1.34 µm Nd:YVO_4 laser passively q-switched by V:YAG and optimized for LIDAR

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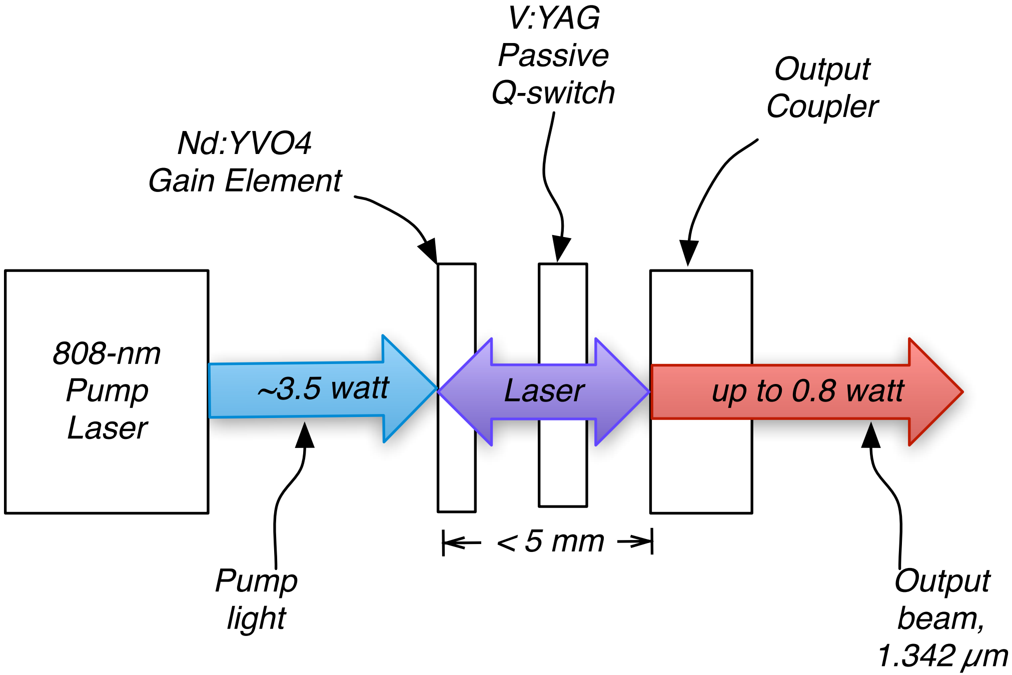
Demonstrated Results

Specification	Value and comment
Pulse duration	1.08 nanosecond
Peak power	1800 watts
Pulse Energy	3.8 microjoules (μJ)
Beam quality	Diffraction limited and polarized
Pulse repetition frequency (PRF)	1.8 MHz, with increased pulse duration and lower pulse energy
Average Power	Up to 25% of the pump power (0.75 watts out for 3 watts in)
Wavelength	1342±1 nm. In the best range for eye-safety – better than 1500 nm
Pulse timing jitter	This depends on design choices; there are design trade-offs

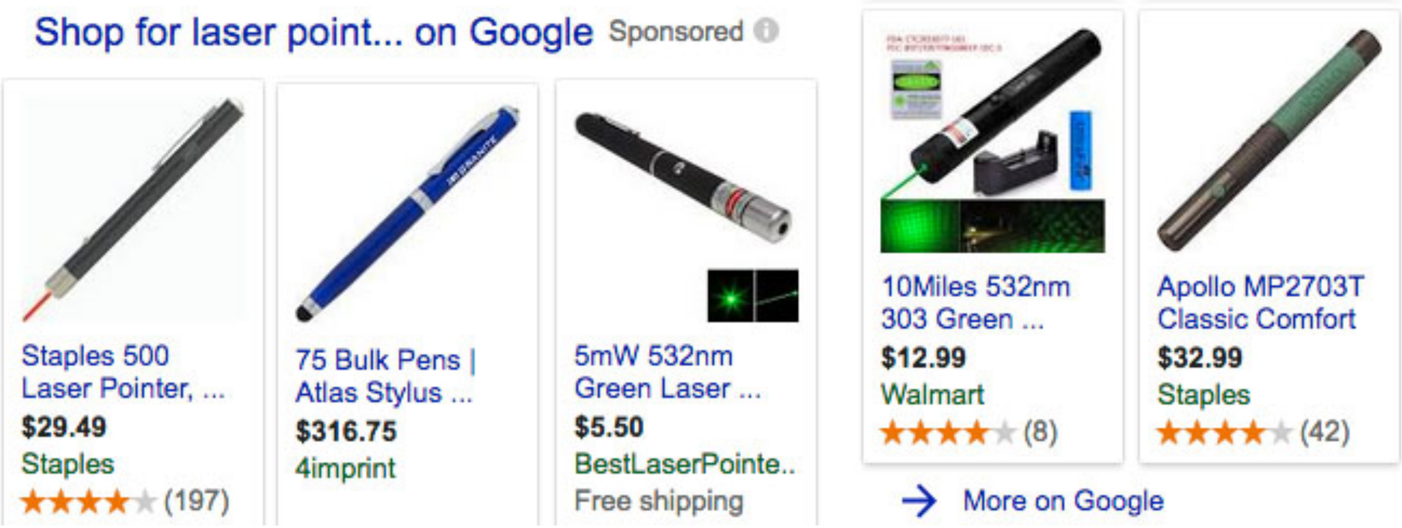
Diode-pumped “Microchip” laser

- Gain Material:
  - Nd:YVO_4
- Q-switch material
  - Vanadium:YAG
  - “Saturable Absorber”
- Very similar to well-known Nd:YAG / Cr:YAG system
- Better in most ways



Almost identical in design to "pointer" lasers

- Pointer
  - KTP
- This Design
  - V:YAG



Shop for laser point... on Google Sponsored

Staples 500 Laser Pointer, ...
$29.49
Staples
★★★★☆ (197)

75 Bulk Pens | Atlas Stylus ...
$316.75
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5mW 532nm Green Laser ...
$5.50
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★★★★☆ (8)

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$32.99
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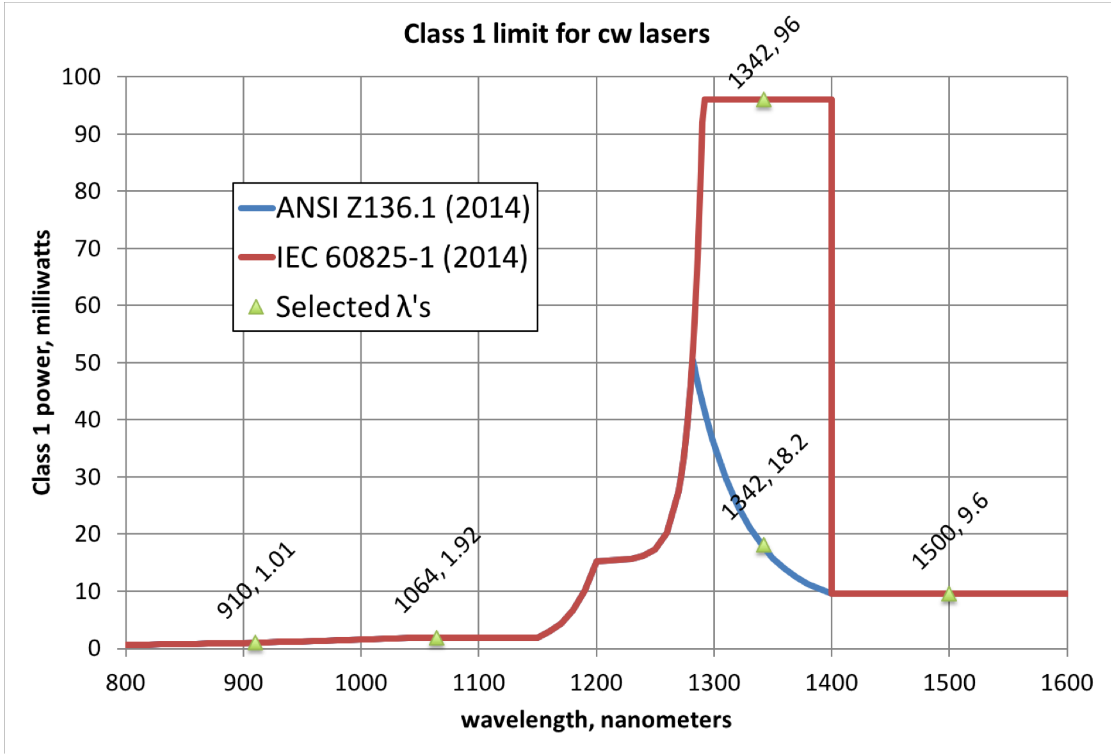
→ More on Google

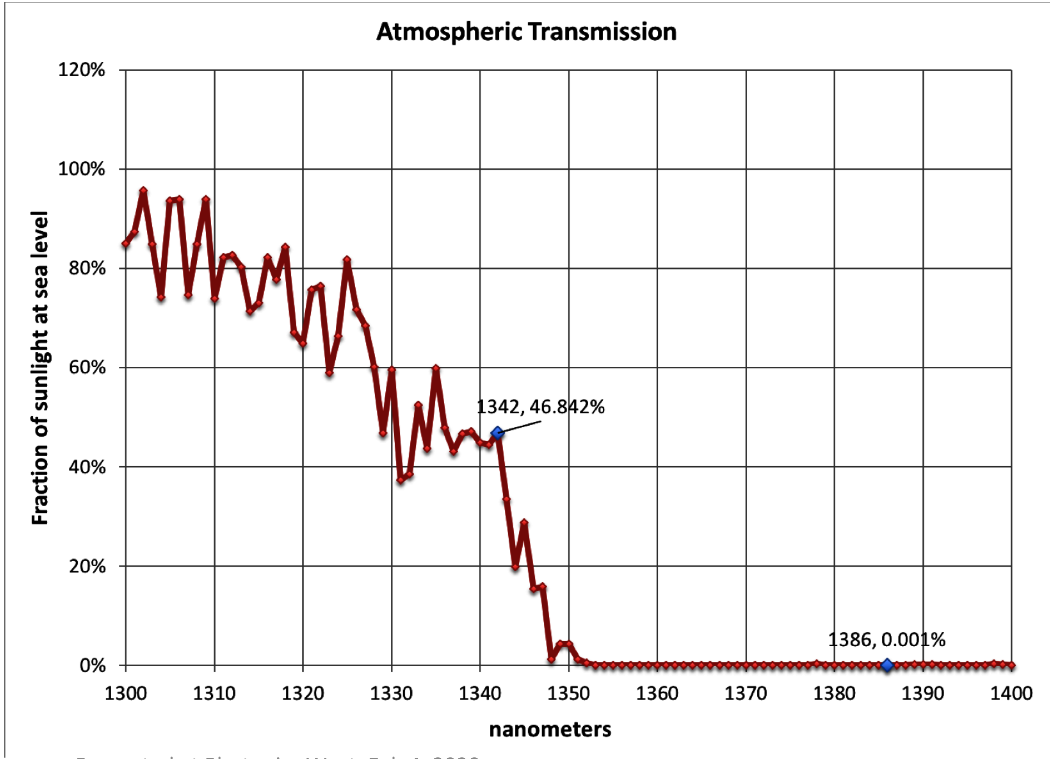
Eye safety at 1342 nm

- Strong water absorption protects the retina
- But not so strong that surface heating is maximized
- The 2014 European and US standards disagree about the size of the advantage



1342 nm is in a good atmospheric window

- Data at right is for a 13 kilometer path at sea level, with typical humidity
- It implies a 16 kilometer absorption depth in a typical atmosphere

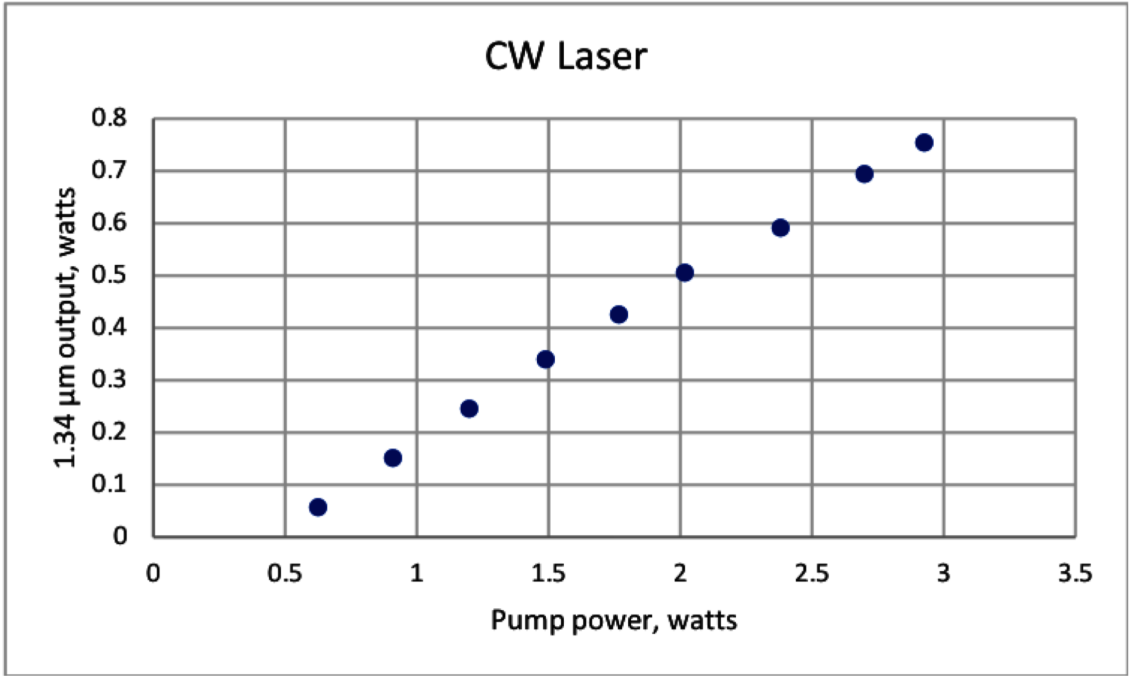


Used industry standard semiconductor pump

- Typical input
  - ≤ 4 amps, 2 Volts
- Output
  - ≤ 3.5 watts
- 105 µm core fiber
  - Beam N.A. 0.12
- Unpolarized, unless fiber cut to a few cm
- 808 nm
- Future: 885 nm?

Continuous wave result (V:YAG absent)

- Slope efficiency
  - 30%
- Threshold
  - 0.4 watts
- Overall efficiency
  - 25%
  - 0.75 w out for 3 w in
- Output coupling
  - T = 4%



Two important adjustable parameters

- ***A***: the pump area in the Nd:YVO_4
  - Smaller value increases PRF
  - Bigger value increases pulse energy and peak power
  - Has little effect on pulse duration
  - Adjusted by choice of lenses in pump beam
  - I used two pump configurations
    - Diameter 105 µm
    - Diameter 63 µm

- q_0, the saturable absorption in the V:YAG
  - Smaller value increases PRF
  - Bigger value reduces pulse duration
  - Bigger values reduce overall efficiency
  - Adjusted by changing thickness of V:YAG
  - Values I used:
    - 0.16, 0.32, 0.67 and 1.22 mm

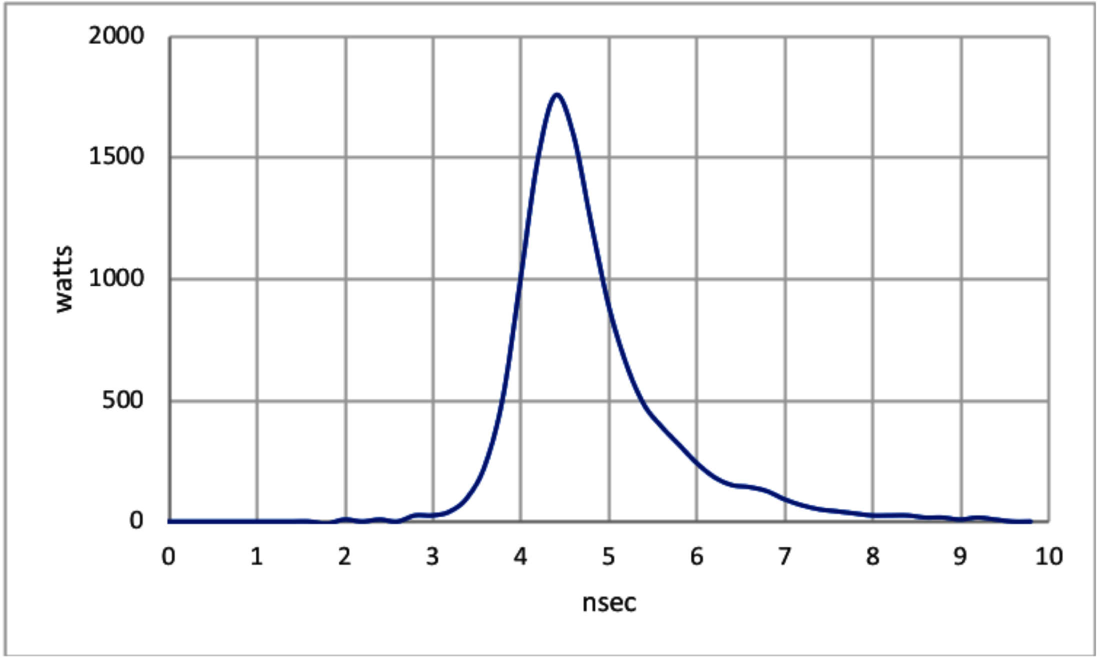
V:YAG Parameters

- Transmission is due to saturable plus unsaturable absorption
- Polarization of light parallel to <100> axis of V:YAG (important)
- All V:YAG parts AR-coated at 1342 nm

V:YAG Thickness	V:YAG Transmission @1342 nm, single-pass
0.16 mm	97.5%
0.32 mm	95%
0.67 mm	90%
1.32 mm	79%

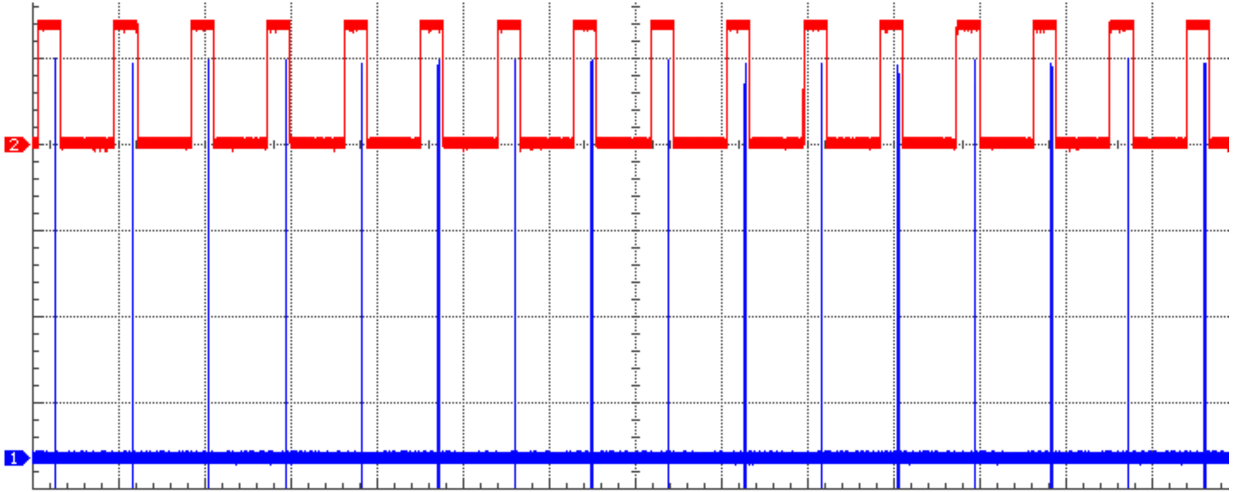
Config #1: shortest pulses and highest peak power

- FWHM: 1.08 nsec
- 10%-90% rise: 0.75 nsec
- Pulse energy: 2.5 µJ
- PRF: 24 kHz
- Peak power: 1750 watts
- V:YAG
  - 1.22 mm, (thickest)
- Pump beam
  - 105 µm (largest)



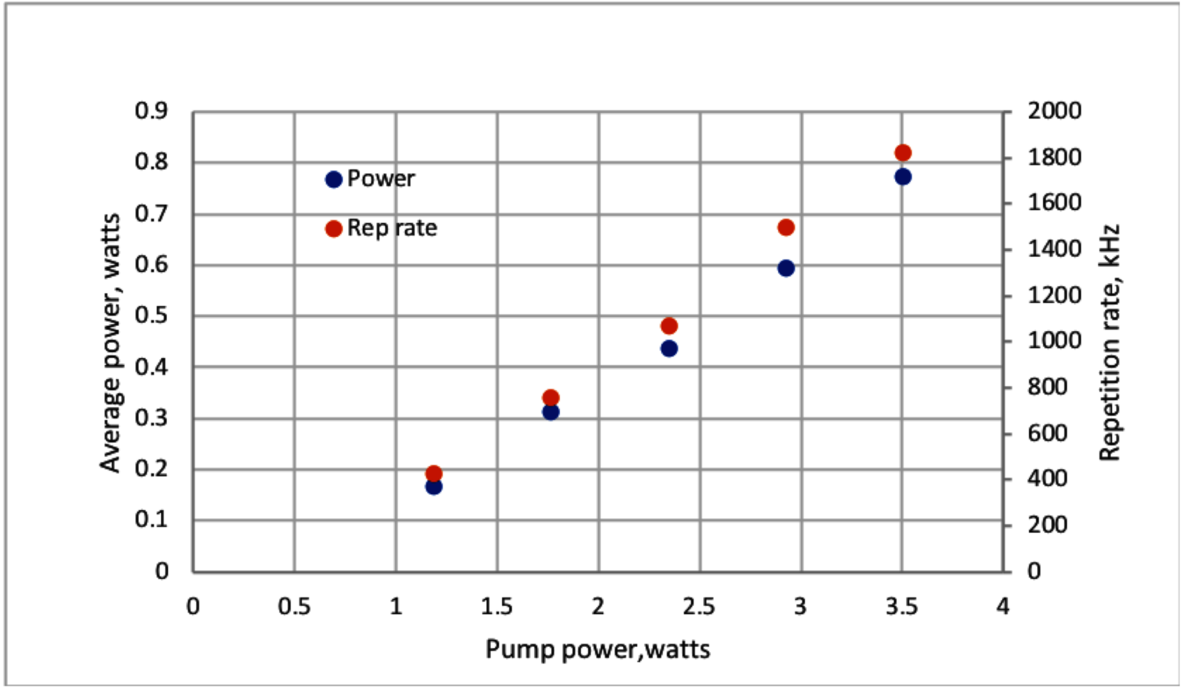
Config #2: best timing and energy stability

- FWHM: 1.3 nsec
- Pulse energy: 3.2 µJ
- PRF: 11 kHz
- V:YAG and pump
  - Same as previous
- Pump is pulsed to reduced PRF to 11 kHz (30% duty cycle)
- Gives precise control of pulse timing



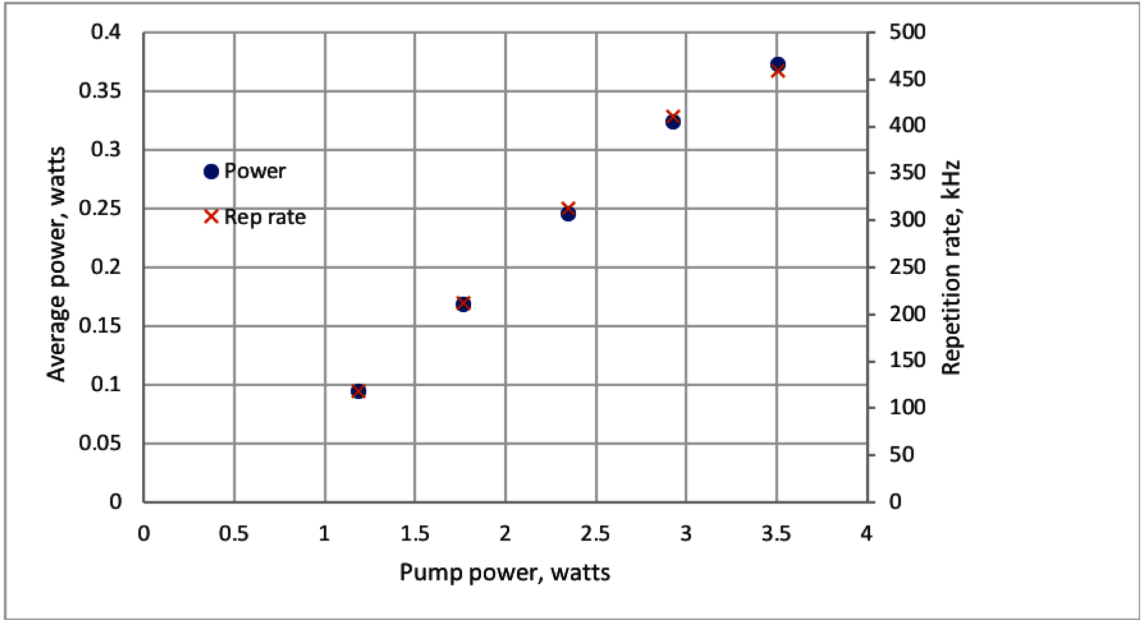
Config #3: Maximize PRF

- FWHM: 4.8 nsec
- Pulse energy: 0.43 µJ
- PRF: 1820 kHz
- Peak power: 67 w
- Average power: 0.78 w
- V:YAG
  - 0.16 mm, (thinnest)
- Pump beam
  - 63 µm (smallest)



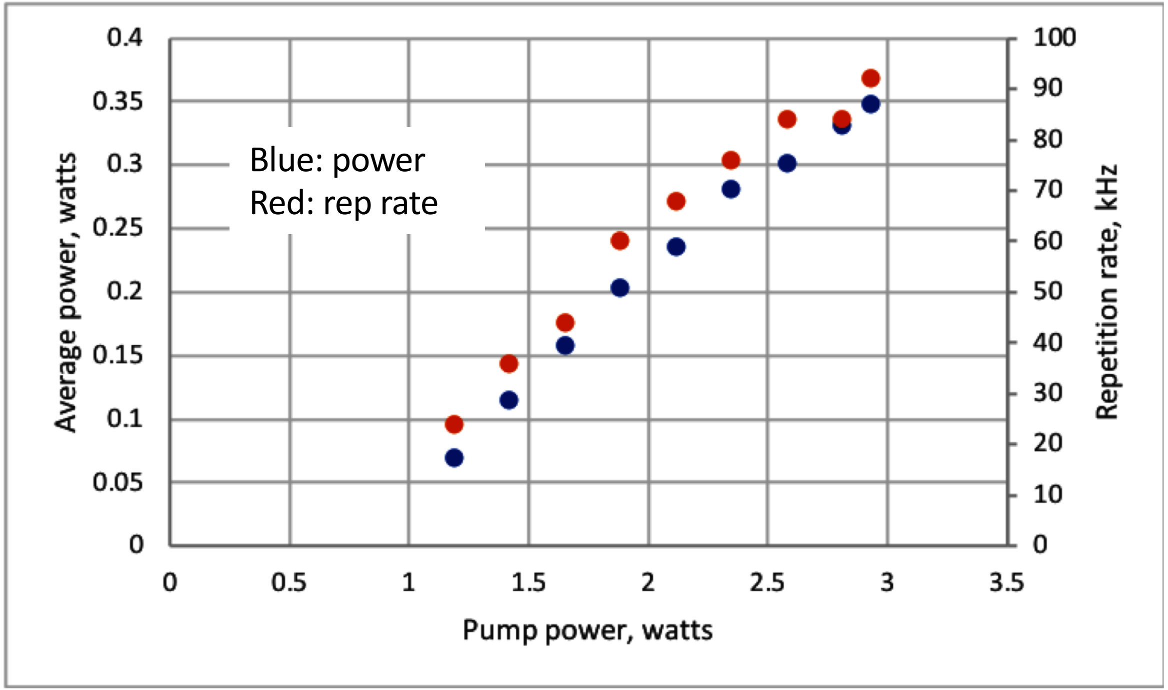
Config #4: Intermediate with “tight” pump

- FWHM: 1.6 nsec
- Pulse energy: 0.8 µJ
- PRF: 460 kHz
- Peak power: 375 w
- Average power: 0.37 w
- V:YAG
  - 0.67 mm (2nd thickest)
- Pump beam
  - 63 µm (smallest)



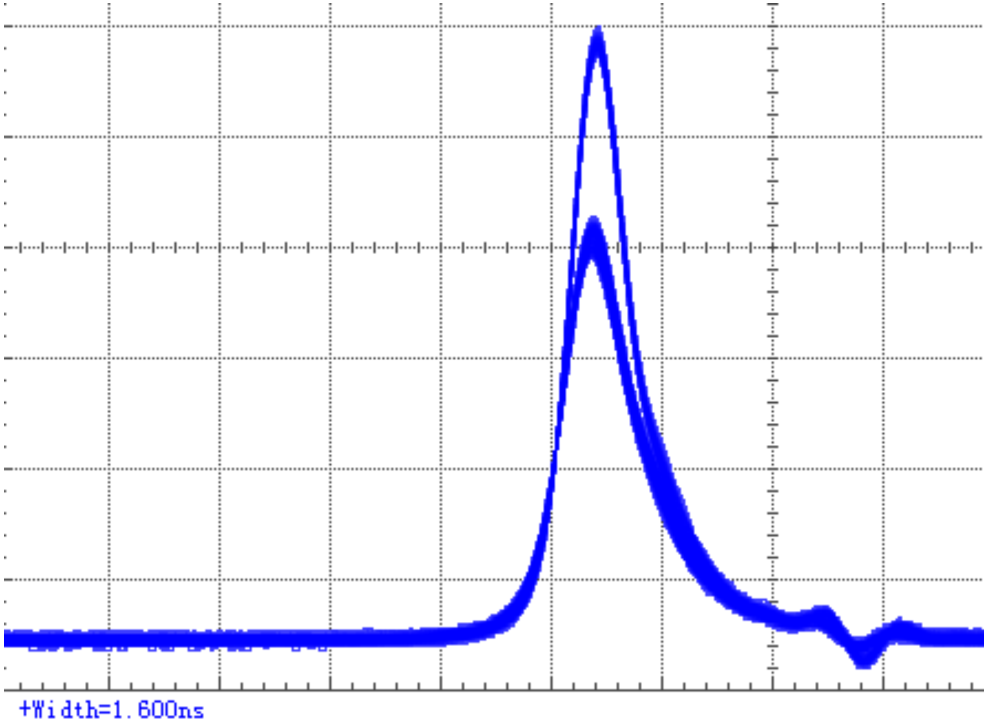
Config #5: Intermediate with “loose” pump

- FWHM: 1.6 nsec
- Pulse energy: 3.8 µJ
- PRF: 92 kHz
- Peak power: 1800 w
- Average power: 0.35 w
- V:YAG
  - 0.67 mm (2nd thickest)
- Pump beam
  - 105 µm (largest)
- This config only:
  T=14%



Pulse timing and energy variability

- For all but Config #2:
- ±20% pulse-to-pulse variability in energy and interval
- Pulse duration stable
- Caused by pulse-to-pulse variation in axial mode
- Problem absent for PRF <15 kHz



Complete table of results

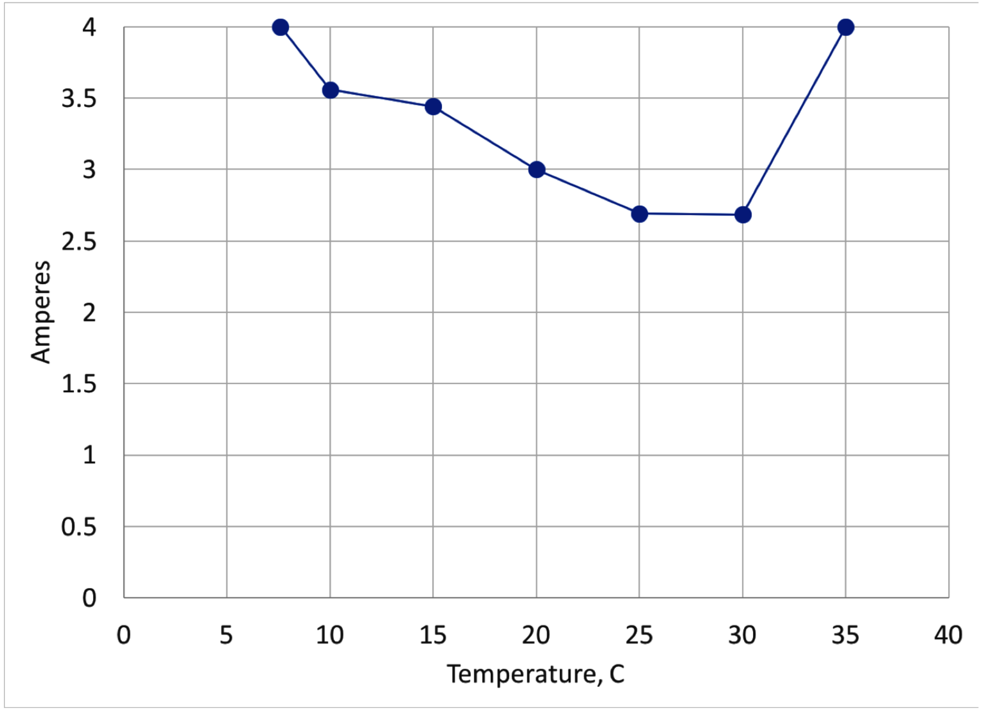
"Config"	V:YAG, mm	Pump ϕ, µm	PRF, kHz	Energy, µJ	FWHM, nsec	Energy/ FWHM, watts
3	0.16	63	1820	0.43	4.8	89
	0.16	105	680	0.92	6.4	144
	0.32	63	616	0.76	2.2	344
	0.32	105	295	1.38	3.6	383
4	0.67	63	460	0.8	1.6	500
5	0.67	105	92	3.8	1.6	2400
2	1.22	105	11	3.2	1.3	2500
1	1.22	105	24	2.5	1.08	2300

Where this laser type exceeds Nd:YAG / Cr:YAG

- Shorter lifetime of the saturable transition allows higher repetition rates
  - $\tau_{\mathrm{Cr:YAG}}$ = 4.1 μsec; $\tau_{\mathrm{V:YAG}}$ = 22 nsec
- Ratio of cross sections enables the use of Nd:YVO_4 – the best material for small diode-pumped lasers
  - Strongest pump absorption
  - Widest pump absorption in terms of pump wavelength or temperature
- Eye-safety

Range of temperature

- Temperature was varied
- Current was adjusted to hold PRF & power constant
  - 114 kHz
  - 150 mW



Conclusions

- The range of pulse rise time, peak power and PRF covers the range needed for many LIDAR applications
  - <1 nsec, >1000 watt, >1 MHz, with trade-offs
- Simple, inexpensive lasers are possible, needing no high-speed, high-current electronics to achieve < 1 nsec rise time
- Control of pulse current can ensure exactly one pulse per pulse window, but jitter within this window must be tolerated
- Temperature control is required for field use
  - Future wavelength-locked pump lasers?