High efficiency multijunction VCSEL arrays for 3D sensing

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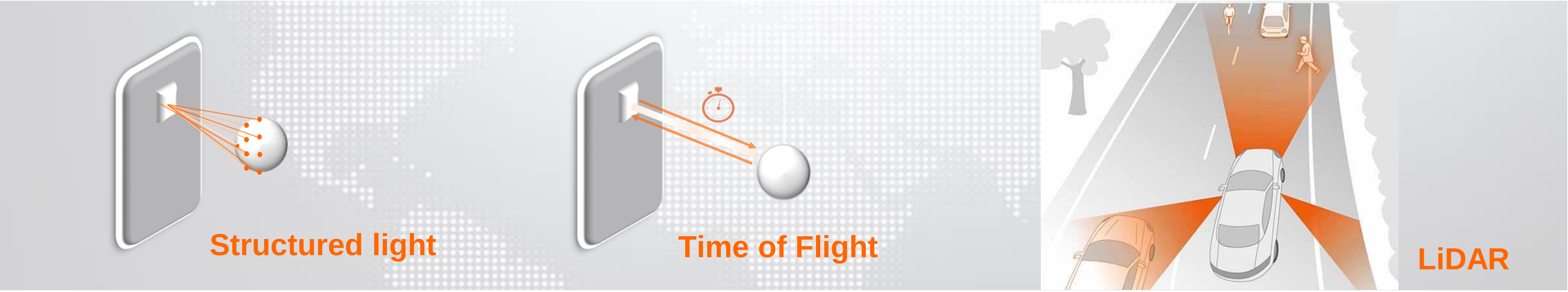
VCSELs in 3D sensing



- 3D optical sensors are becoming widespread in consumer, industrial, and automotive applications
- Several approaches depending on required range and resolution:
  - Structured light (short distance)
  - Time of flight (medium distance)
  - LiDAR (long distance)

VCSEL TOF illuminator

VCSEL based sensors:

Benefits:
- Beam quality (small spot, low divergence)
- Narrow spectral width
- Wavelength stability
- Fast rise time

Challenges:
- Power scaling
- Conversion efficiency (compared to edge emitters)

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940nm VCSEL development at Vixar

940nm wavelength preferred for 3D sensors

- Low interference from ambient light
- Outside visible wavelength range
- Compatible with CMOS cameras

Rapid improvements in 940nm VCSEL performance

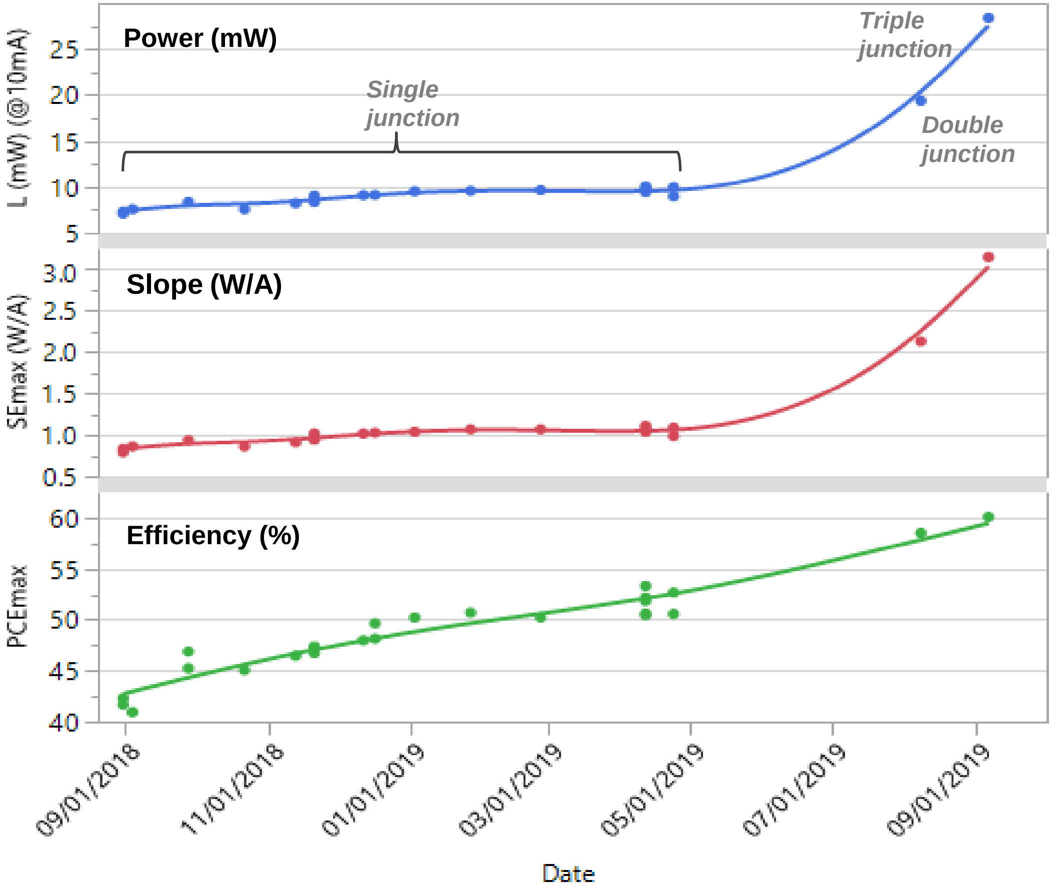
- Slope efficiency improvement from 0.85 W/A → 1.1 W/A
- 42% → 53% power conversion last year

Recent introduction of multijunction VCSELs

- Slope efficiency: >3 W/A
- Power conversion: >60%

Vixar 940nm VCSEL performance history

Single aperture VCSELs at room temp, CW



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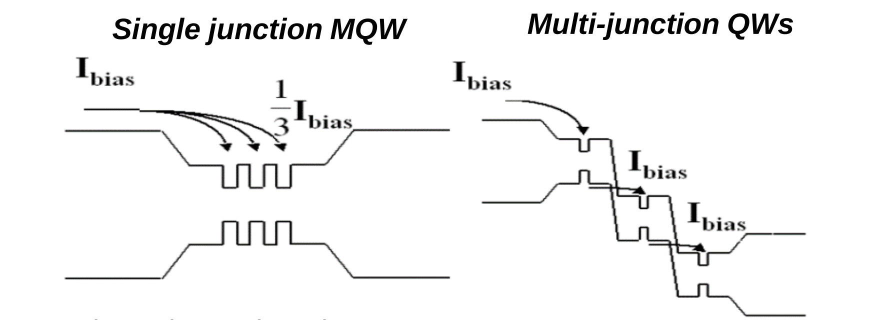
Multijunction VCSEL design

Motivation:

- Increase gain volume by periodically stacking active regions in cavity
- Carrier regeneration in tunnel junctions → increased slope efficiency
- Re-optimize gain & loss in cavity for net efficiency improvement
- Trade off voltage and current for driver compatibility (faster rise time)

Challenges:

- Requires low resistance & low absorption tunnel junction
- Precise layer tuning to align QWs and TJ with standing wave



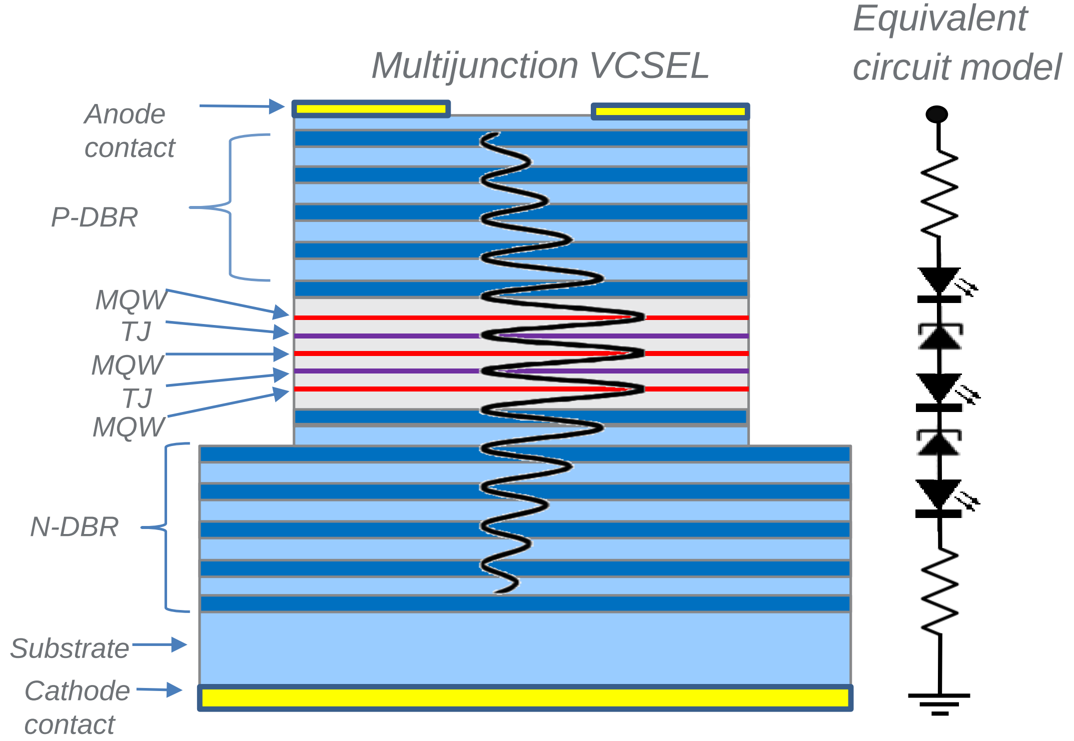
R. Koda et al, APL (2005)

Design Features:

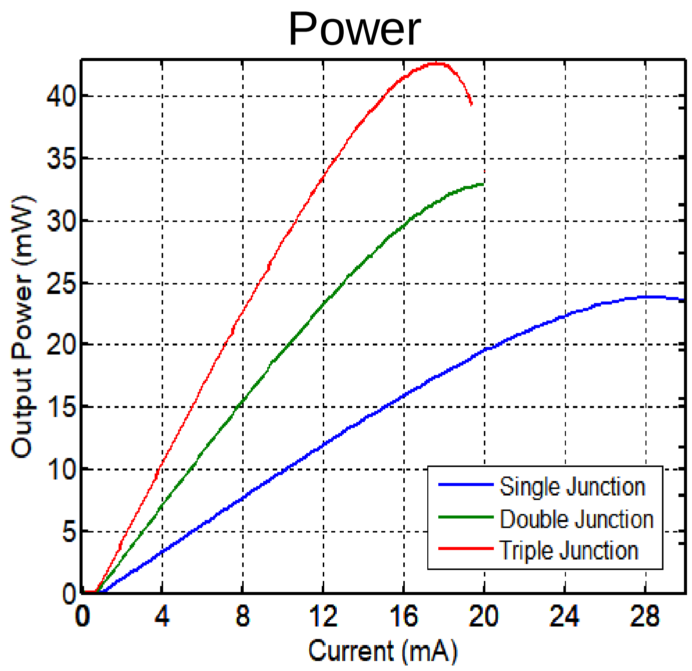
- Top emitting VCSEL with backside cathode
- Oxide aperture confinement
- p- and n-type AlGaAs DBRs
- Strained InGaAs MQWs
- Low resistance n+/p+ tunnel junction

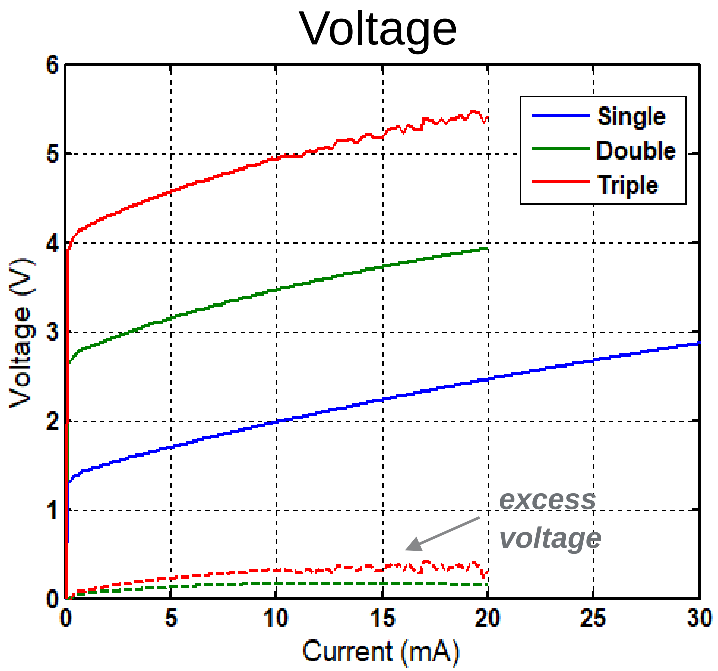
Compatible with high volume fabrication:

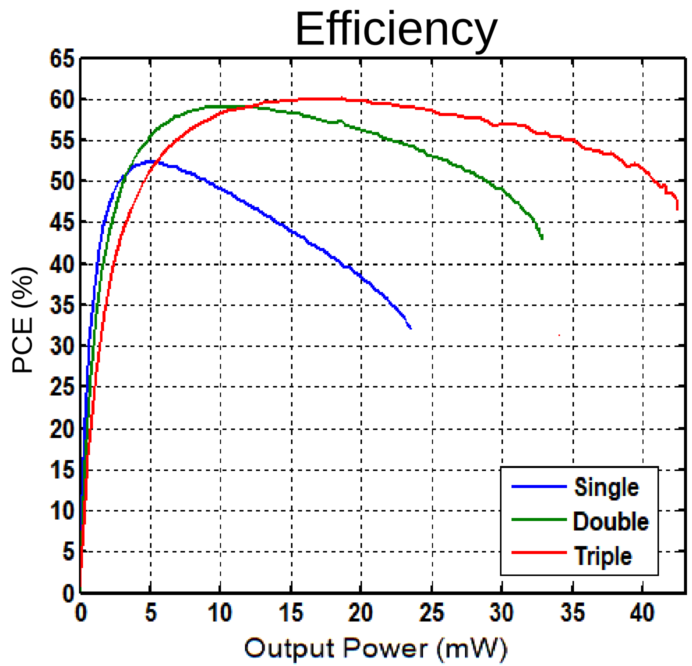
- n-type GaAs substrates
- MOCVD grown epi
- 6-inch wafer processing



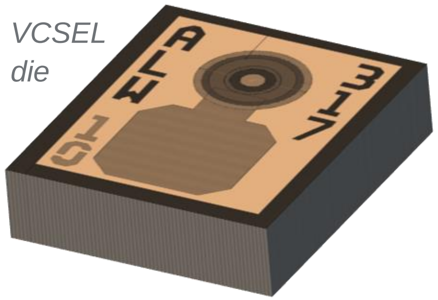
Single, double, triple junction 940nm comparison







VCSEL die



- Single 10um aperture VCSEL characterization
    - Continuous wave, room temp operation
- Slope efficiency and voltage scale with junctions
    - 2.1 W/A → 160% DQE
    - 3.15 W/A → 240% DQE
- Higher power & higher efficiency achieved
    - 60% PCE for triple junction VCSEL

Peak performance comparison:

Design	PCE	Power (mW)	Voltage (V)	Slope Eff. (mW/mA)
Single	52%	5.0	1.9	1.1
Double	59%	10	3.3	2.10
Triple	60%	17	4.6	3.15

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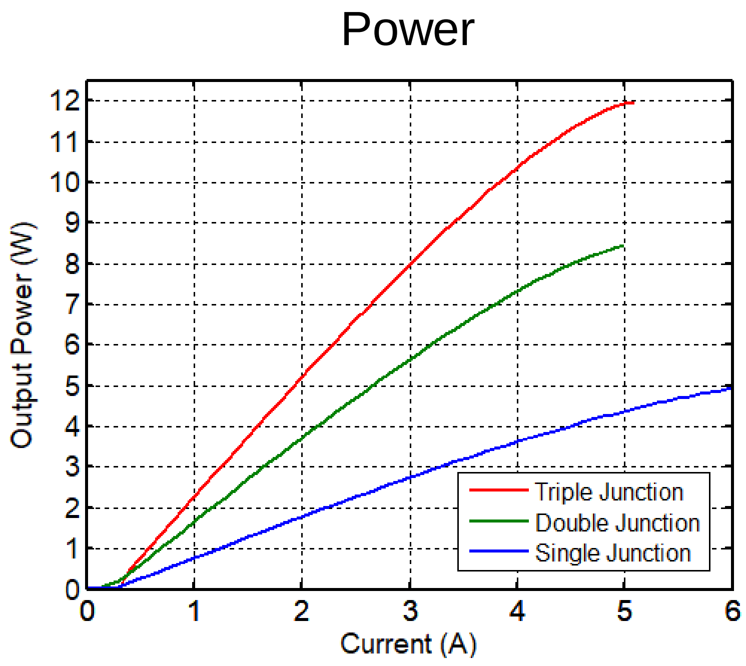
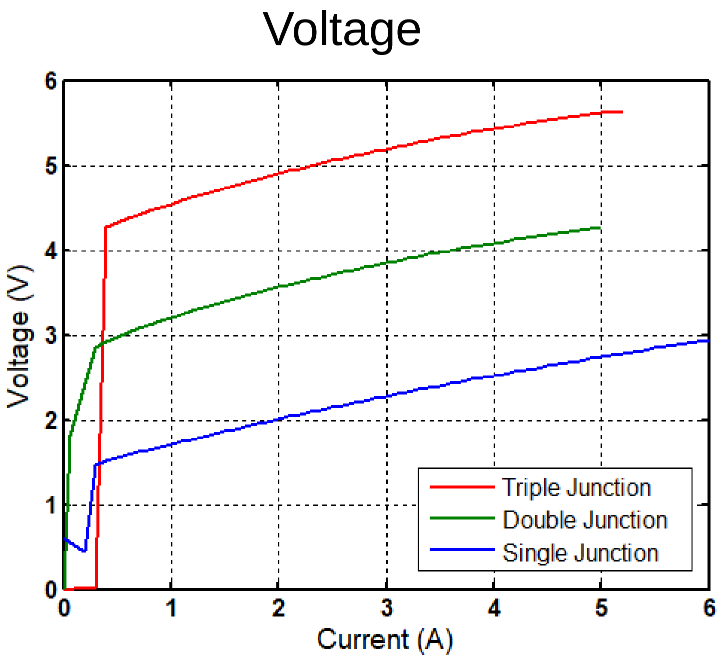
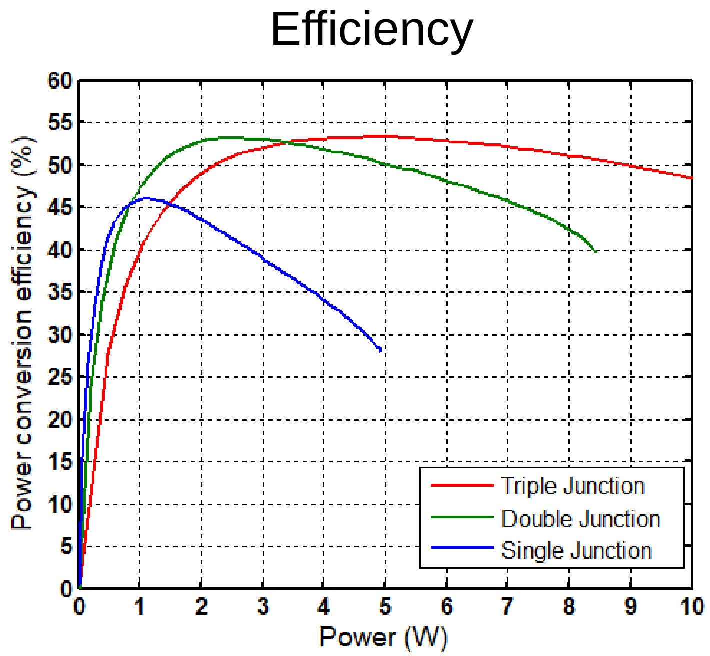
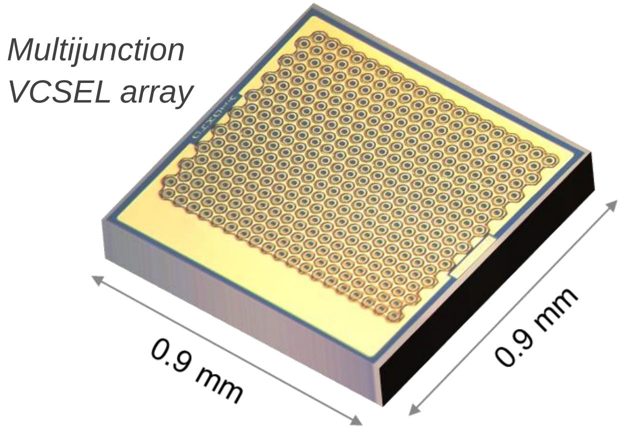
VCSEL array performance (single, double, & triple junction)









Fabricated VCSEL array die for high power

- 0.9 x 0.9 mm chip footprint
- 361 apertures (10um diameter)

LIV Comparison

- Operating condition: 100µs pulse width, 1% duty cycle, T=20ºC
- Peak efficiency of 53.3% at 2.5W & 5W (double and triple junction)
- Peak slope efficiency: 2.1 W/A & 3.0 W/A
- > 10W power at I=4A

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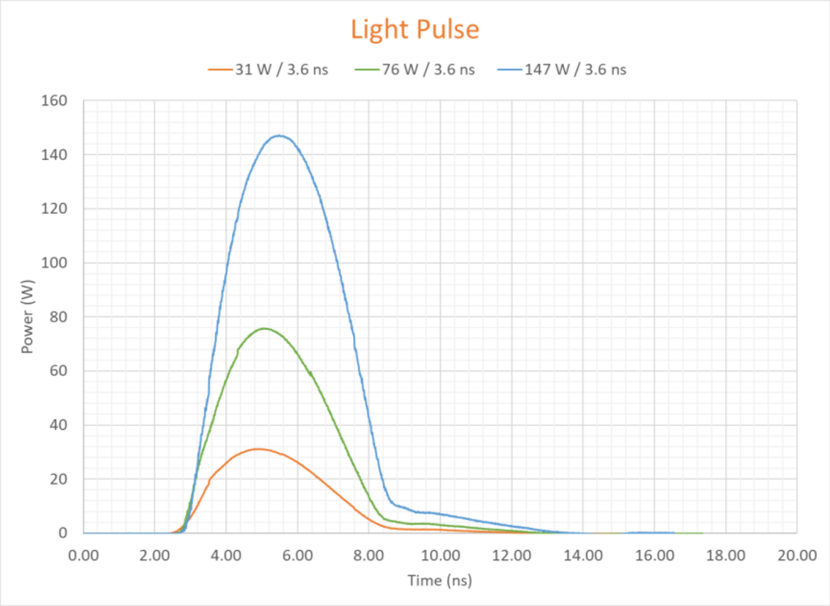
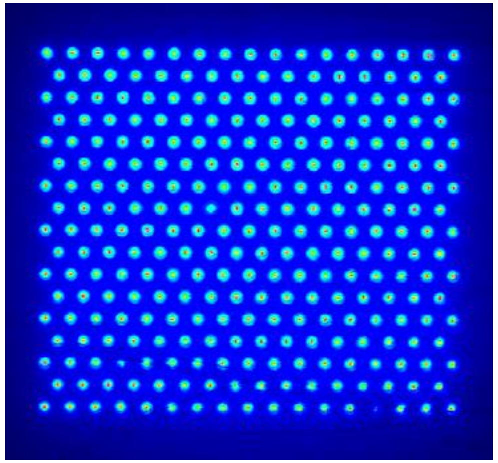
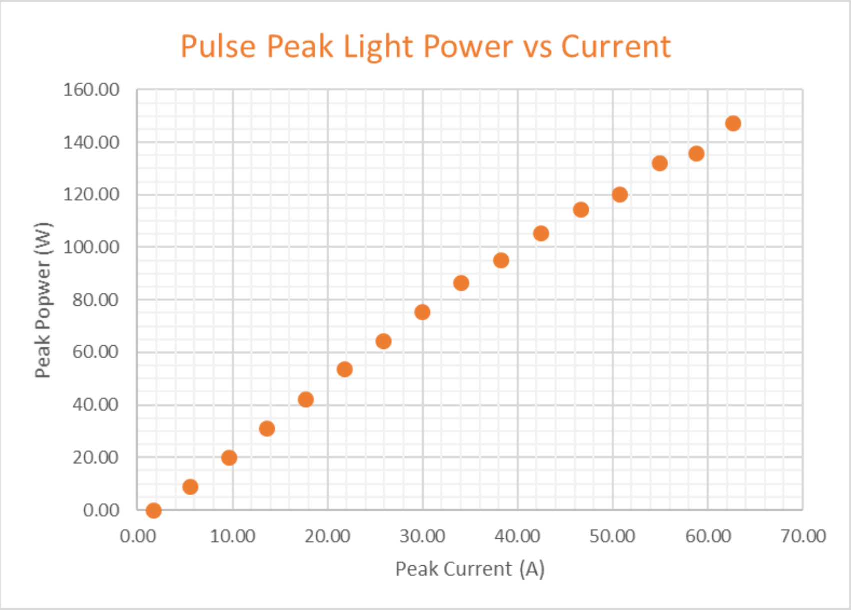
Short pulsed operation





3.6 ns
200 kHz
(0.1% duty cycle)



High power pulsing experiments conducted with GaN-FET based driver

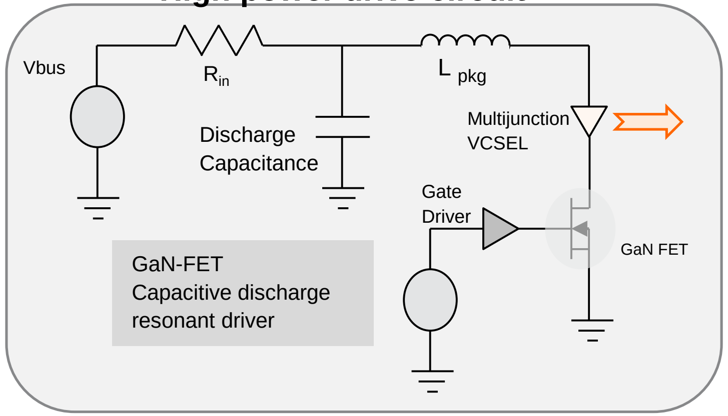
Triple Junction VCSEL array driven with 3.6ns pulses, 0.1% duty cycle

- Peak pulse power of **147W** recorded for 64 A peak current
- No rollover observed (power limited by driver)

Equivalent irradiance: **281W/mm²**

- Emission area: 0.77 x 0.68 mm²

High power drive circuit



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Conclusion

Demonstrated high power, high efficiency multijunction VCSELs at 940nm

- Measured slope efficiency: 2.1 W/A & 3.16 W/A (double & triple junction)
- Differential quantum efficiency: 160% & 240%
- **60% power conversion efficiency achieved**
    - Highest reported for a multijunction VCSEL

Demonstrated high power VCSEL arrays in small footprint (0.9 x 0.9 mm)

- 9W output power with >50% efficiency & only 3.5A required
- >100W peak power achievable with short pulsed operation (peak irradiance 281W/mm^2)

Multijunction VCSELs are promising devices for time-of-flight and LiDAR applications

Thank you

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