Advanced solid state lasers for Lidar applications

1994 OSA Annual Meeting
October 3, Dallas, Texas

SEO
RESEARCH
DIVISION

OUTLINE

Laser requirements

Review of IR source technology

- **Rare-earth lasers**
- **OPOs**

CREDITS

Researchers at SEO

- John Flint, David Rines, Andy Finch, Jim Harrison

Support

- Geophysics Directorate, Phillips Lab, Air Force
- ARPA

APPLICATIONS OF COHERENT LIDAR

Ground-based

- Basic studies of wind, tornados
- Wake-vortex detection at airports

Aircraft-based

- Basic studies of upper-level winds
- Air-speed sensing
- Wind-shear detection (competition from radar)
- Wind measurments to correct for munitions releases

Space-based

- Global winds for basic science, weather forecasting

TRANSMITTER REQUIREMENTS

Need a pulsed source for range-resolved measurements

Also need a cw source for use as a local oscillator and, in some architectures, for use as a seed

PULSED SOURCE - PROPERTIES

- **Want transform-limited pulses**
- **Pulsewidth determined by range, velocity resolutions and wavelength**
  - **Shorter wavelengths (with larger Doppler shifts) yield a better range resolution for a given velocity resolution**
- **Typical widths range from 200 nsec to 3 μsec**
- **Energy/pulse ranges from 1 mJ to 20 J**
- **Pulse rates fall between 10 and 1000 Hz**
- **Eye safety strongly encourages use of wavelengths longer than 1.5 μm.**

CW SOURCE - PROPERTIES

Single frequency

Tunable, to handle offsets from moving platforms

Frequency jitter set by round-trip time (μsec to msec) and desired velocity resolution

Typical short-term jitter less than 1 MHz

Long-term stability set by other system requirements

Output power levels 10-100 mW

SOLID STATE SOURCES FOR COHERENT LIDAR

Almost always compared to the "gold standard" CO_2 laser

Operate in 1-3 μm wavelength range

Recent advances in materials, pump sources have made them usable in coherent systems

Semiconductor lasers as optical pumps make possible

- Stable, single-frequency operation
- Increased efficiency, reduced size and weight
- Increased operating lifetime
- Room, or near-room temperature operation for some

New materials and doping schemes improve performance of non-Nd-doped lasers

SOLID STATE SOURCES - PROS

No gases, high voltages

With diode pump sources, long lifetime

High output/volume compared to gases

Possibility of fiber delivery for cw beams

More than sufficient tuning range to cover platform offsets

SOLID STATE SOURCES - CONS

Scaling to multi-Joule outputs has not been accomplished

Lower efficiency (?)

Short wavelengths lead to

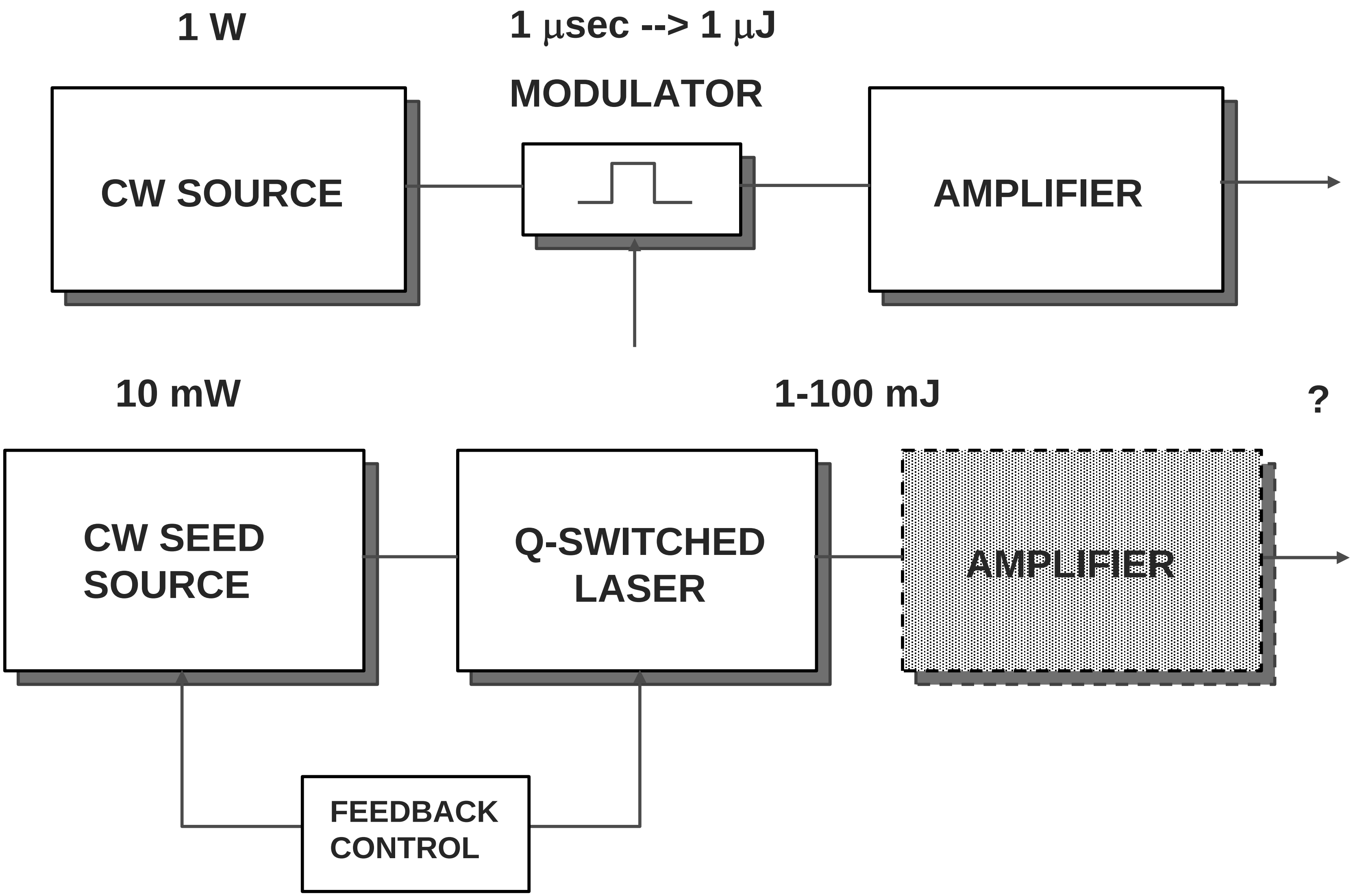
- **Small field-of-view**
- **Stressing beam-pointing requirements**

Difficult to operate with long pulses

Optical damage problems with some eye-safe systems

Optimum operation requires cooling below ambient for some

COMMON SOLID STATE ARCHITECTURES



1 W

1 μsec --> 1 μJ

MODULATOR

CW SOURCE

AMPLIFIER

10 mW

1-100 mJ

?

CW SEED SOURCE

Q-SWITCHED LASER

AMPLIFIER

FEEDBACK CONTROL

Q-SWITCHED LASERS: THE PULSEWIDTH PROBLEM

High-gain (i.e. large cross section) lasers

- **Make good amplifiers and are saturable at low intensities/fluences**
- **But, with high gain lasers the Q-switched pulsewidth is only several times the cavity round-trip time**
- **High-gain, short pulsewidths go together**

Low-gain lasers

- **Are lousy amplifiers and need high intensities to saturate, with damage limiting extraction**
- **But, Q-switched pulses are many times the cavity round-trip time**
- **Several-100 nsec pulses are possible (forget 3 μsec)**

SOLUTIONS TO THE "Q-SWITCH PROBLEM"

- **Use long optical cavities**
  - **alignment, stability, packaging challenge**
- **Run high-gain lasers just over threshold**
  - **low energy**
  - **jitter in energy, timing**
- **Cw pump, repetitively Q-switch the laser**
  - **low energy (but sufficient for short ranges)**
  - **need pulse selector if amplifier runs at lower rate?**
- **Develop controlled Q-switch**
  - **can set pulsewidth to arbitrary values, in theory**
  - **in practice, fast electronics, switch, feedback needed**

SOURCE TECHNOLOGY: RARE-EARTH LASERS

Nd-doped lasers are nearly ideal for energy levels up to 1 J, but are out of the running because of eye-safety issues

Everything goes downhill away from Nd-doped materials

The other possible rare earths and transitions are:

- **Er at 1.55 μm**
- **Tm at 2.0 μm**
- **Ho at 2.1 μm**
- **Er at 2.9 μm**

Er can be eliminated quickly, except perhaps for doped-fiber systems at 1.55 μm

BASICS OF Tm AND Ho LASERS

Both Tm and Ho lasers terminate on levels in the ground manifold

- **Generally want to cool crystals to reduce lower-level population density and the threshold**
- **Tm:YAG has unusually high-lying lower level and works OK at room temperature**

Ho gain cross sections higher than those of Tm, in YAG and YLF be a factor of 5-6. Use of Tm as amplifier is highly optimistic, except in fibers

Pumping of Ho is aided by Tm sensitization, which gets better at lower temperatures

Lamp pumping of either is aided by Cr sensitization

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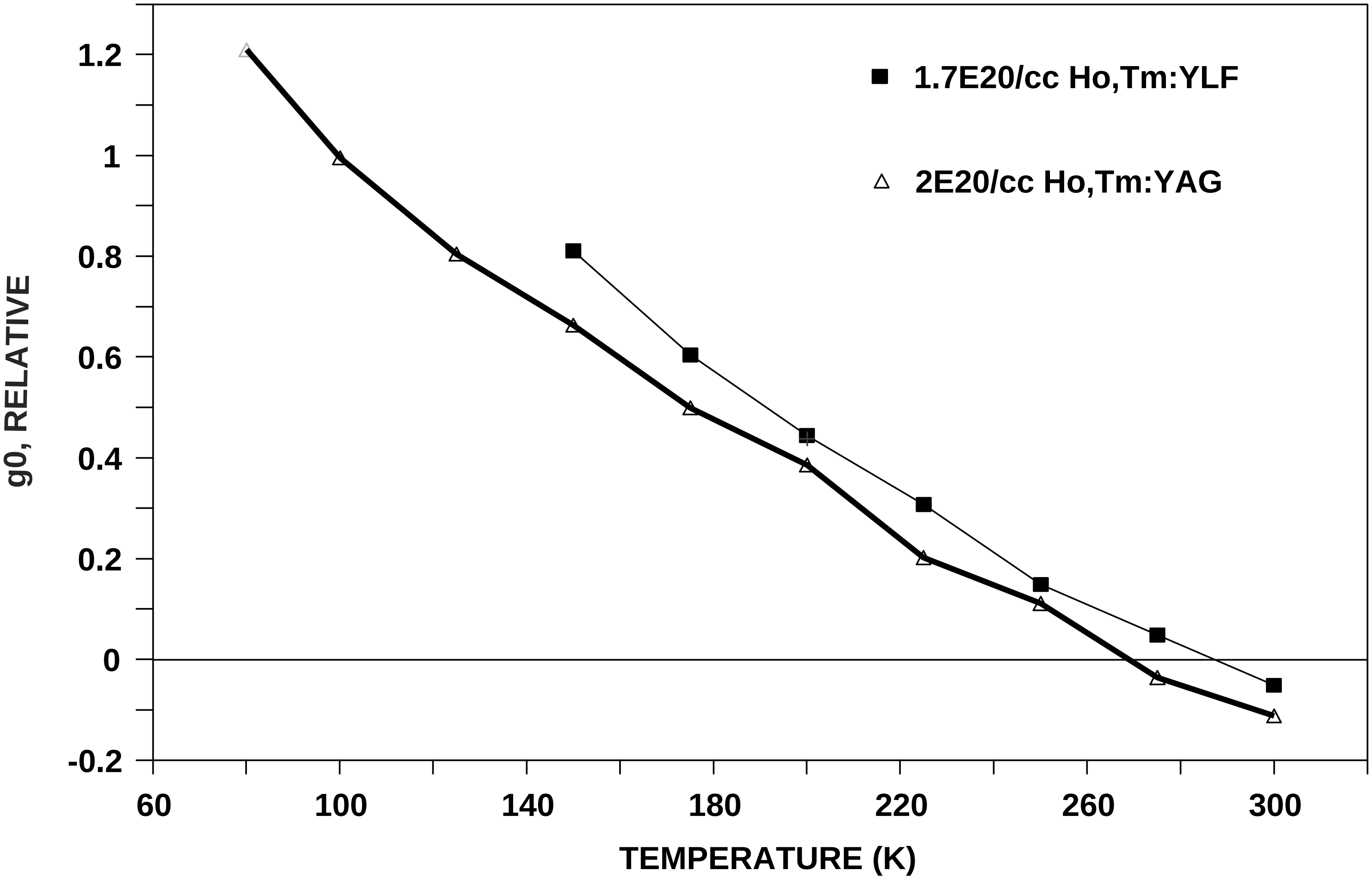
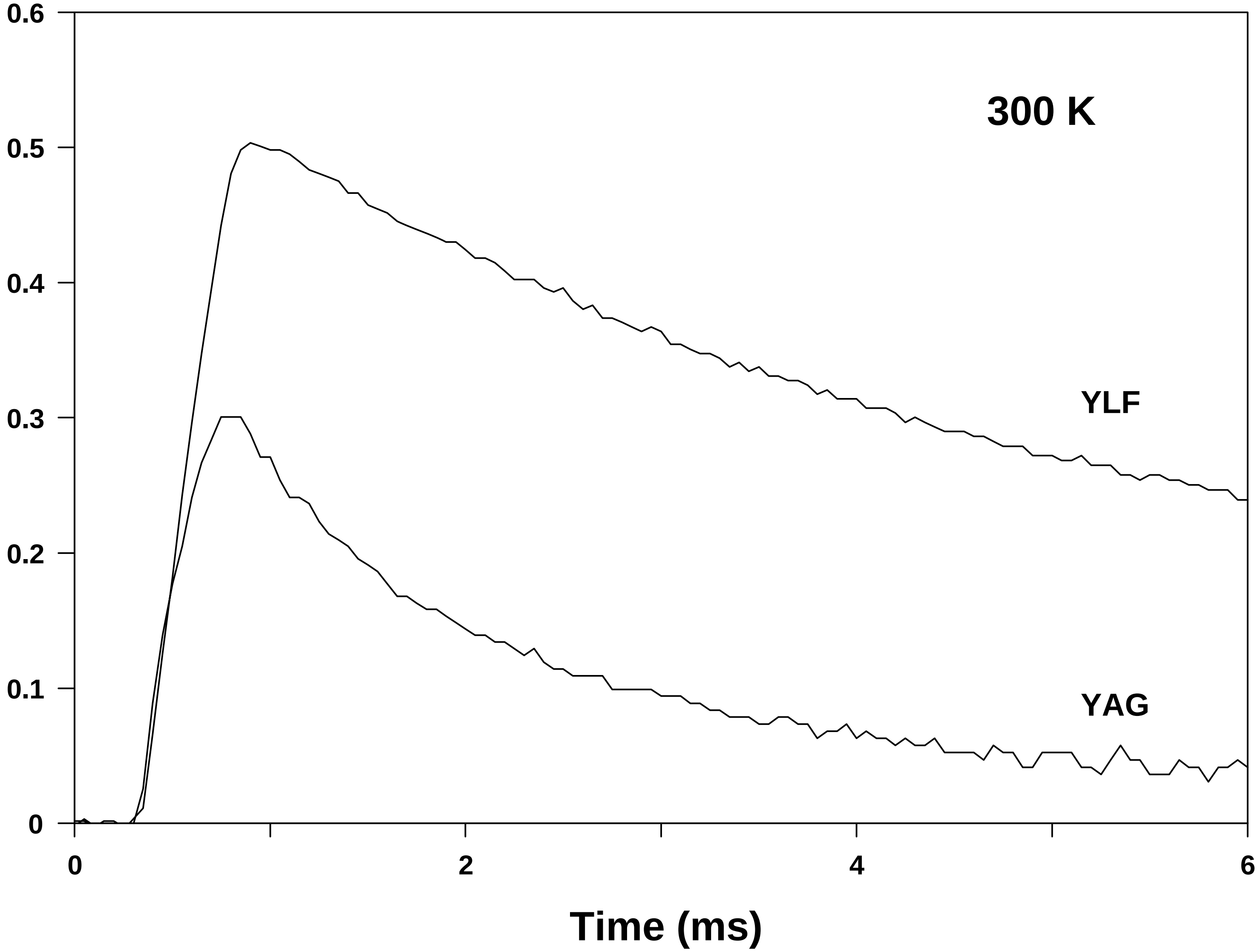
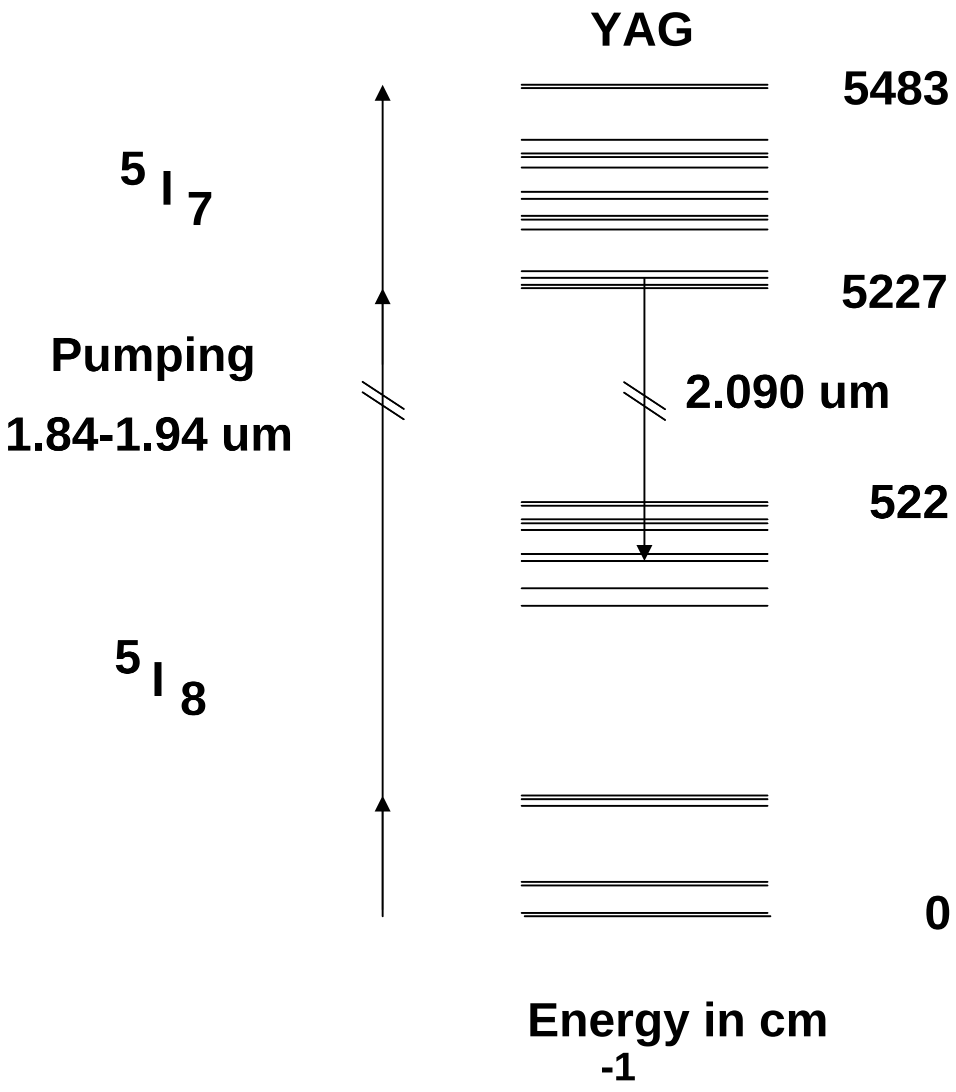
COMPARISON OF GAIN IN YAG AND YLF HIGH Ho CONCENTRATIONS



GAIN DECAY: YAG vs. YLF
HIGH Ho CONCENTRATIONS



Ho:YAG RESONANT PUMPING



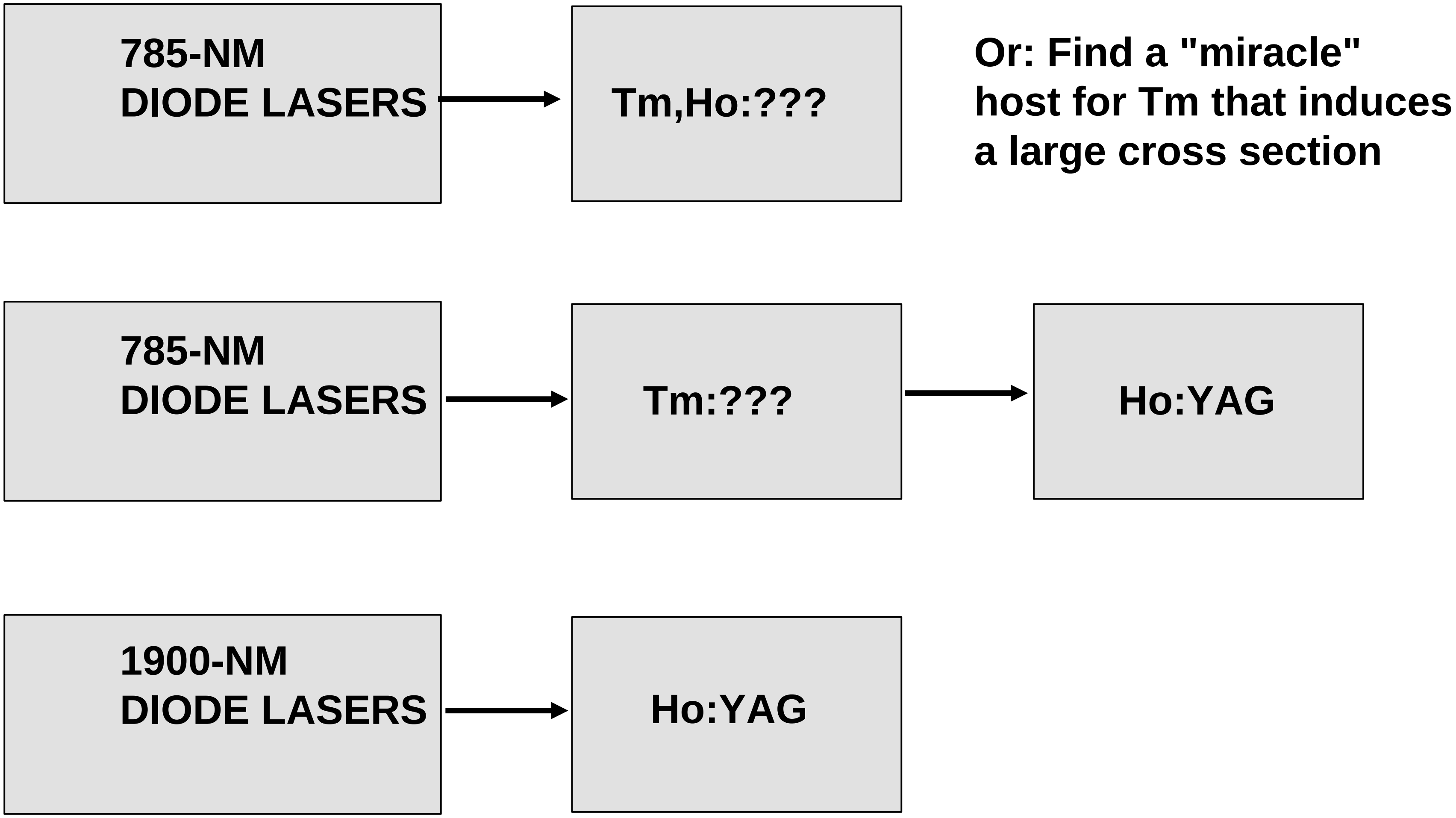
Why?

Low heating
No back-transfer to Tm
No upconversion through Tm

How?

Tm:??? as pump
New mid-IR diode lasers

PUMPING OPTIONS FOR HIGH-ENERGY SYSTEMS



785-NM DIODE LASERS → **Tm,Ho:???**

Or: Find a "miracle" host for Tm that induces a large cross section

785-NM DIODE LASERS → **Tm:???** → **Ho:YAG**

1900-NM DIODE LASERS → **Ho:YAG**

CW Tm,Ho:YLF LASER

Design:

- End-pumped by 500-mW, 100-um-aperture diode laser
- Proprietary line-narrowing scheme

Performance

- 2.06 μm wavelength
- >60 mW, single-frequency output power
- Quasi-continuous tuning over 140 GHz range
- <1 MHz/min stability
- 10 khz/ 1msec short-term linewidth

SUMMARY

Practical use of solid state lasers for coherent lidar has been made possible by advances in high-power diode lasers and laser materials

Advantages over CO_2 lasers are accompanied by new challenges

Problem of cw, single-frequency source is crushed

Diode-pumped, Tm:YAG and cooled Tm,Ho:YLF lasers are sources for low-energy (mJ-level) pulses at 100-1000-Hz rates

Higher energies need osc-amp architectures and aggressive cooling with solid state sources (Tm,Ho:YLF a candidate)

OPOs and OPAs offer and interesting alternative