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Addressable High-Performance Multi-Junction VCSEL Arrays for Advanced Sensing Applications

David Cheskis
Eric Hegblom
Matt Everett
Ken Huang

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Lumentum – A leading 3D sensing optical solutions provider

$1.74B
FY21[1] revenue, 5600 employees

Markets Served:
- Telecom + Datacom
- Consumer + Industrial ***includes 3D Sensing***
- Lasers for manufacturing

1. Fiscal year ended July 3, 2021

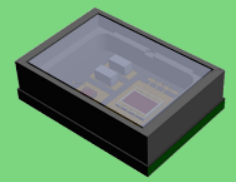
Highest quality and reliability

Established high-volume, manufacturing infrastructure

Largest global supplier of 3DS illuminators

#1

Laser chips integrated packages reference designs



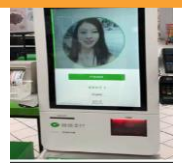
Integrated packages reference designs

Wearables

AR VR

Automotive

AI Facial Recognition



IoT Markets

Smartphones

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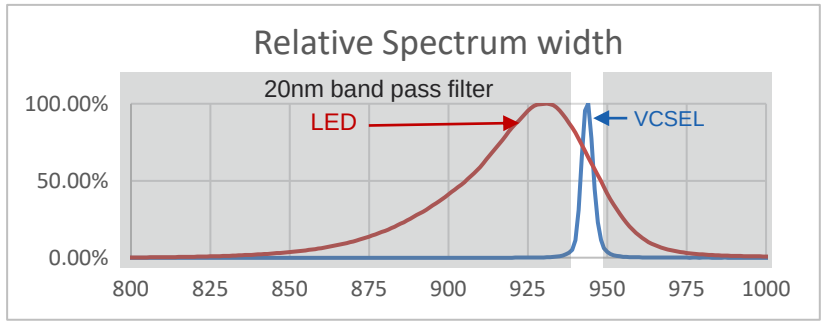
VCSELs enable advanced sensing systems

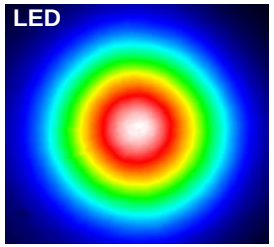
VCSEL benefits vs. LEDs

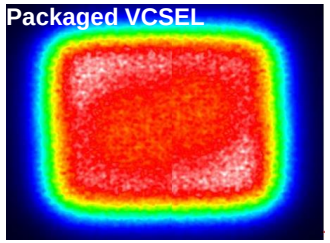
Narrow spectral band width, Spectral stability
FOI flexibility & optimized beam shape fit to sensor FOV
20x faster rise and fall times

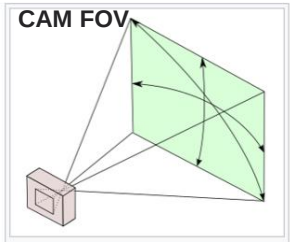
➔ Allow narrow Band Pass Filter for depth quality improvement
➔ Less light loss outside FOV for higher system efficiency
➔ Improve precision of depth resolution



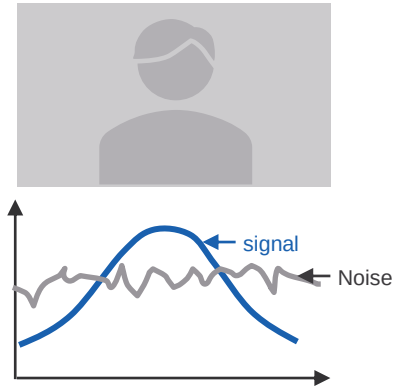
	VCSEL	LED
Spectral Width	< 3nm	40nm
Spectral Shift with Temperature (0°C to 50°C)	< 4 nm	15nm
Overall Spectral Span	< 20 nm	90 nm
tr/tf	<0.5ns	>10ns



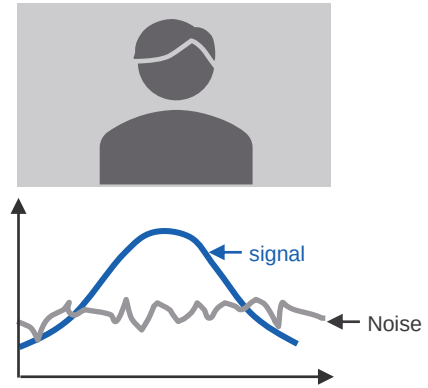




LED with wide BPF

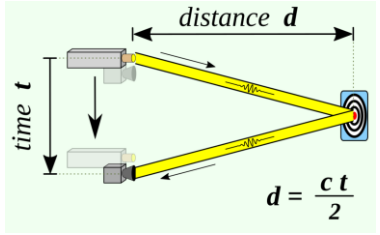


VCSEL with narrow BPF



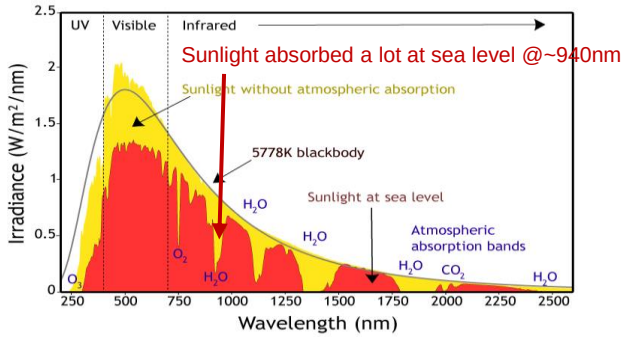
Depth resolution

- VCSEL tr <0.5ns = 7.5cm pulse edge
- LED tr >10ns = 150cm pulse edge



Source: https://en.wikipedia.org/wiki/Time-of-flight_camera#/media/File:20200501_Time_of_flight.svg

Spectrum of Solar Radiation (Earth)



Source:https://en.wikipedia.org/wiki/Sunlight#/media/File:Solar_spectrum_en.svg

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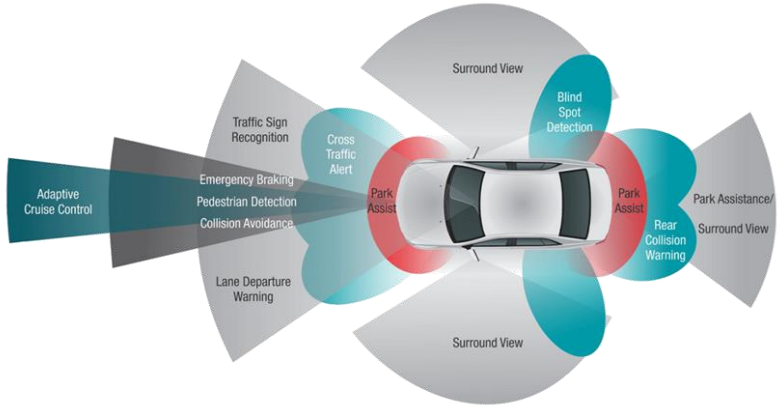
Automotive applications

LiDAR



Range
0 – 200 m

Resolution
~30 cm at 200 m

Field of View (FoV)
10^{o}_{vert} x 50^{o}_{horiz} to 30^{o} x 120^{o}

Object reflectivity
10%

Probability of detection
>95%

Measurement frame rate
10 Hz to 25 Hz

Immunity to ambient light and other LiDARs

In-cabin

Occupancy Monitoring System/Driver Monitoring System (OMS/DMS)

Seatbelt fastened/unfastened
Passenger size and positioning
Facial recognition
Alert to check rear seat when exiting or entering the vehicles
Detect movement after vehicle is parked or moved
Monitor occupant biometrics like heart rate, temperature

Gesture recognition in-cabin controls

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3D depth sensing systems brings value to AIoT markets

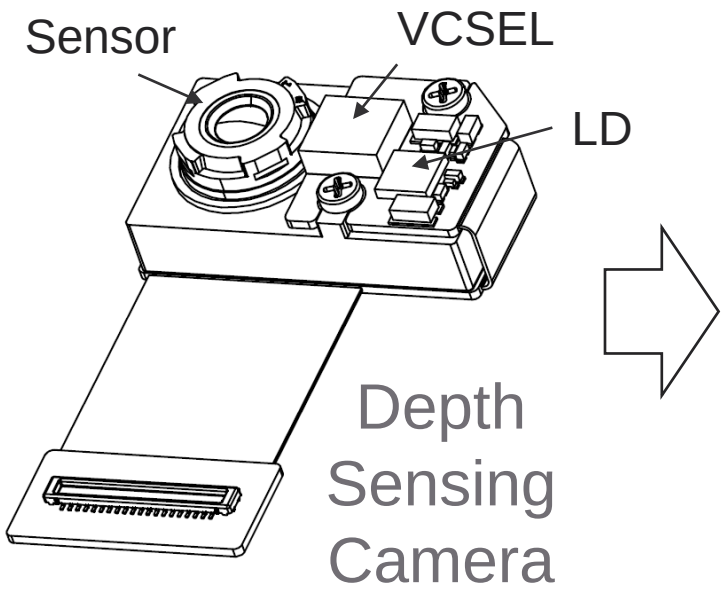
Smart Home

Smart Building

Smart Healthcare

Smart Retail

Smart Manufacturing



AR/VR Examples:

- **Burberry launches AR tool with Google Search**
- Lancôme use spatial computing for Immersive Shopping Event In Paris
- Museum of Future Experiences (MoFE) announces ‘Liminality’, curated VR pieces
- VR Experience to open at Perez Art Museum Miami
- ‘New Comedy Show’ takes place simultaneously in VR and in person
- IMVU teams up with emerging designers for Metaverse Fashion Show
- Inditex launches ‘Pacific Game’ a new AR game
- London's Design Museum showcases an AI-Designed AR Sneaker

Source from *https://www.forbes.com/sites/cathyhackl/2021/06/13/metaverse-weekly-60-minutes-covers-the-metaverse-lancme-uses-spatial-computing-pacsun-on-roblox-and-more/?sh=3c32b72d3af2*

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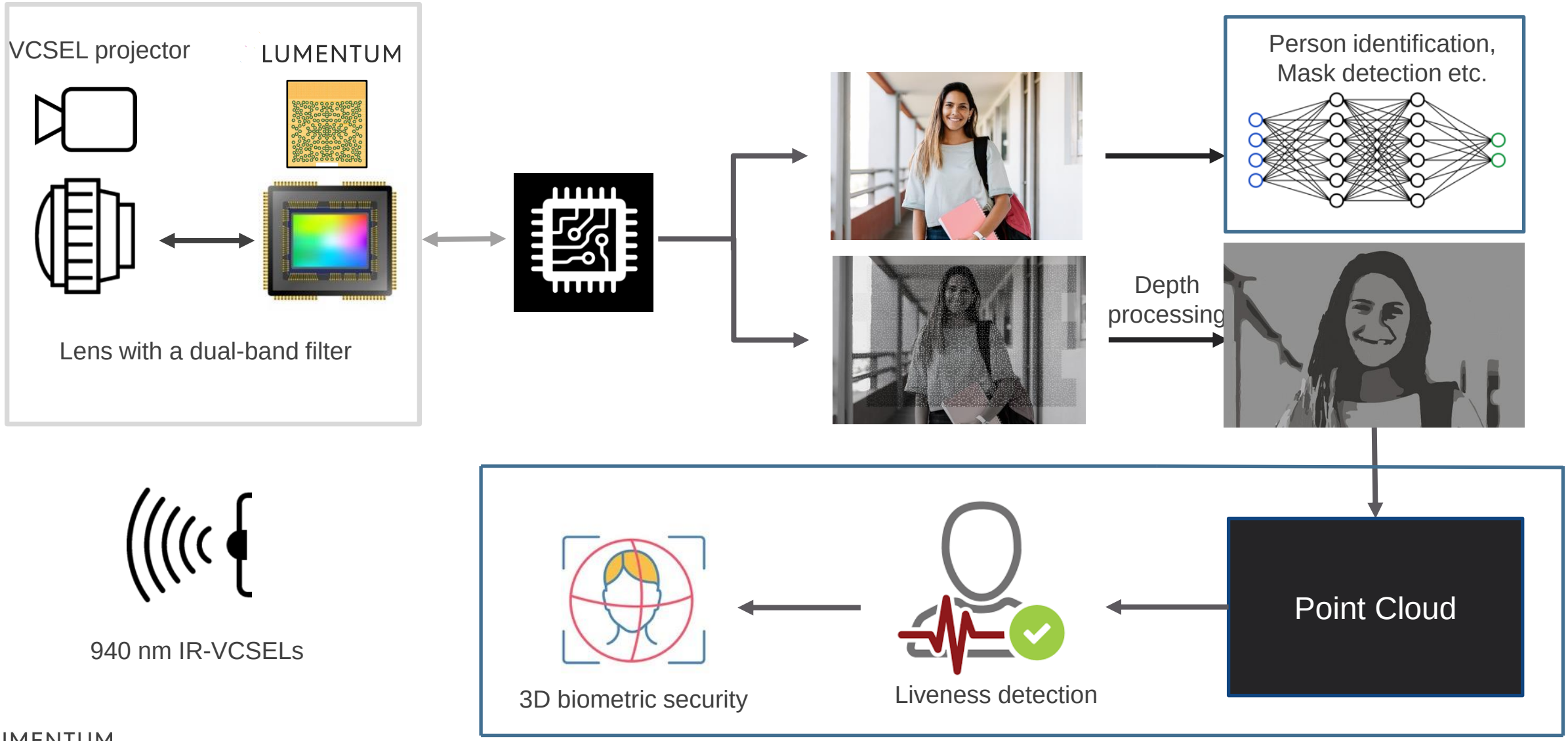
Biometric facial security for access control



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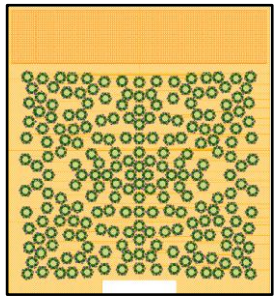
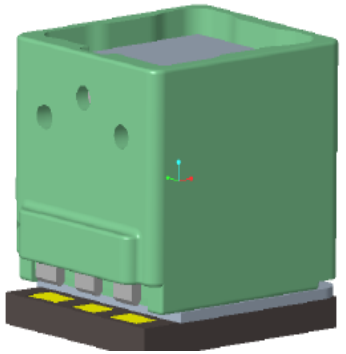
Illumination and biometric facial security using 3D sensing

VCSEL Array Pattern



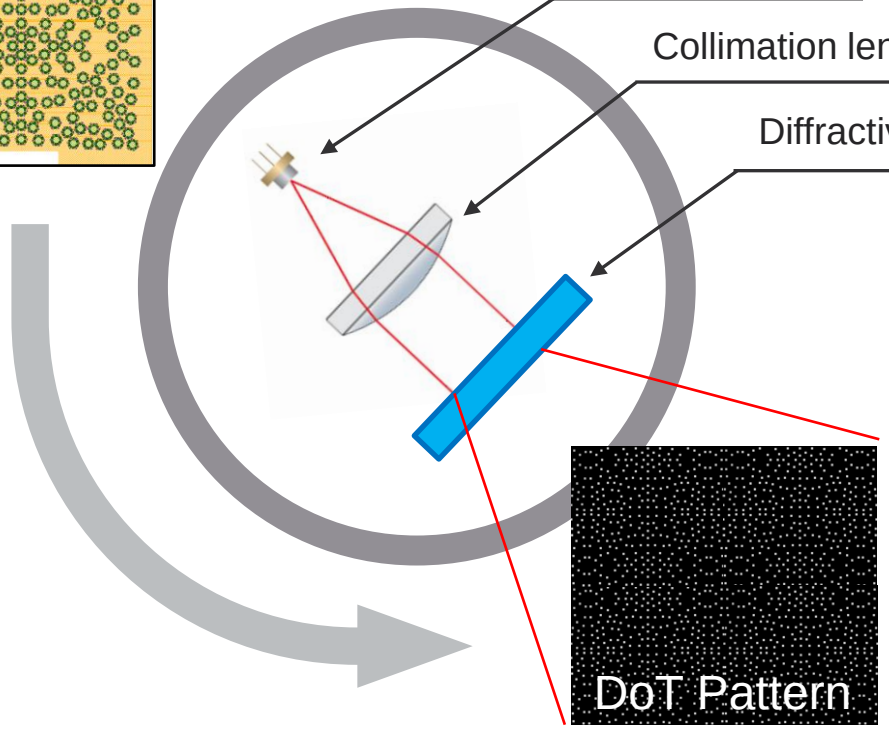
Dot Projector



VCSEL package

Collimation lens

Diffractive optic element



Biometric facial security
All feature points

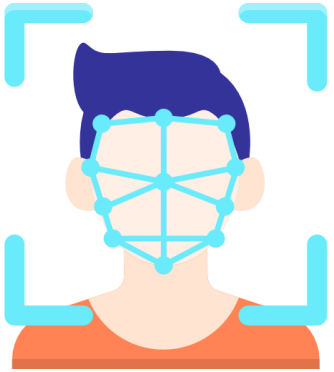


Image capture

Depth map calculation

Replicate VCSEL pattern by 35x

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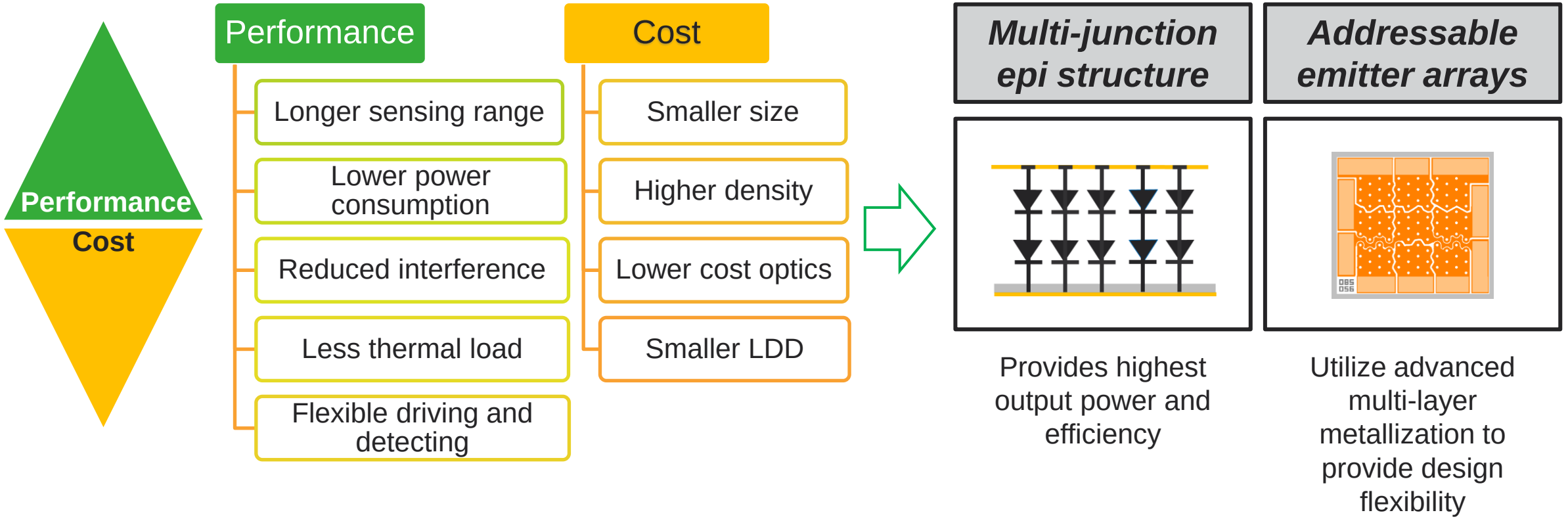
A VCSEL-based illuminator provides all the possibilities

Smart Illumination….

- New solutions, new features, new applications enabled by laser innovations
  - Multi-junction VCSEL chips realize the same peak power but with small die size
  - Addressable emitters can be lit up more efficiently to reduce power consumption



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Smart illumination – Multi-junction stack structure

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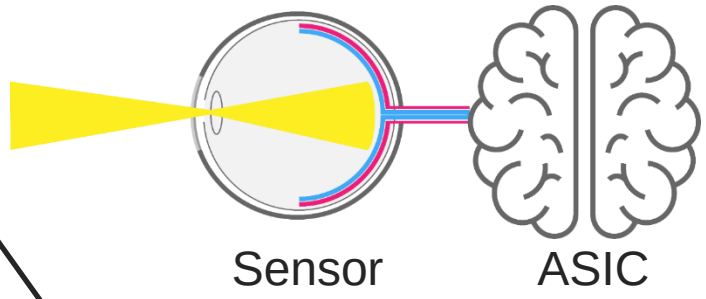
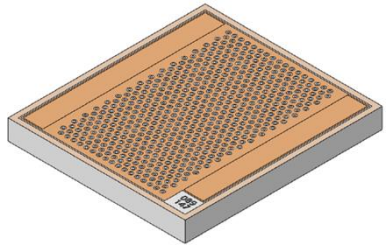
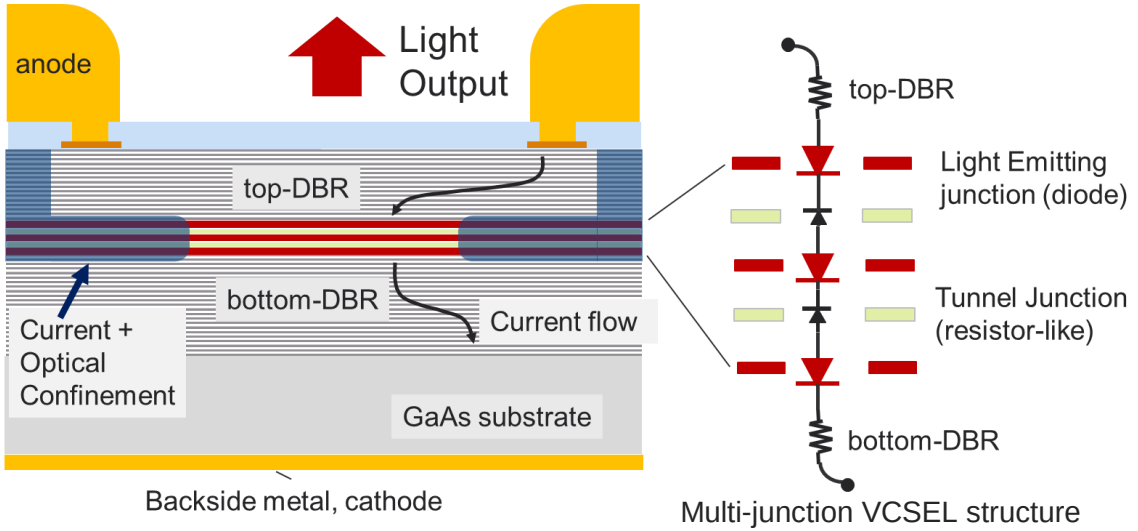
Tx – VCSEL Illuminator





Single junction to multi-junction

- Improve power consumption
- Increase power per emitter



Adding junctions enables more photons to be generated from the same input current

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Smart illumination – Addressable emitters

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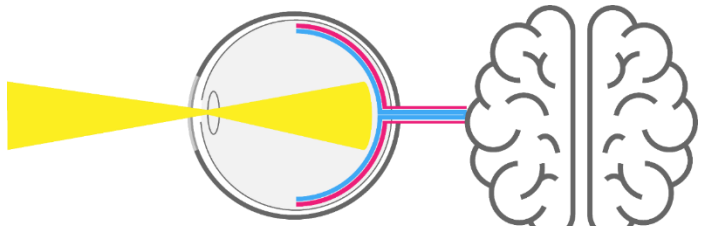
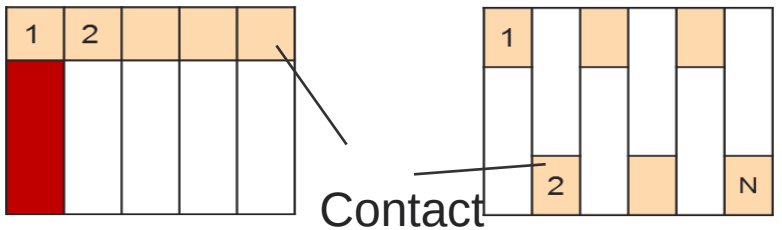
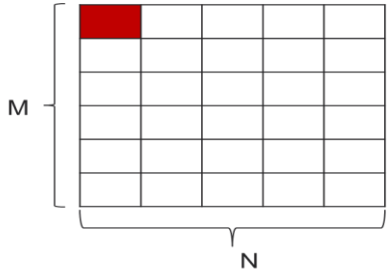
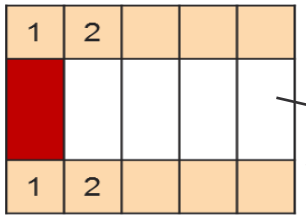
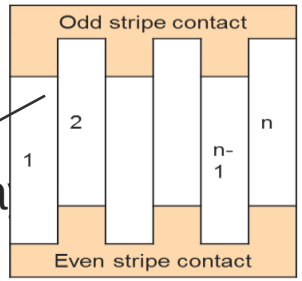
Tx – VCSEL Illuminator

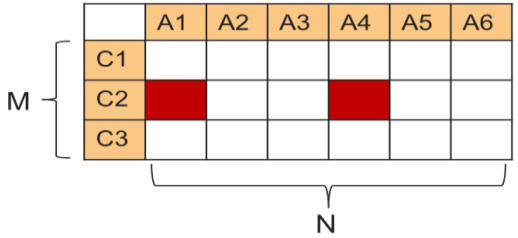


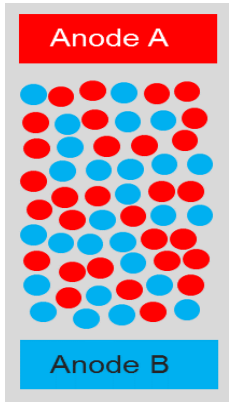












1D Addressable

Interleaved Addressable

2D Addressable

Interleaved Array

Flexibility of high/low pattern dots density

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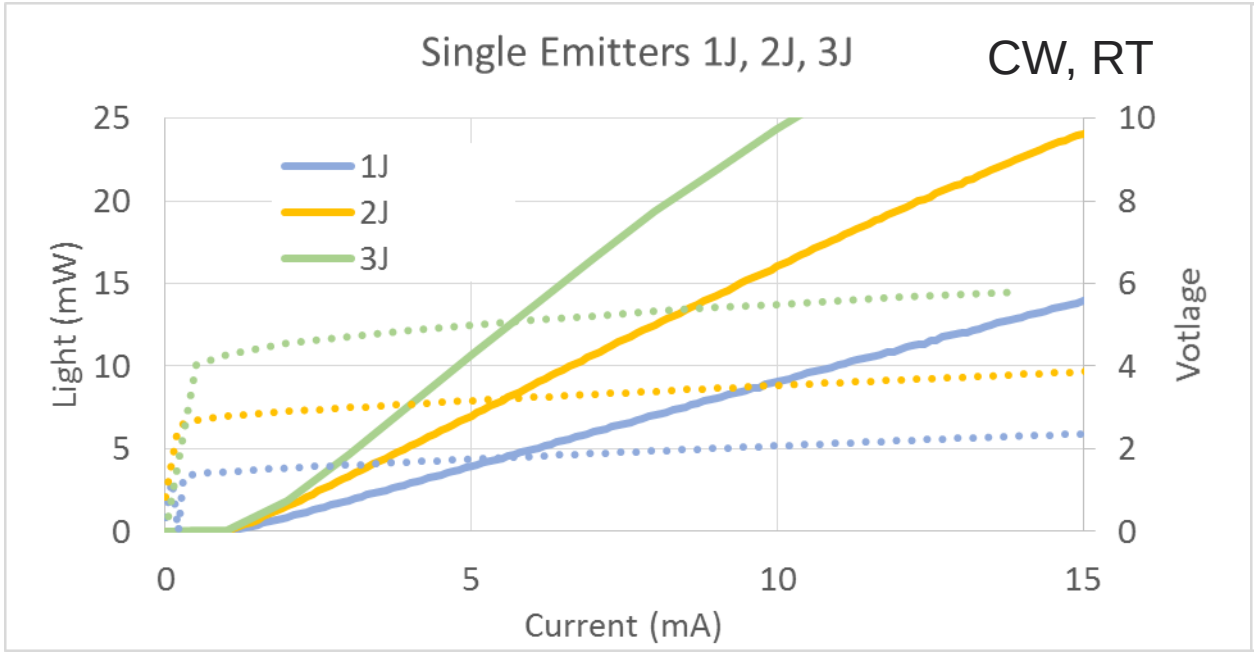
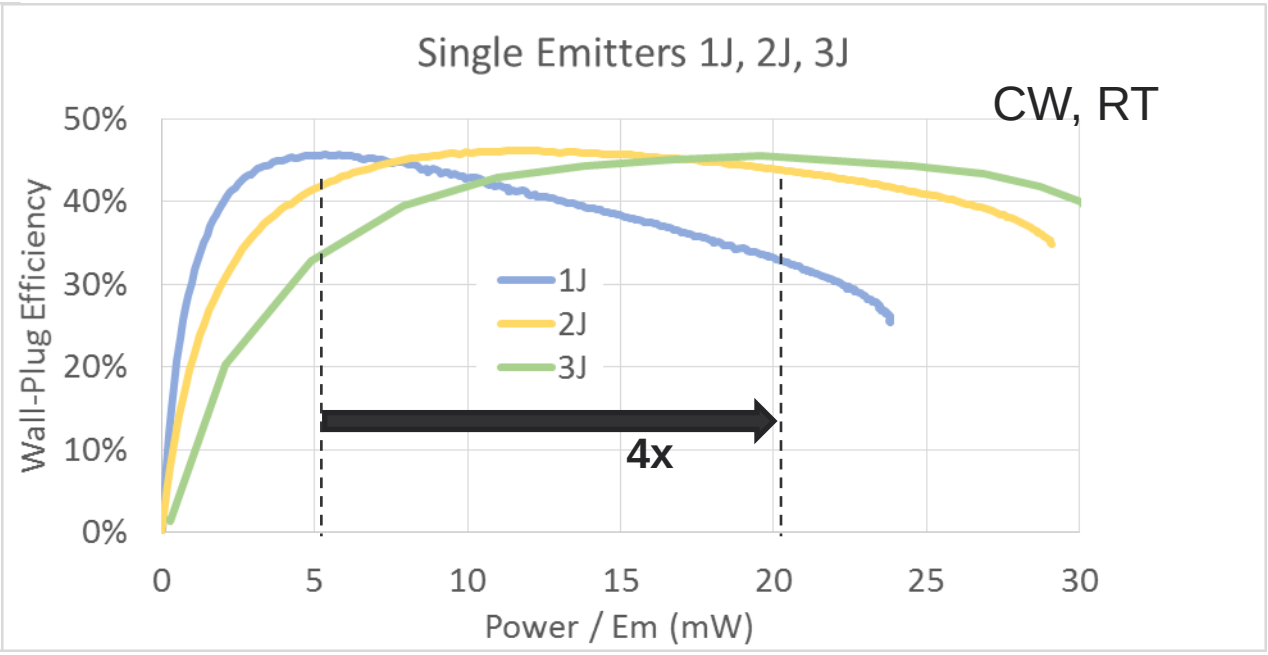
Motivation for multi-junction VCSELs and performance

Increasing peak power with multi-junction VCSEL design and short pulses

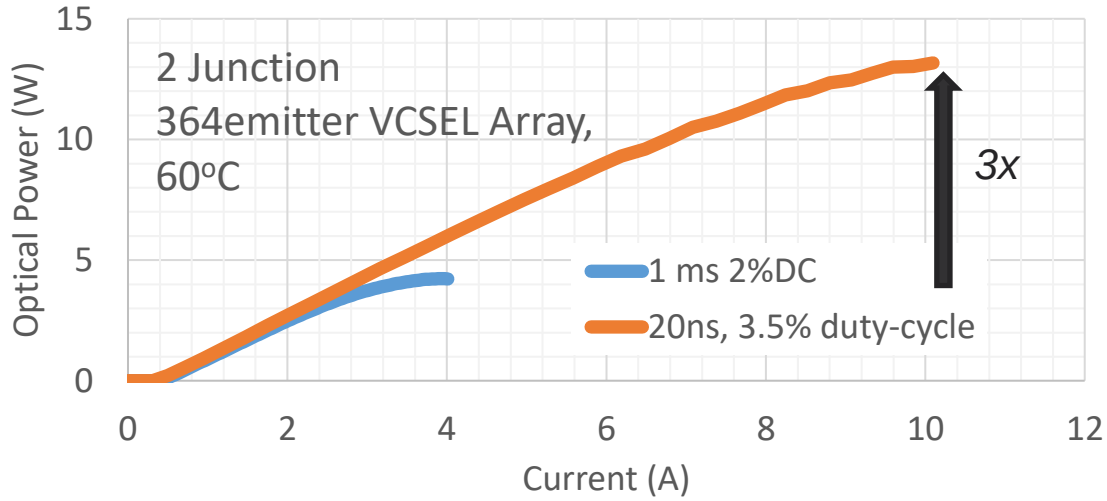




- More junctions increases voltage
- Lower current to reach same power

- Lower current -> Lower I^2R losses –>
  Peak wall-plug efficiency extends to higher power

- Higher power purely from efficiency increase limited … need to reduce heating with shorter pulses.



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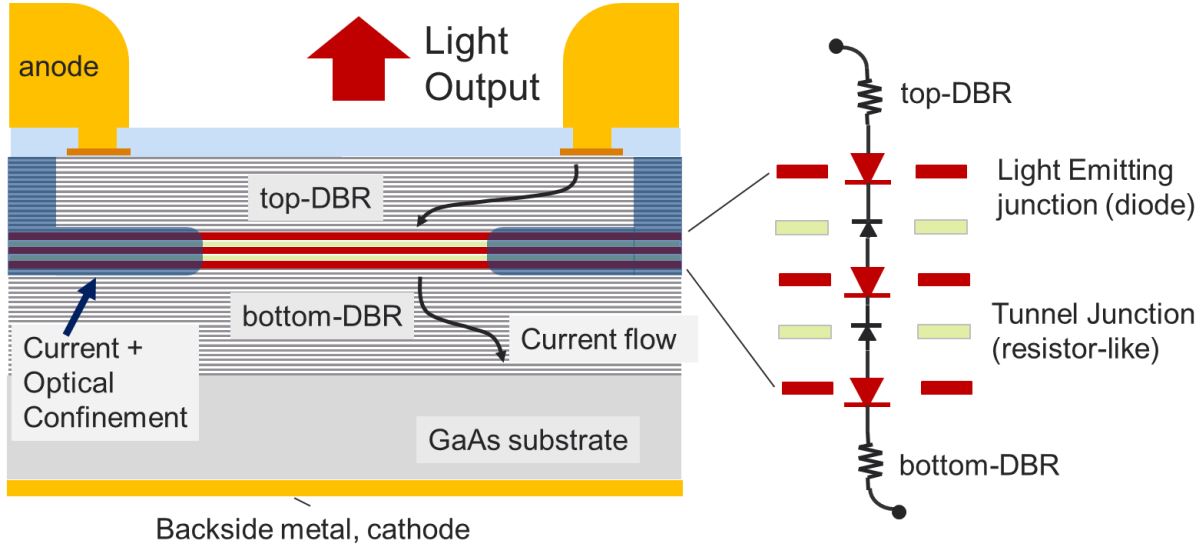
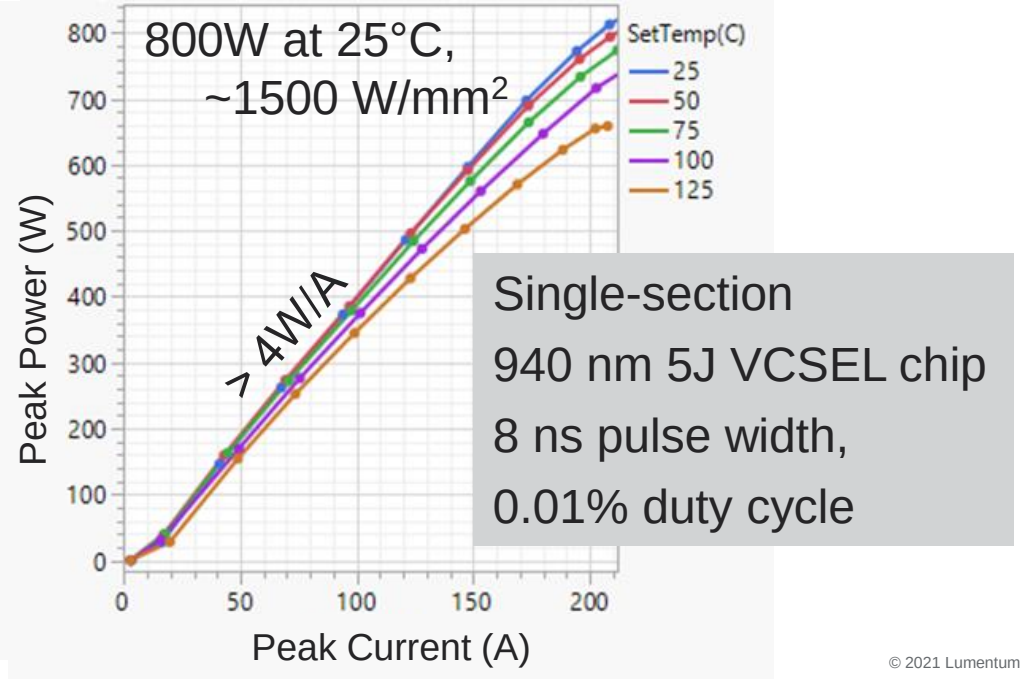
Multi-junction for high power VCSELs

- More junctions -> More photons (higher output power) for the same input current.
- Higher power normally requires Higher current -> Higher I^2R losses
- Adding more junctions improves efficiency of laser at higher output power enabling higher output power
- Reducing current improves driver efficiency
- At low (~<0.1% duty-cycle)
  - 200mW to 3W / emitter
  - High power density (100W/ mm^2 to 1.5 kW / mm^2)





Single-section
940 nm 5J VCSEL chip
8 ns pulse width,
0.01% duty cycle

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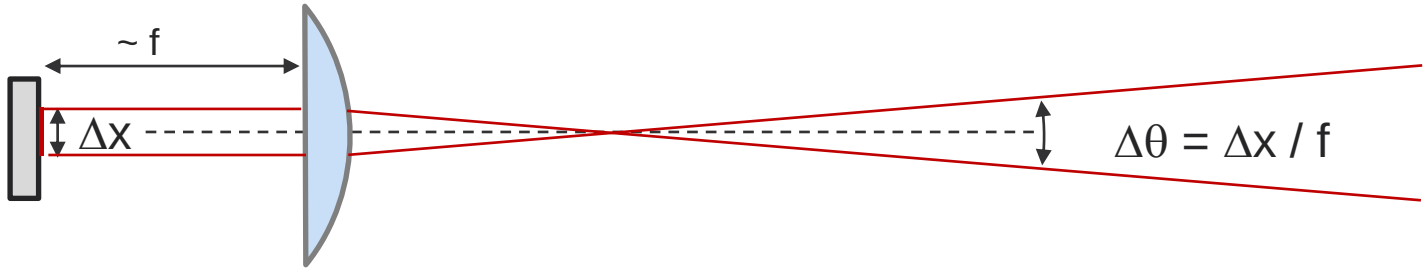
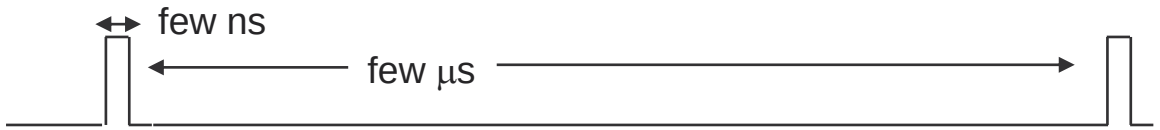
LiDAR's need for high power density at low-duty cycle

- For longer range (10 – 200m), Time-of-Flight LiDAR require higher power within narrow angular slices or blocks

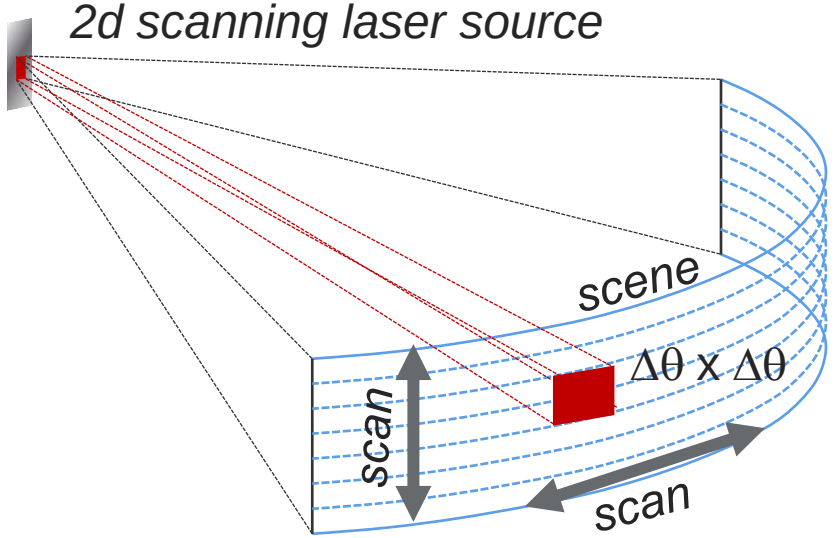
- Higher power per angle or angle^2 means
  - Higher power / mm or
  - higher power / mm^2 at light source



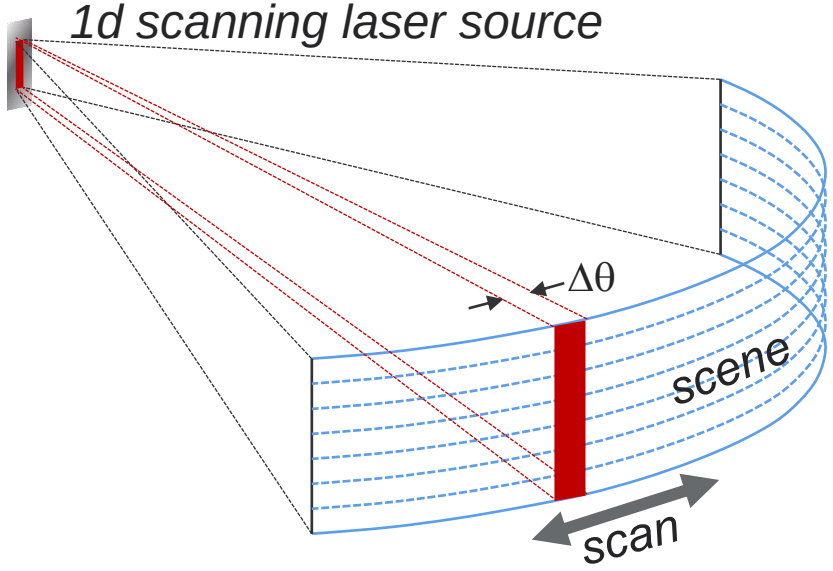
- Power may be delivered at low ~<0.1% duty-cycle
  - Short, ns, pulses desired for reasonable z-resolution (1 ns round trip ~ Δz = 0.15m)
  - Need ~us intervals (1 us roundtrip ~ z = 150m away)



2d scanning laser source



1d scanning laser source



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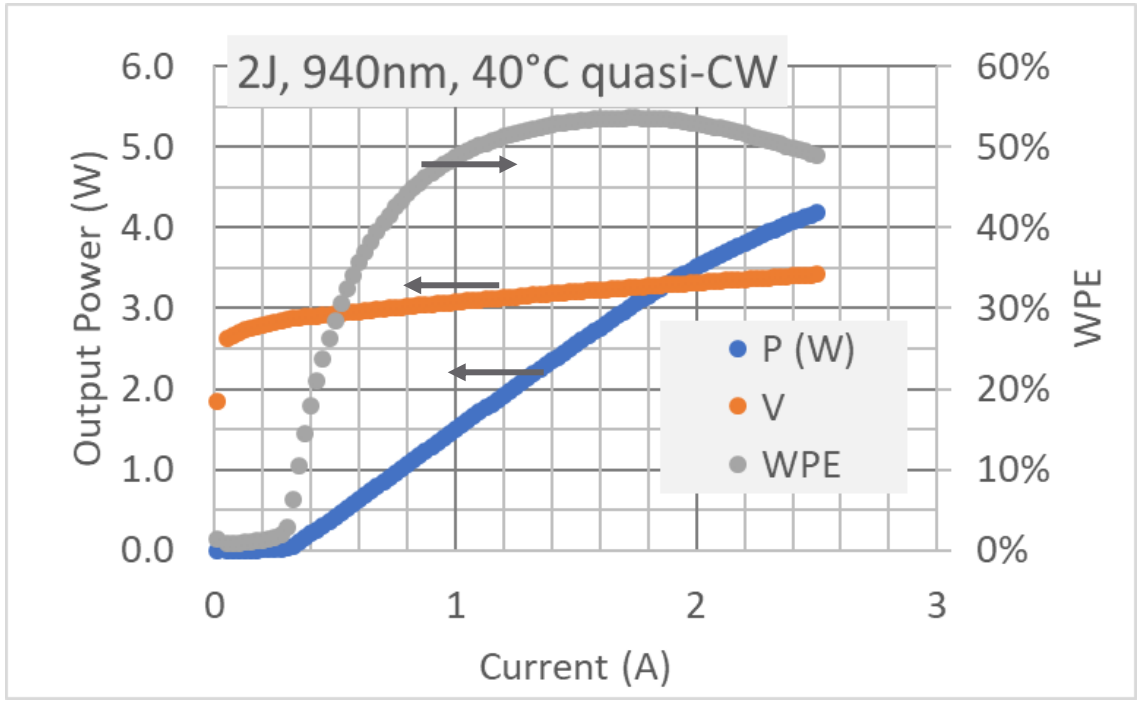
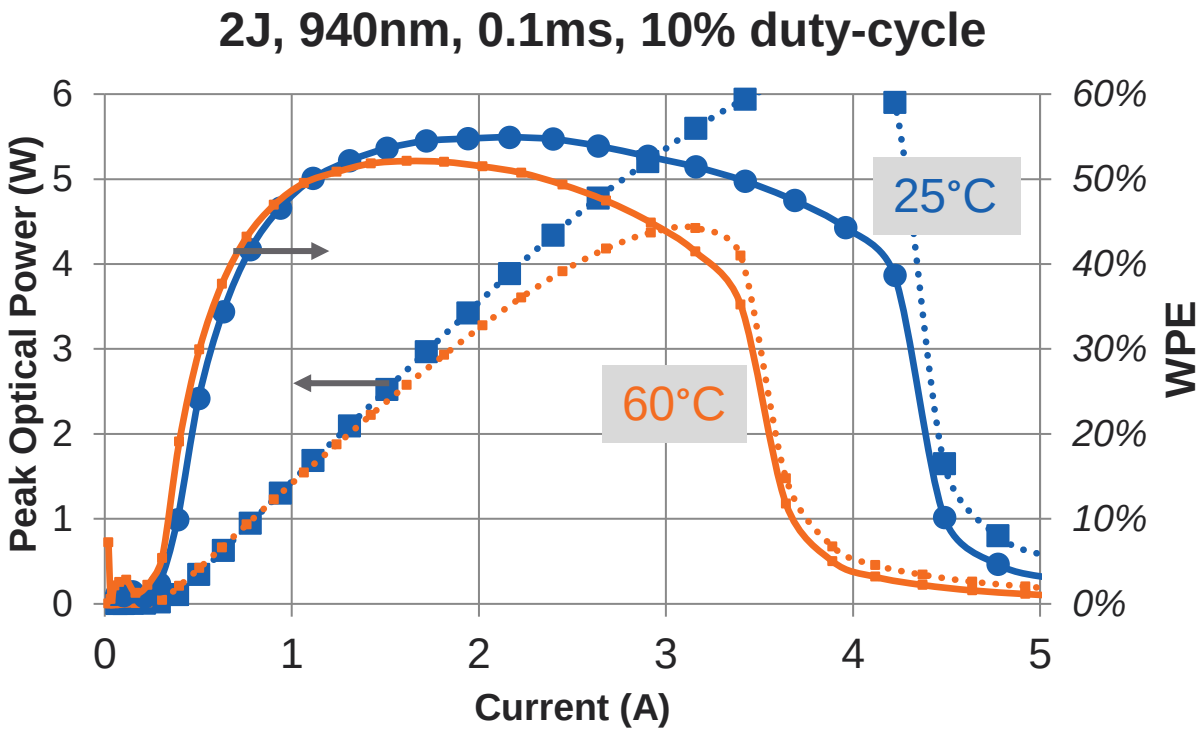
Aside … 2J can improve efficiency even at high duty-cycle



55% Peak Wall-plug efficiency at room temperature

- Over 50% peak Wall-plug efficiency at 40°C qCW
- 2J better than best 1 J even in quasi-CW operation



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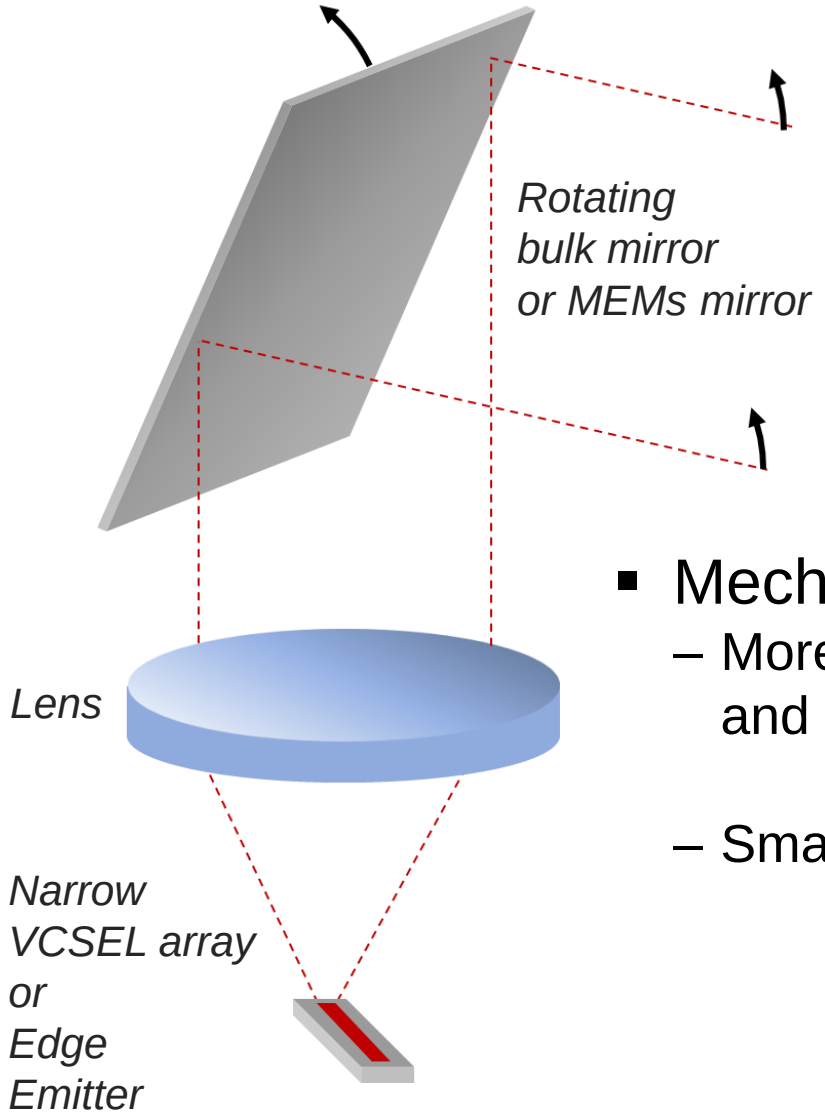
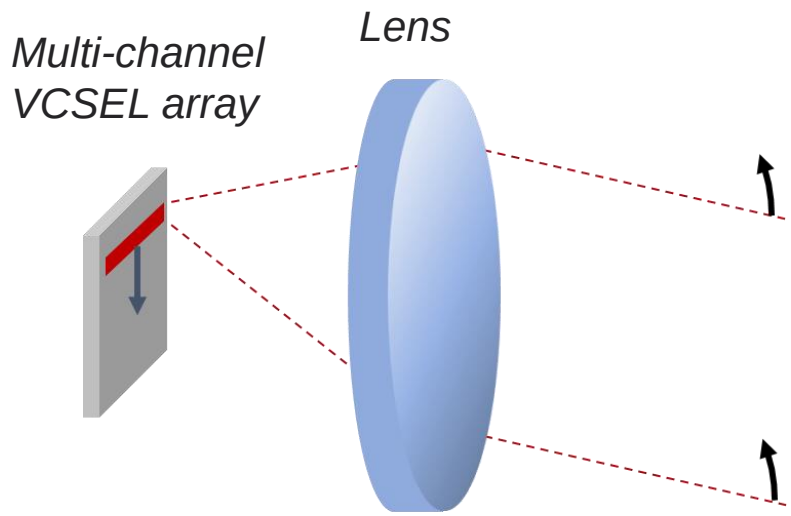
Scanning and chip geometry

Electronic vs. mechanical scanning



- Mechanical Scan:
  - More complex, costly and larger optics
  - Smaller laser diode chip



- All electronic scan LiDAR:
  - Simple, compact, robust optics
  - Already employed in consumer electronics for few meter range
  - Larger laser chip required vs. mechanical scan approach

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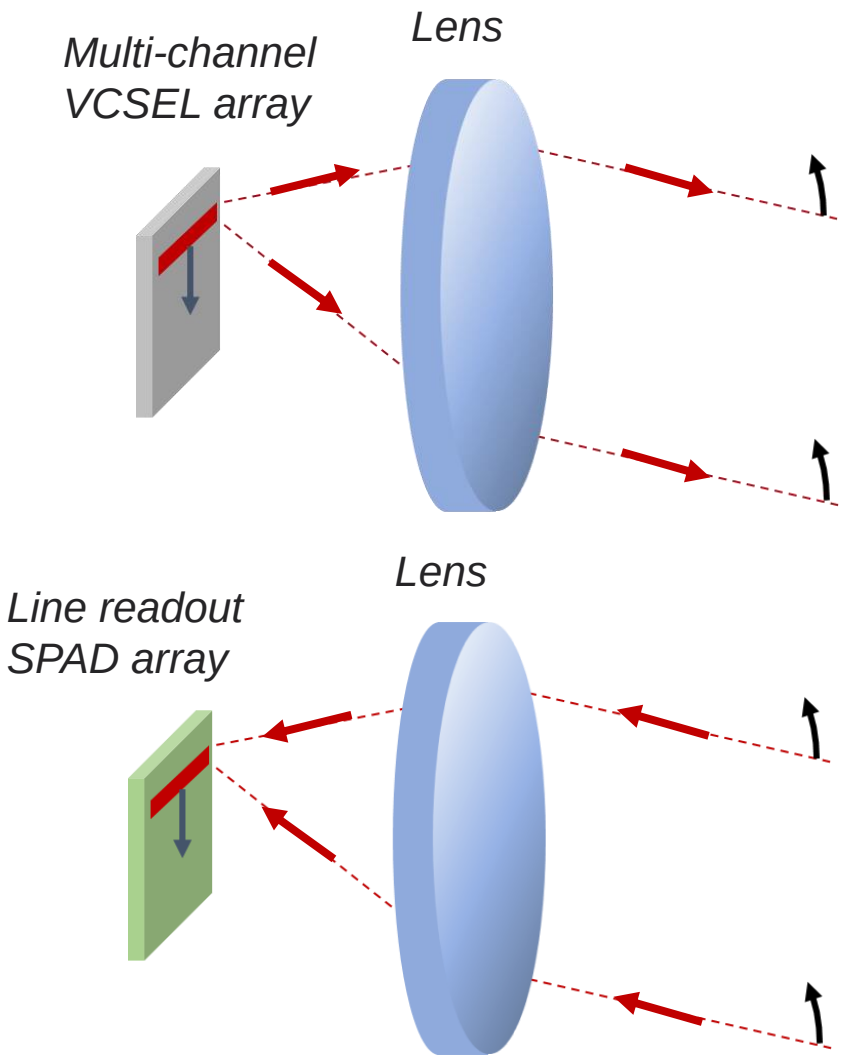
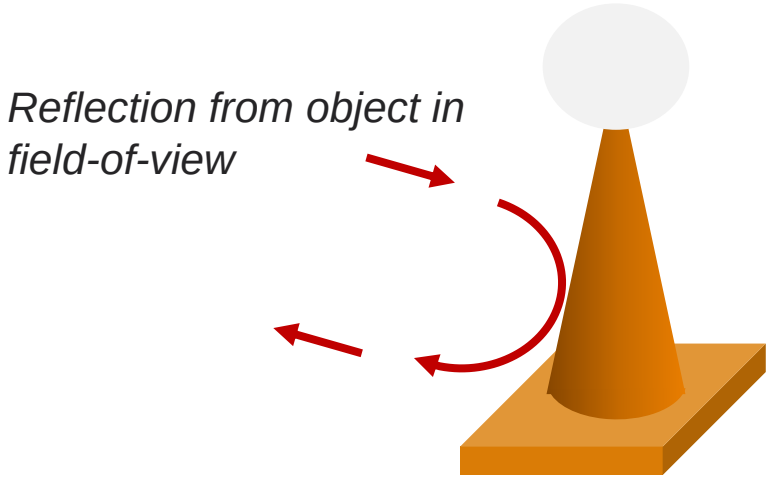
Electronic scan – matching to detector array



- All electronic scan requires match between VCSEL array and single photon avalanche detector (SPAD) array



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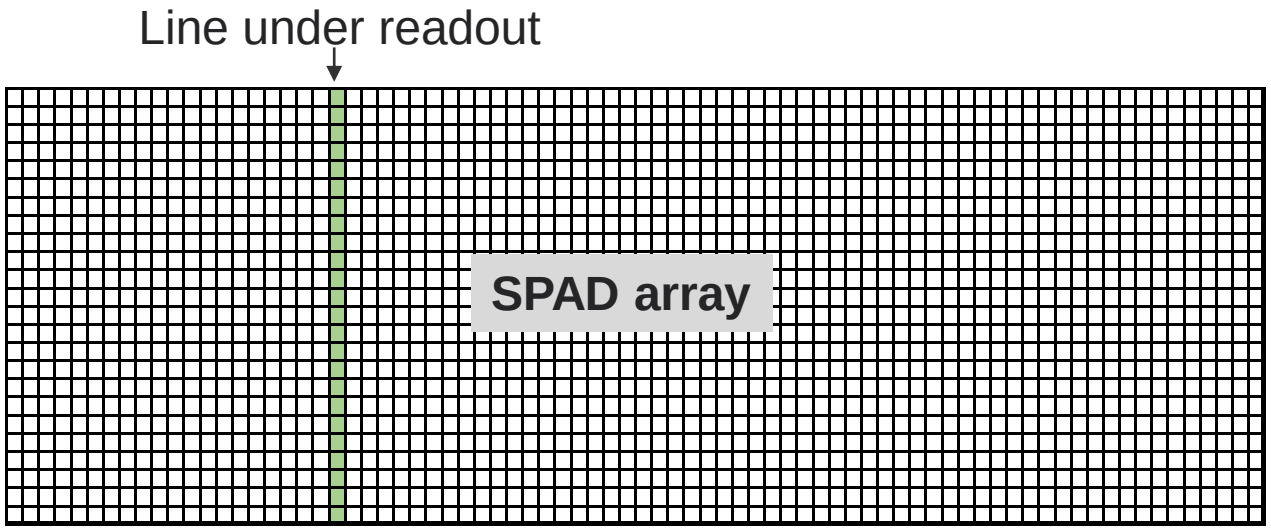
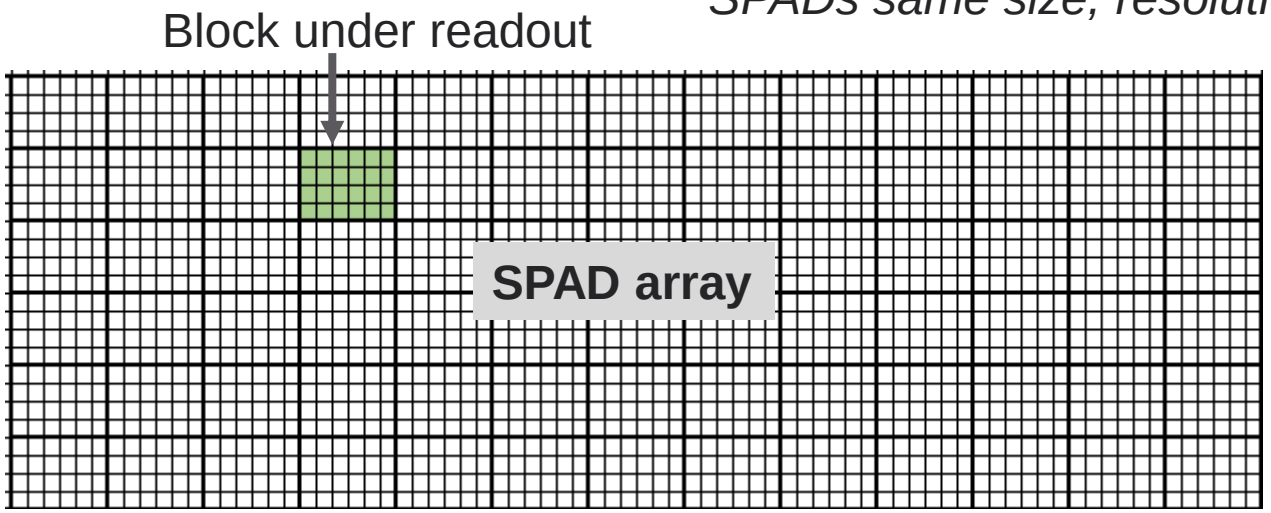
Matching to single-photon avalanche photodiode (SPAD) arrays

- SPAD arrays may have hundreds of columns
- VCSEL array also requires hundreds of channels
- Newer SPADs can readout in blocks rather than lines
- Block readout different from macro-pixels. *Pixels not summed, but read-out individually*



Both read-out zone same # of pixels. SPADs same size, resolution



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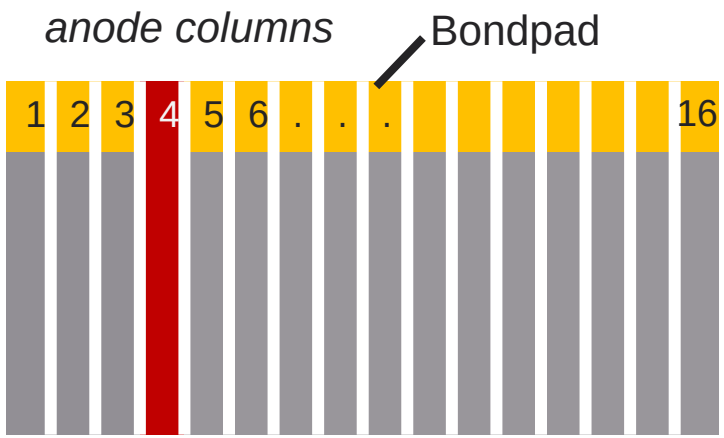
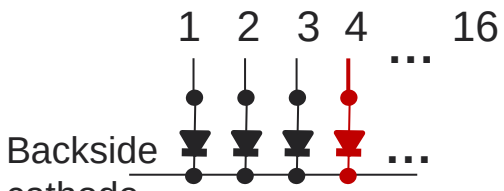
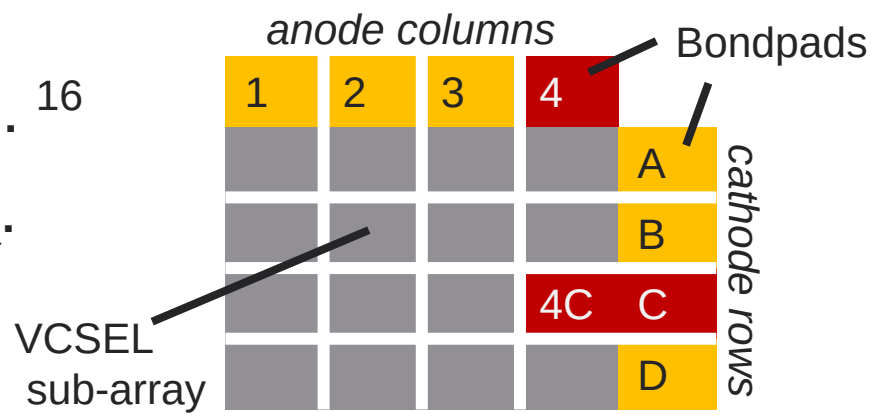
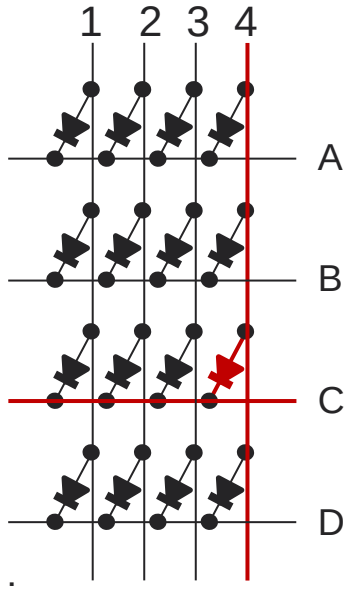
Addressable VCSEL array geometries









Column addressable

- Typ. config front side anodes, backside cathode
- Conductive substrate

Pro / Cons:

- Simple fabrication
- Works with commonly available line read-out SPADs
- Large chips or many bond-pads often required
- Trade-off for width / number of channels
  - Narrow -> higher resistance, worse uniformity + better overlap with SPAD column
  - Wider -> lower resistance, better uniformity, worse overlap with SPAD column

Matrix addressable

- Frontside anode and cathodes – overlapping
- Isolated substrate

Pro/Cons:

- More complex fabrication, but can be smaller than column add. for similar number of channels
- Requires detector have block read-out
- Current flows over wider path, better uniformity over sub-array
- More efficient with optical power, enables longer distance
- Fewer contact pads (M+N) pads for M x N sub-arrays

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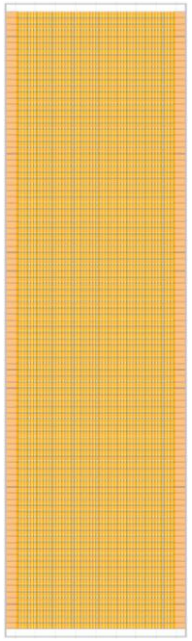
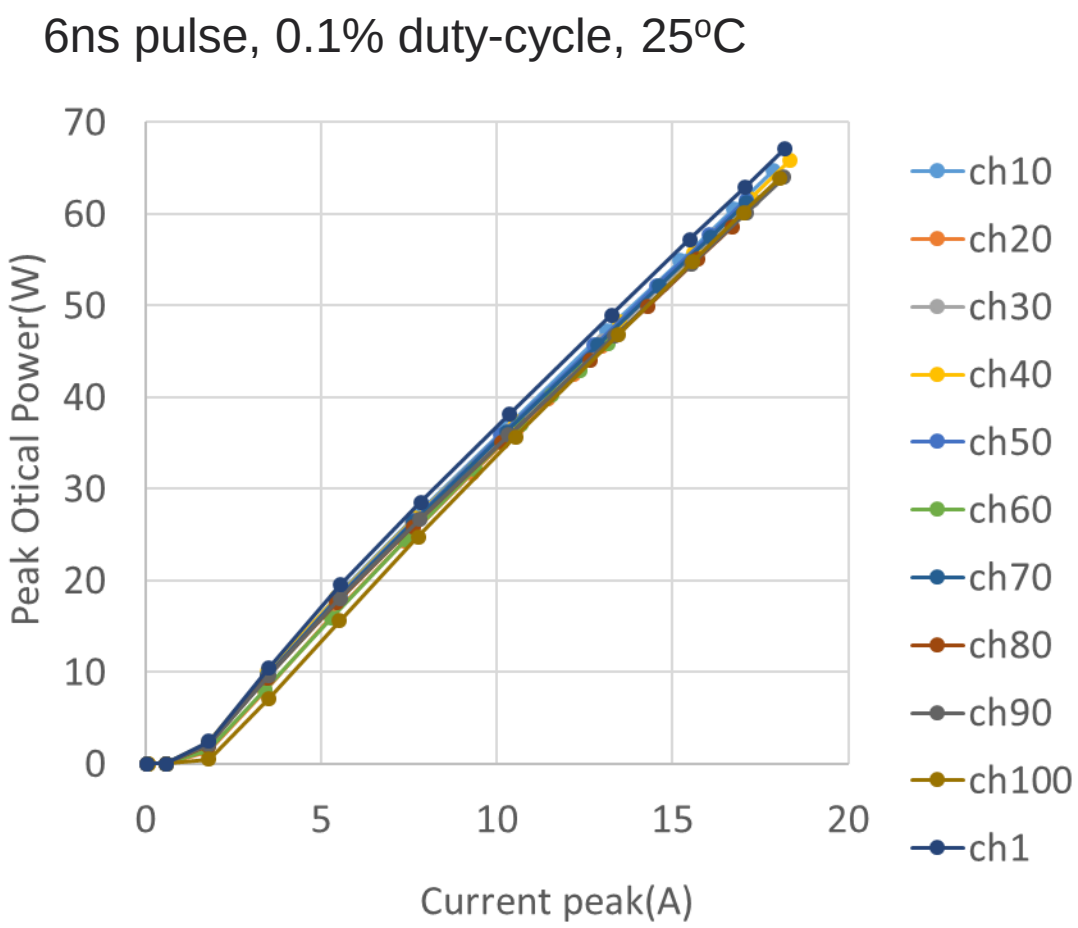
High-power 1D addressable array

- 1d addressable chip
- 100 channels
- Chip size **16mm** x 4.5mm > 70mm^2
- 940nm, 5 Junction design





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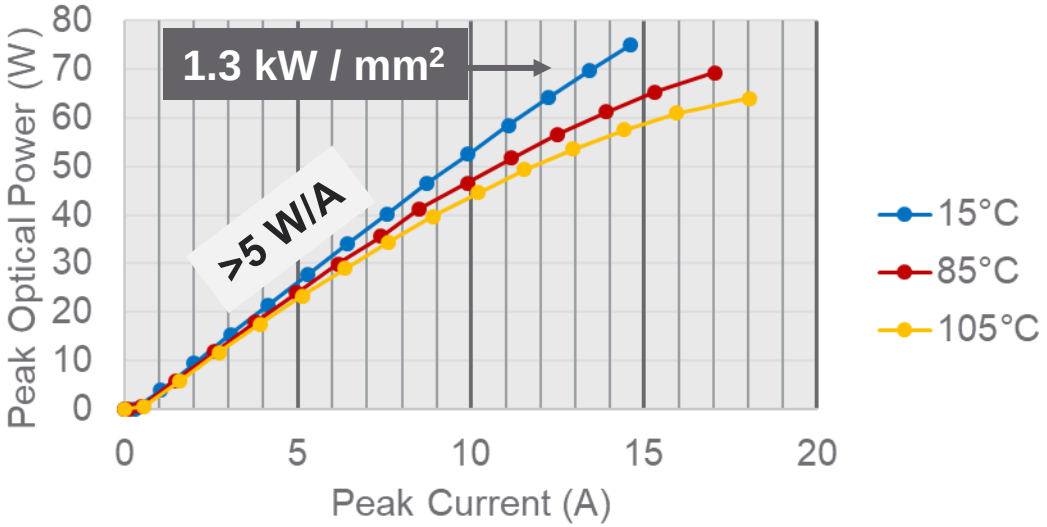
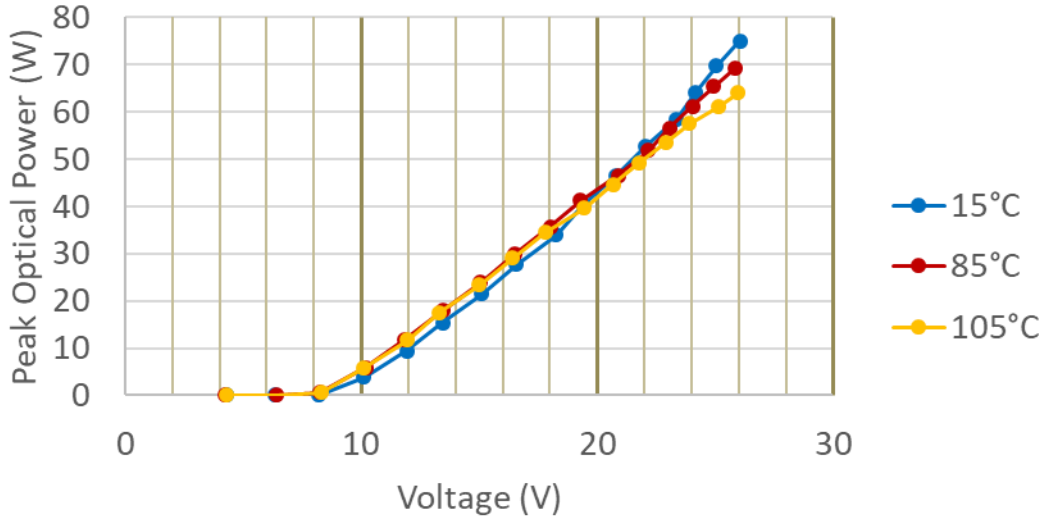
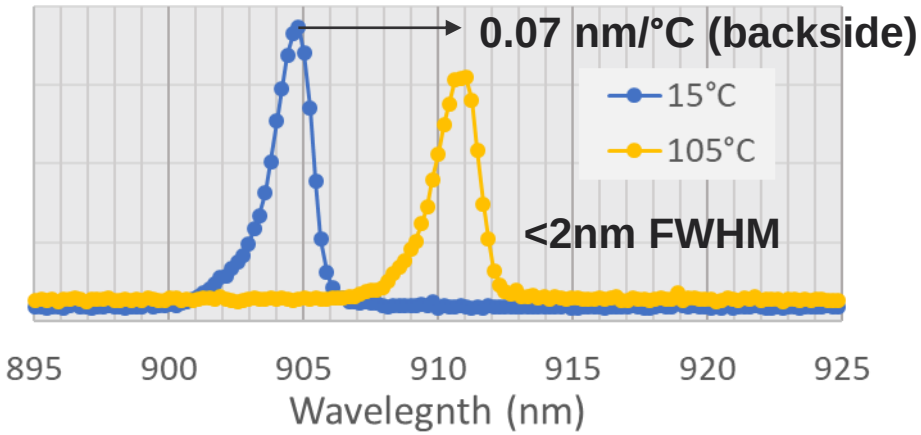
Matrix addressable performance

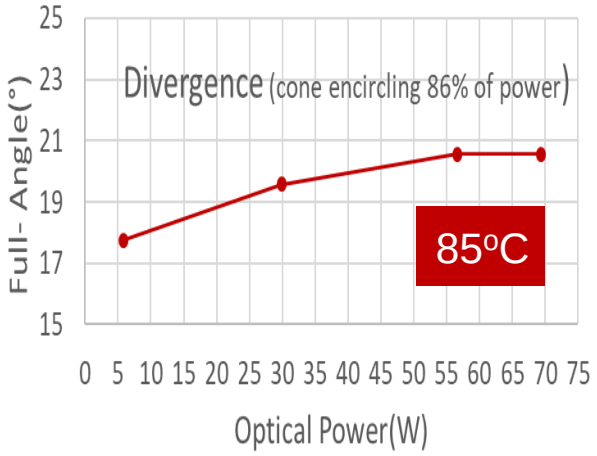
Results 2D array, individual sub-array *(in array of ~200 elements)*

- 905nm, 6 Junction design
- ~7ns pulse, 0.1% duty-cycle.
- Sub-array size ~0.05 mm^2 Overall chip ~12mm^2









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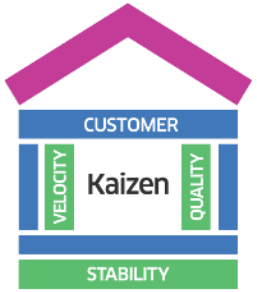
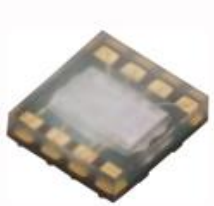
Reliability is a key Lumentum VCSEL difference



- Lumentum's **Kaizen** quality culture
- Submarine proven fiber optical component history
- >900M units of VCSEL chips shipped, zero field failures!

- VCSEL module for automotive in-cabin applications **completed AEC-Q102 qualification**
  – Qualified in a packaged solution



RoHS Compliant | Pb | Hg | AEC-Q102 Qualified

- **IATF 16949-2016 certified** VCSEL fab

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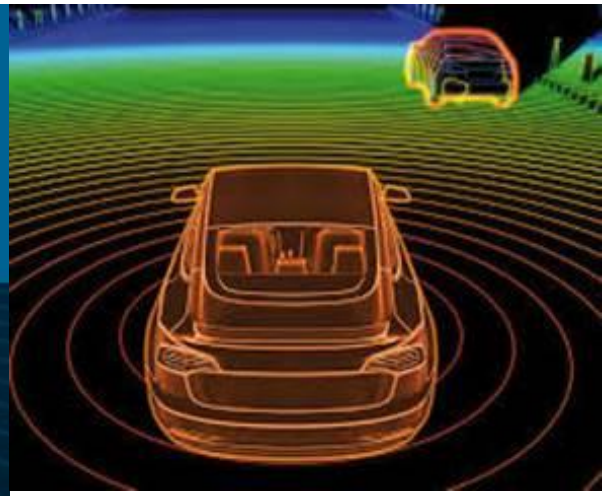
For more information on automotive LiDAR VCSEL technology…



DVN

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Summary

- The latest generation of VCSEL chips are the light sources of choice for advanced sensing solutions
- Matrix addressability opens additional options for LiDAR architectures
- Higher peak power densities using multi-junction epitaxial materials enable > 1kW/mm^2 (low-duty-cycle, few ns pulse) permit extension to longer distances
- VCSEL development has advanced rapidly as high-volume applications drive innovation and infrastructure
- Lumentum is focused on advancing VCSEL technology, the manufacturing platform, products, and integration
- Ecosystem partners are established for module integrators, detector solutions, and electronic integration

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Leading 3D sensing VCSEL innovation
Thank you!
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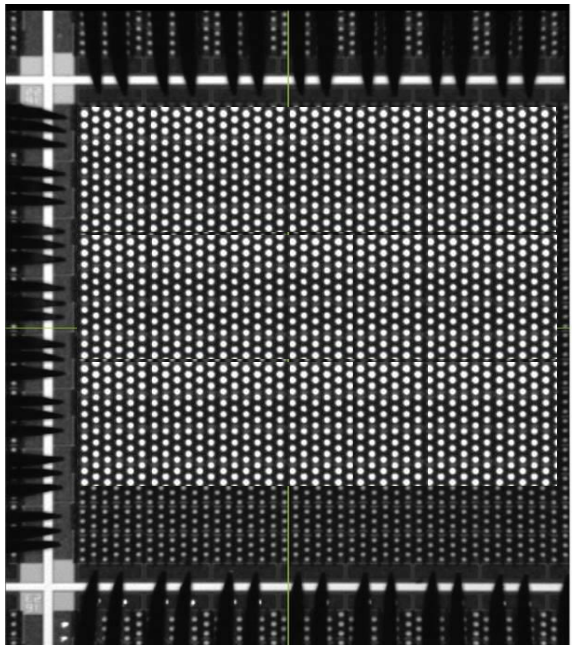
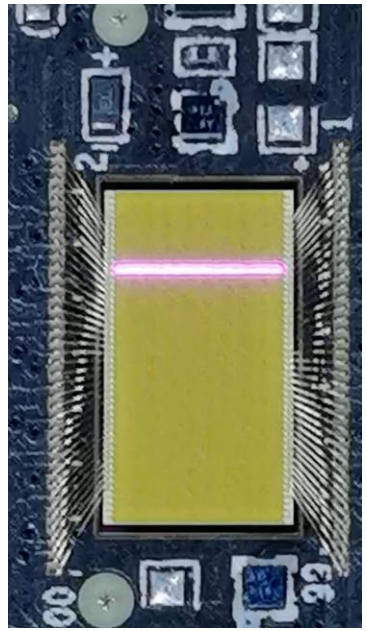
Addressable VCSEL array examples

Matrix addressable VCSEL array



1D VCSEL array



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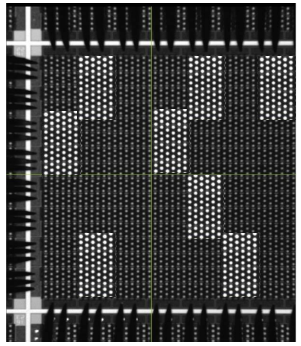
Addressable VCSEL array examples

2-D Matrix addressable VCSEL array



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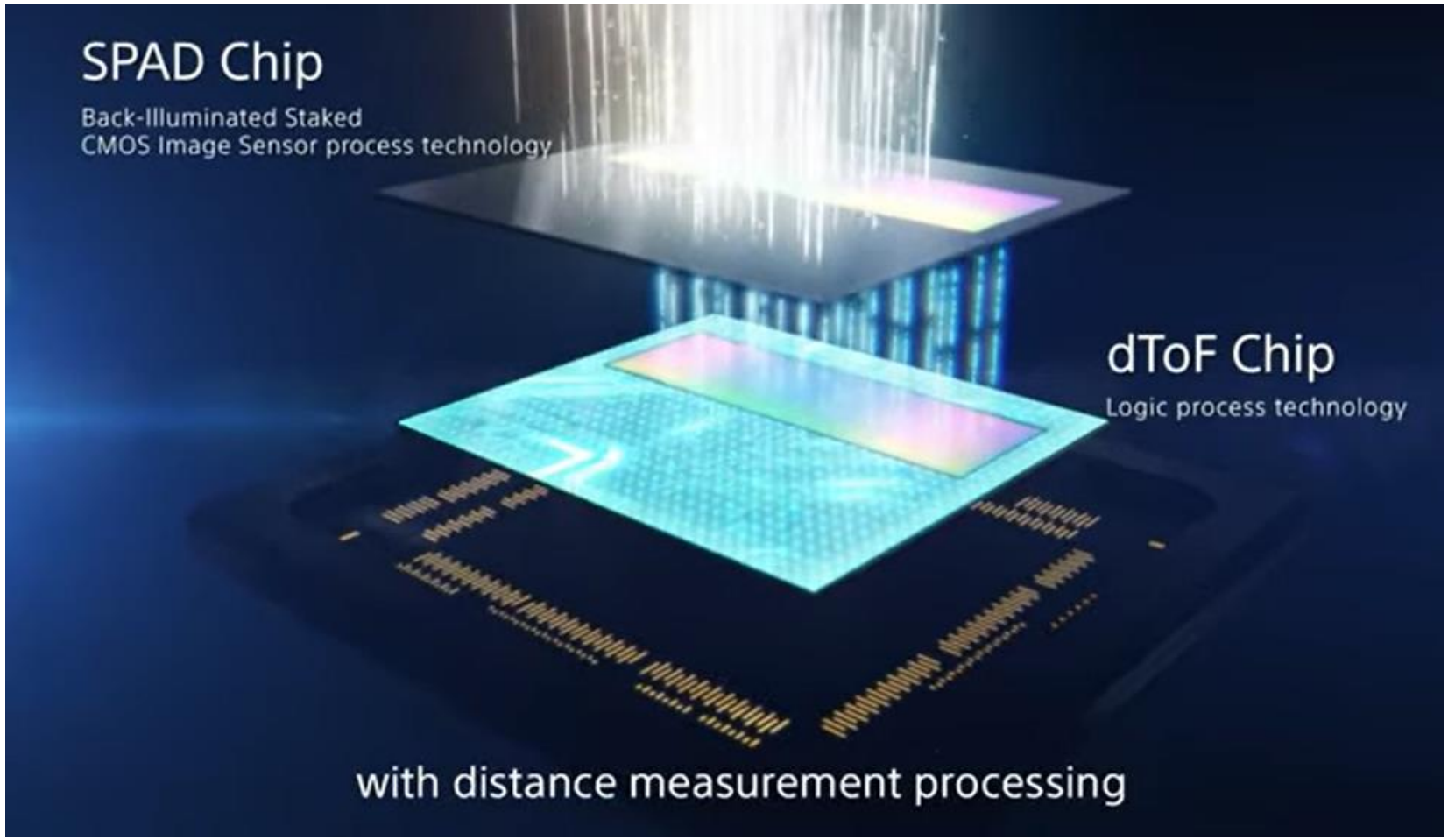
Stacked SPAD image sensor



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Summary

- Matrix addressability opens additional options for LiDAR architectures
- Higher peak power densities using multi-junction epitaxial materials enable > 1kW/mm^2 (low-duty-cycle, few ns pulse) permit extension to longer distances
- Simpler optics + no need for TEC
- Proven at manufacturing processes at consumer volumes

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Summary

- The latest generation of high-power, multi-junction VCSEL chips are the light sources of choice for automotive ToF LiDAR architectures
- Addressability of individual emitter sections allows a perfect match of the emitter to available and future detector devices
- VCSEL development has advanced rapidly as high-volume applications drive innovation and infrastructure
- Lumentum is focused on expanding its automotive VCSEL portfolio
- Ecosystem partners are established for module integrators, detector solutions, and electronic integration

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Automotive in-cabin sensing applications

Occupancy Monitoring System/Driver Monitoring System (OMS/DMS)

Seatbelt fastened/unfastened
Passenger size and positioning
Facial recognition
Alert to check rear seat when exiting or entering the vehicles
Detect movement after vehicle is parked or moved
Monitor occupant biometrics like heart rate, temperature

Gesture recognition in-cabin controls

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