LUMENTUM

High-power VCSEL arrays for next-generation LiDAR Systems

DVN Lidar Conference

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Agenda

- Lumentum introduction
- Today’s automotive LiDAR requirements and challenges faced
- Vertical-cavity surface-emitting lasers (VCSELs) as the solution
- Introduction to multi-junction VCSELs
- LiDAR approaches
- Motivation for multi-junction VCSELs and improved performance
- Lumentum VCSEL array performance for 1D + matrix addressable arrays
- Summary

Lumentum – A Leading 3D Sensing Optical Solutions Provider

$1.74B
FY21[1] revenue, 5600 employees

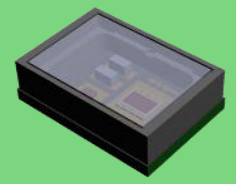
Markets Served:
- Telecom + Datacom
- Consumer + Industrial ***includes 3D Sensing***
- Lasers for manufacturing

1. Fiscal year ended July 3, 2021

Largest global supplier of 3DS illuminators

#1

Laser chips, integrated packages, reference designs



Integrated packages
reference designs

Highest quality and reliability

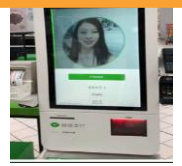
Established high-volume, manufacturing infrastructure

Wearables

AR VR

Automotive

AI Facial Recognition

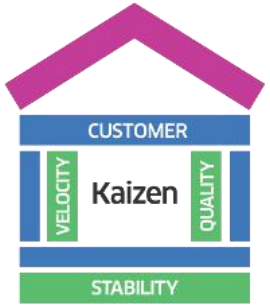


IoT Markets

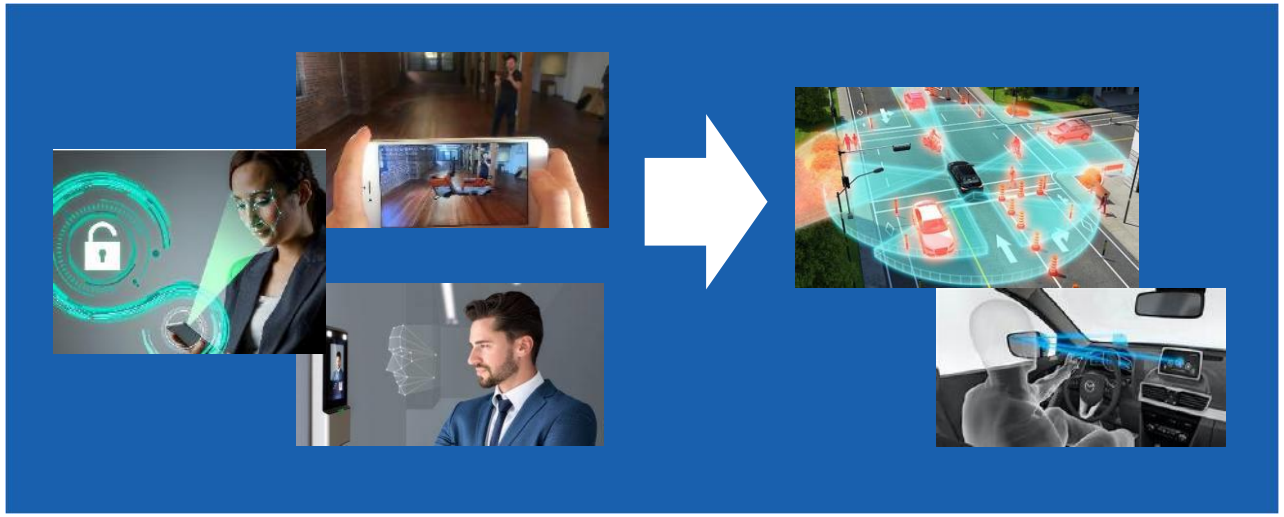
Smartphones

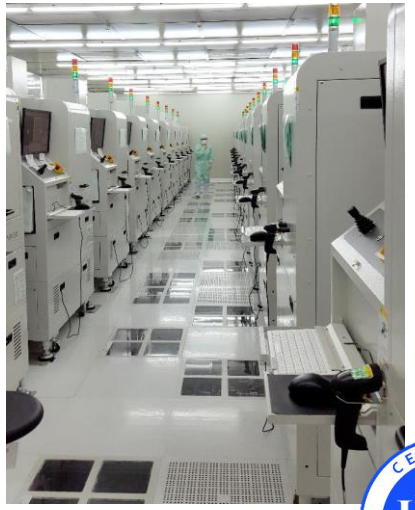
Lumentum Automotive Synergy

- Lumentum history lends itself well to automotive industry
  - High quality, reliable products
  - Proven product excellence under challenging conditions (temperature, vibration)
  - High volume manufacturing – Millions of VCSELs shipped every week



- Lumentum's **Kaizen** quality culture
- Submarine proven fiber optical component history
- >1B units of VCSEL chips shipped, zero field failures!





- **Scale, quality and cost structure to support automotive LiDAR requirements**
- **IATF 16949-2016 certified VCSEL fab**
- **VCSEL module for automotive in-cabin applications completed AEC-Q102 qualification**

IATF 16949:2016 CERTIFIED COMPANY

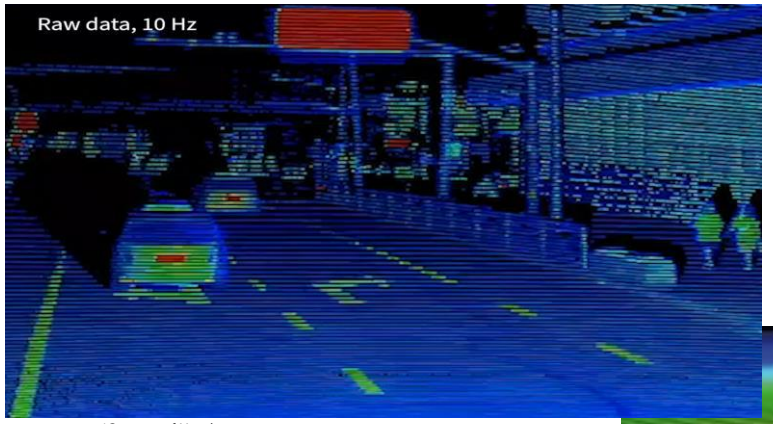
RoHS Compliant | Pb | Hg | AEC-Q102 Qualified

Automotive LiDAR

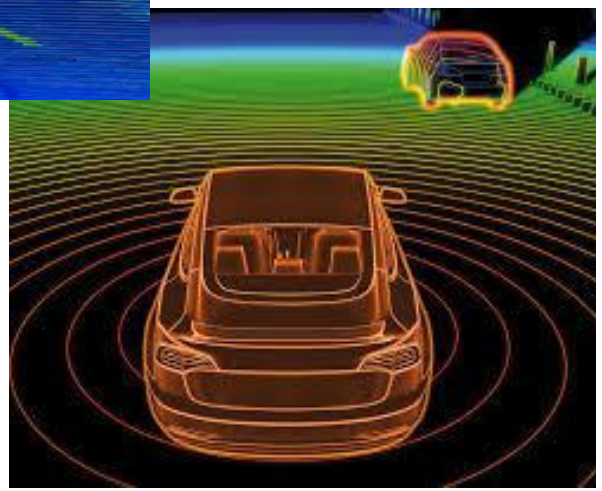
- High Power VCSEL arrays are enabling LiDAR system performance…
  - Long range
  - Best field of view (FoV)
  - High resolution
  - High object detection accuracy (<10 cm)

- … While meeting strict implementation requirements…
  - Eye safety limits
  - High reliability, no moving parts
  - Environmental robustness
  - Compact, easy to integrate in a vehicle
  - Low cost

- … making visions of the future reality
  - Robotaxis
  - Fully autonomous vehicles



*Courtesy of Hesai



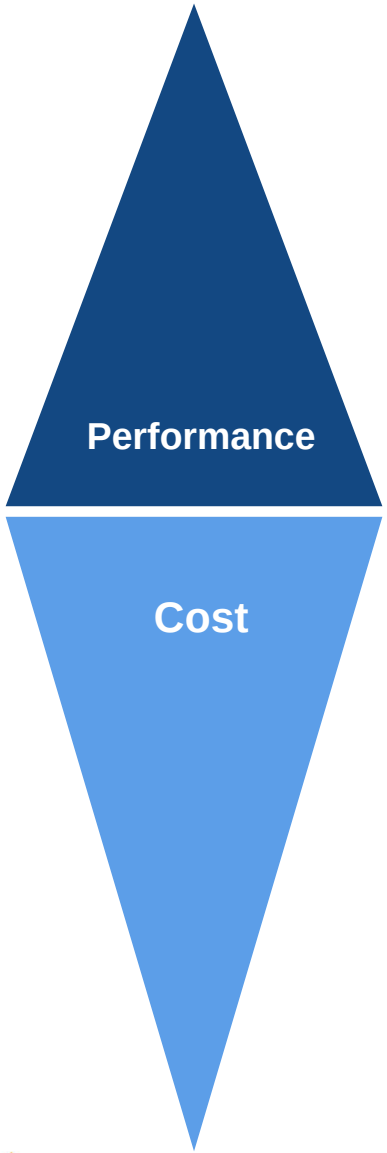
*Courtesy of Driving Vision News

*Courtesy of Cruise

Challenges for the ToF LiDAR Illuminator

LiDAR Requirement	Challenges for LiDAR Illuminator
▪ Longer reach	▪ Highest possible power – Pulse power >100 W at <30 A (10 ns, 0.1% DC) – Slope efficiency >3 W/A over temp range – Power density of up to 800 W/mm2
▪ Stay within eye safety limits	▪ Nano second pulses capability (<10 ns)
▪ No moving parts ▪ Compact, easy to integrate	▪ Addressable VCSEL sections ▪ Small chip, illumination matched to SPAD read-out ▪ Low wavelength shift over temp (<0.07nm/°C) without cooling
▪ Automotive reliability	▪ Chip must pass AEC-Q qualification ▪ IATF16949 certified fab
▪ Cost Effective	▪ Proven manufacturing and test processes ▪ Scale!

Why Lumentum VCSELs?



Versatility

- Scalable power, from just a few mW to hundreds of watts
- Almost infinitely configurable and adaptable
- Easy packaging and integration with existing and future detector, driver, and optical technologies
- Addressable, which paves the way to truly solid-state systems with no moving parts!
- Small size (and decreasing!) and performance enable higher density and flexibility

Cost

- High volume fab shipping millions of VCSELs every week
- Already scaled to meet coming LiDAR demand
- Proven semiconductor manufacturing and test processes
- Lower cost on optics - lens and DOE

Stability

- Performance stability over temperature with minimal power drop
- Wavelength stability over operating temperature range <10nm shift; no need for TEC or other means
- Multi-junction technology reduces loss at higher currents

Excellence

- High power with nanosecond pulse capability (<10 ns) and low duty cycles
- High efficiency with low power consumption and thermal load
- Proven high quality and reliability
- Ideal for d-ToF applications with increasingly Longer sensing range
- No Burn-in required

Lumentum

- Market leading slope efficiency and power density
- World's leading supplier of 3D sensing illuminators
- Proven kaizen history and quality culture
- Over 1B shipped with zero field failures
- VCSEL chips and modules undergo AEC-Q102 qualification
- IATF16949 certified fab

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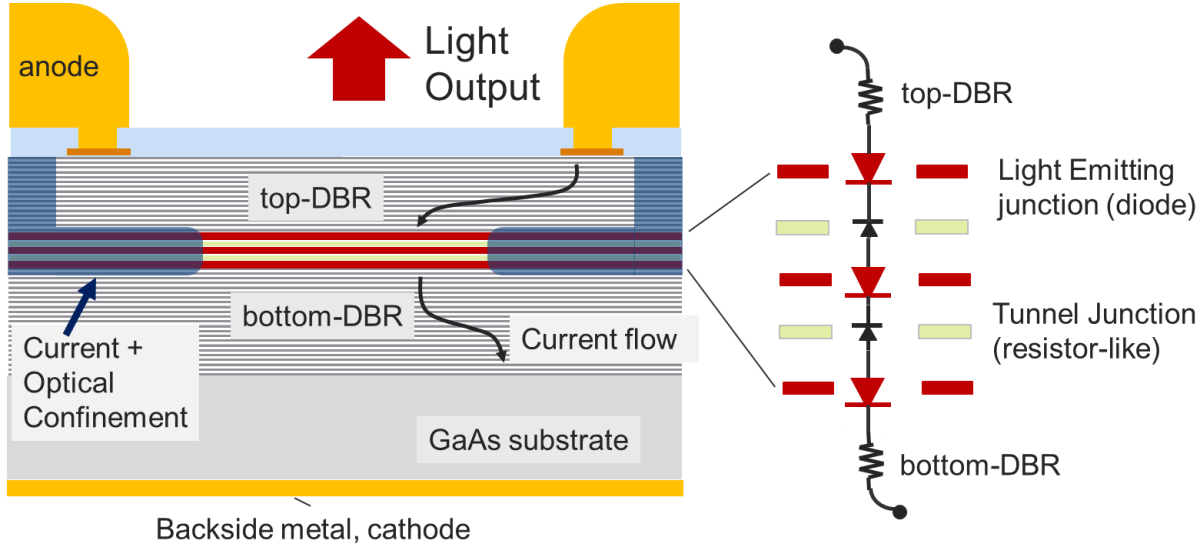
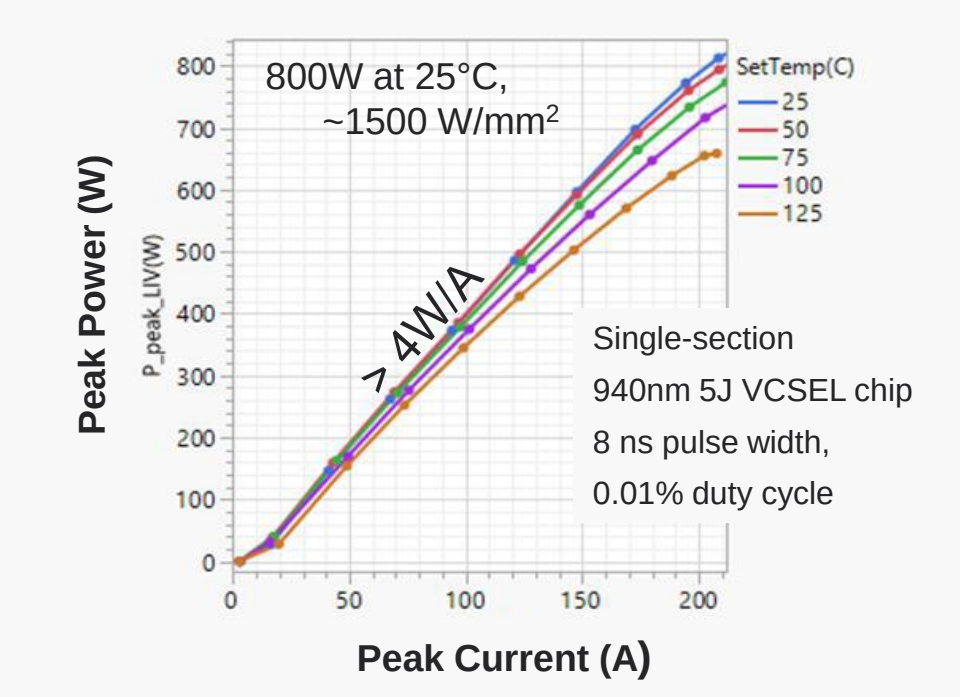
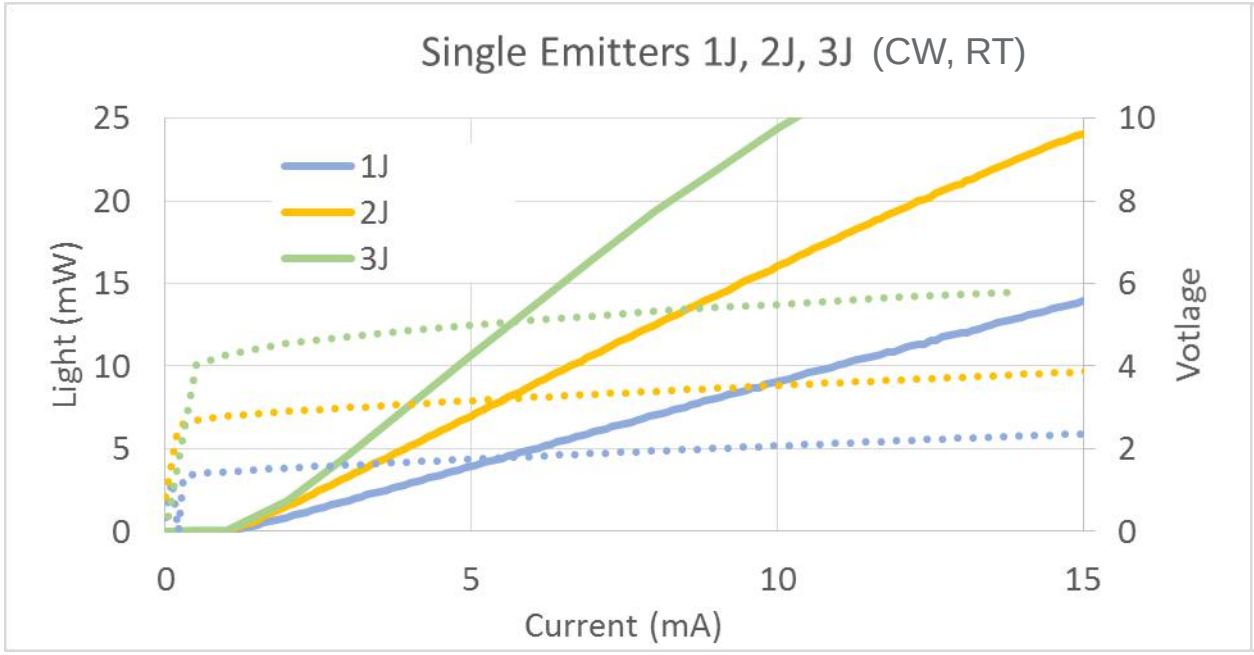
Multi-Junction for High Power VCSELs

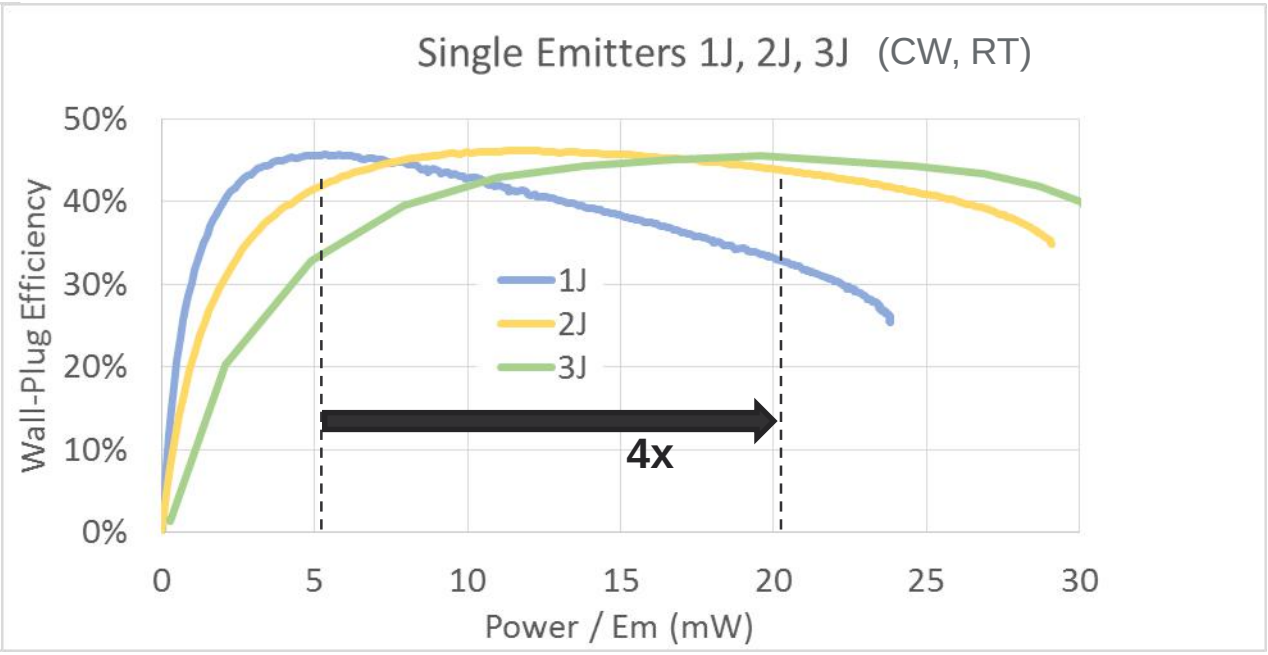
- More junctions → More photons (higher output power) for the same input current and area
- Higher power normally requires Higher current → Higher I^2R losses
- Adding more junctions improves efficiency of laser at higher output power enabling higher output power
- Reducing current improves driver efficiency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



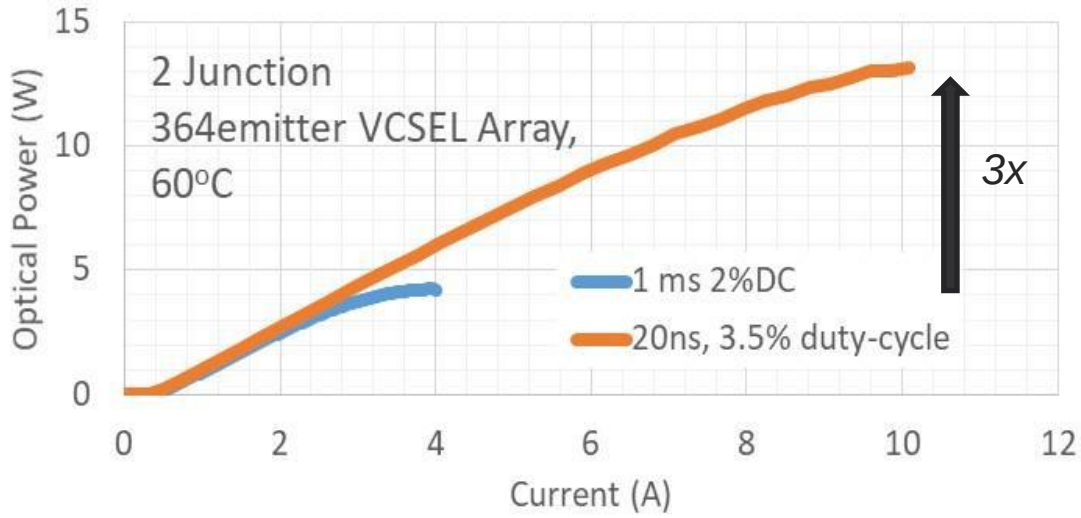


Increasing Peak Power with Multi-Junction VCSEL Design and Short Pulses



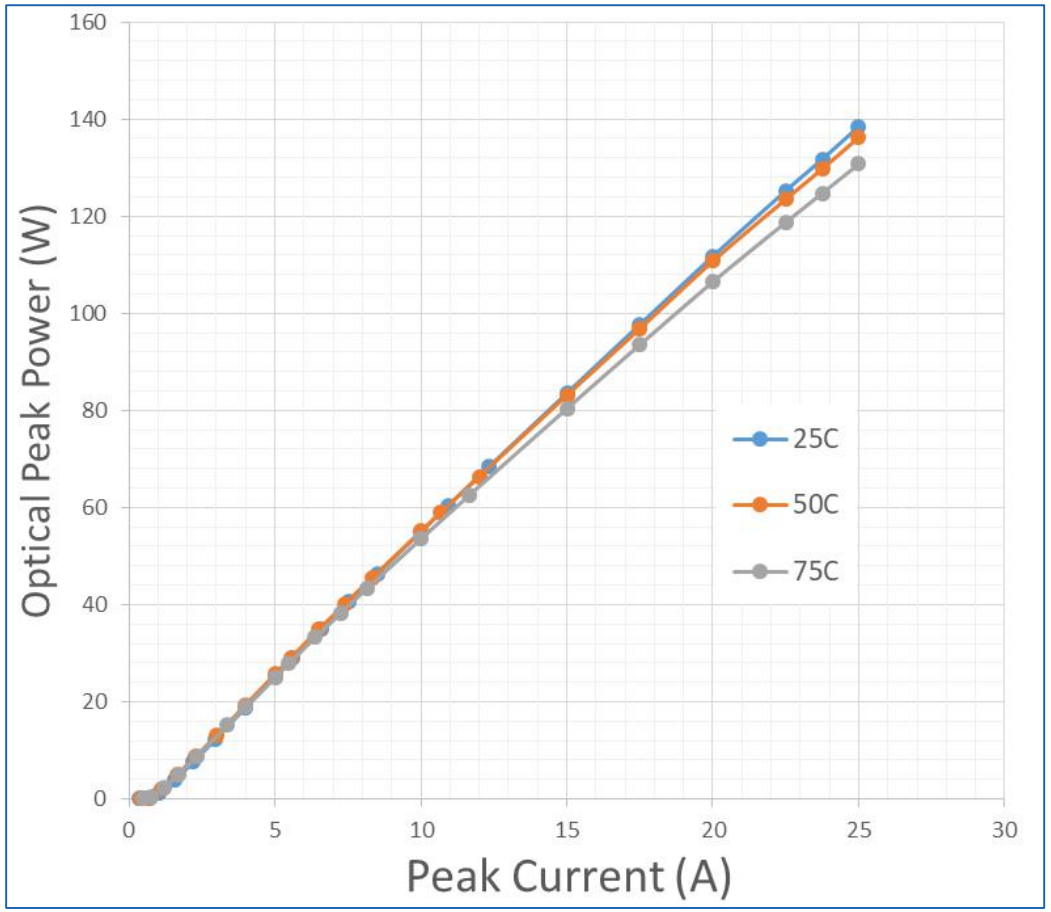


- More junctions increases voltage → *Lower current to reach same power*
- Lower current -> Lower I^2R losses → *Peak wall-plug efficiency extends to higher power*
- Higher power purely from efficiency increase limited … need to reduce heating with shorter pulses



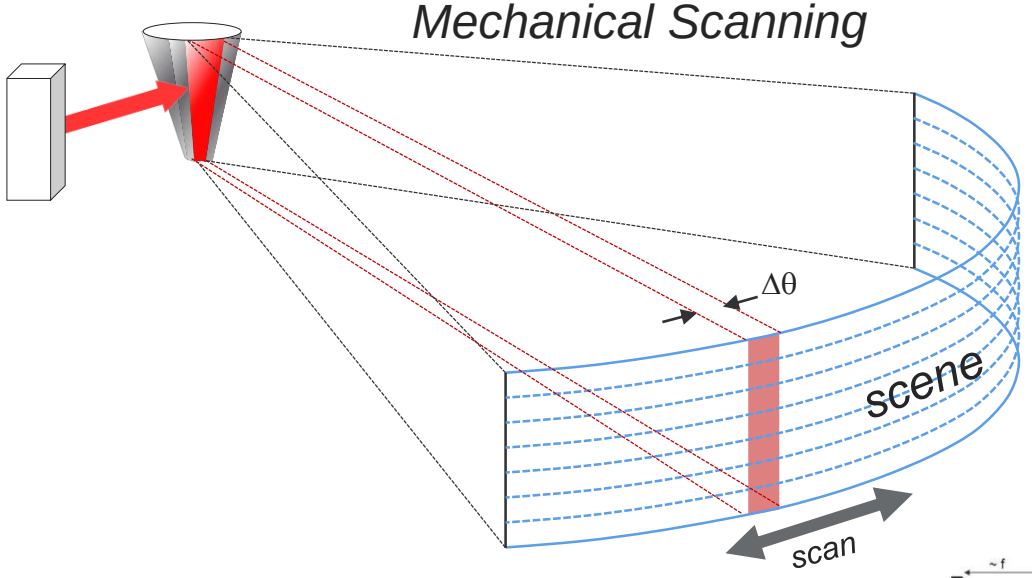
Multi-Junction for LiDAR: 905 nm

- 905 nm array for LiDAR application
- 6 Junction EPI design
  - Aperture diameter 17.3 um
  - 152 emitters
- 8 ns pulse width, 0.05% duty cycle, using commercial high-speed driver which limits maximum current to 25A
- 140W peak power at 25A peak current at 25°C, >1500 W/mm^2 power density (0.85W/emitter at 75ºC)
- High slope efficiency
  - 6.1 W/A peak SE at 25°C
  - 5.9 W/A peak SE at 75°C

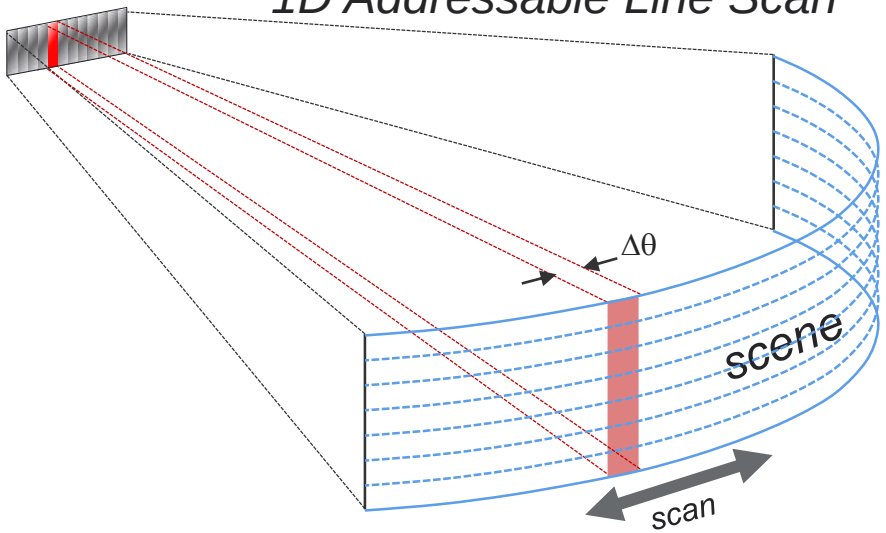


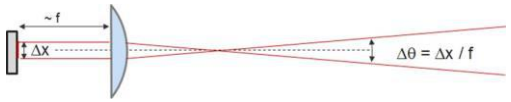
LiDAR Architectures

Mechanical Scanning

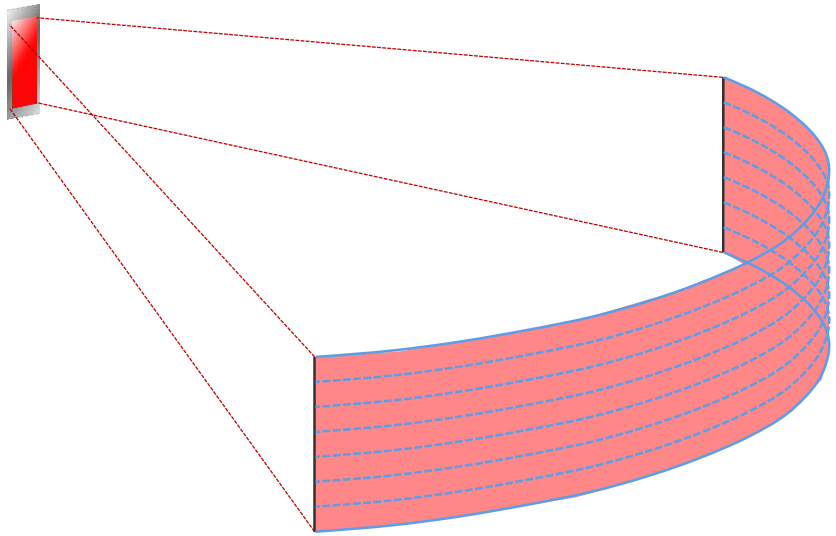


1D Addressable Line Scan

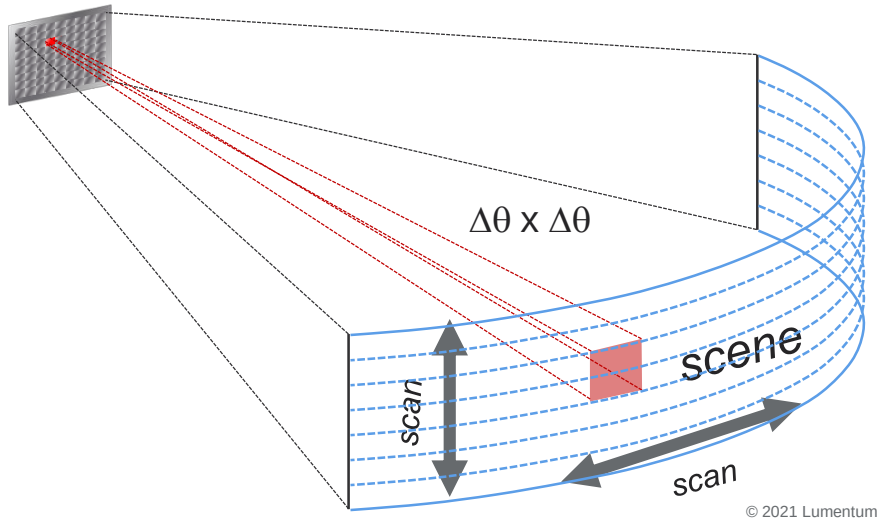




Flash ToF



2D Addressable



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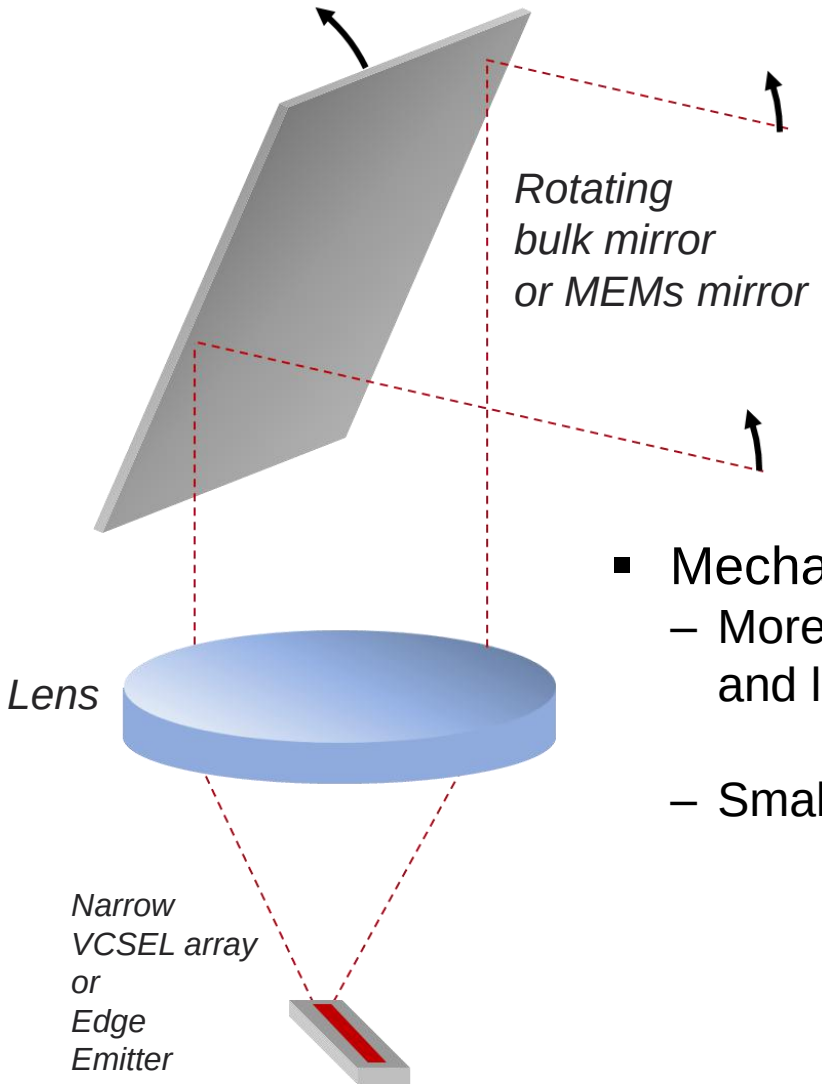
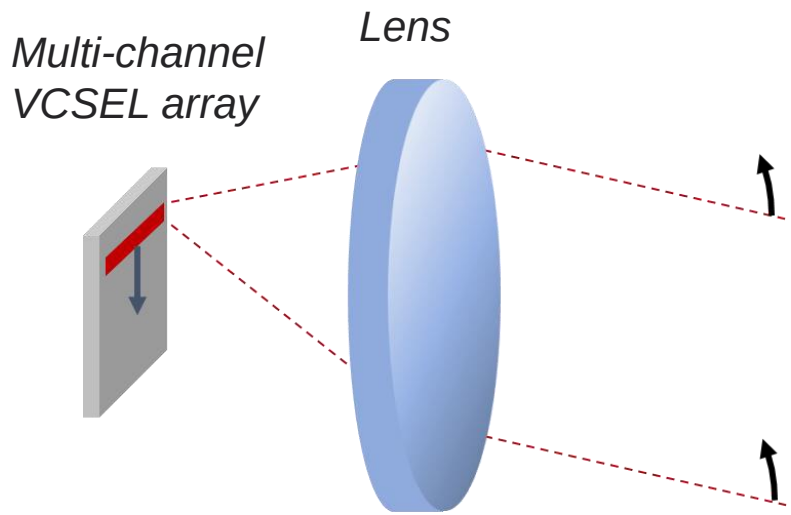
Electronic vs. Mechanical scanning

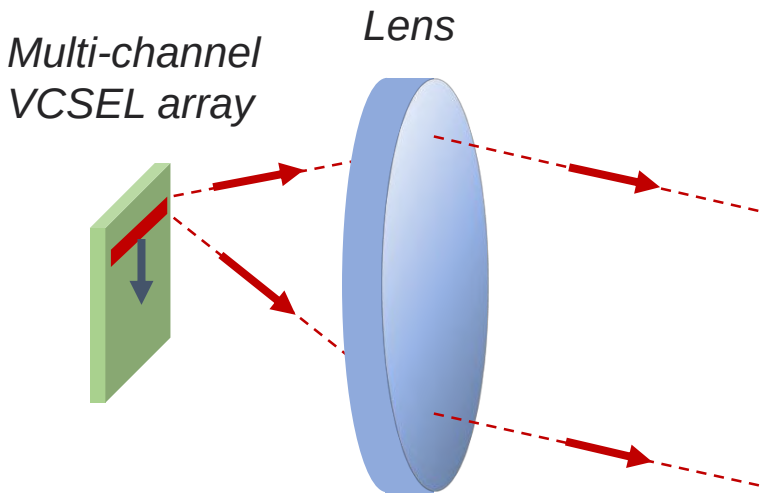


- Mechanical Scan LiDAR:
  - More complex, costly and larger optics
  - Smaller laser diode chip

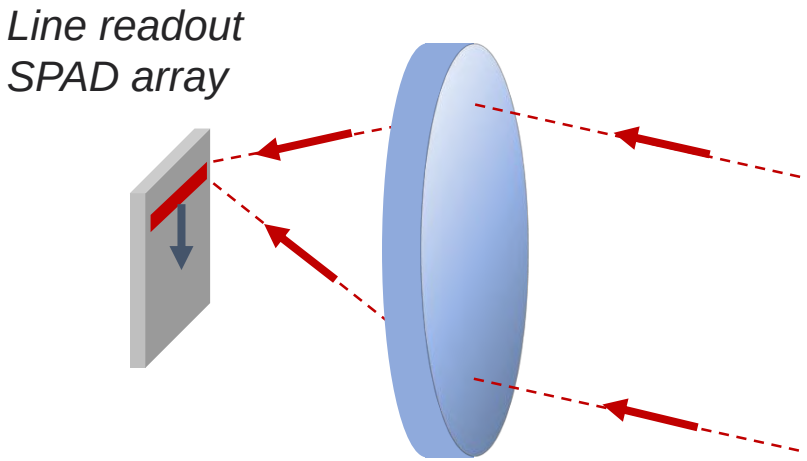


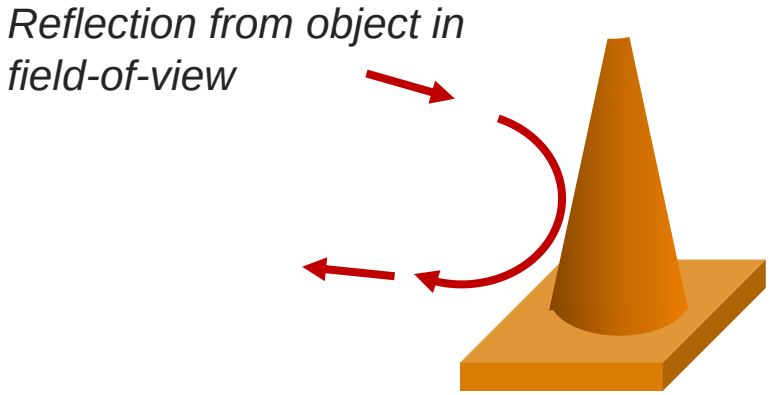
- All electronic scan LiDAR:
  - Simple, compact, robust optics
  - Already employed in consumer electronics for few meter range
  - Larger laser chip required vs. mechanical scan approach

Electronic Scan – Matching to Detector Array



- All electronic scan requires match between VCSEL array and single photon avalanche detector (SPAD) array
- Low complexity of optical solution(s) possible





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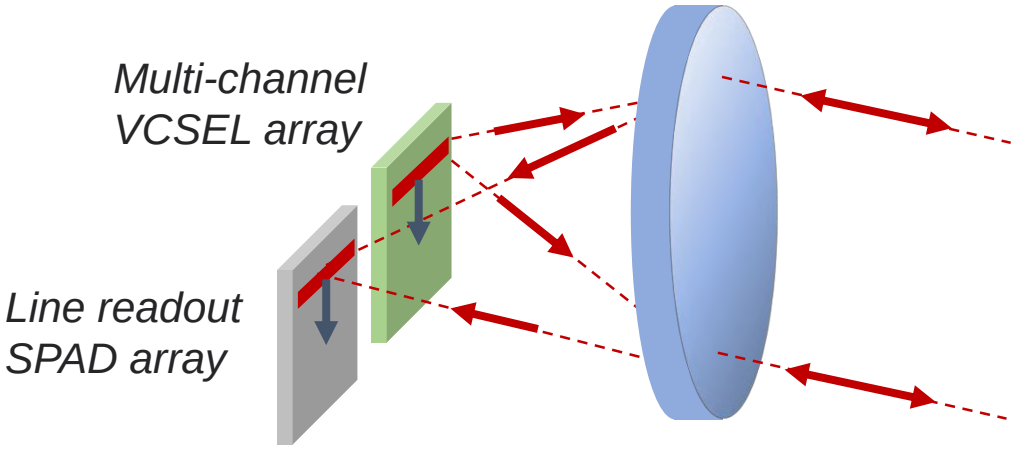
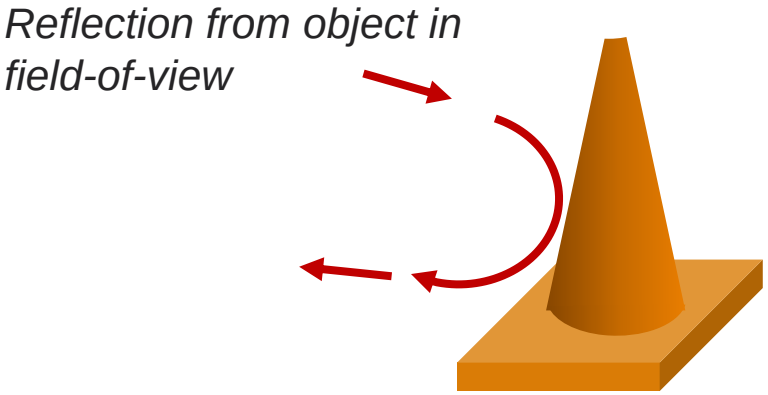
Electronic Scan – Matching to Detector Array

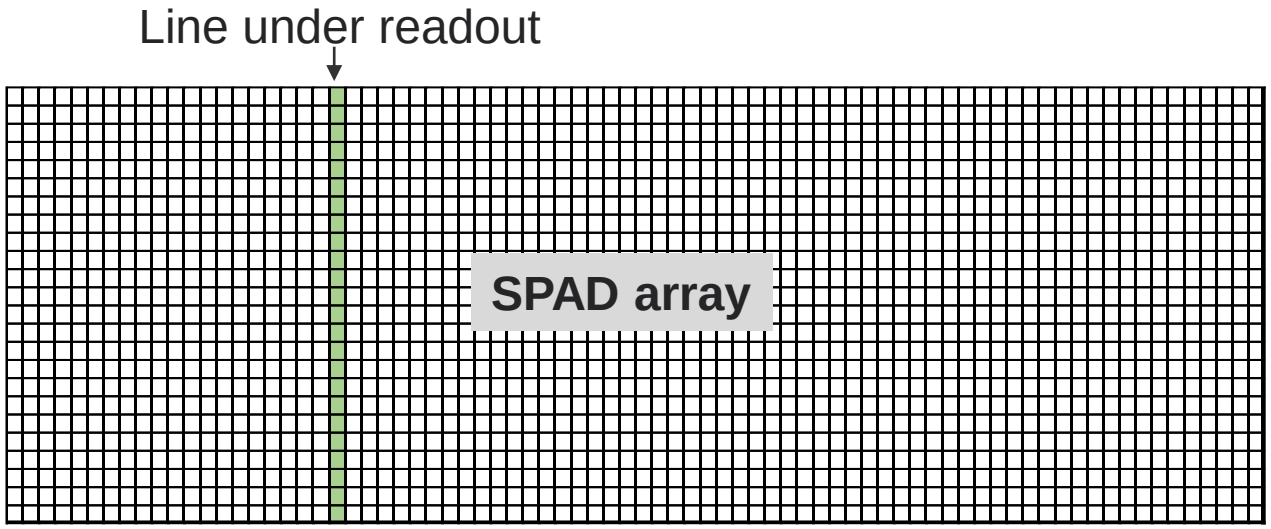


- All electronic scan requires match between VCSEL array and single photon avalanche detector (SPAD) array
- Low complexity of optical solution(s) possible
- Coaxial designs possible and already demonstrated!

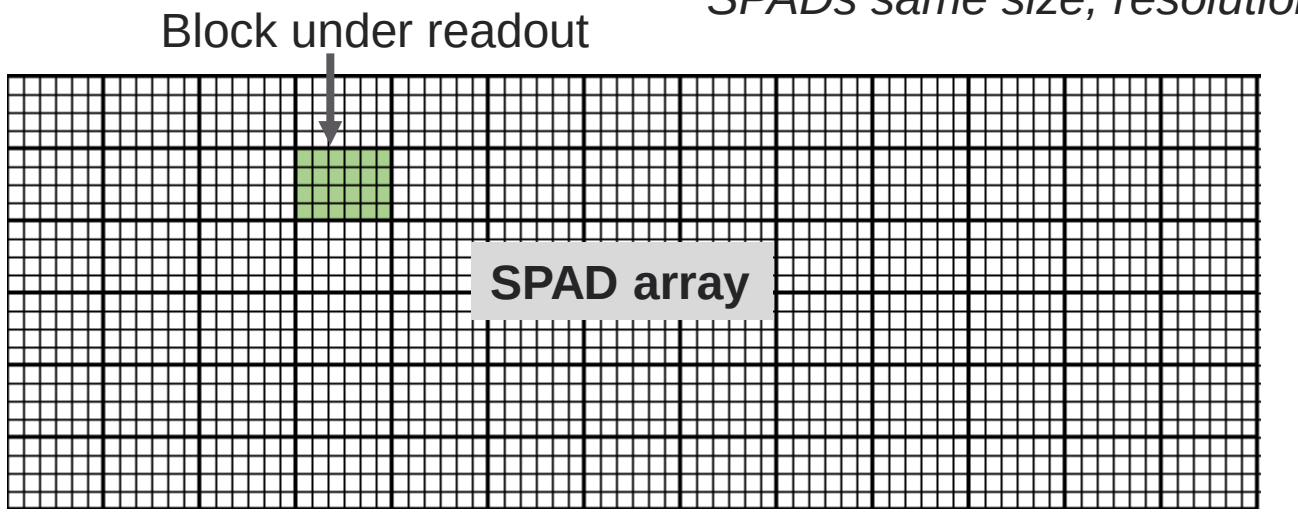


Matching to Single-Photon Avalanche Photodiode (SPAD) Arrays

- 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

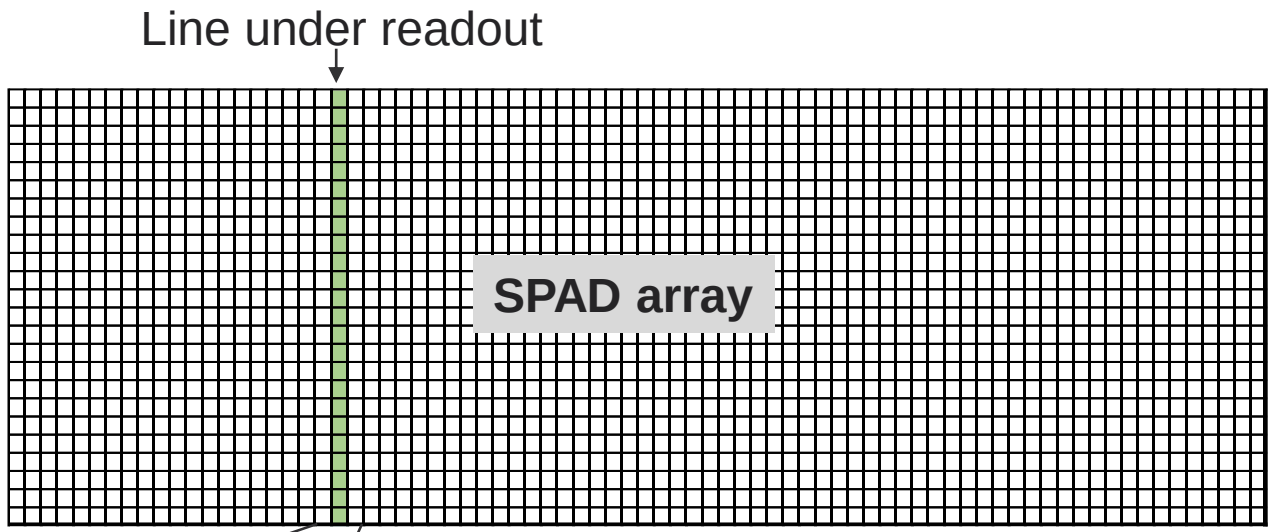


Both read-out zone same # of pixels.
SPADs same size, resolution

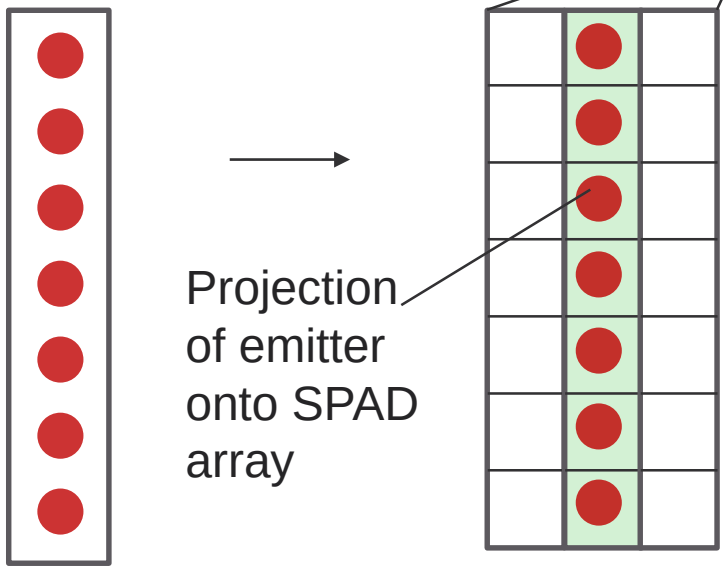


Matching Column Addressable VCSEL to Line Read-Out SPAD

- Trade-offs with line readout for column VCSEL arrays



VCSEL channel emitter pattern



1 to 1 match – many narrow VCSELs channels, large chip

VCSEL emitter pattern within channel

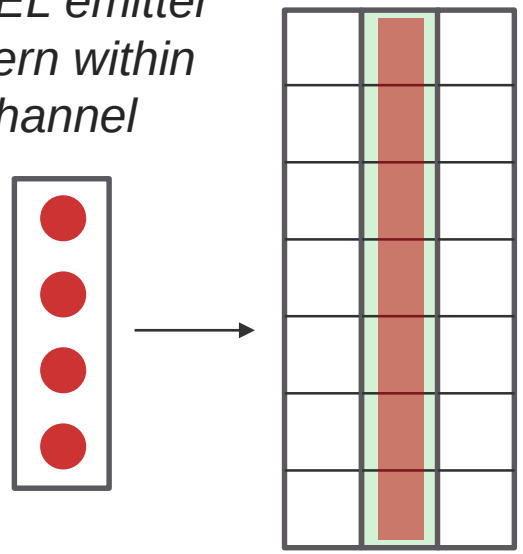


Image only x, diffuse in y:

- VCSEL channel lower aspect ratio, smaller chip
- Requires more complex optics
- Requires near 100% fill-factor of SPAD sensor pixel

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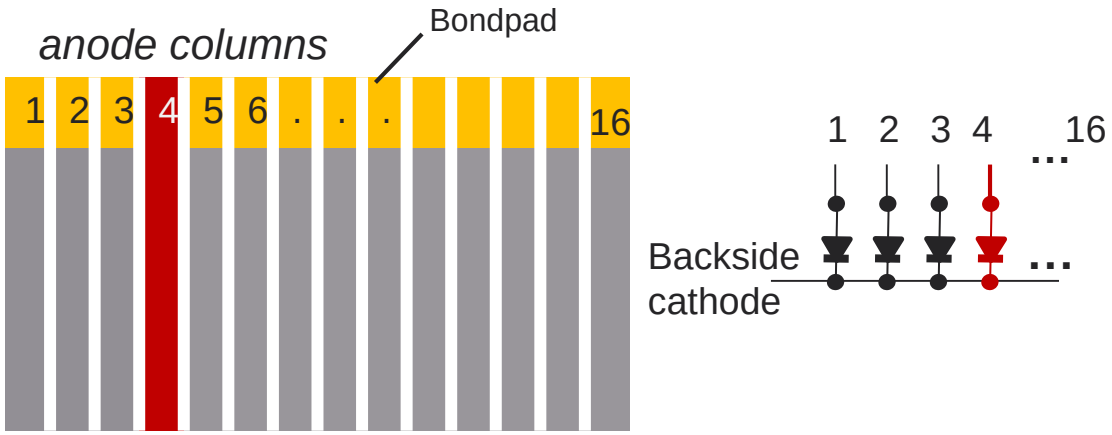
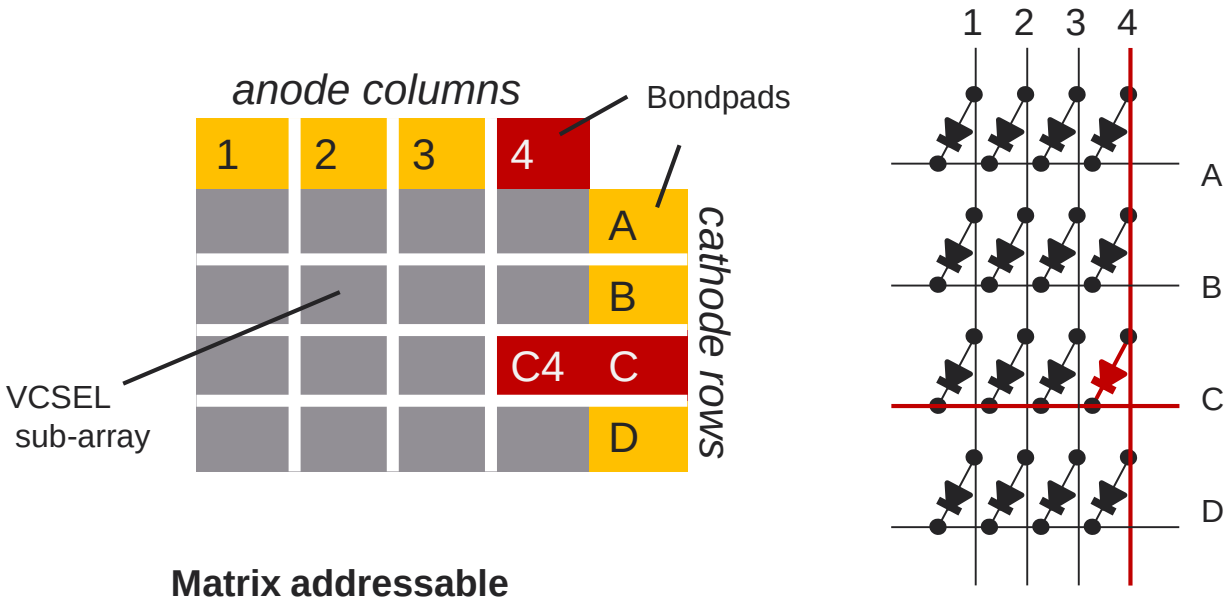
Addressable VCSEL Array Geometries





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

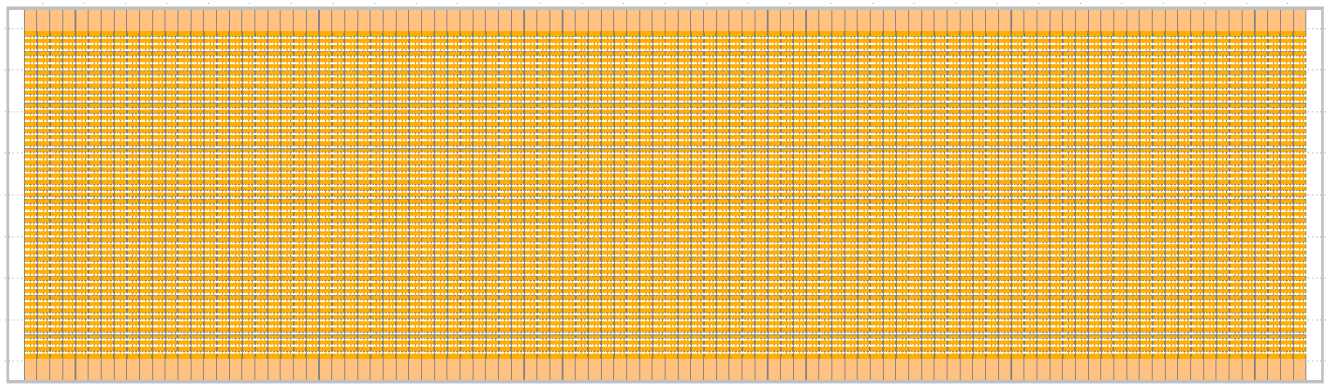
- Frontside anode and cathodes – overlapping
- Isolated substrate

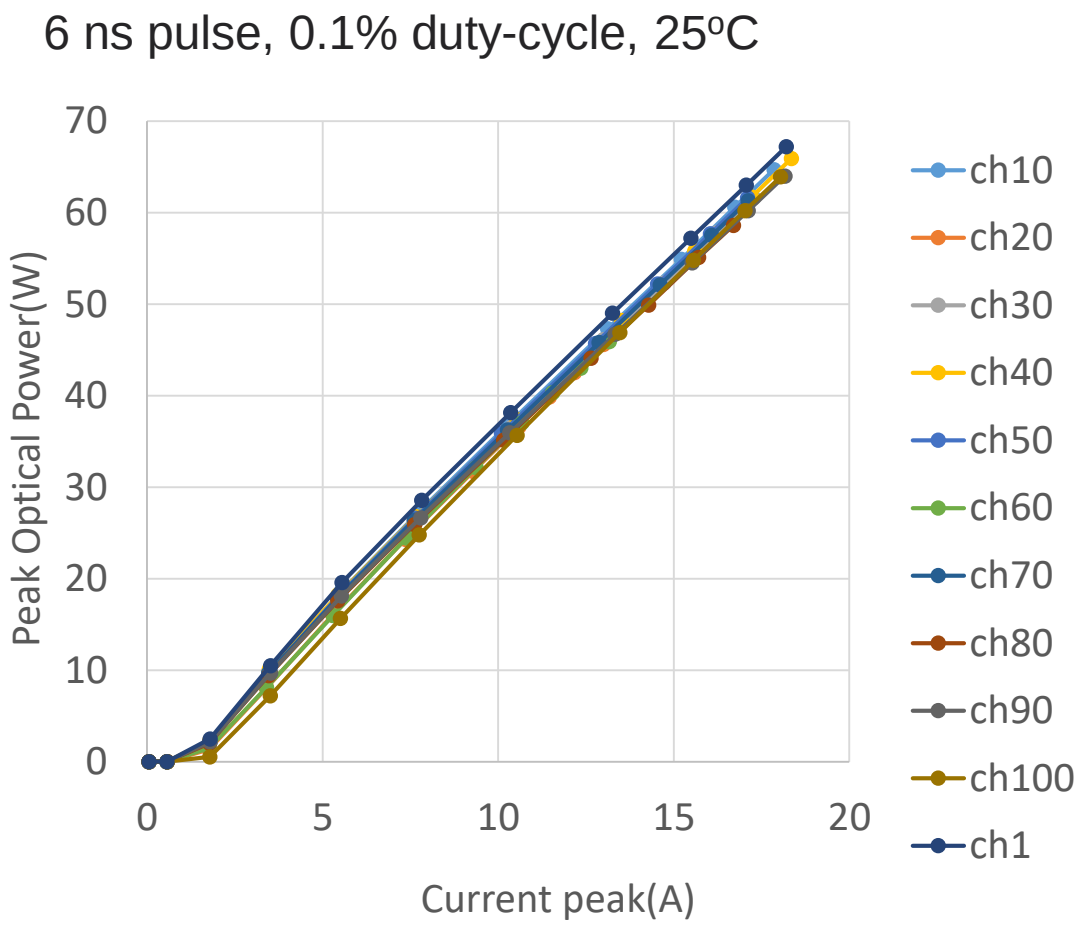
Pro/Cons:

- More complex fabrication but can be smaller than column addressable for similar number of channels
- Requires detector to 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

High-Power 1D Addressable Array

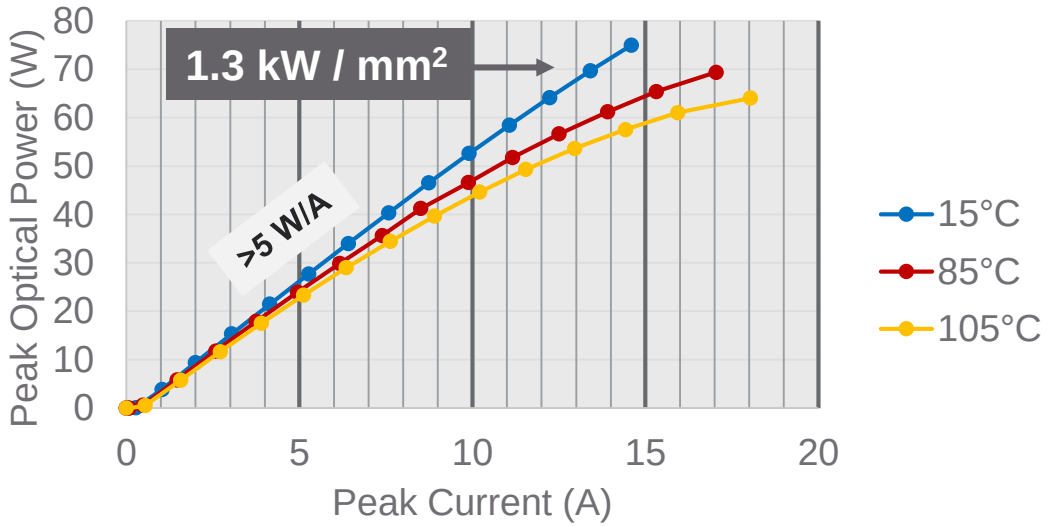
- 1d addressable chip
- 100 channels
- Chip size **16mm** x 4.5mm > 70mm^2
- 940nm, 5J

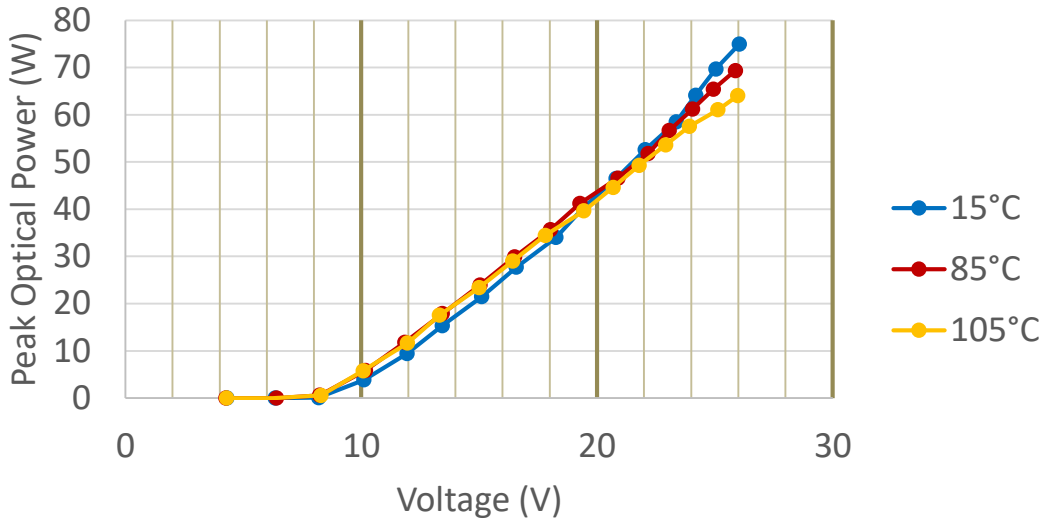


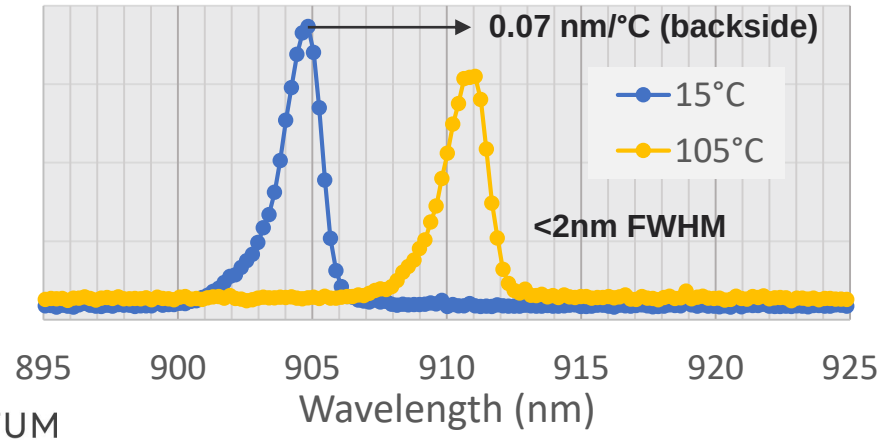


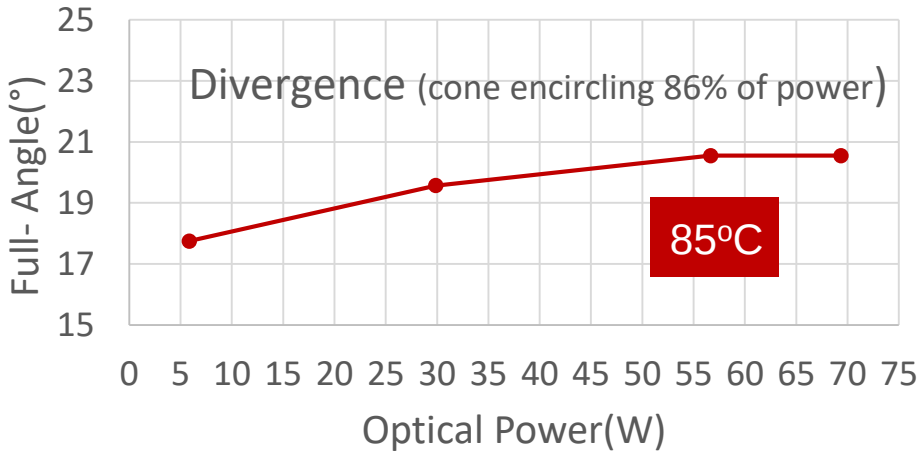
Results 2D Array, Individual Sub-Array *(in array of ~200 elements)*

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









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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

- These VCSEL laser chips are highly reliable and the infrastructure for cost efficient volume production is in place today

- Addressable VCSEL arrays for LiDAR
  - Simpler optics + no need for TEC
  - Proven at consumer volumes for shortest distances
  - Higher peak power densities > 1kW/mm^2 (low-duty-cycle, few ns pulse) permit extension to longer distances
  - Matrix addressability opens additional options for LiDAR architectures

Thank You