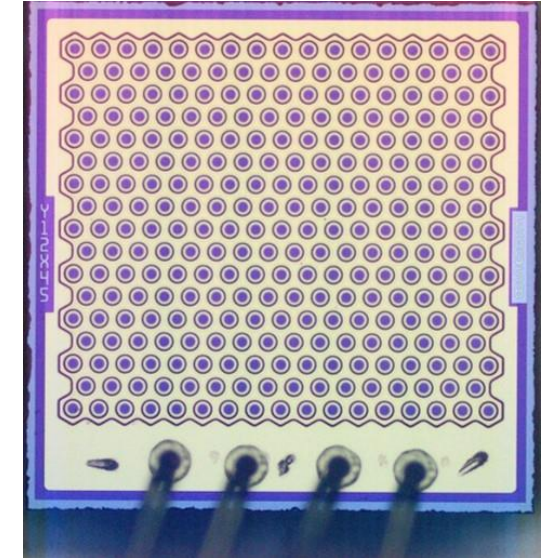
# VCSEL Product Portfolio



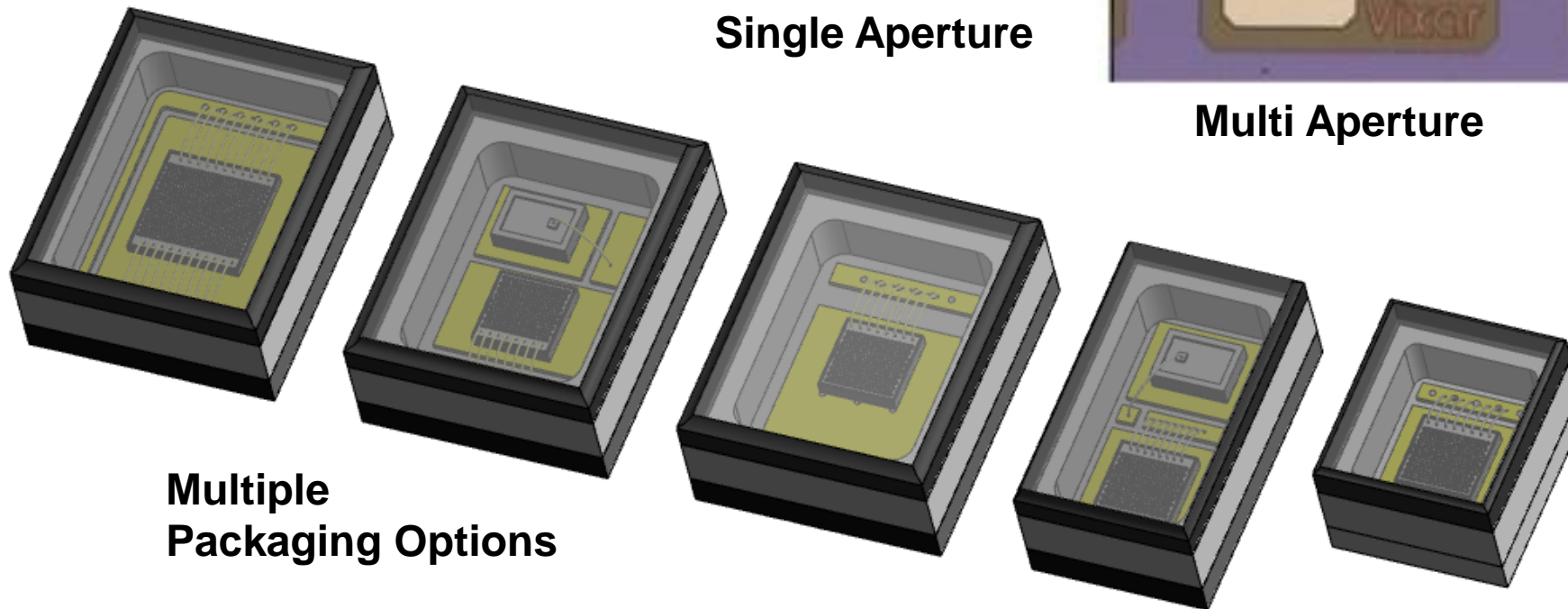
**Single Aperture**



**Multi Aperture**



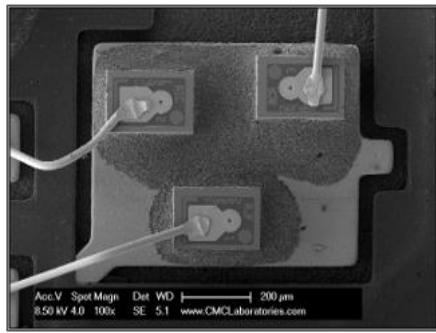
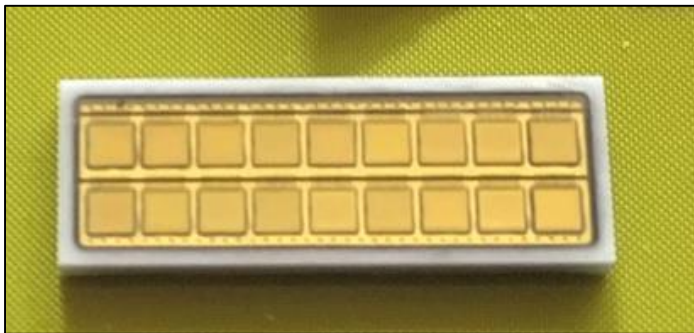
**Power Arrays**



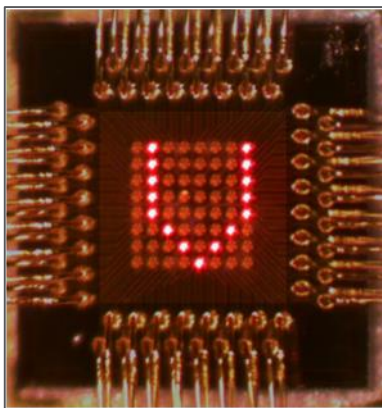
**Multiple Packaging Options**



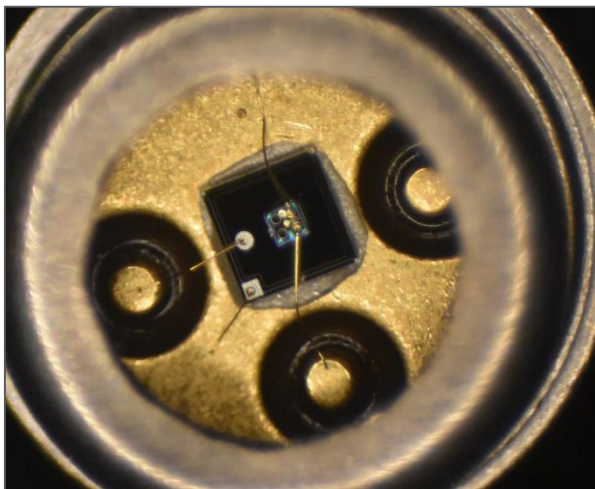
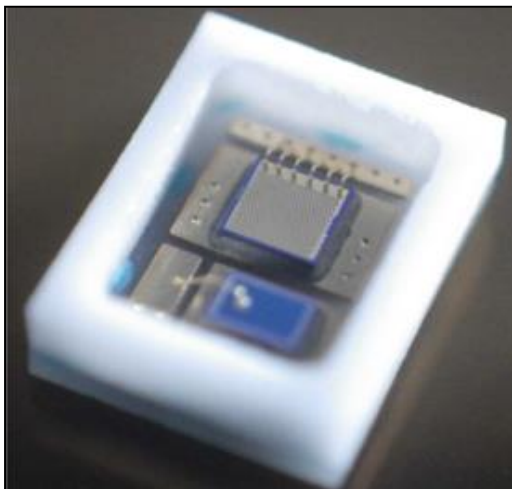
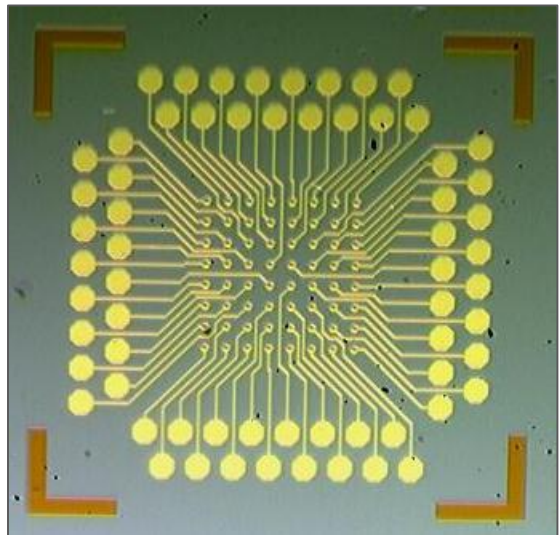
# Custom VCSEL Solutions



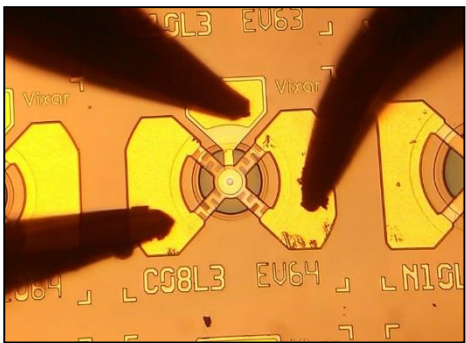
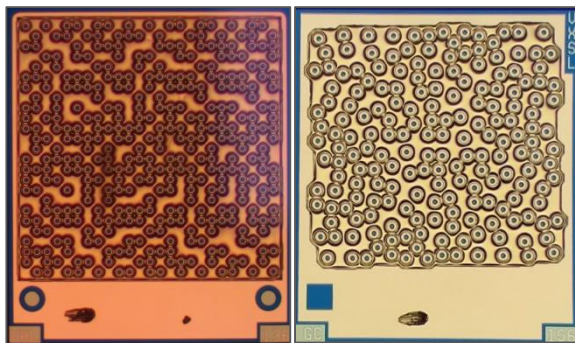
Custom Arrays & Packaging



Individual Addressability



Module integration – PD / TECs / ESD Diodes



Custom Die Layouts

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# 3D Sensing and Imaging Markets and Applications

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## Consumer



- Face ID for personal security
- Photography assistance, e.g. bokeh
- CAD file input

## Industrial



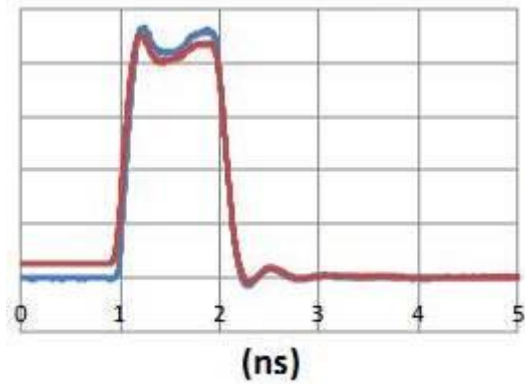
- Robotic vision
- CAD file input
- Distance sensing for safety and automation control

## Automotive



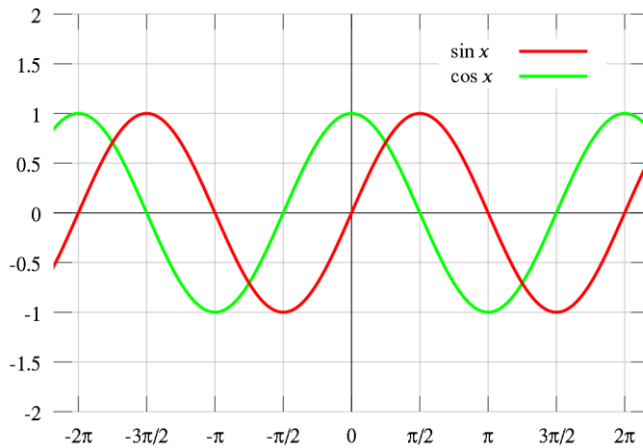
- Driver monitoring (interior)
- Gesture recognition (interior)
- Collision avoidance (external)

# Sensing Mechanisms: 3D Sensing/Gesture Recognition

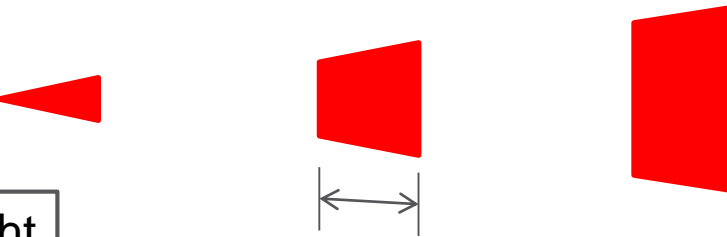


Time of flight

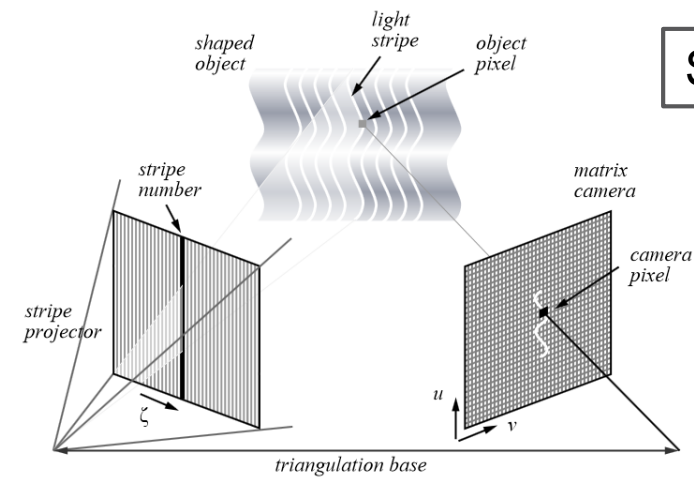
$$100 \text{ psec} = 3.3\text{cm}$$



Modulated  
phase shift

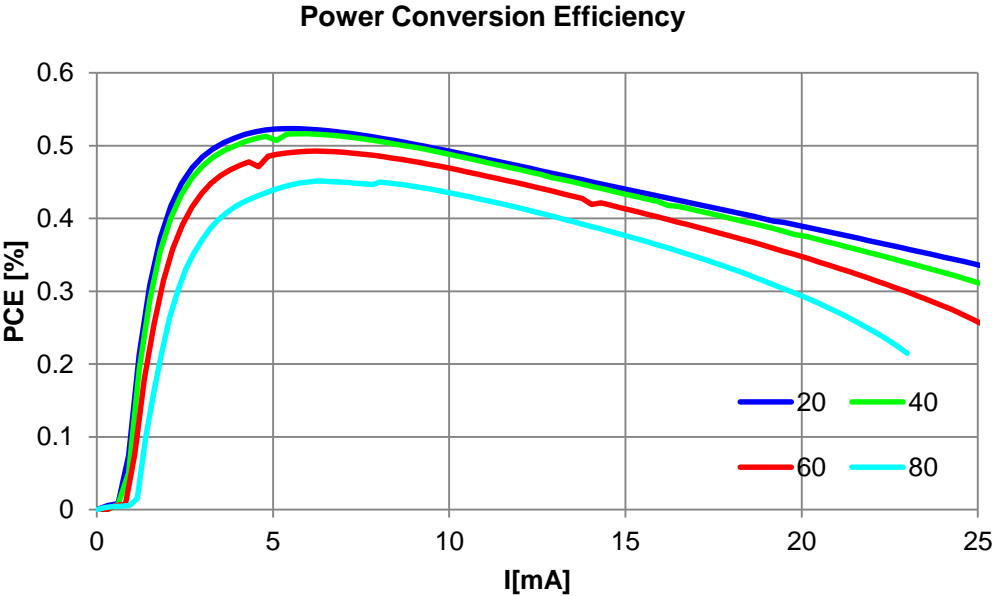
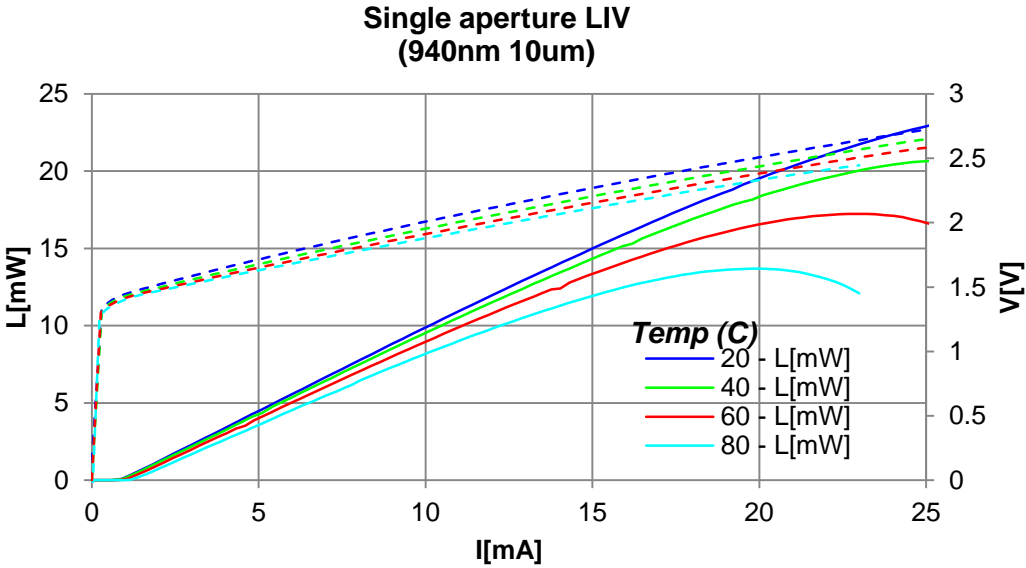


Structured lighting

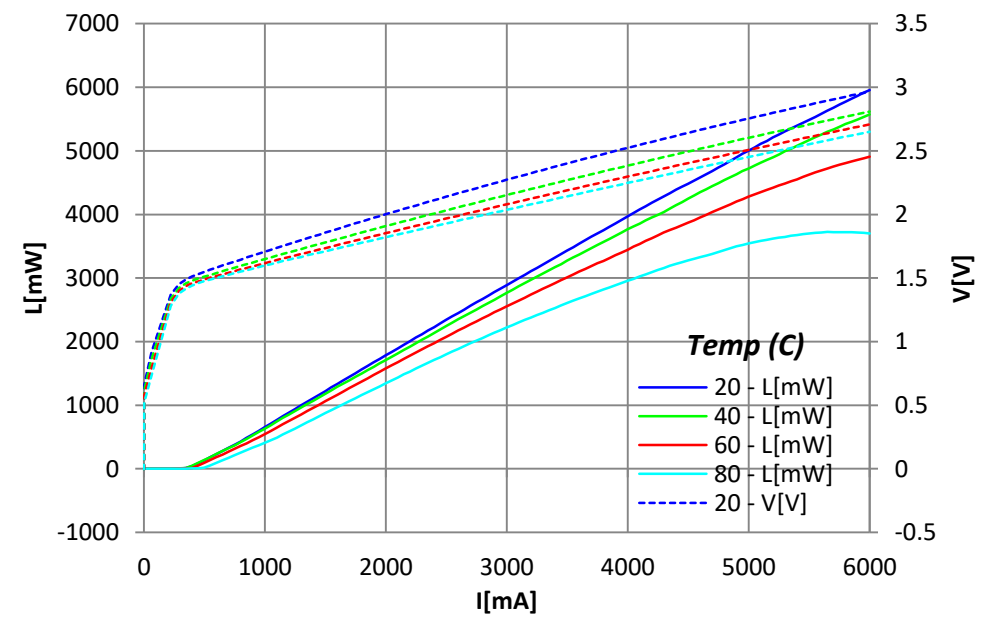
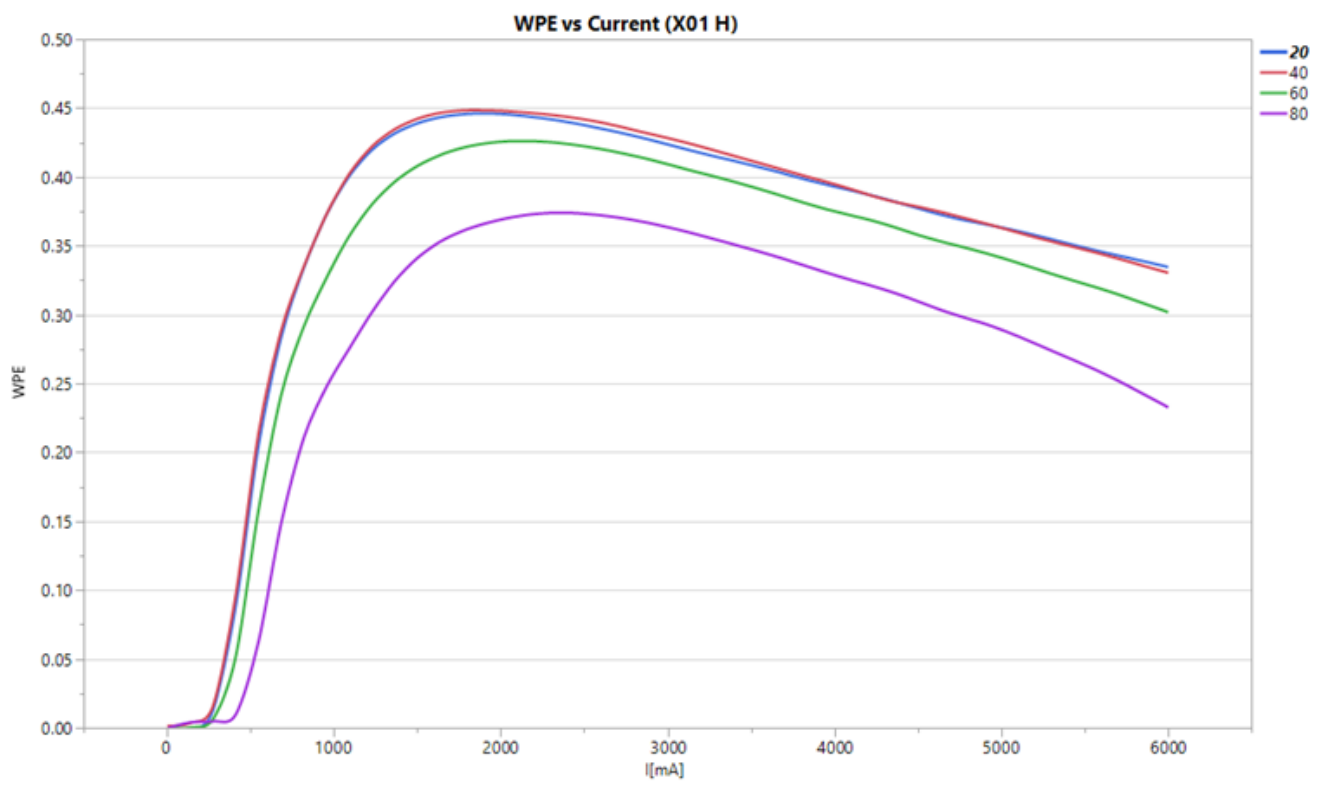




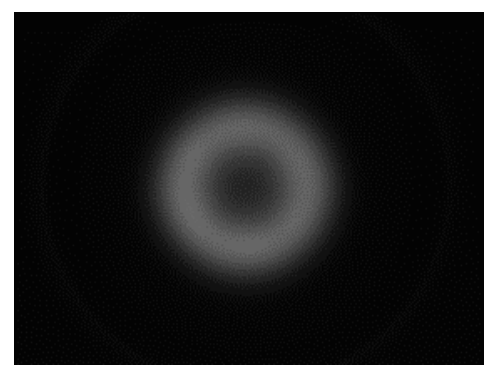
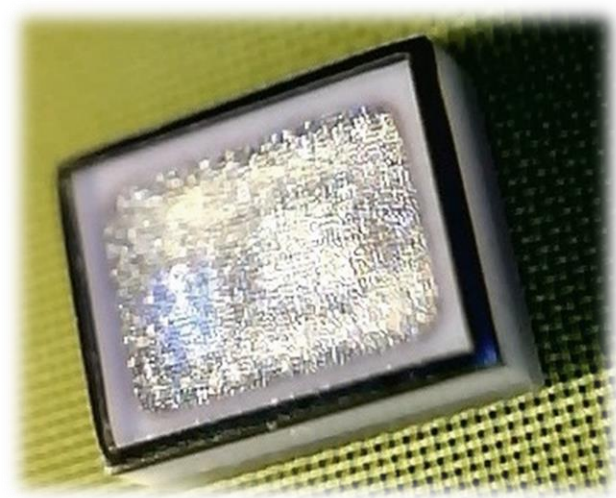
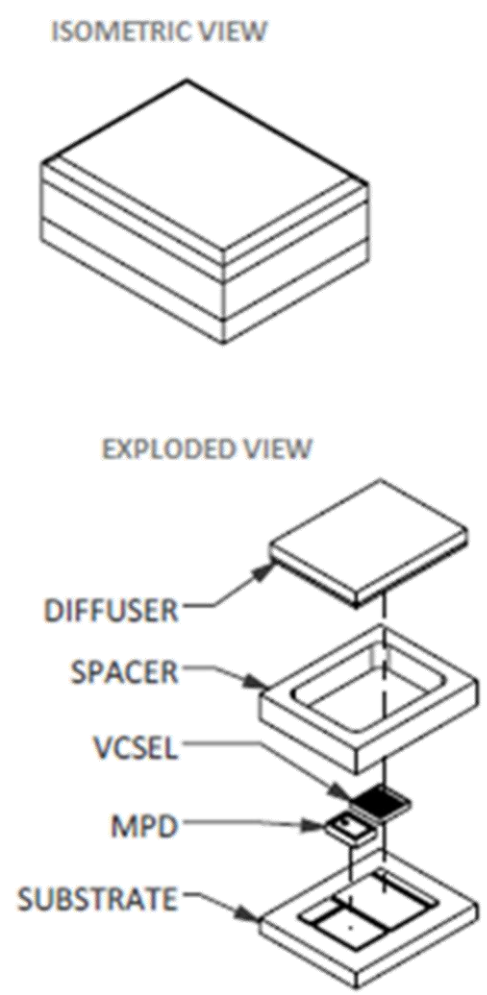
# 940nm 53% Power Conversion Efficiency



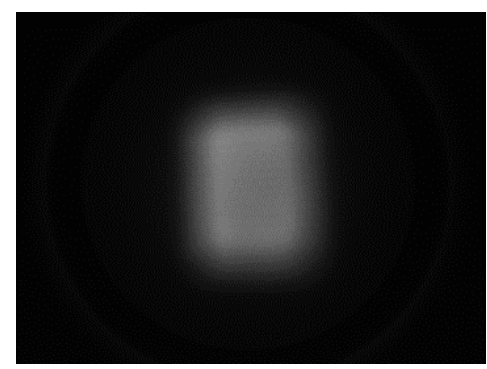
# 3W VCSEL Array



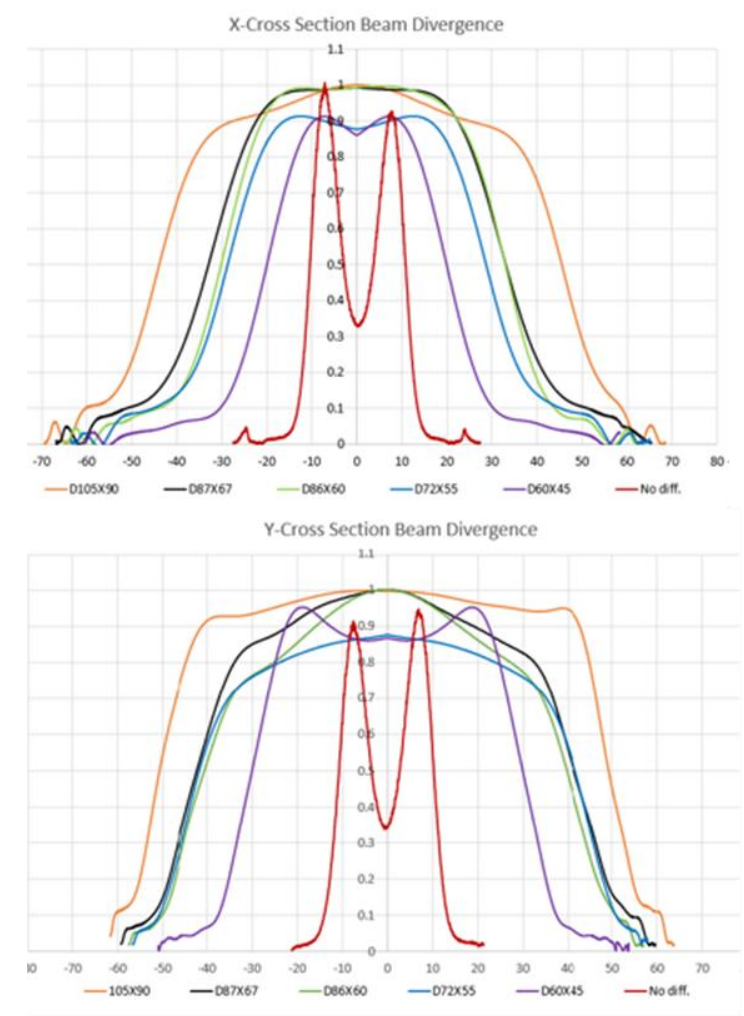
# VCSEL Ceramic Package – Diffusers



VCSEL die



Diffuser Package



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## 4 Alternate VCSEL Technology and Applications

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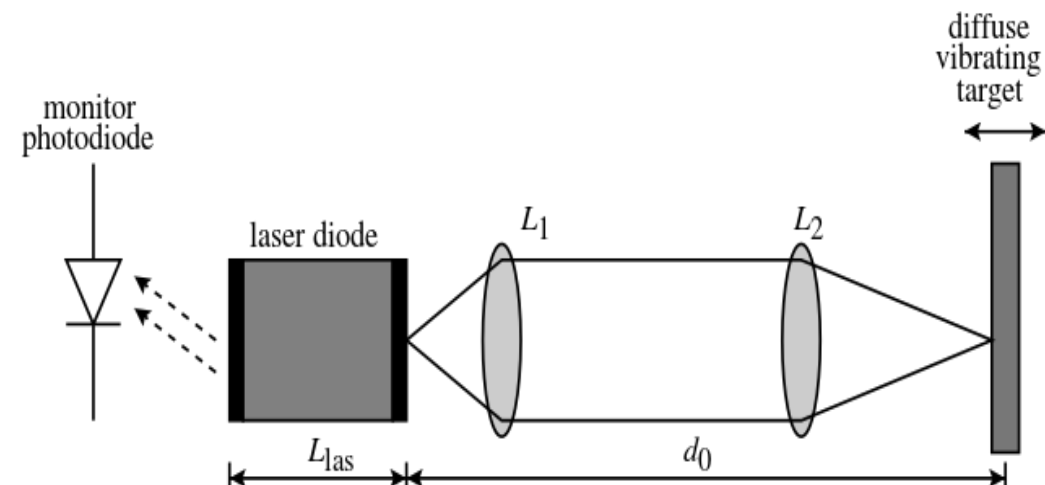
- **Industrial applications**
  - Atomic clock and self-mixing sensing mechanisms
  - Single-mode VCSELs for atomic clocks
  - Single-mode VCSELs for self-mixing
- **Medical applications**
  - Absorption, fluorescence and scattering mechanisms
  - Red VCSEL performance
  - Tunable VCSELs
  - Integration

# Target Applications

## Industrial



Chip scale atomic clock



Vibration sensor based on self-mixing

By Krishnavedala - Own work, CC BY-SA 4.0,  
<https://commons.wikimedia.org/w/index.php?curid=34976449>

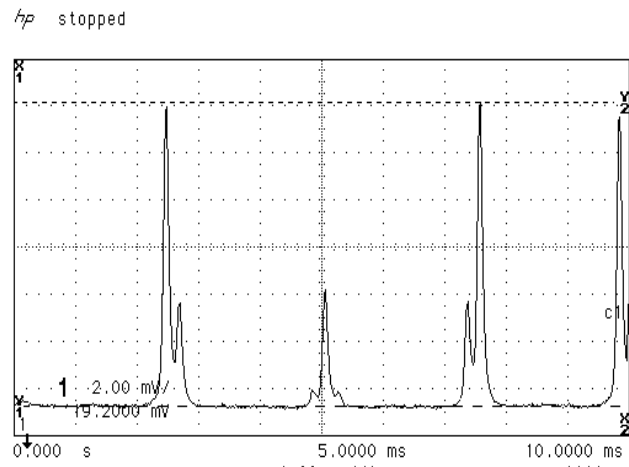
### Vixar Value Proposition

- Power Efficiency
- Miniaturization
- Higher performance due to:
  - Narrow spectrum
  - Ease of beam shaping
- Short pulse width for LIDAR/Time of Flight

# Sensing Mechanisms: Atomic Absorption, Interferometry and Self-Mixing

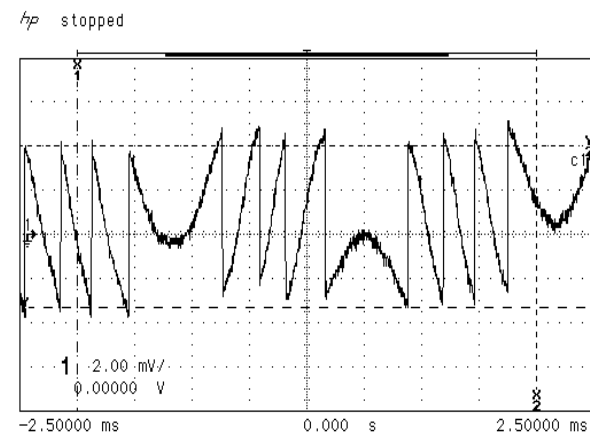
## Atomic sensing:

- Magnetometer
- High accuracy time clock



## Motion tracking with self-mixing effect:

- Light scattered back into the laser causes self-mixing
- Each oscillation corresponds to movement of  $<1\mu\text{m}$



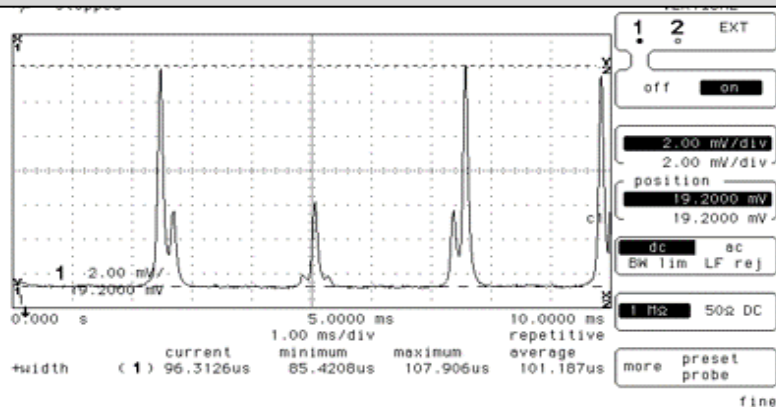
**Senses:**  
Rotation  
Vibration  
Speech

# 795/895/940nm single-mode VCSELs for atomic sensors, interferometry, and self-mixing

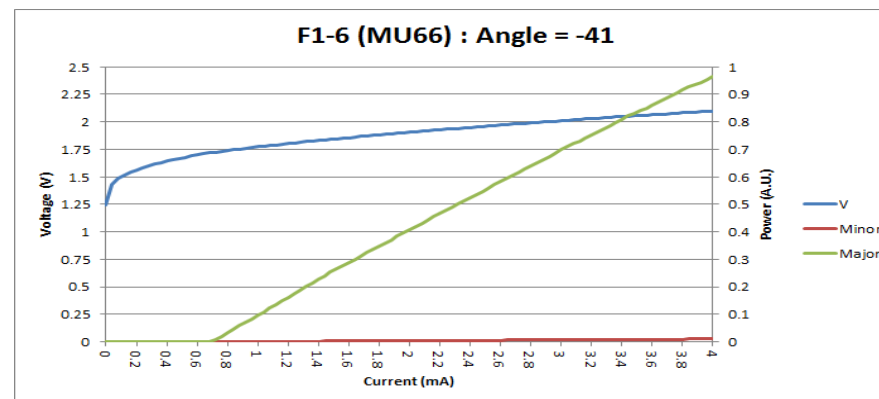
TEC integrated into package



< 50MHz Linewidth and sidebands under modulation

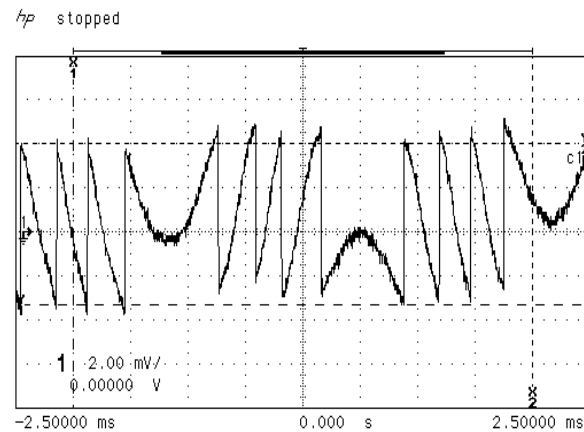
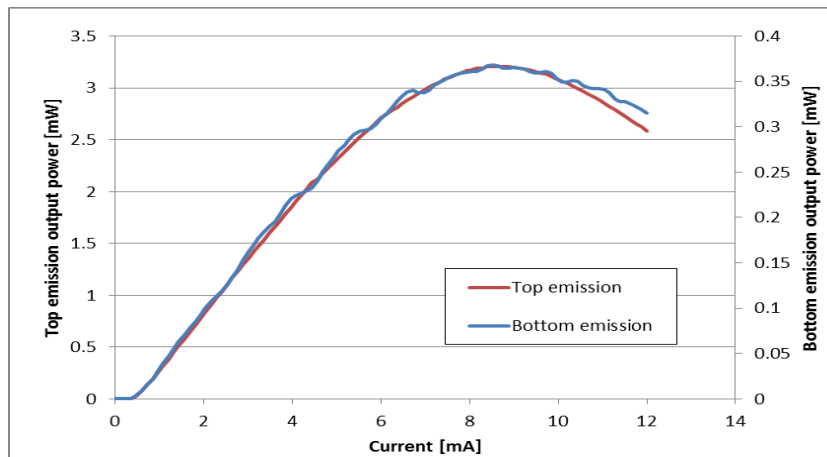
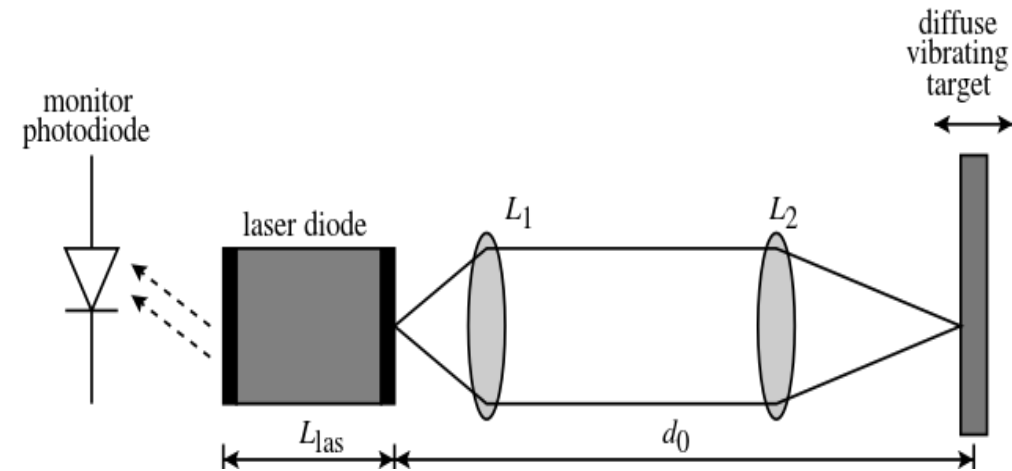
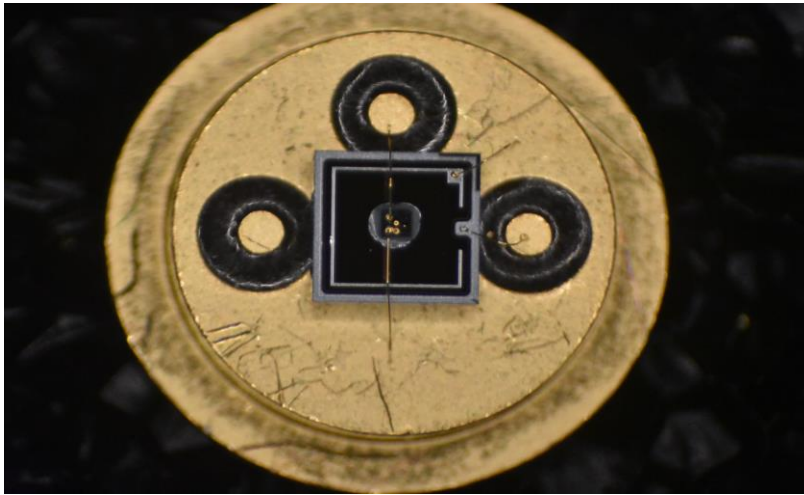


Stable, linear polarization





# A 940nm VCSEL with back monitor diode

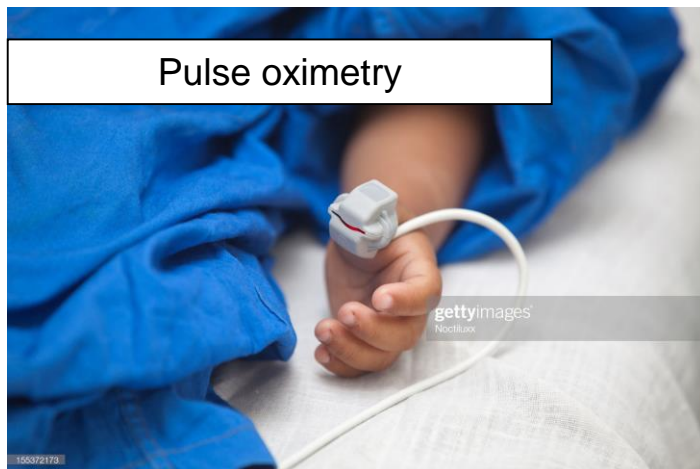


- Benefits
  - Monitoring for eye safety
  - Monitoring to optimize S/N
  - Tracking self-mixing signal

# Target Applications

## Medical

Pulse oximetry



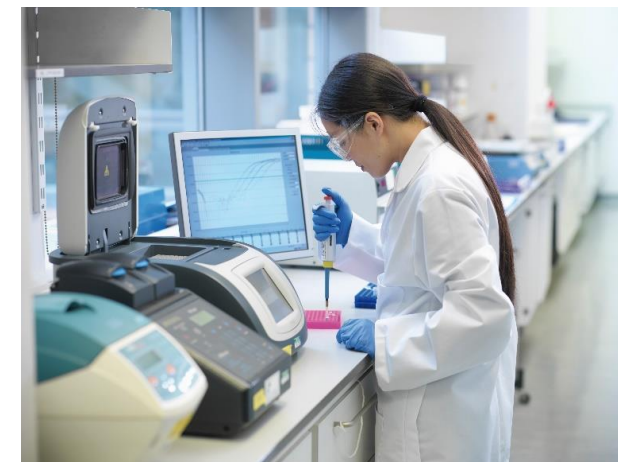
Wearables: biometric sensing



### Vixar Value Proposition

- Power Efficiency
- Compact packaging
- Improved image: narrow spectrum and reduced speckle

Medical diagnostics and imaging



# Sensing Mechanism:

## Absorption / Fluorescence / Scattering

### Absorption:

Narrow spectrum sources can be used to probe an absorption profile

- Medical diagnostics
- Chemical or environmental sensing

### Fluorescence:

Excites fluorescence with a narrow spectral linewidth that doesn't interfere with the emission wavelength

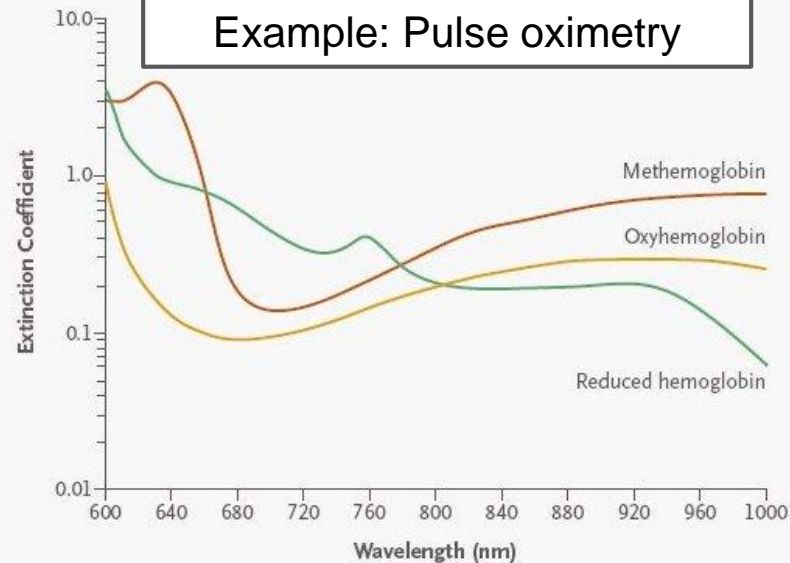
- Medical diagnostics
- Chemical or environmental sensing

### Scattering:

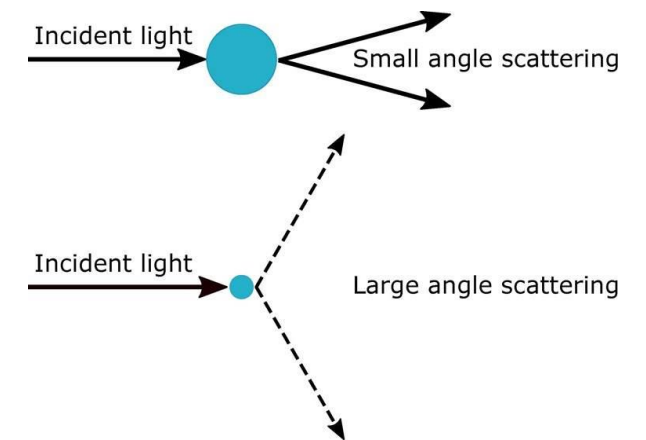
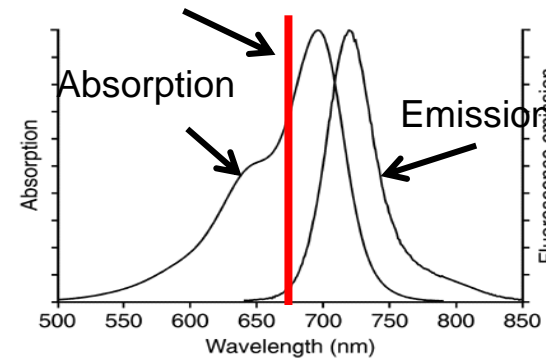
Particle size affects scattering pattern

- Particle count
- Particle size distribution analysis

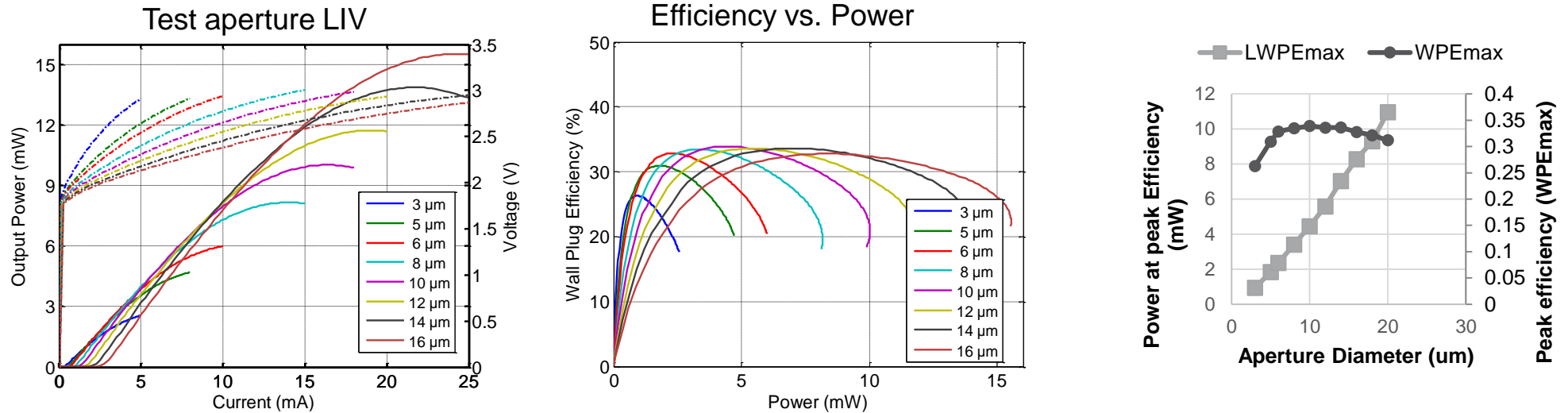
### Example: Pulse oximetry



### VCSEL line width



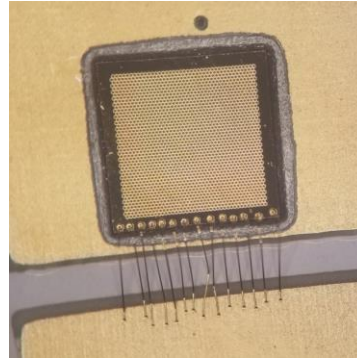
# Single Aperture Red VCSELs (680nm)



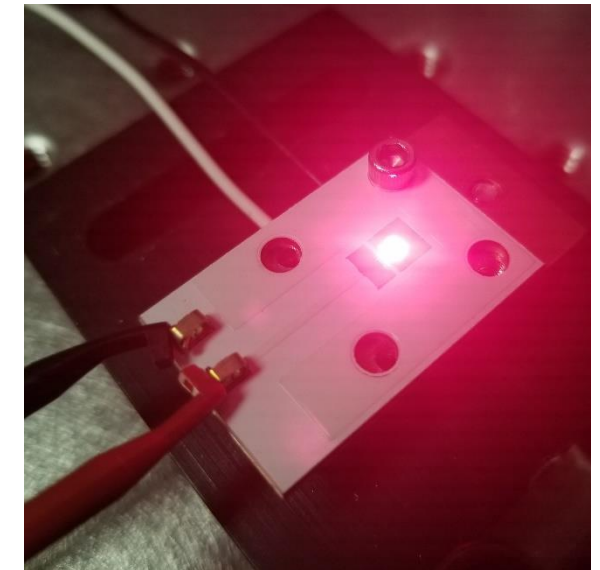
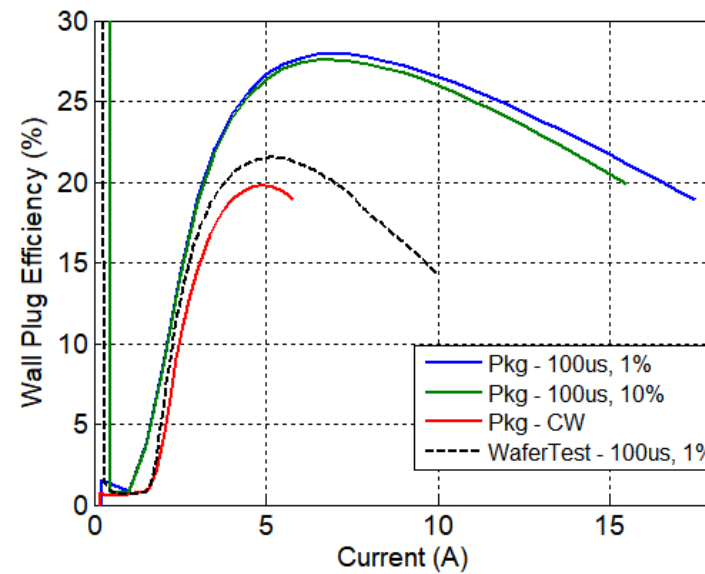
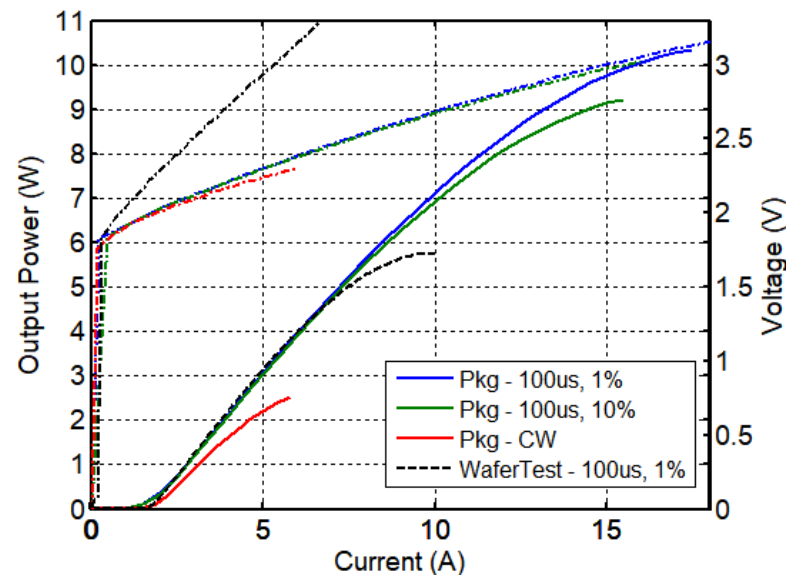
- Manually measured LIV characteristics for single-aperture test structures on 680nm wafer
  - Test conditions were continuous wave (CW) at room temperature (25C)
  - Observed successful lasing for VCSEL aperture sizes between 3 & 20 $\mu\text{m}$  diameter
- Peak performance for 10 $\mu\text{m}$  aperture was 34% power conversion efficiency at 4.5mW output power



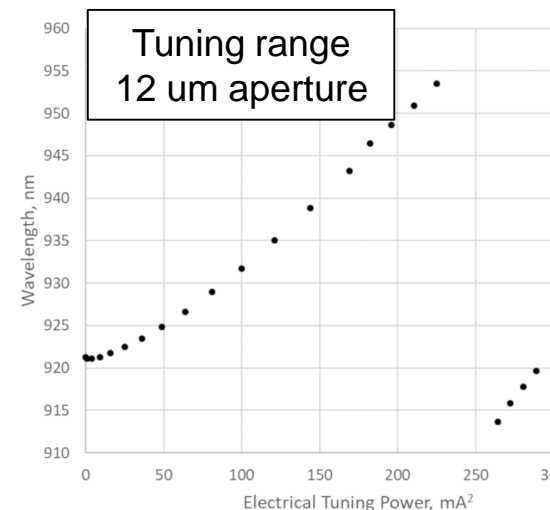
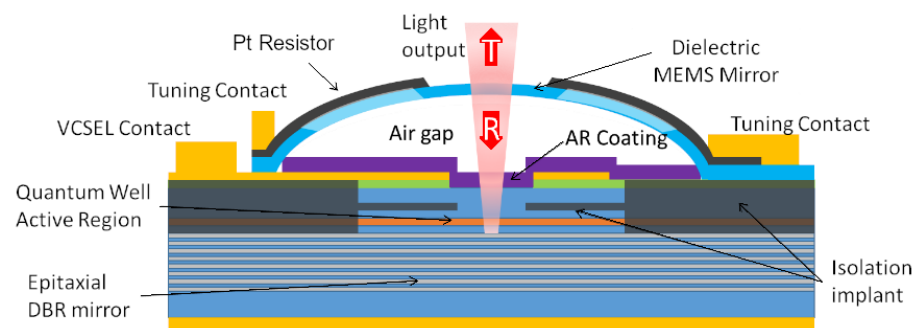
# Red 680nm VCSEL High Power Array



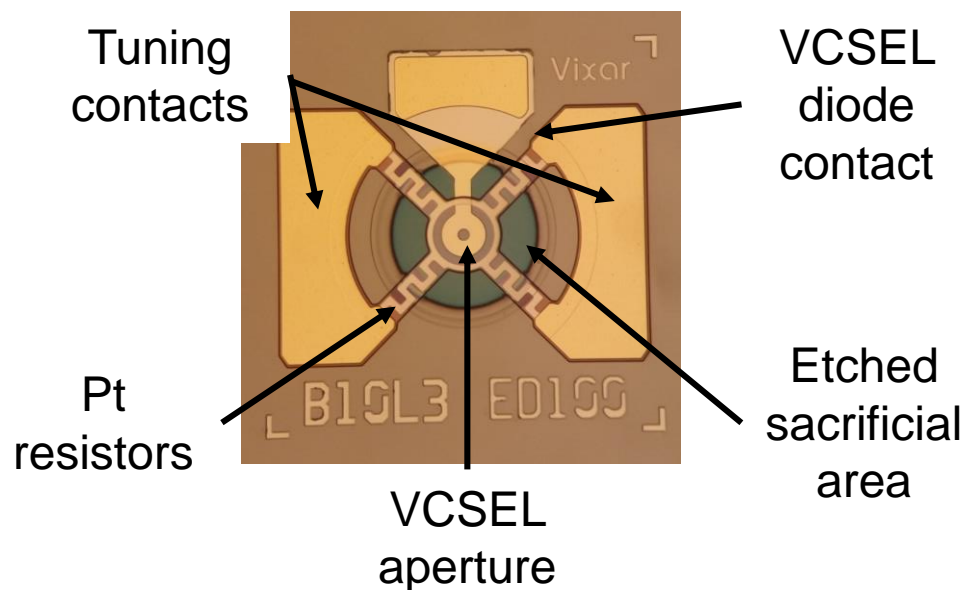
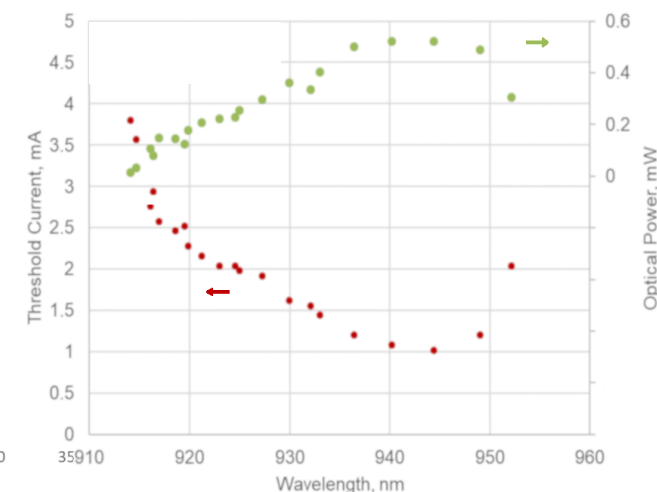
2mmx2mm die size



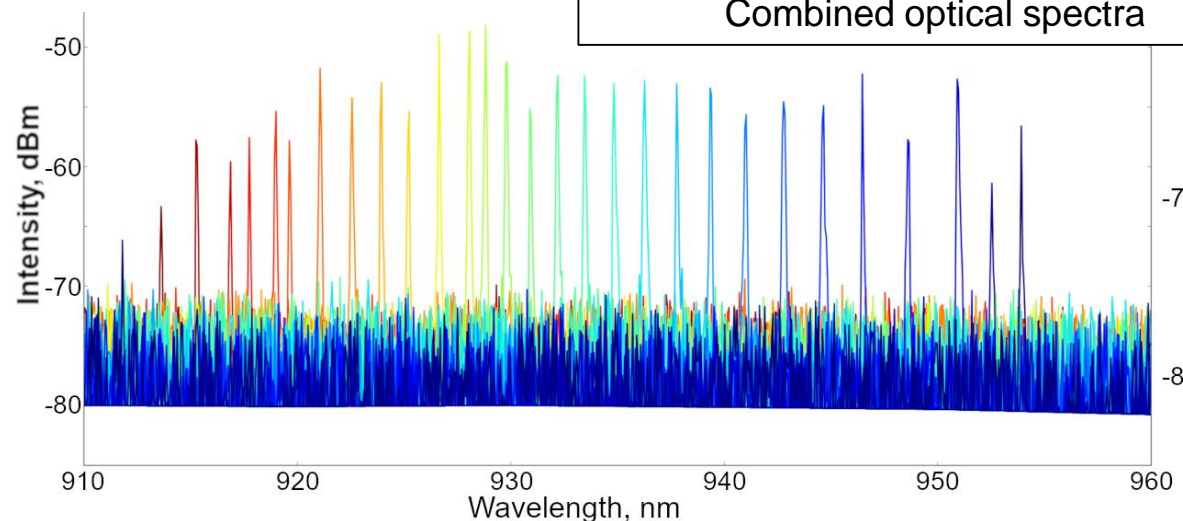
# Tunable VCSEL, 940 nm center



Optical Power and I threshold

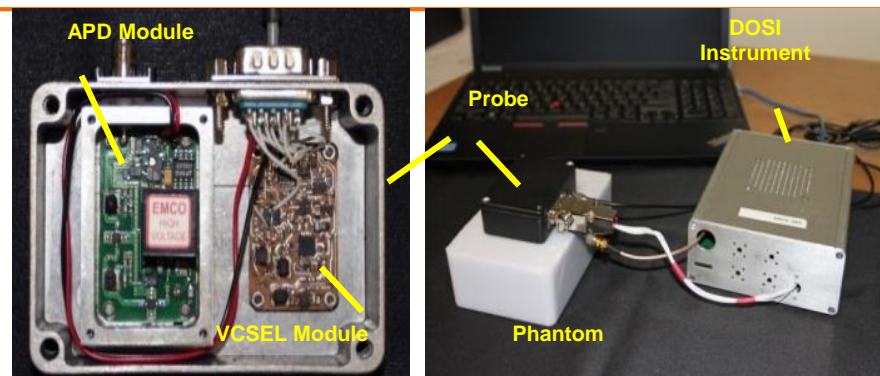


Tuning range > 40 nm  
Combined optical spectra



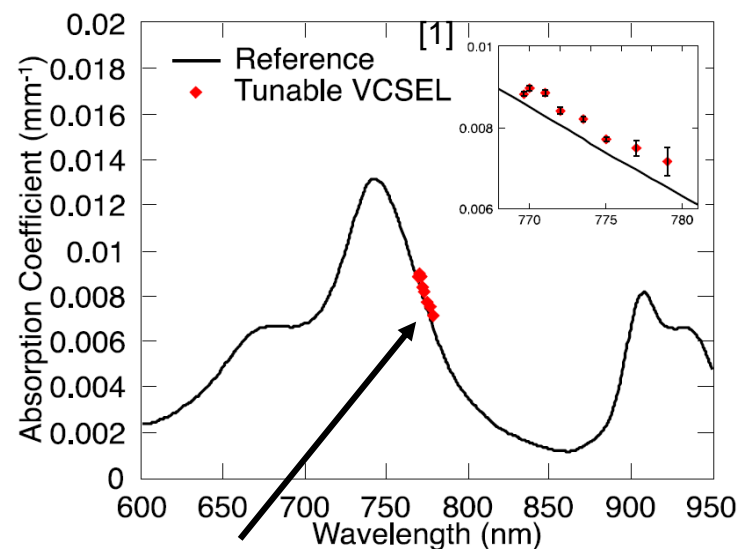
# Diffuse Optical Spectroscopic Imaging (DOSI)

- Image tissue abnormalities without invasive biopsies
- Hand held device with VCSELs
- Fast bandwidth for tuning could lead to near real time scanning of tumor behavior

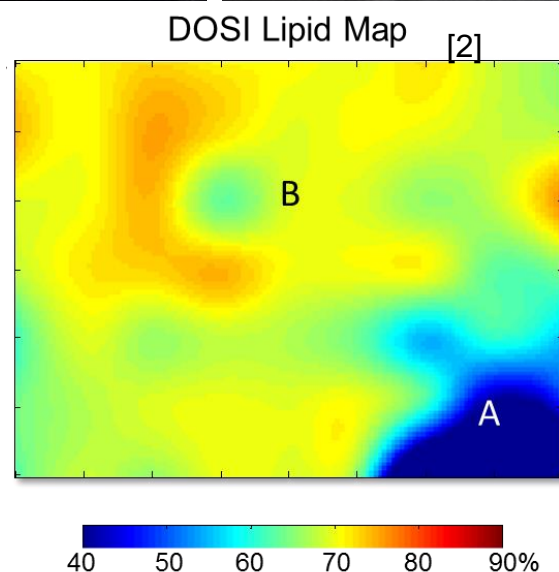


[1]

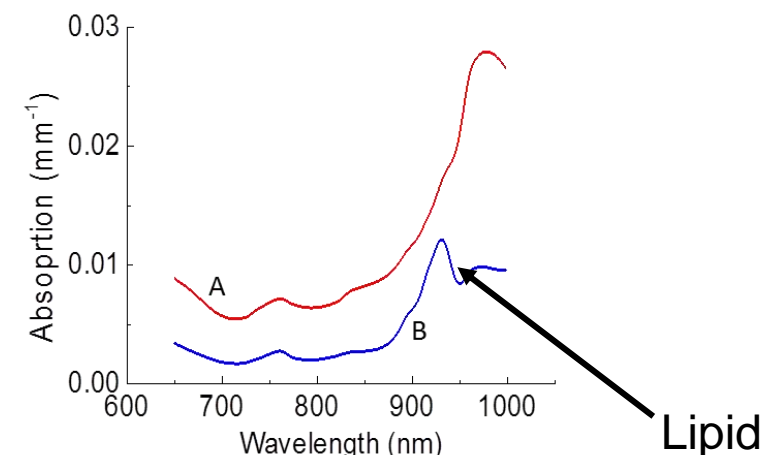
Near-IR tissue absorbers [1]:  
785 – 820 nm hemoglobin  
910 – 950 nm lipid  
950 – 1000 nm water



Hemoglobin



% lipid concentration

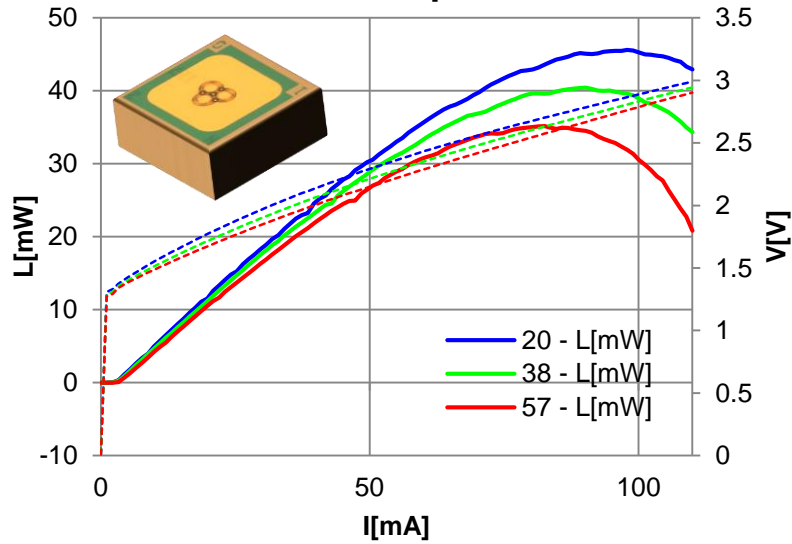


Data and images provided by our collaborator Prof. T. O'Sullivan from University of Notre Dame, IN, USA

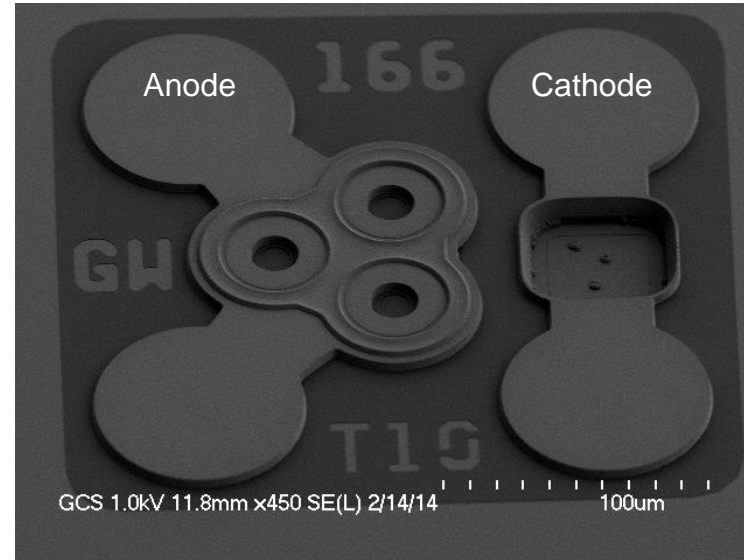
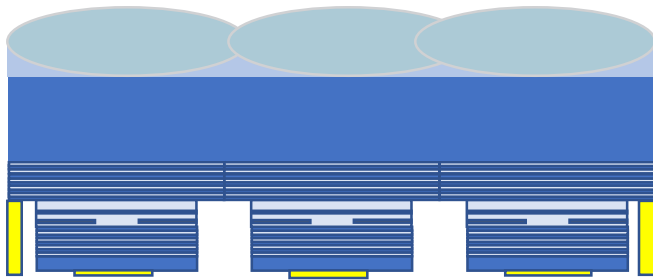


# Integration Technologies

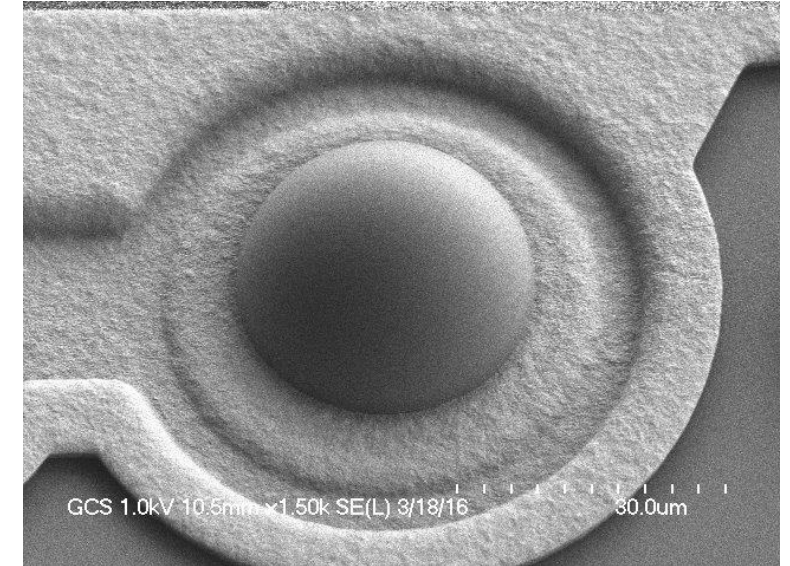
LIV vs. Temperature



Bottom Emitter  
VCSEL



Top Emitter VCSEL  
Flip Chip  
Co-planar contact



VCSEL aperture with  
integrated lens

## Summary

- ✓ Vixar is experienced with bottom emitting VCSEL process already today.
- ✓ Vixar has developed flip chip experience already
- ✓ Vixar is familiar with integrated optics on aperture level.

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## Future Challenges: Technology and Applications

Category	Technology extension	Example application area	Challenge
Wavelength	> 1µm (e.g. 1310, 1550nm)	Larger range of LiDAR, environmental	Materials
	Visible (blue, green)	Displays: Augmented and virtual reality	Materials
	Tunable	Environmental and medical sensors, medical imaging	Stability
Packaging	For higher power arrays	LiDAR, laser therapy	Heat sinking capability
	Low cost optical packaging	Many	Solder reflow compatibility; assembly and alignment
	Eye safety measures	Everything	Cost
Integration	Addressable arrays	Communication, displays, power management	Interconnects for large arrays
	Multi-function (VCSEL, PD, driver, optics)	Mobile; wearables	Cost benefit

## Future Challenges: Manufacturing and Cost

Category	Improvement needed	Challenge
Die cost	Labor	Not much leverage
	Capital costs	Insource/outsource; time efficiency
	Yield	Substrate defects; process uniformity, process automation
	Chip area	Interconnect schemes, thermal heat dissipation
	Wafer size	Requires the whole ecosystem to shift
Other manufacturing issues	Reliability for large arrays	Substrate and process defects; redundancy
	Reliability for high current density	Substrate and process defects; thermal package design
	Multi-function integration	Designs for minimizing process steps and chip size

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