Advanced Solid State Lasers for Lidar Systems

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19th International Laser Radar Conference

Annapolis, Maryland

July 9, 1998

Research Division of Schwartz Electro-Optics, Inc.

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SEO Boston (name change)

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Q-Peak, Inc. (wholly owned subsidiary)

Credits

- **Researchers**
  - **Glen Rines, Richard Schwarz, Andy Finch, Mark Webb**
  - **David Welford, Jeff Russell, Kevin Wall, Anton Zavriyev, Yelena Isyanova, Kevin Snell, Dicky Lee, Jeff Manni, Alex Dergachev, Bhabana Pati**
- **Collaboration**
  - **Ushio, Inc. (UV generation)**
- **Government Support**
  - **NASA Langley (OPOs, Ti:sapphire UV generation)**
  - **NASA Goddard (microlasers)**
  - **Army ERDEC (OPOs, Ti:sapphire UV generation)**
  - **DARPA (intracavity OPOs)**
  - **Air Force (Ti:sapphire, OPOs)**

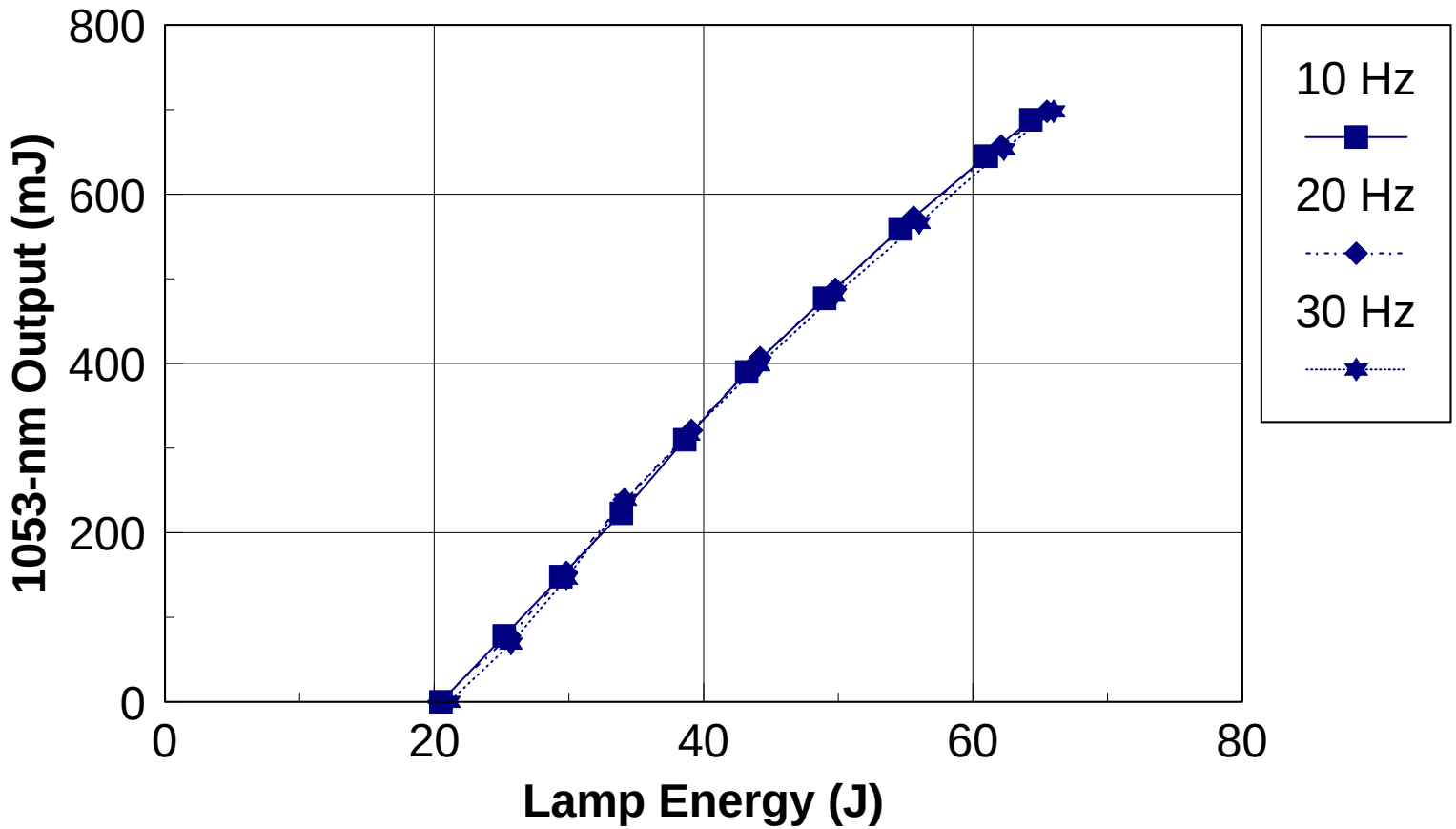
Outline

- Lamp-pumped, compact Nd lasers
- High-energy OPOs for eyesafe systems
- Ti:sapphire lasers for UV generation
- Tandem OPO for mid-IR generation
- CW, diode-pumped lasers for next-generation lidar systems

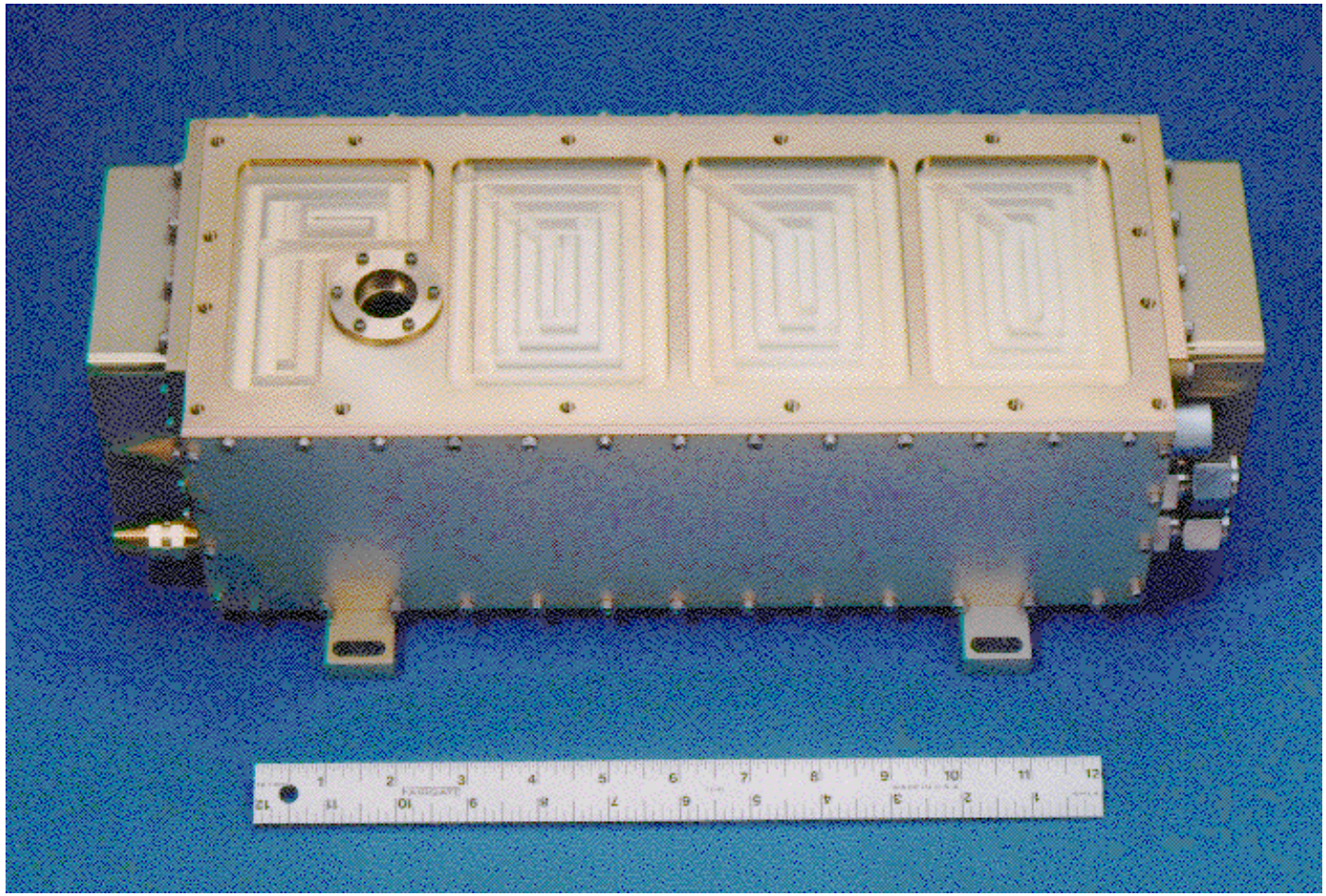
Properties of Compact Laser Head (CLH)

- Rugged, compact, flashlamp-pumped 1-micron laser
- Nd:YLF oscillator / amplifier design
- Output: 700 mJ @ 10 - 30 Hz @ 1053 nm (15 ns pulse)
- Beam quality: M = 15
- Optical head: 5" x 6" x 17", 16 pounds
- All optics hard-mounted; final alignment w/ Risley wedges
- Power supply & closed-loop cooler in shock-mount cases
- Serves as multipurpose pump source
  - Pump for NCPM KTP-family OPOs
  - Frequency doubled for Ti:sapphire pumping

Input-Output curves for CLH are independent of pulse rate to 30 Hz



CLH Photograph



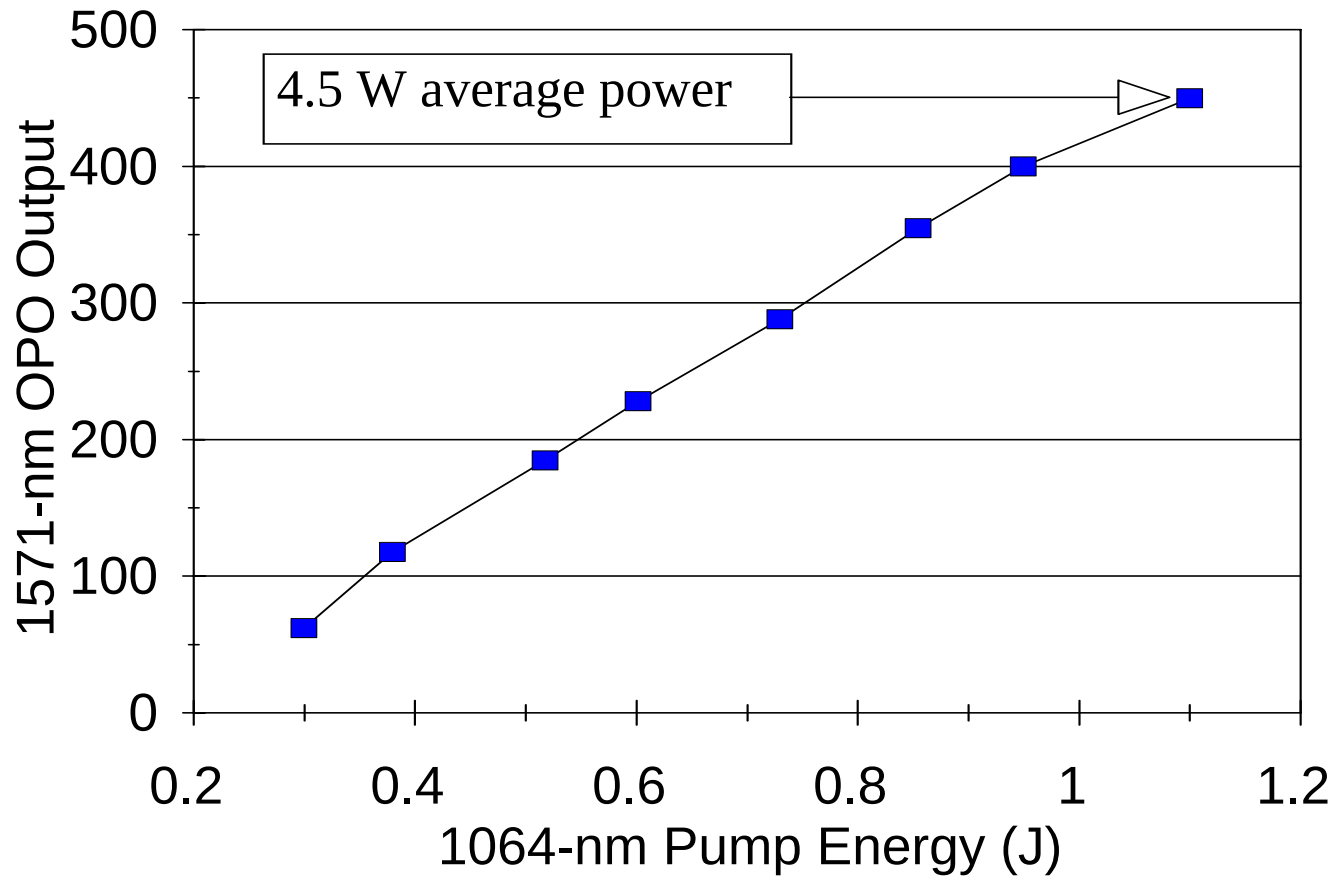
Optical Parametric Oscillators (OPOs)

- **Optical parametric oscillators are nonlinear optical devices that convert a fraction of the output of a laser (the pump) into two outputs, the signal and idler, both at longer wavelengths**
- **The frequencies of the signal and idler sum to that of the pump**
- **For a given pump, the signal and idler wavelengths are determined by the characteristics of the nonlinear crystal used in the OPO**

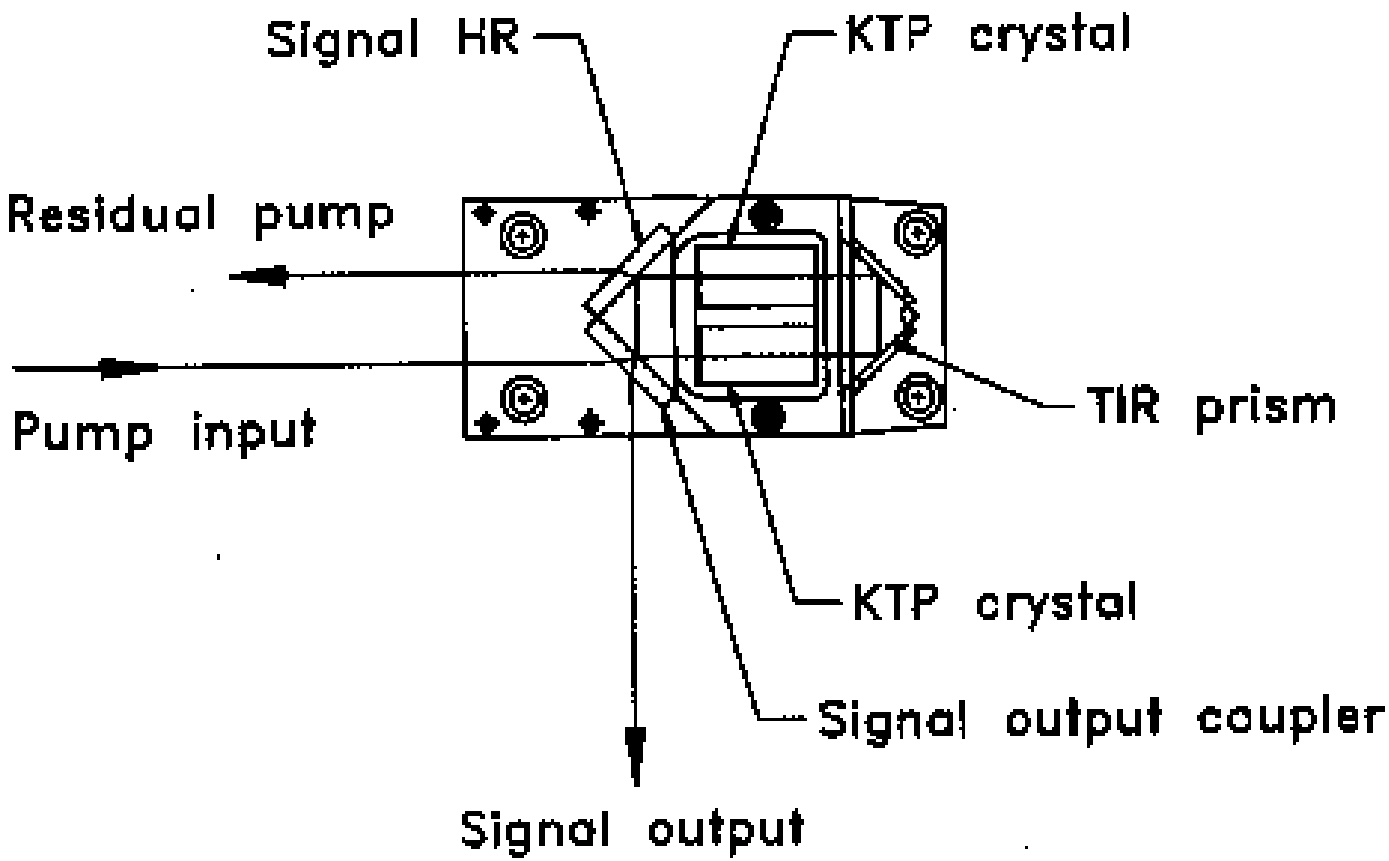
KTP-family OPOs are used as eyesafe sources

- **Several crystals belonging to the KTP family, when pumped by Nd-doped laser pumps around 1050-1070 nm, generate signal wavelengths around 1550 nm, the maximally eyesafe wavelength region**
- **The advantages of the KTP family include:**
  - **non-critical phase-matching, which allows good OPO conversion efficiency even with poor-beam-quality pump lasers**
  - **large available crystal sizes, which allows generation of high energies**

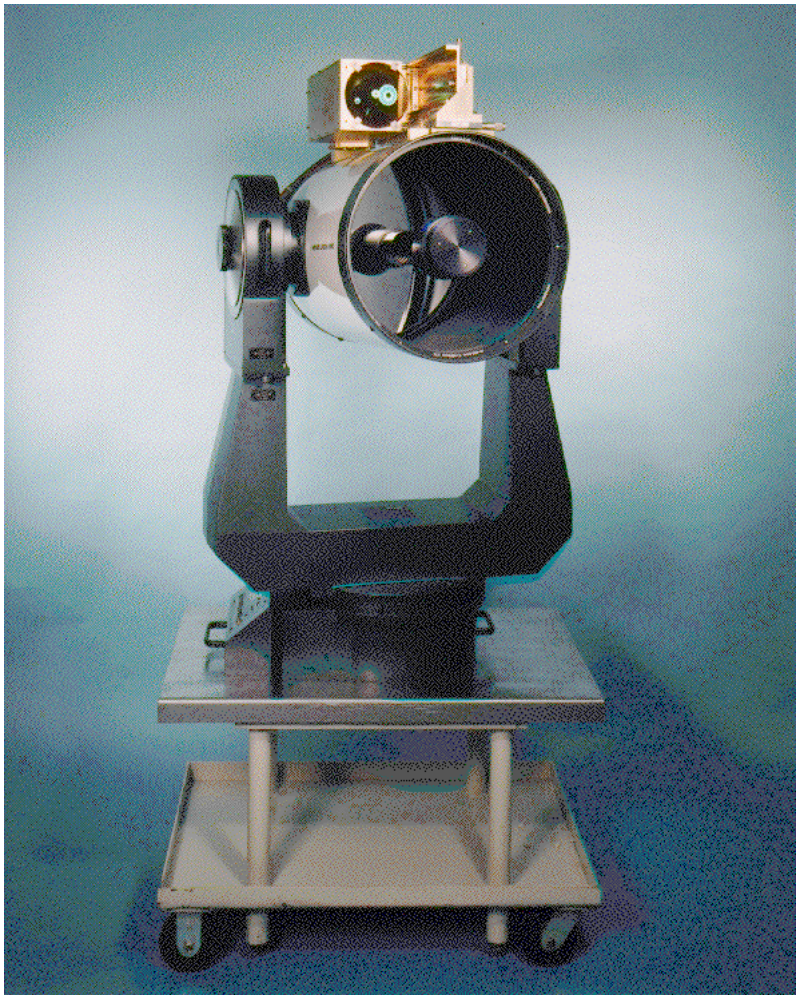
KTP OPO generated a record energy in 10ns pulses



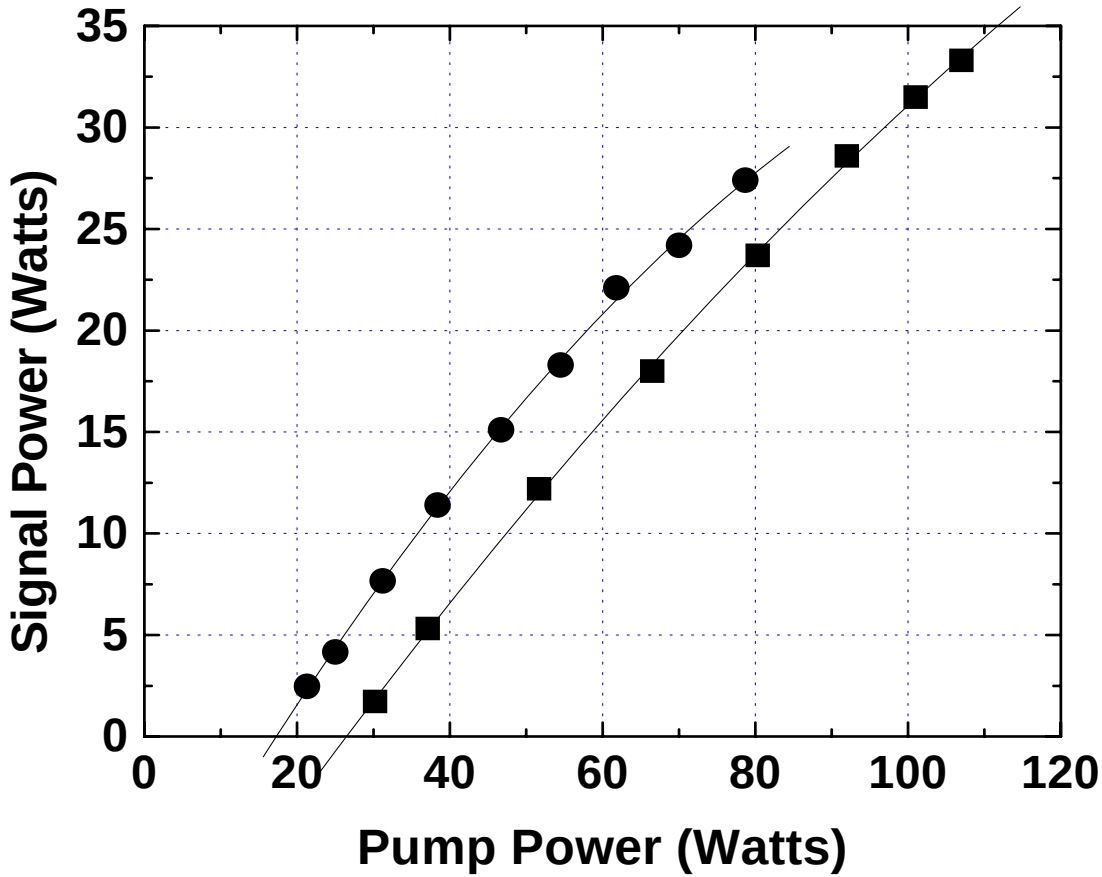
KTP OPO engineered for CLH



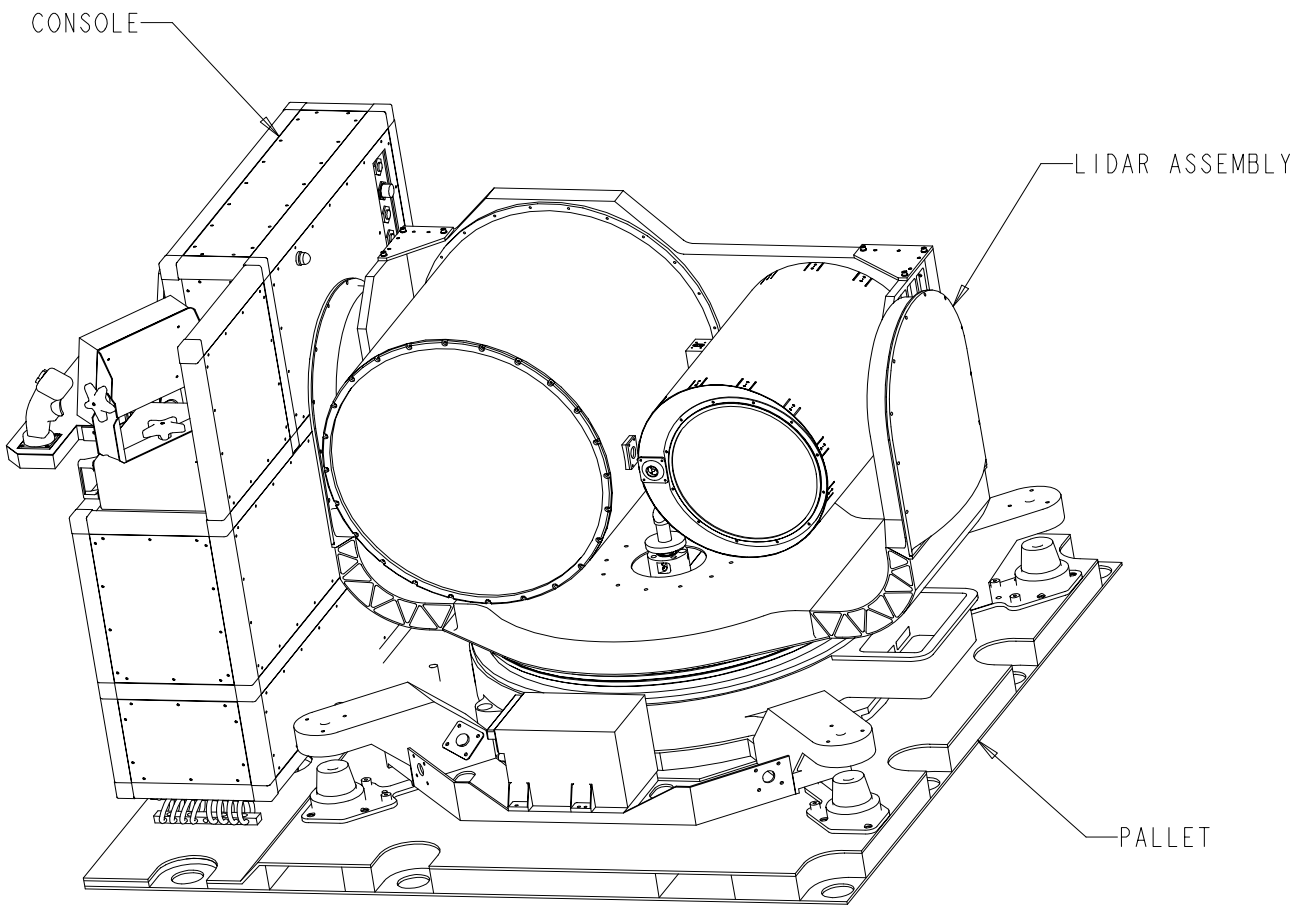
Picture of complete OPO-based lidar



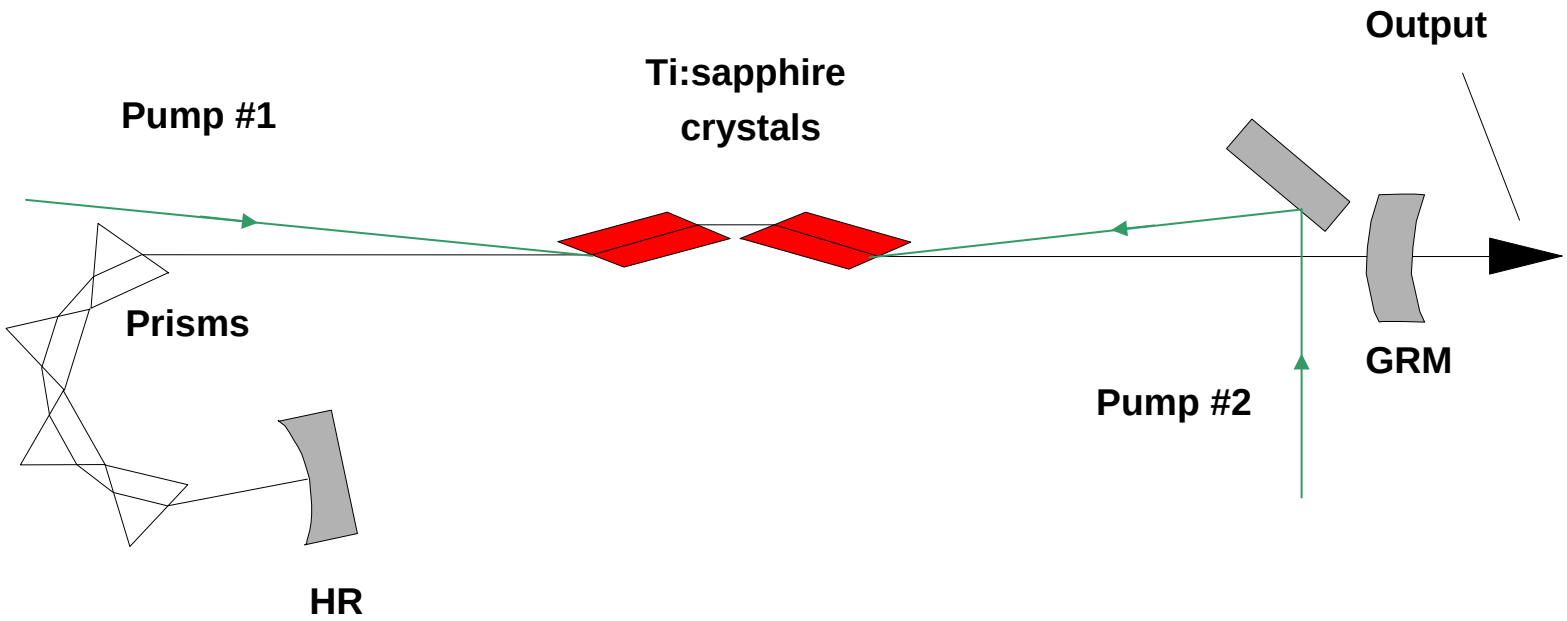
KTA OPOs generated record powers at 100 Hz



Biological Standoff Detection System (BSDS)

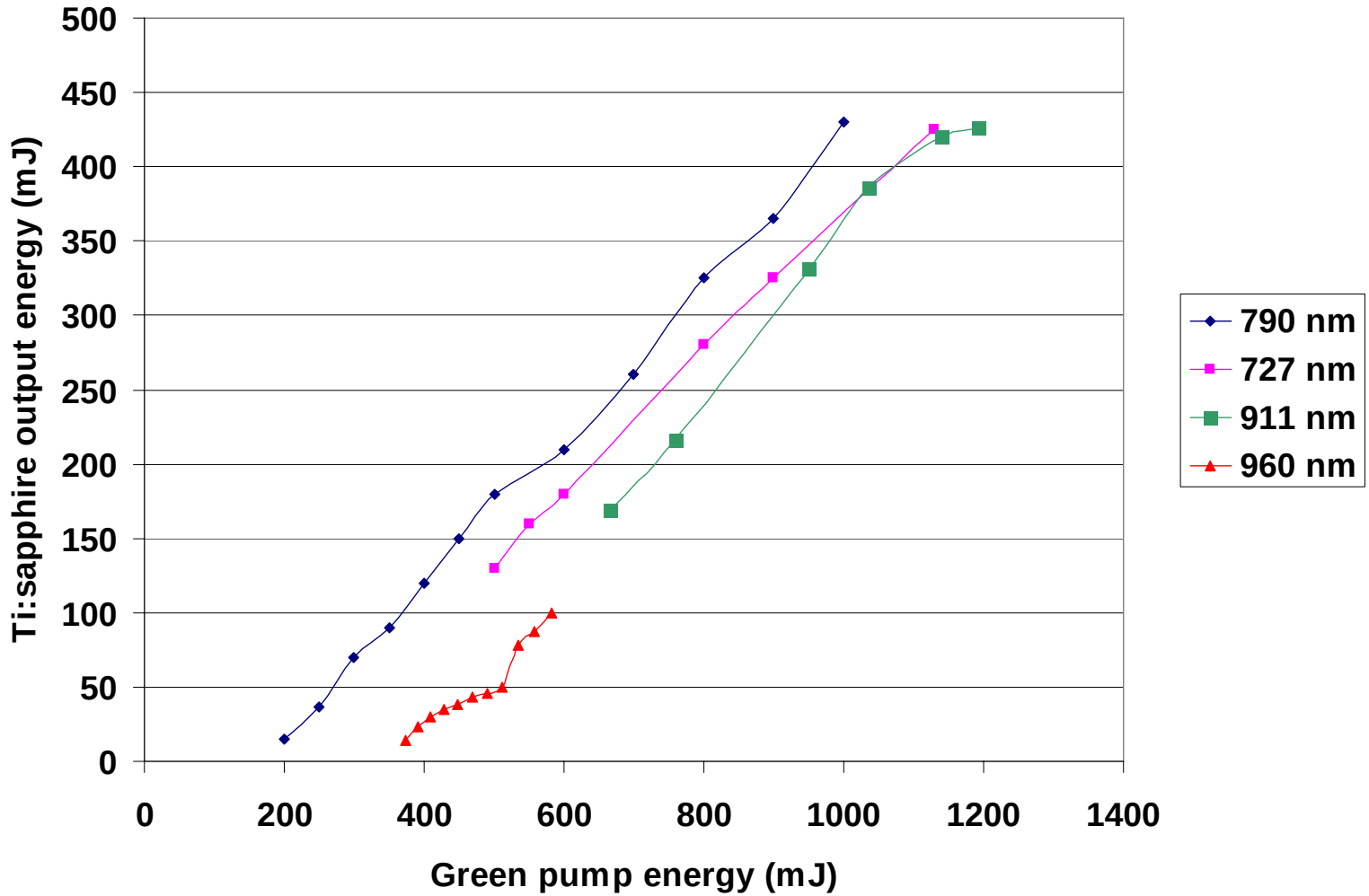


Laser-pumped, high-energy Ti:sapphire laser

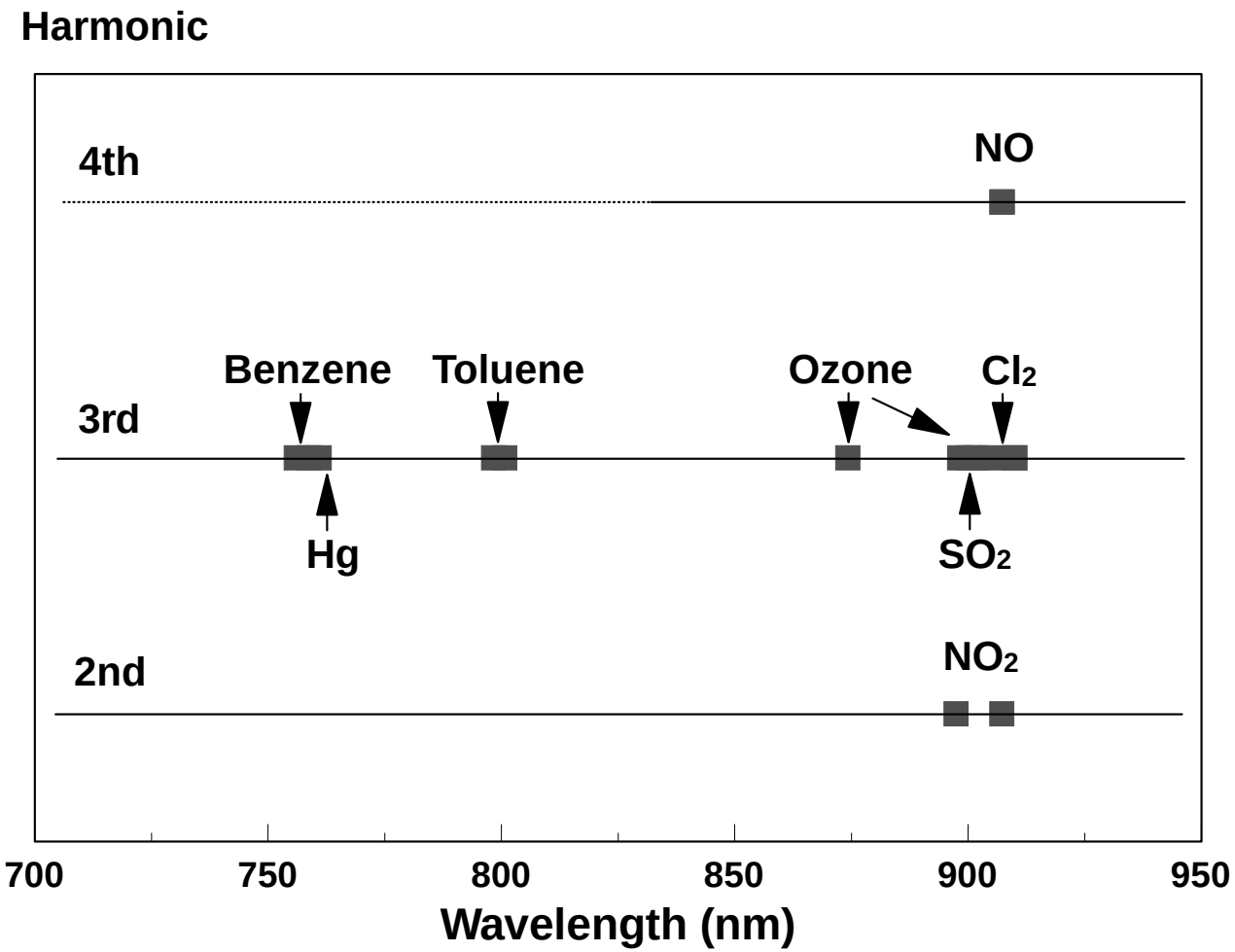


Developed with NASA Langley, DARPA support, 1986-1992

Ti:sapphire input-output, 727-960 nm



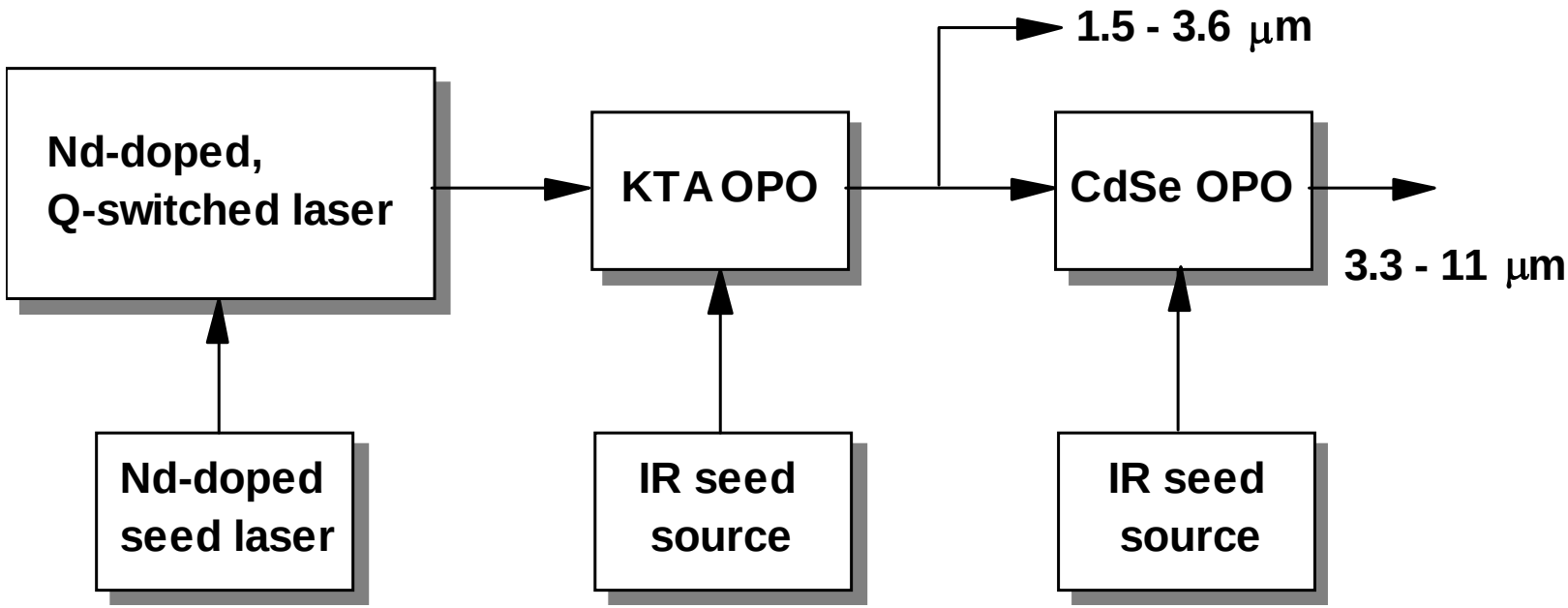
Harmonic generation extends Ti:sapphire wavelength coverage for DIAL



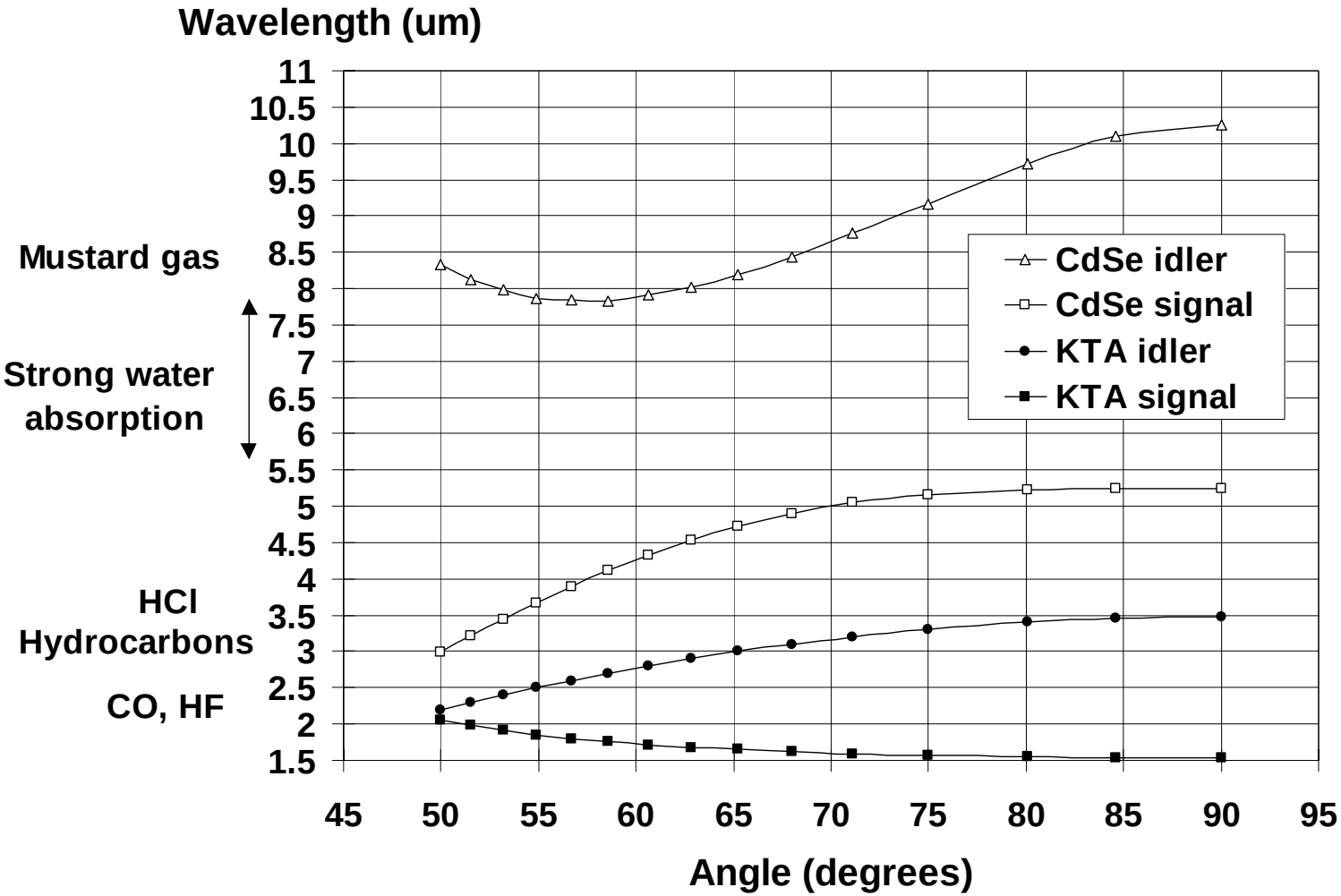
Ti:sapphire provides high energies at fundamental and harmonics

- **Fundamental (700 - 980 nm region)**
  - **> 400 mJ at selected wavelengths**
- **Second Harmonic (350 - 490 nm region):**
  - **250 mJ at selected wavelengths (60% conversion)**
- **Third Harmonic (233 - 327 nm region):**
  - **> 40 mJ at selected wavelengths (254, 290 nm)**
  - **Currently investigating double-pulse system for ozone lidar, improved harmonic conversion**
- **Fourth Harmonic (210 - 245 nm region):**
  - **10 mJ at selected wavelengths**

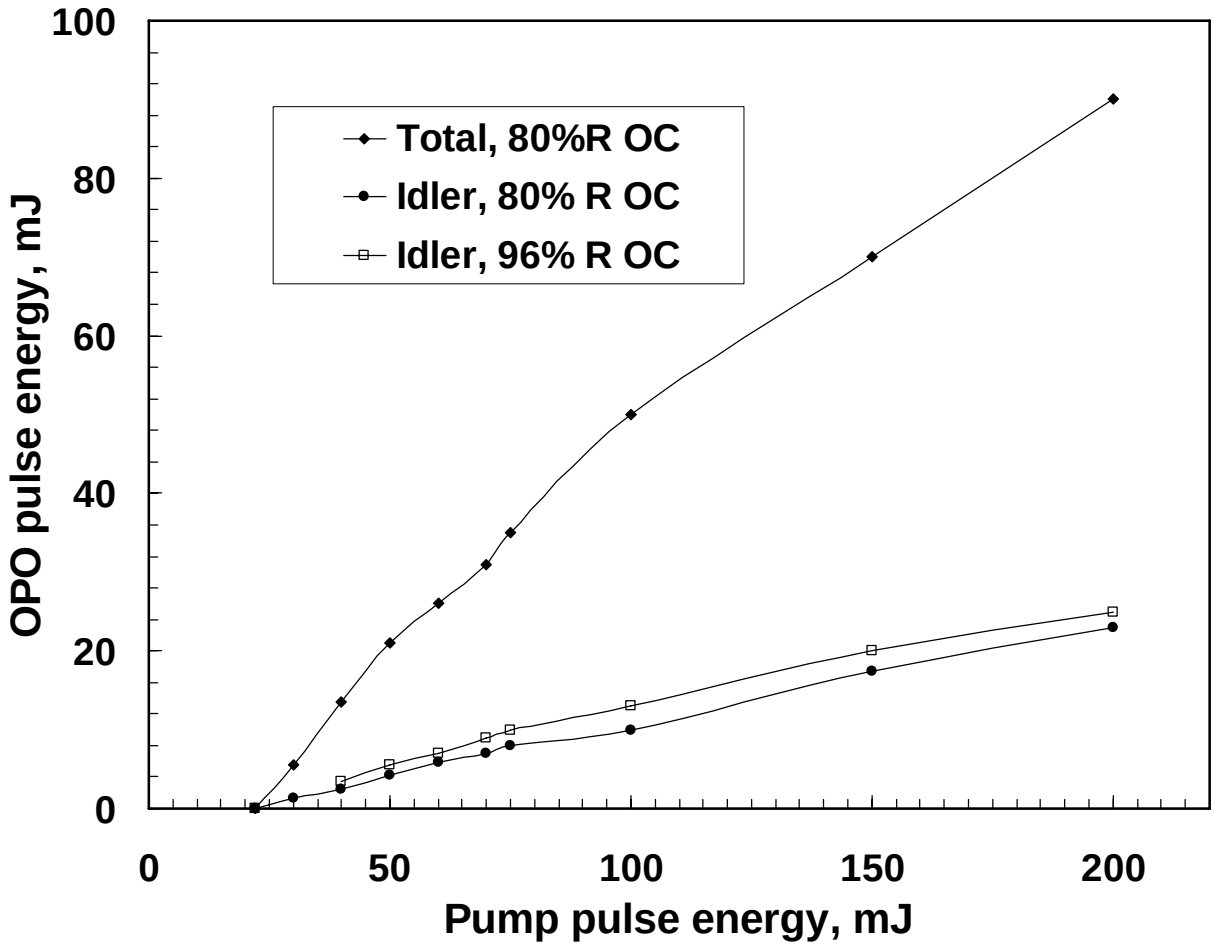
Tandem OPO provides broad IR wavelength coverage



Tuning curves for Tandem OPO design



Input-output curves for KTA OPO



Pump: 1053 nm
Signal: 1514 nm
Idler: 3456 nm
(x-cut crystal)

Also:
Signal: 1483 nm
Idler: 3631 nm
(y-cut crystal)

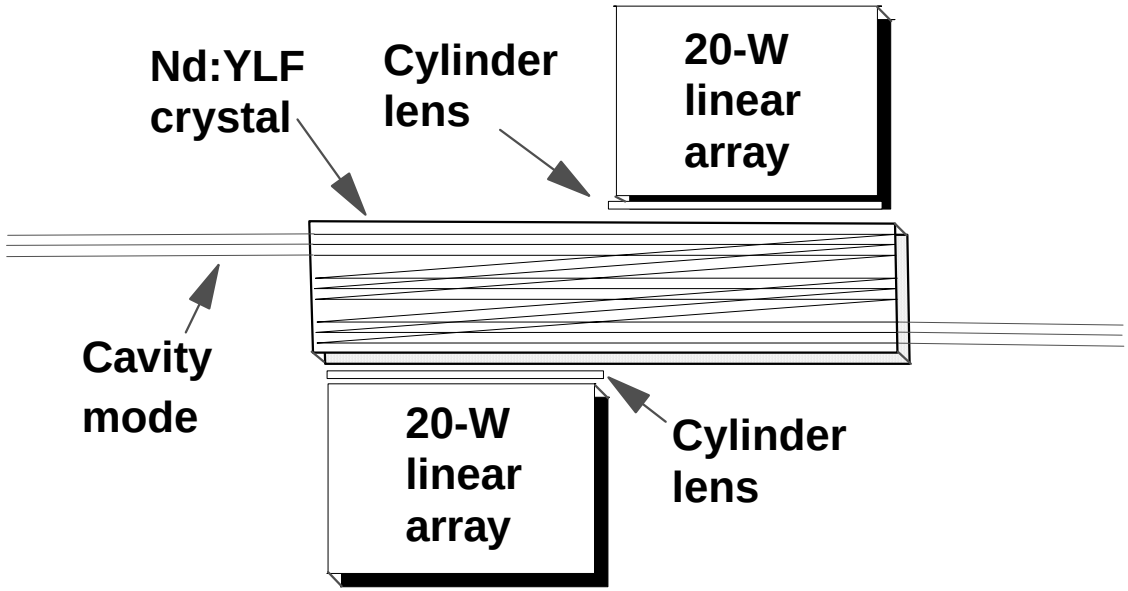
Next-generation lidar sources will be cw pumped

- The current generation of solid state lidar sources is based on lamp-pumped Nd-laser technology
- Diode-pumped solid state lasers are more reliable, more efficient and provide better beam quality per W of output power
- Diodes are cw devices - they produce essentially the same power whether pulsed or cw
- Generation of high pulse energies requires many diodes - and many $$
- The most output per $ occurs for cw diode-pumped solid state lasers

CW-pumped lidar sources

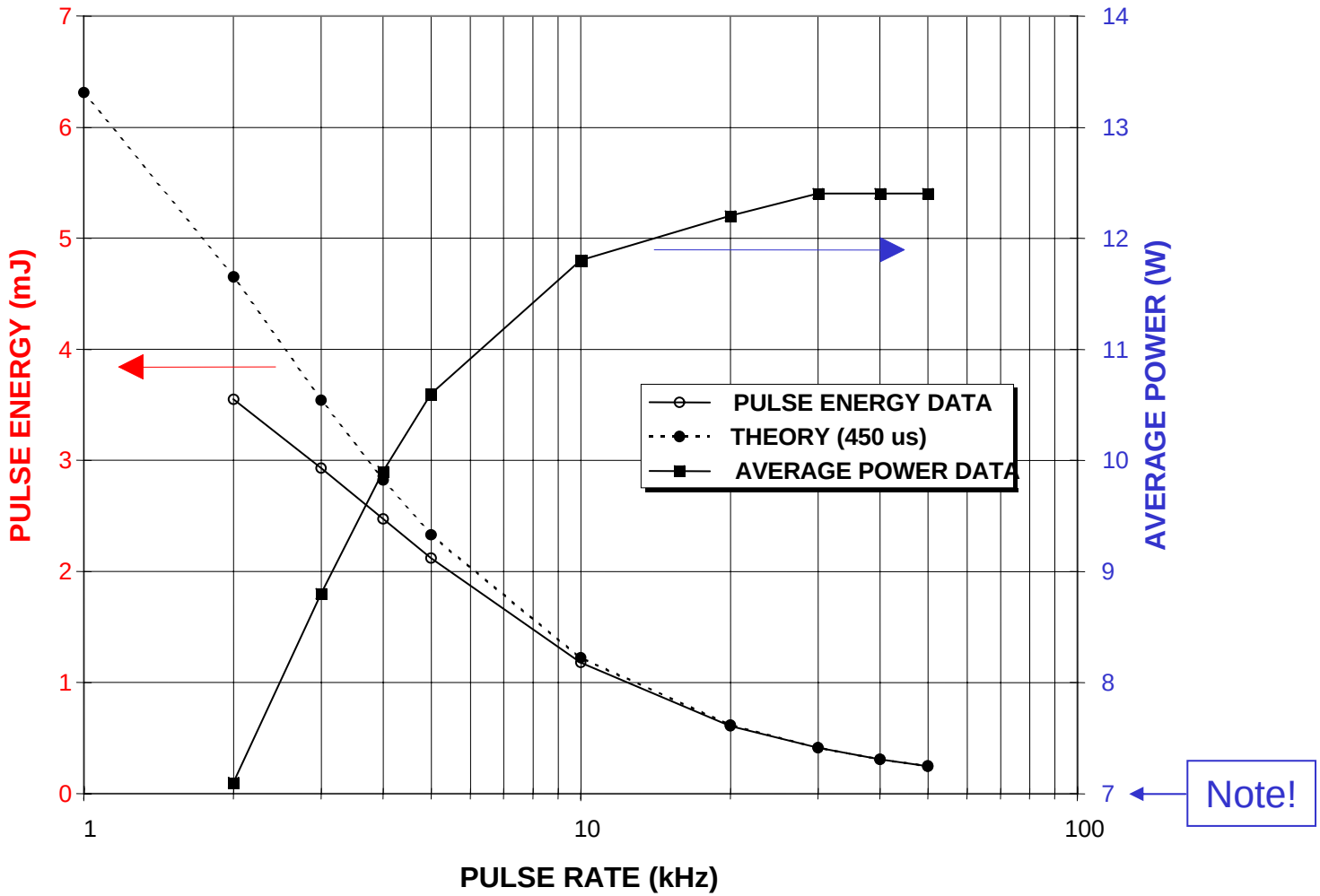
- CW-pumped repetitively Q-switched lasers are common in industry for applications such as materials processing, marking and IC trimming
- Diode-pumped, repetitively Q-switched lasers can produce 10-20-ns pulsewidths (or shorter) under the right conditions, and thus providing range resolution comparable to pulsed-pumped lasers
- For the same average power, the trade-off is that the repetitively Q-switched sources will produce high pulse rates and lower pulse energies
- More sophisticated signal averaging is needed
- Nonlinear devices can work well at the high rates, providing frequency diversity

Nd:YLF "Gain Module" uses transverse pumping

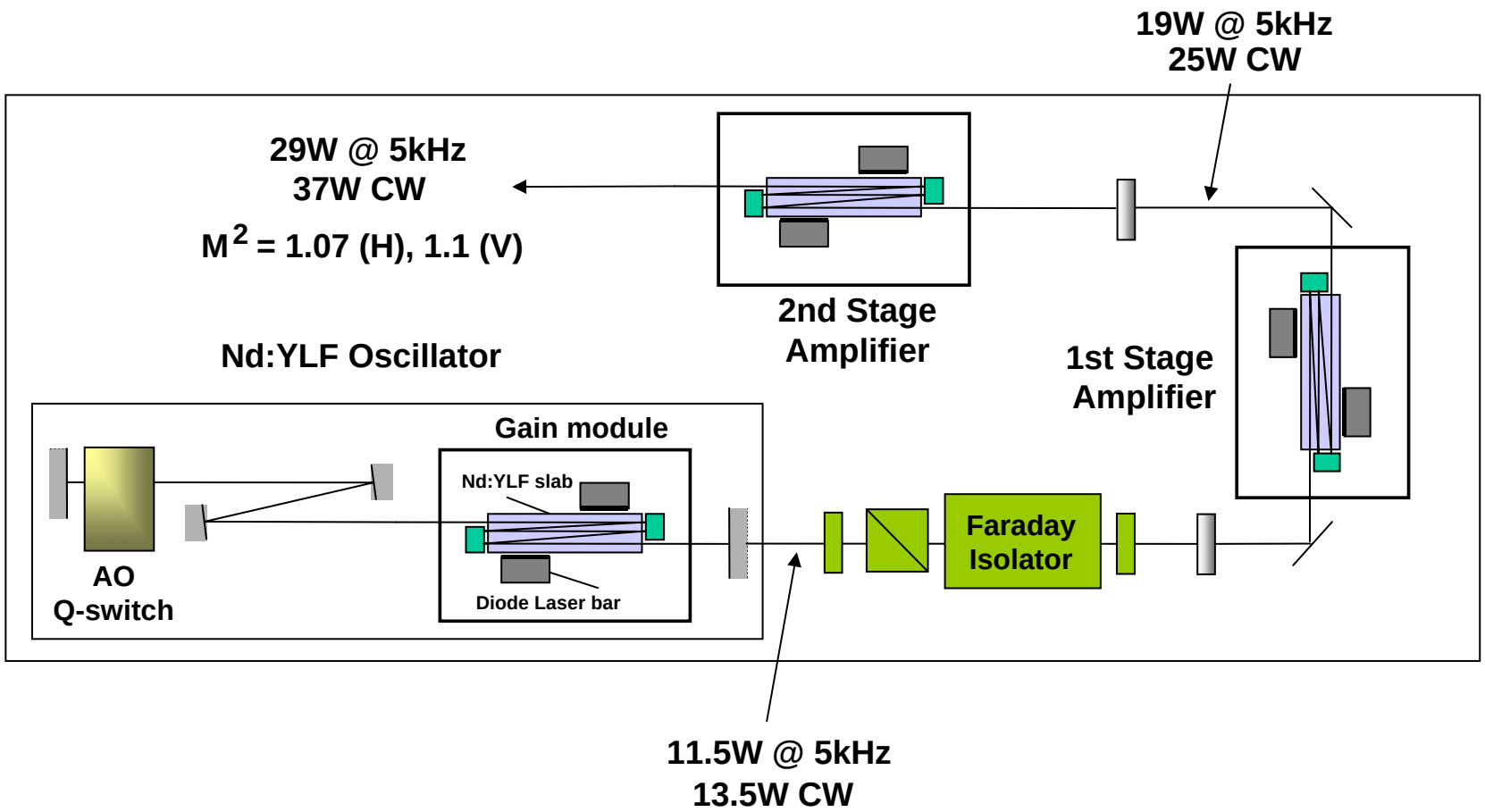


- Multi-pass design extracts large fraction of available power in TEM_{00} mode, has high gain
- Low average excitation density minimizes stress, beam distortion
- Simple, single-element pump optics

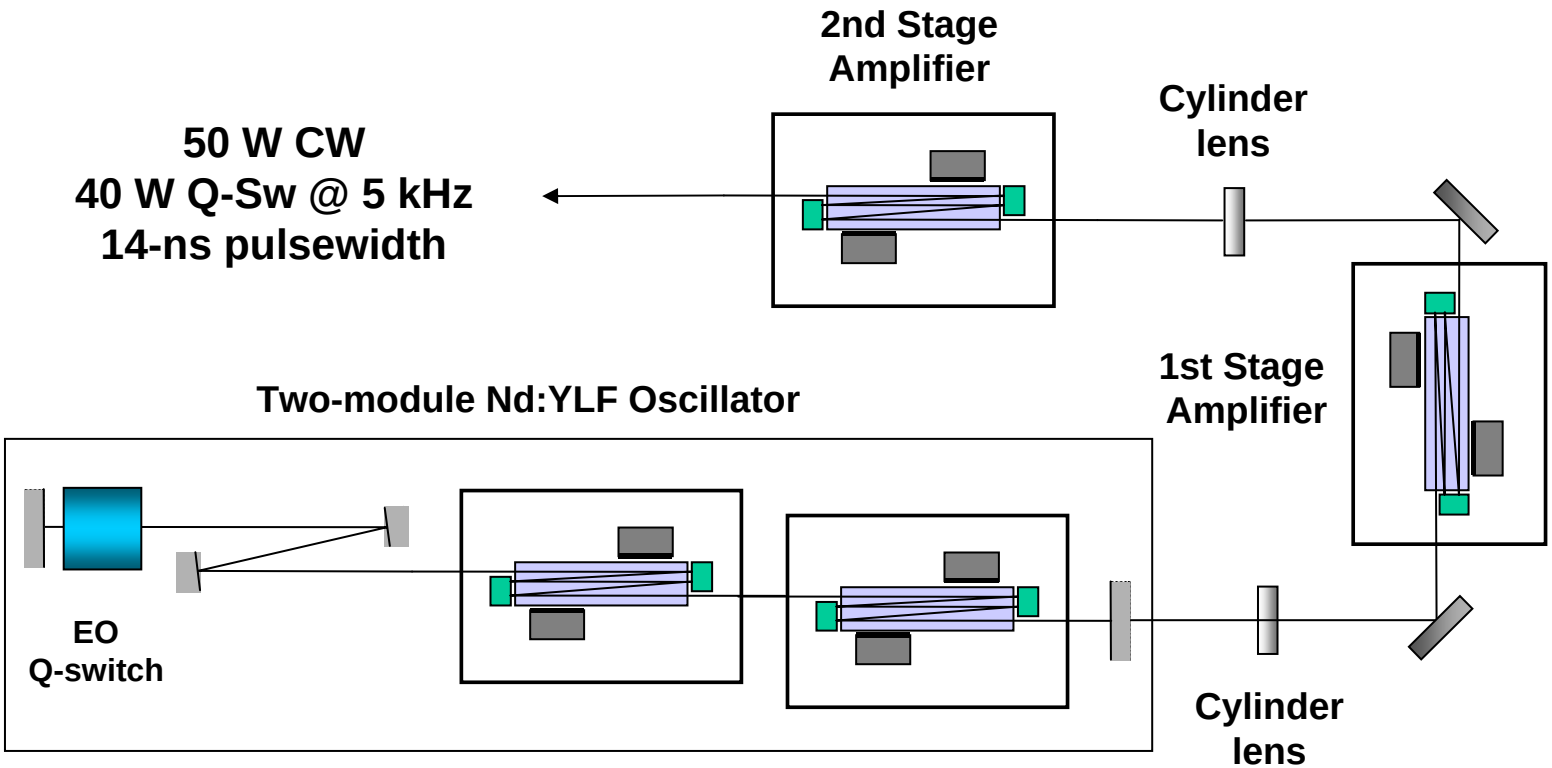
Q-Switching results for single gain module show >12 W above 10-kHz PRR



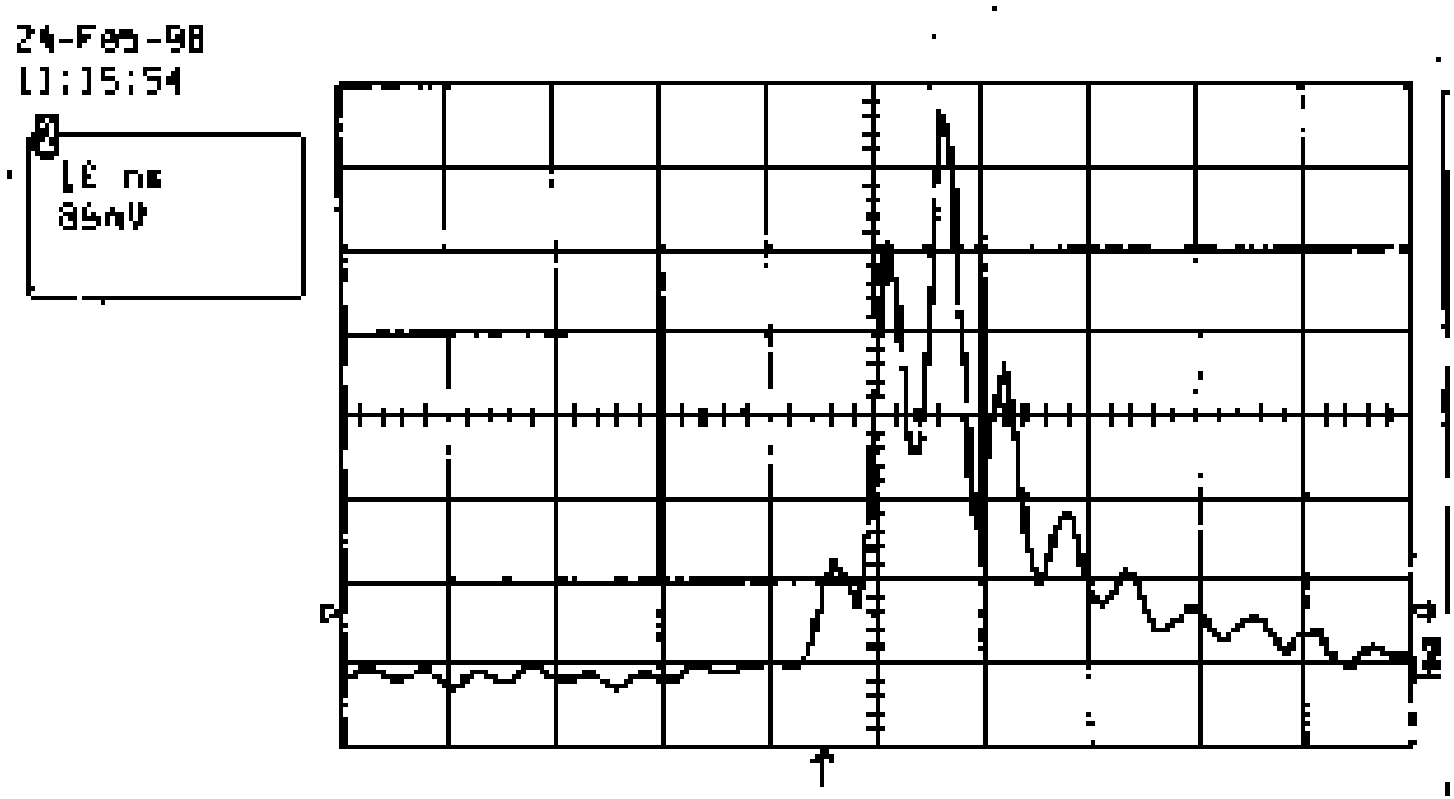
MOPA #1 design generates higher power



MOPA #2 design uses a two-gain-module oscillator, generates 0.6-MW pulses at 5 kHz

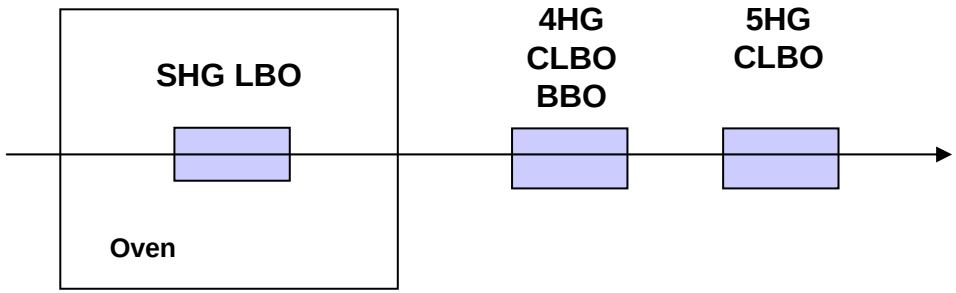


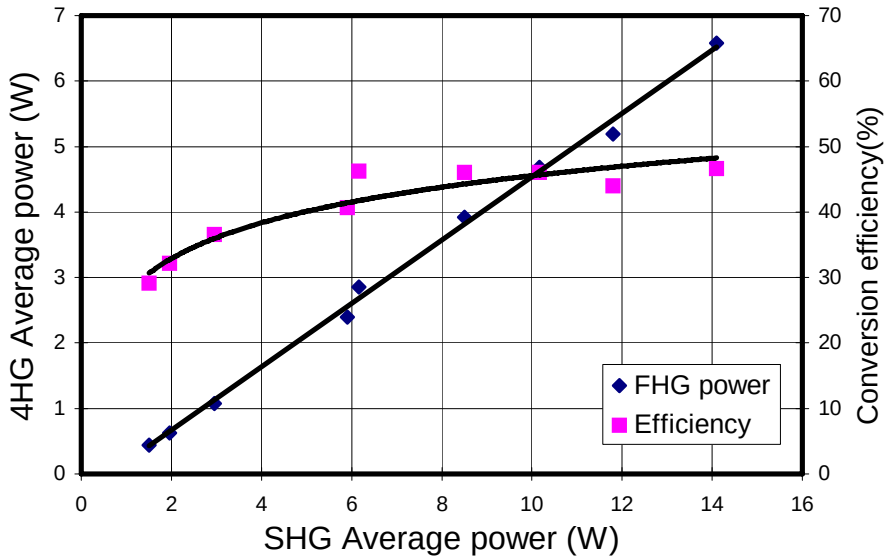
Two-gain-module oscillator generates 14-ns pulses at a 5-kHz pulse rate



10 ns per division

Harmonic conversion generates visible, UV power





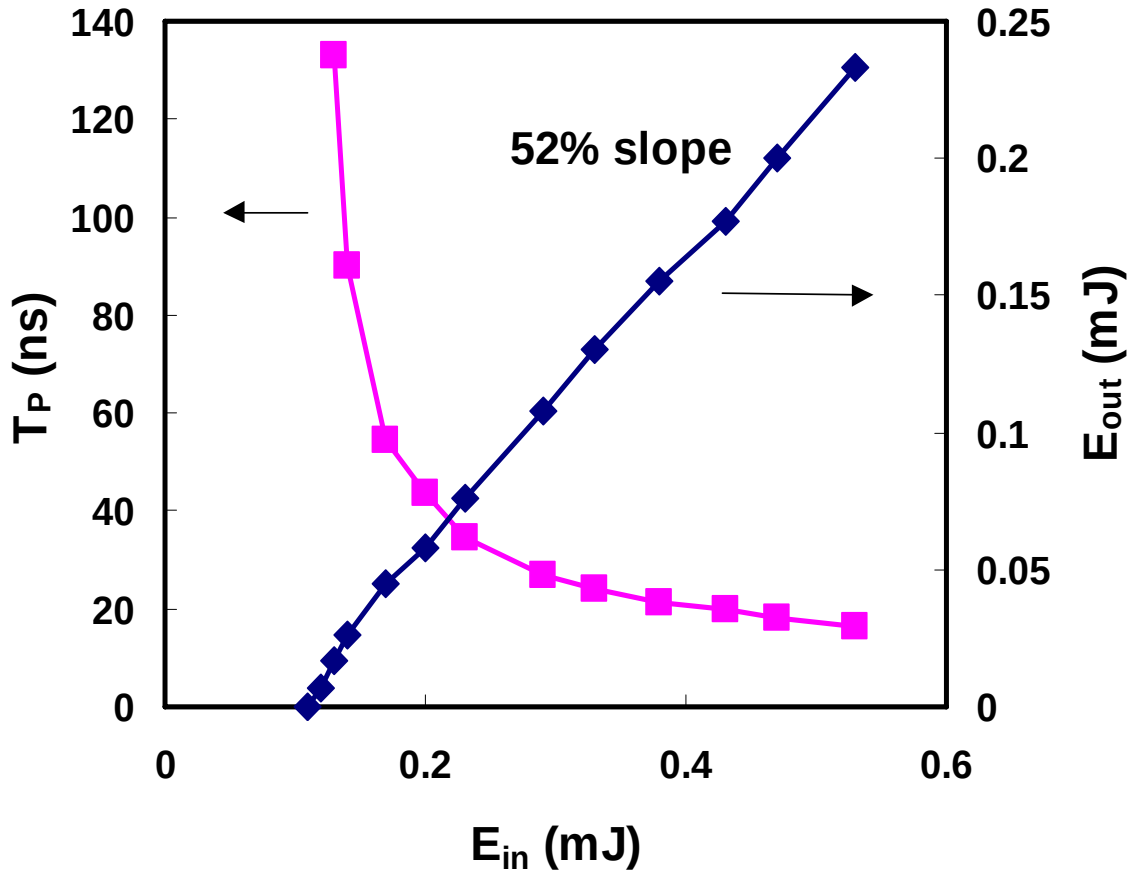
Best results:

SHG (523.5 nm):
14 W at 5 kHz
and 65% conversion
in LBO

4HG (262 nm):
6.6 W (internal)
at 5 kHz with CLBO
2.5 W at 10 kHz in BBO

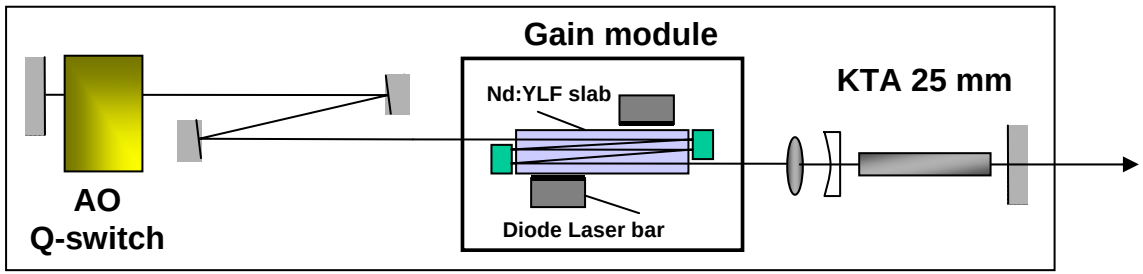
5HG (207 nm):
2 W (internal)
at 5 kHz with CLBO

Ti:sapphire laser pumped by doubled Nd:YLF laser has 44% conversion efficiency at 10 kHz PRR



OPOs provide high power at eyesafe wavelengths

Intracavity OPO



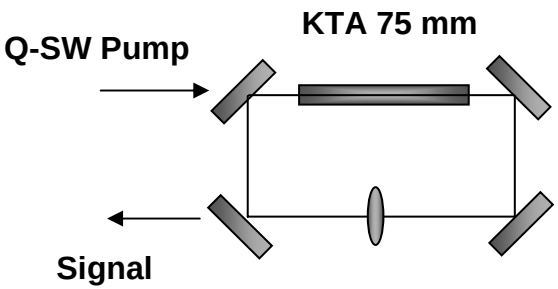
1 W output

at 1507 nm

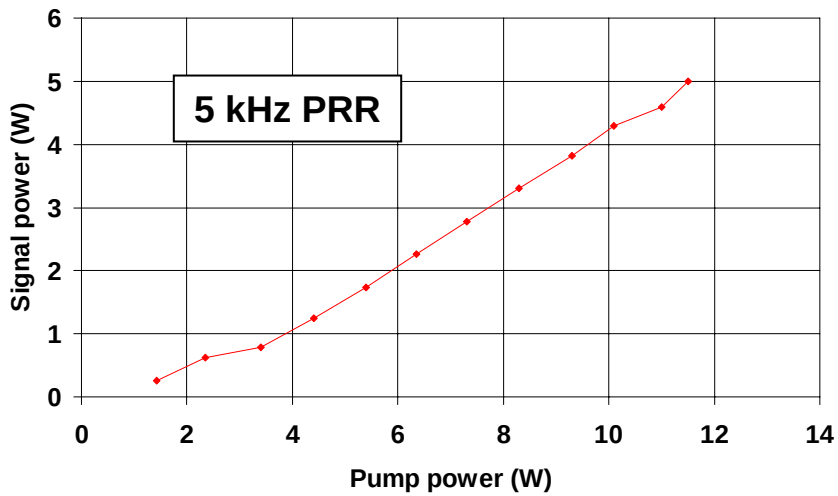
12.5 kHz PRR

6 ns pulsewidth

External OPO



43% conversion to 1507 nm



KTA and PPLN OPOs provide longer-wavelength IR

- **Pump source: MOPA #2**
- **KTA OPO**
  - **60-mm crystal length, 80-degree cut**
    - 30 W pump, 5 kHz PRR
    - 10 W at 1530 nm, 3 W at 3340 nm
  - **40-mm crystal length, 60-degree cut**
    - 33 W pump, 5 kHz PRR
    - 5-6 W of idler tunable from 2300-3000 nm
- **PPLN OPO**
  - **19-mm crystal length, 30.8-um pitch**
    - 30 W pump, 5 kHz PRR
    - 5.2 W at 2610-nm idler, 3W at 1720-nm signal

Closing Comments

- The “next generation” solid state lidar transmitters will replace the lamp-pumped Nd-doped laser “engine” with a diode-pumped Nd-laser “engine”
- To be cost-effective (and reliable) the diode-pumped lasers should be cw-pumped and repetitively Q-switched
- A full range of nonlinear optics (harmonic generators, OPOs) and tunable lasers (Ti:sapphire, etc.) are usable with the cw-pumped “engines” to provide wavelength diversity and tunability