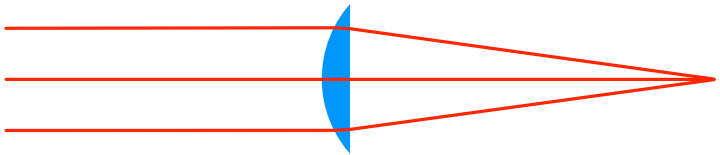
Eye-safe passively-q-switched lasers at 1.3 µm with >1 W average power and nsec pulses

Tom Kane & John Nightingale

Tom.Kane@ieee.org or JohnNightingale@aol.com

www.KaneOE.com

KANE OE



Presented at SPIE Defense + Commercial Sensing Conference, May 4, 2023. Paper 12515-13

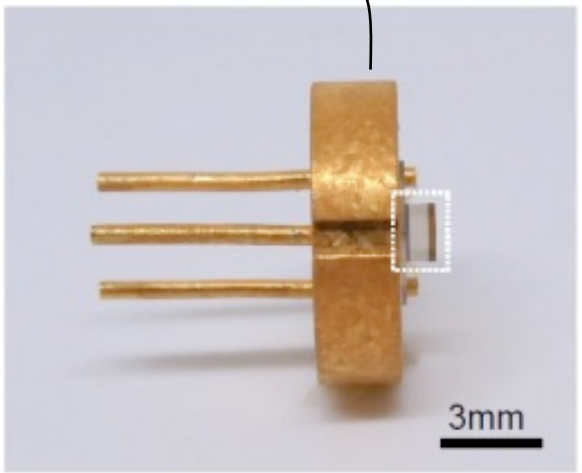
Overview

- Nd:YVO_4 / V:YAG laser operating at 1.3 µm optimized for >100 meter 3-D imaging
- Exploration of Nd:YAG / V:YAG operational space
- Comparison with 1.5 µm lasers

Why passively-q-switched lasers for LIDAR?

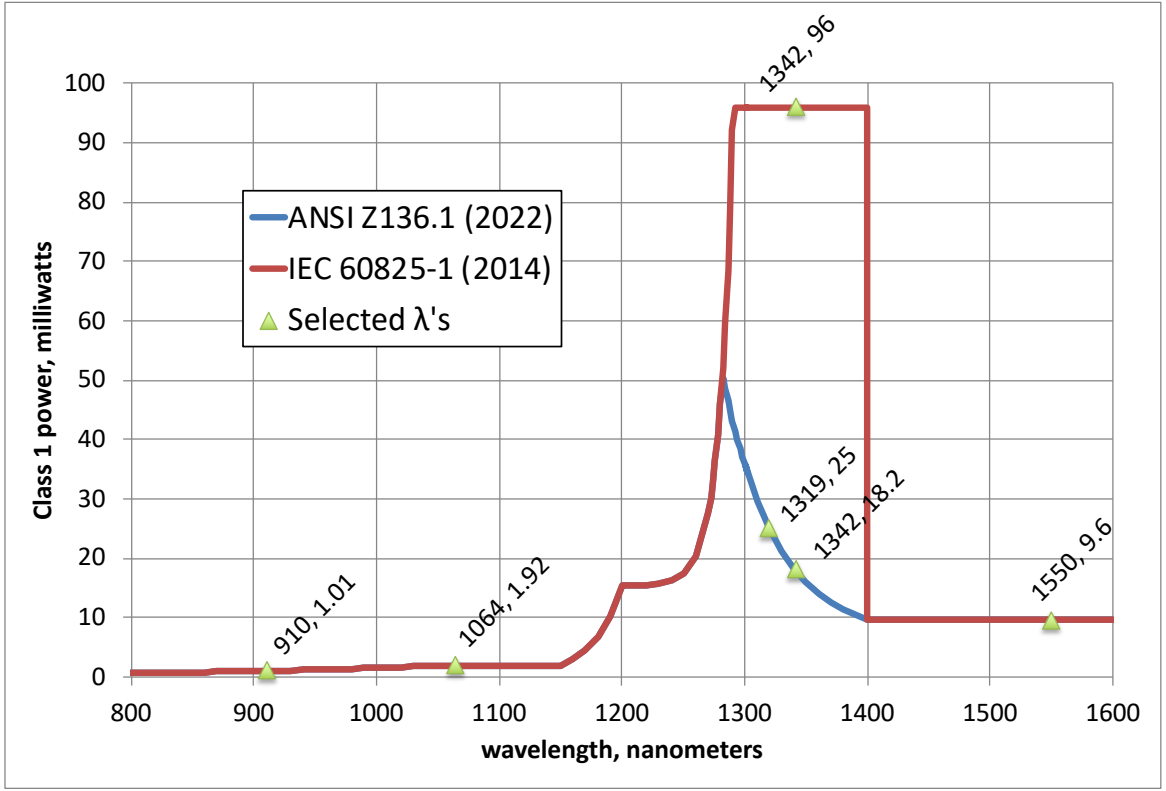
- Kilowatt-scale peak power
  - >> Semiconductor lasers
- Nanosecond pulses with no high-speed electronics
- Diffraction limited output, TEM_{00}
- Polarized output
- Fixed wavelength
- Small size
- Potentially inexpensive
  - Similar to laser pointer
- Eye-safe operating wavelength

Passively-switched laser from Kamata, et. al. CLEO, 2022 paper JTh6B.3



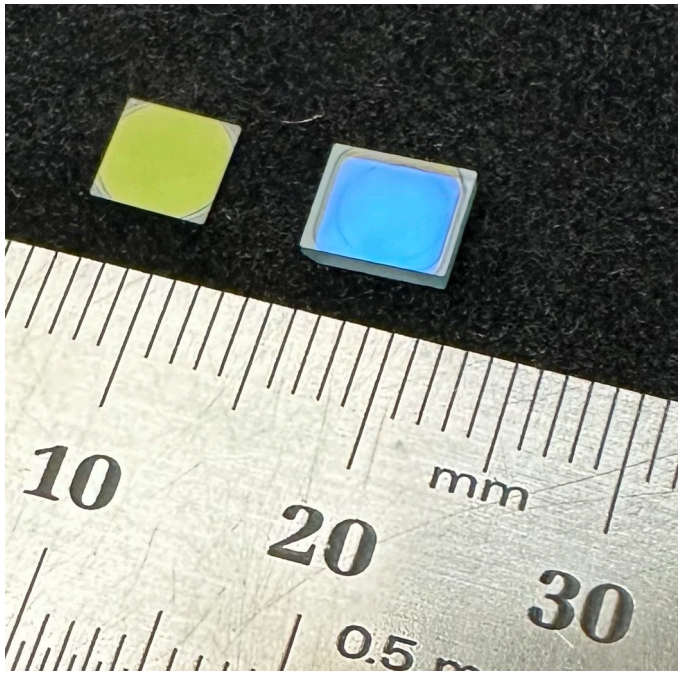
Eye safety window at 1.2 µm – 1.4 µm

- Exposure limit:
  - 0.9 µm << 1.5 µm < 1.3 µm
  - cw or >kHz rep rate



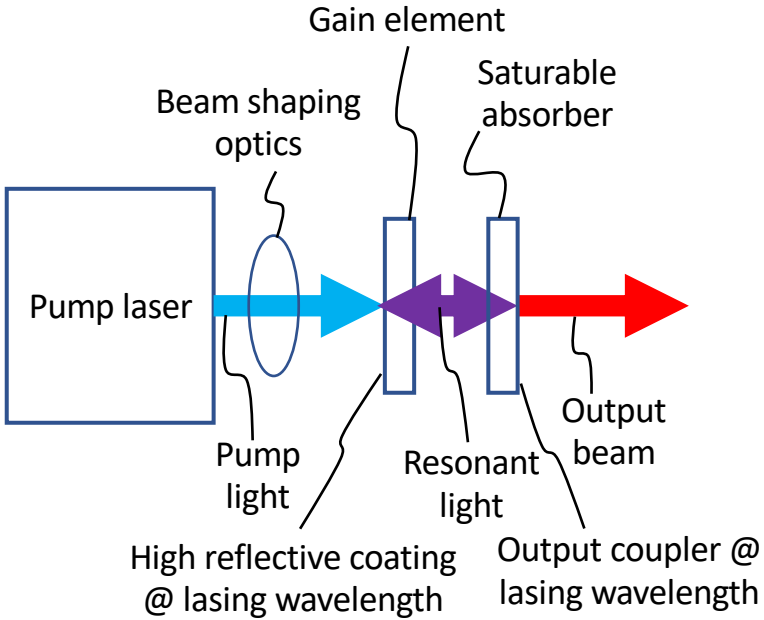
Background

- Passively-q-switched “microchip” lasers demonstrated in early ‘90’s
  - *Zayhowski*
- Demonstration of 1.3 μm operation using V:YAG as saturable absorber in mid ‘00’s
  - *Malyarevich, Šulc*
- Exploration of Nd:YVO_4 / V:YAG “envelope”
  - *Kane, Photonics West, Feb. 2020*

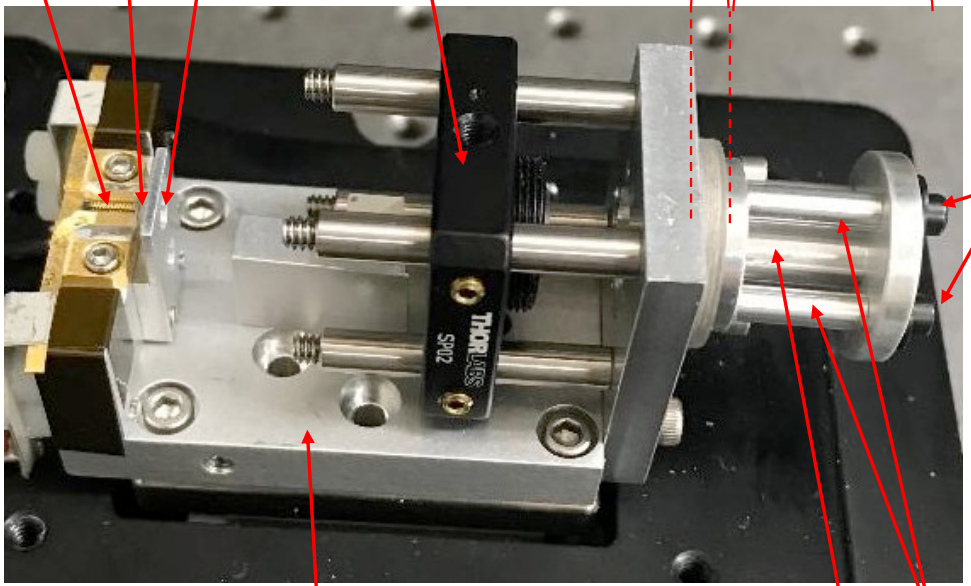


“Microchip” passively q-switched laser basics

- Pump laser
- Beam shaping optics
- Gain element
- Saturable absorber



LIDAR field test laser

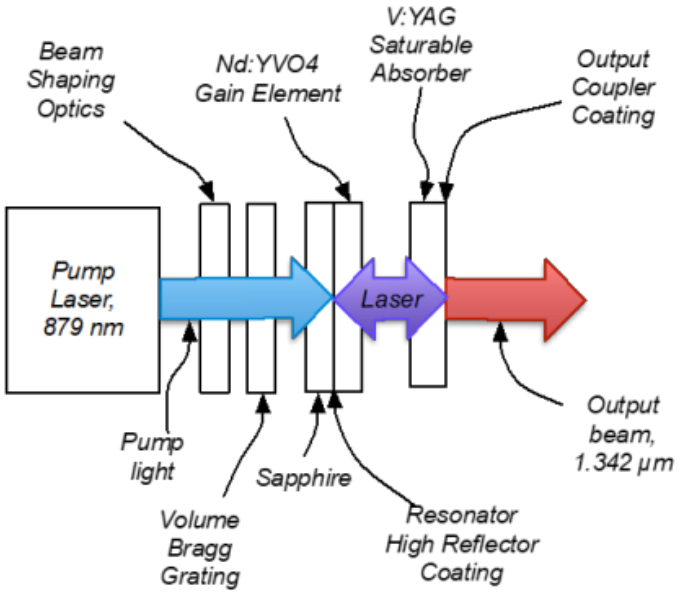


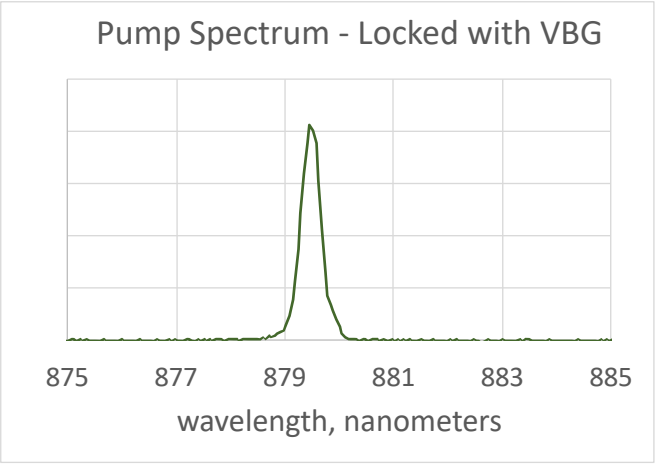
Material comparison

Material	$Nd:YVO_4$	Nd:YAG	Yb,Er:YAB
Eye-safe lasing wavelengths	1342 nm	1319 nm 1338 nm	1522 nm 1531 nm 1555 nm
Pump wavelength and tolerance	809±5 nm 879±1.5 nm	806.5±2 nm 869±1 nm	976±8 nm
Saturable absorber material	V:YAG		$Co:MgAl_2O_4$
Optical-optical slope efficiency, cw	35%	35%	35%
Pump 1/e absorption depth, mm (standard doping)	0.3 at 808 nm 0.6 at 879 nm	4 at 869 nm 4 at 806.5 nm	0.6 at 976 nm
Thermal conductivity, W/(m•K)	5	11	7
Gain cross section (10^{-20} cm^2)	26	10	2.6

$Nd:YVO_4$ lasers

- Pump grating stabilized to 879 nm
- Sapphire heat spreader
- Two configurations
  - Short pulse, > 1 µJ pulse energy @ 500 kHz pulse frequency
  - "High" efficiency
    - Longer pulse width due to thinner V:YAG



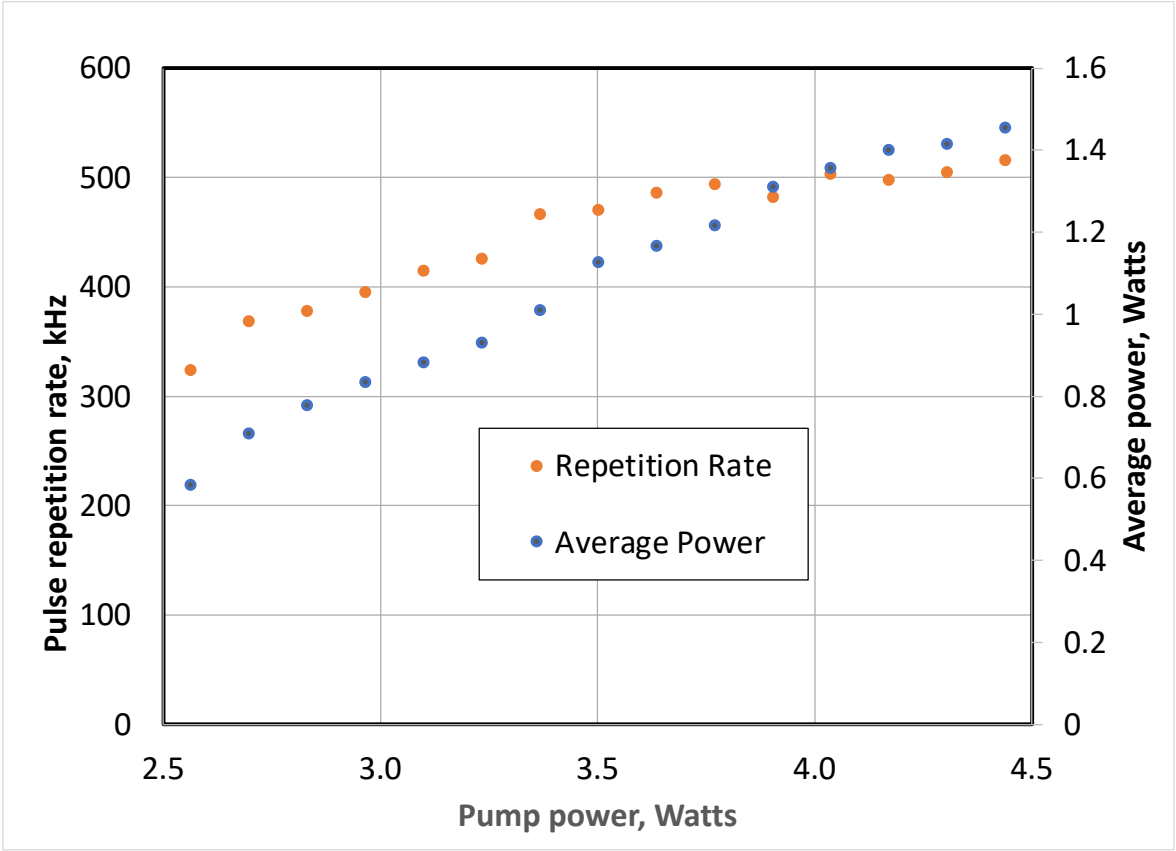


Nd:YVO_4 results & comparison with 1.5 µm lasers

Parameter	#1: Nd:YVO_4 optimized for short pulses	#2: Nd:YVO_4 optimized for efficiency	Yb:Er:YAB cw pumped *Zha, (2021)*	Yb:Er:YAB qcw, 100 Hz, 20% duty cycle
Lasing wavelength	1342 nm		1548 nm	1553 nm
Saturable absorber thickness	0.5 mm	0.4 mm	1.3 mm	
Pulse duration, FWHM	2.0 nsec	4.2 nsec	8.0 nsec	8.3 nsec
Pulse repetition rate	501 kHz	516 kHz	144 kHz	544 kHz (burst)
Pulse energy	2.45 µJ	2.82 µJ	1.7 µJ	3.9 µJ
Average output power	1.23 W	1.45 W	0.24 W	0.42 W
Peak power	1.23 kW	0.68 kW	0.21 kW	0.47 kW
Pump power	5.87 W	4.44 W	6.3 W	20 W (4 W avg.)
Optical-to-optical efficiency	20.9%	32.8%	3.9%	10.6%

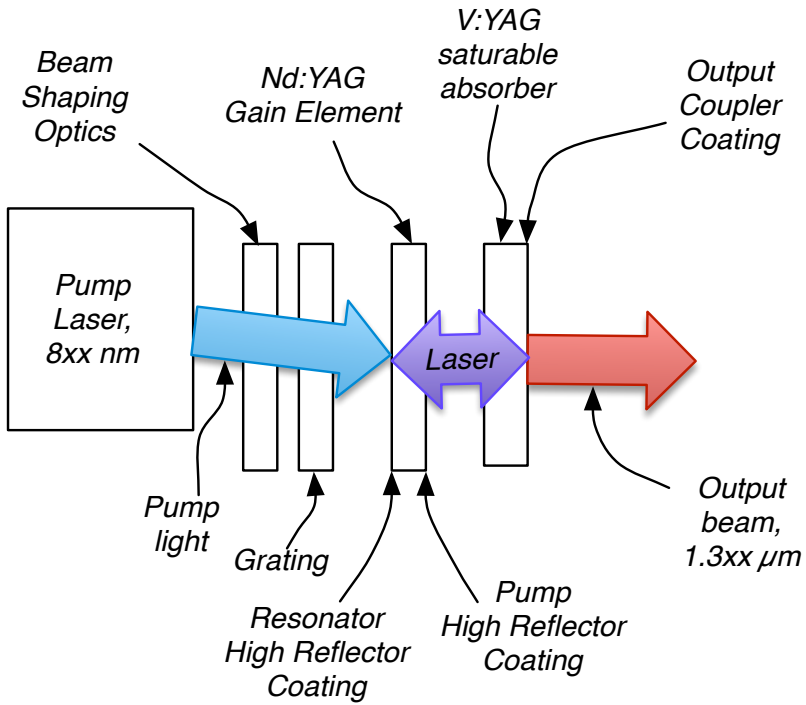
Average power and rep rate vs. pump power

Configuration #2 - efficient



Nd:YAG lasers

- Differences from Nd:YVO_4
  - Pump wavelengths 808 & 869 nm
  - Internal high reflector to double pass pump
    - Angle pump in gain element to minimize feedback into pump laser
  - Thicker gain element 3 mm vs. 2 mm
  - No sapphire heat spreader



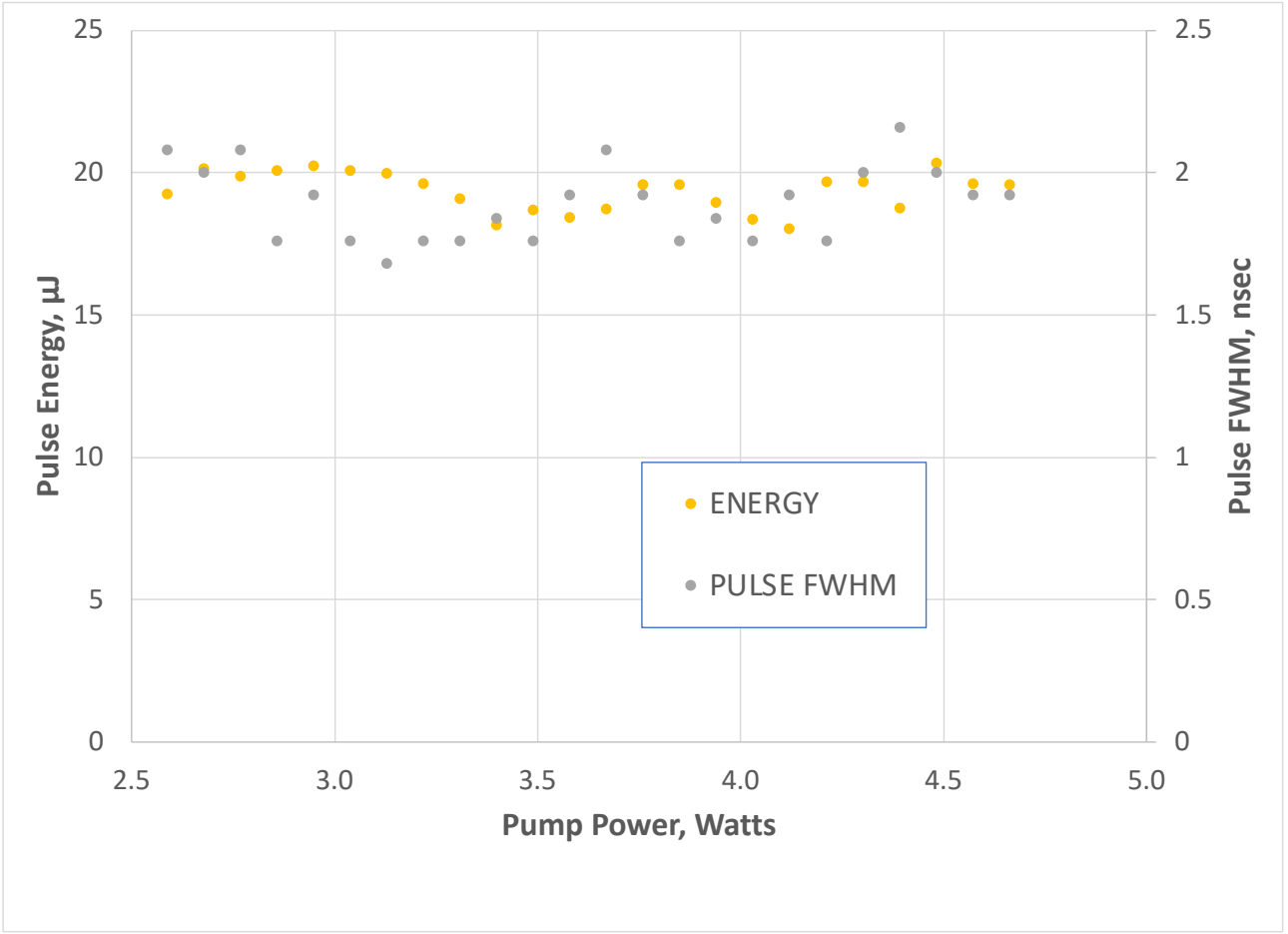
Nd:YAG results & comparison with 1.5 µm lasers (cw pumping)

Parameter	#3: Nd:YAG optimized for peak power	#4: Nd:YAG optimized for efficiency	Yb:Er:GdAB Ref [13]	Yb:Er:YAB Ref [3]
Lasing wavelength	1319 nm, 1338 nm		1550 nm	1553 nm
Saturable absorber thickness	0.6 mm	0.3 mm	0.75 mm	1 mm
Pulse duration, FWHM	1.92 nsec	5.0 nsec	12 nsec	7 nsec
Pulse repetition rate	20 kHz	160 kHz	32 kHz	77 kHz
Pulse energy	19.6 µJ	5.9 µJ	18.7 µJ	10 µJ
Average output power	0.39 W	0.94 W	0.60 W	0.77 W
Peak Power	7 kW	0.8 kW	1.1 kW	1.0 kW
Pump power	4.7 W	4.1 W	5.9 W	7.2 W
Optical-to-optical efficiency	8.2%	22.9%	10.1%	10.7%

Ref [3] Chen (2019) *Ref [13] Gorbachenya (2016)*

Pulse energy and pulse width vs. pump power

Configuration #3 – peak power

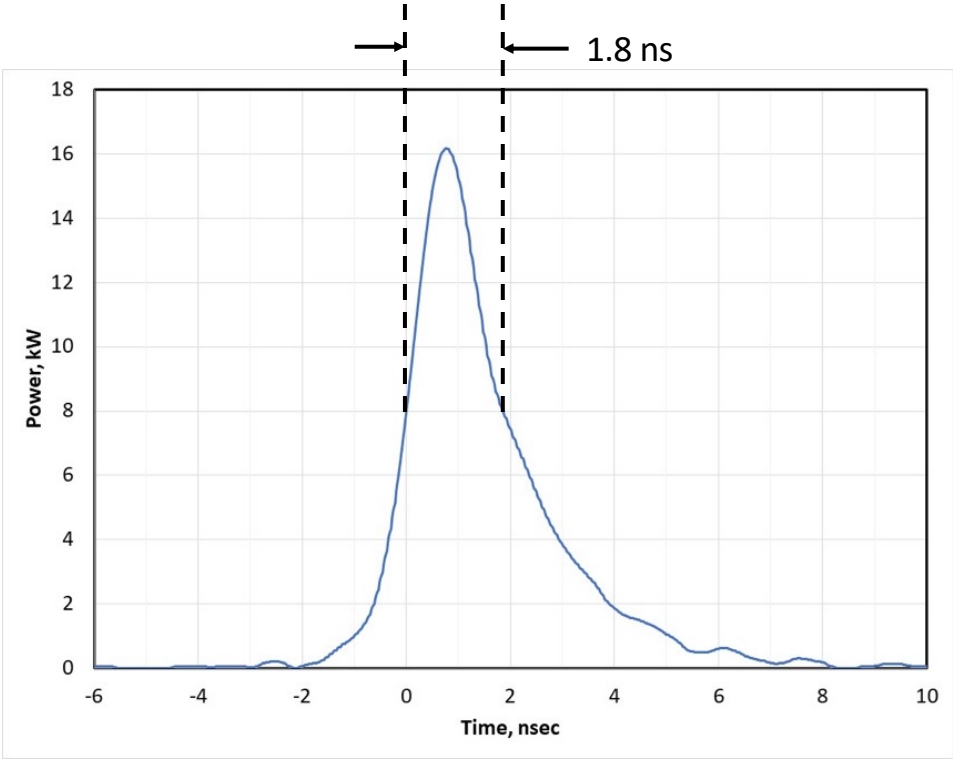


Nd:YAG results & comparison with 1.5 µm lasers (qcw pumping)

Parameter	#5: Nd:YAG_qcw	Yb:Er:LuAB qcw *Chen (2021)*
Laser material	Nd:YAG	Yb,Er:LuAB
Lasing wavelength	1338 nm	1522 nm
Q-switched pulse duration	1.8 nsec	1.9 nsec
Repetition rate	1000 Hertz	100 Hertz
Pulse energy	40 µJ	48.3 µJ
Average output power	40 mW	4.8 mW
Peak Power	16 kW	18 kW
Pump power and duration	4.3 W for 0.25 msec	24.6 W for 0.5 msec
Pump duty cycle	26%	5%
Pump power (average)	1.1 W	1.2 W
Optical-to-optical efficiency	3.8%	0.4%

Pulse shape

Qcw pumped Nd:YAG



Summary

- Nd:YVO_4 microchip lasers can achieve
  - >1 W average power
  - nanosecond pulse width
  - kilowatt peak power
  - 500 kHz pulse repetition rate
  - >30% optical-to-optical efficiency
- Nd:YAG enables >10X higher peak power at lower rep rate
- 1.3 μm lasers are superior to 1.5 μm lasers in terms of eye safety, peak power, efficiency & repetition rate
  - Comparable pulse energies

Possible future work

- Further optimization of 1.3 μm lasers for specific application
  - Thermal management of Nd:YVO_4
  - Higher pump power for Nd:YAG
- Laser packaging
- V:YAG optimization
- Interested in finding partner to integrate laser into LIDAR systems