Diode-Pumped Mid-IR Lasers

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RESEARCH
DIVISION

CREDITS

- SEO personnel
  - John Flint, David Rines, James Harrison - Tm, Ho lasers
  - Brad Dinerman - Er lasers
- Support at SEO
  - AFGL/Phillips Labs - Ho lasers
  - DARPA - Er lasers
- Data
  - NRL, Lightwave Electronics, Coherent Technologies, Lockheed/Sanders

OUTLINE

- Background
- Technology
  - Tm doping
  - Ho doping
  - Er doping
- Applications

WHY DIODE PUMPING?

- Many mid-IR ,rare-earth-doped laser materials have:
  - weak or sparse direct pumping transitions where flashlamps have most output (Cr-doping rescues some materials)
  - high threshold pumping rates because of:
    - partially occupied lower laser level
    - low gain cross section
- Diode pumping allows:
  - resonant, high-intensity pumping
  - minimal heat generation
  - cw operation

COMMON ISSUES FOR MID-IR LASERS

- Ion-ion interactions have a significant effect on laser action
- Good
  - 200% pump quantum efficiency (Tm)
  - Energy transfer from acceptor to donor (Tm,Ho)
  - Depopulation of lower laser level (Er)
- Bad
  - Depopulation of upper laser level (Tm,Ho,Er)
- Why Tm,Ho and Er and not Nd?
  - Higher excited densities
  - Bad luck on level positions

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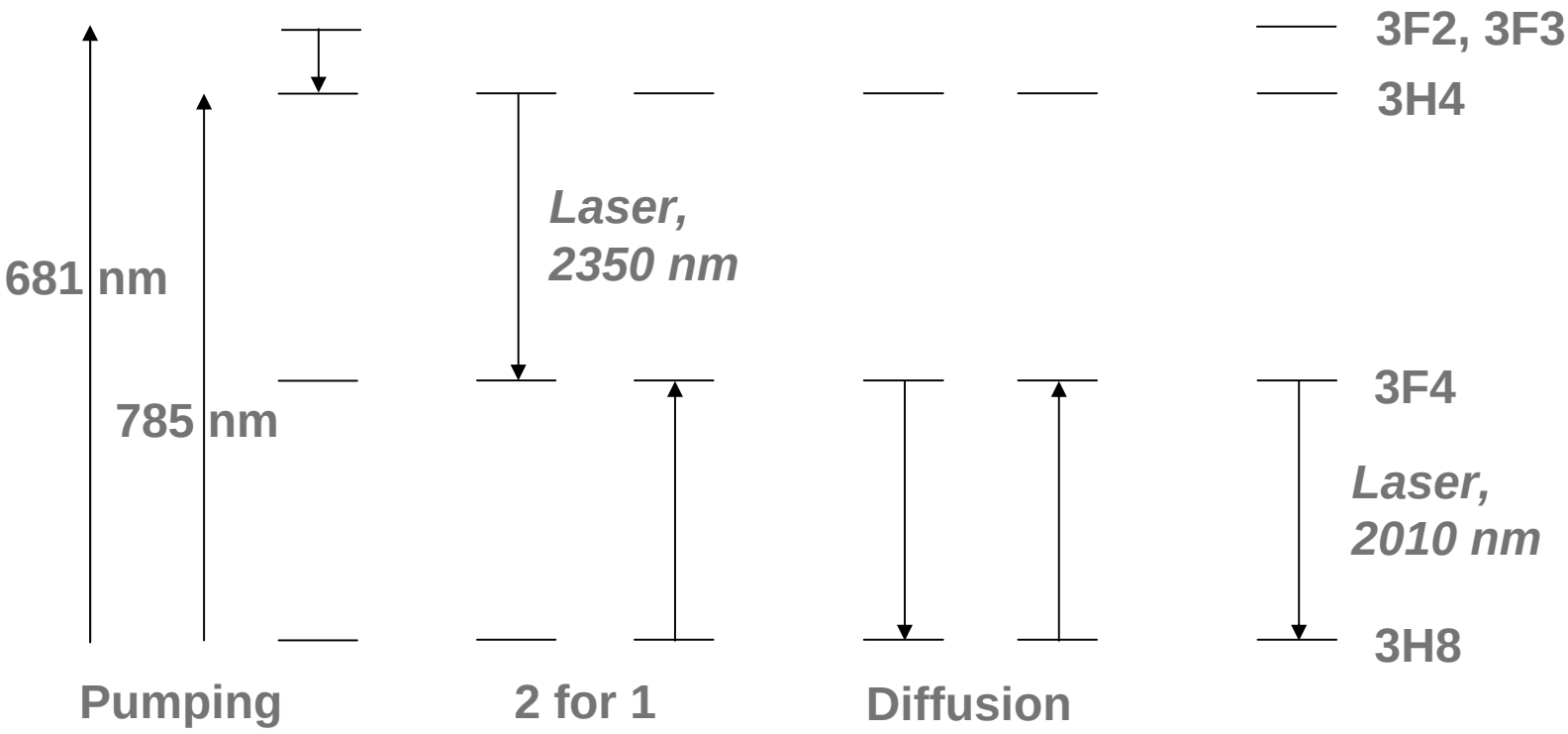
Tm LASER TRANSITIONS AND ENERGY TRANSFER PROCESSES



Laser hosts: YAG, YSGG, YLF, YAlO, YVO4

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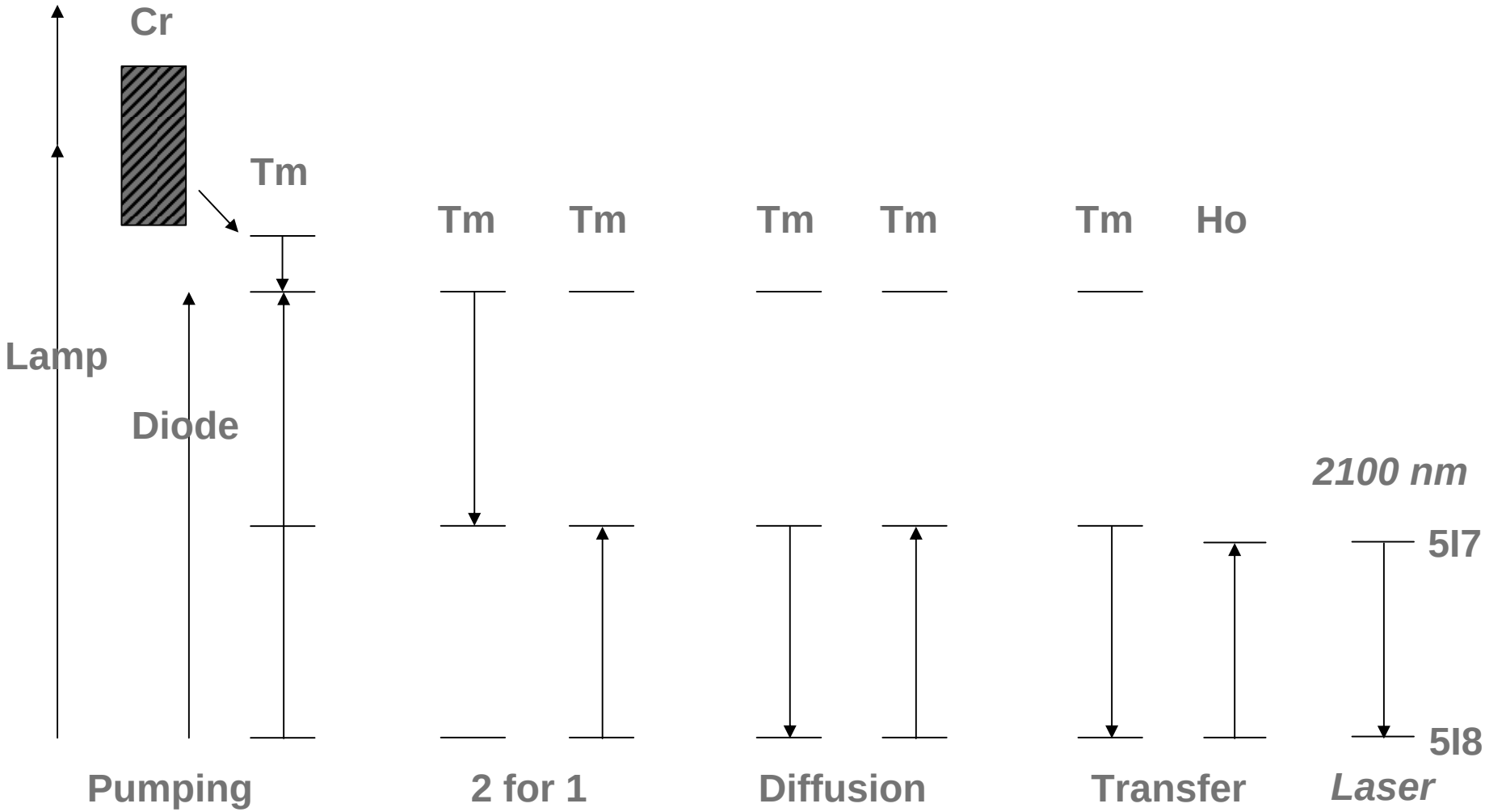
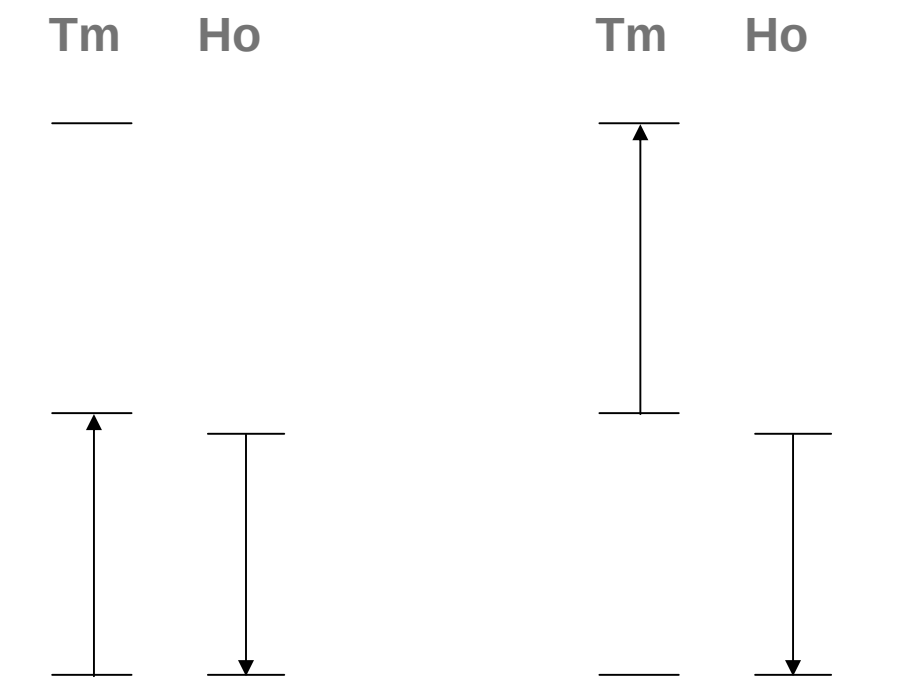
Tm,Ho PUMPING PROCESS



Tm-Ho: BAD NEWS



Back transfer **Cross relaxation**

WHY Tm,Ho INSTEAD OF Tm?

- Gain cross section is much higher
  - Saturation fluence is low enough for reasonable amplifier performance
  - Application to high-energy systems is possible
- But:
  - At room temperature, only a fraction of excitation is stored in Ho ions, typically 50%
  - Upconversion in Ho,Tm process presents a loss
  - Tm,Ho transfer rate drops at high Ho inversions
- Low-temperature operation helps everything

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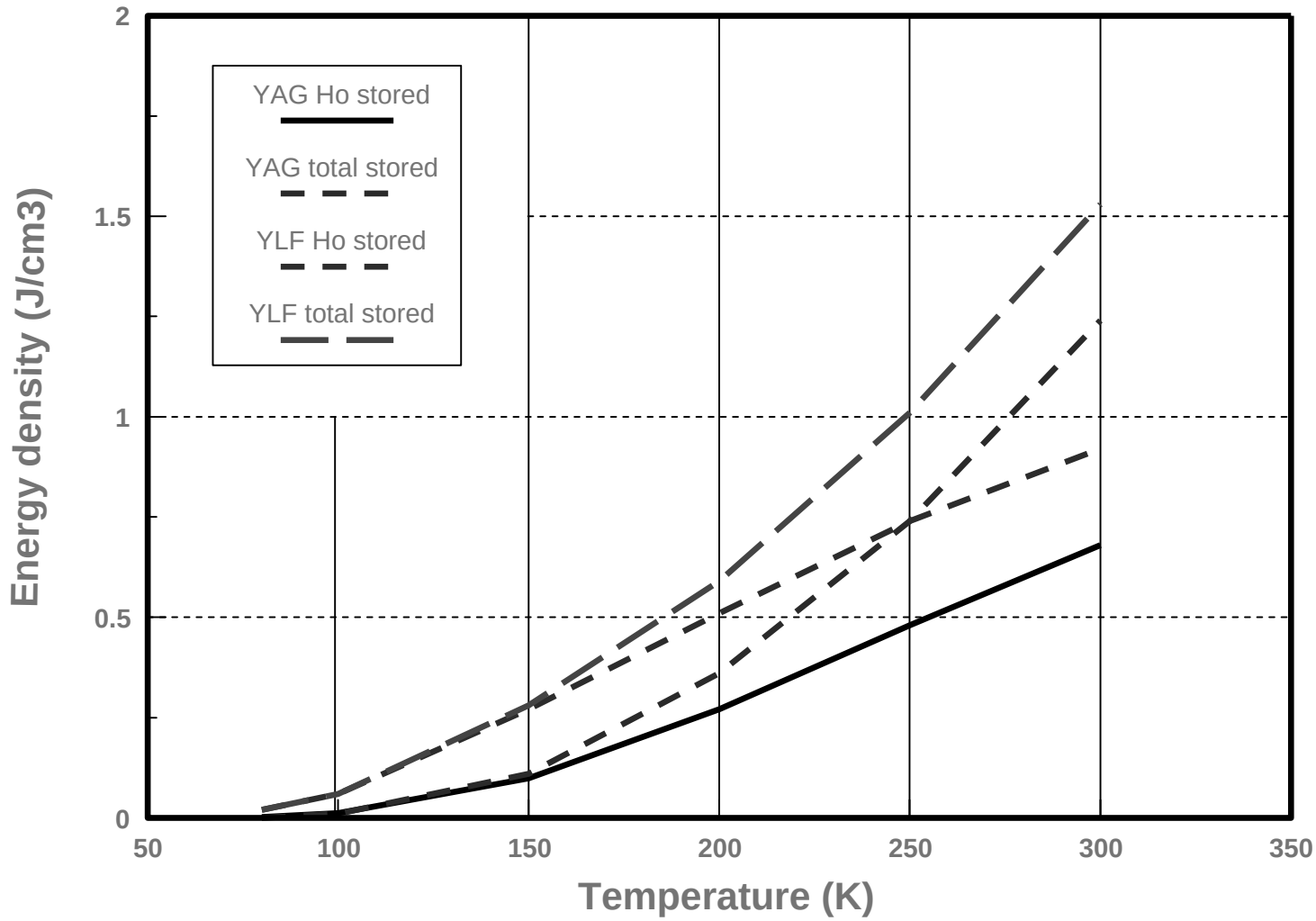
ZERO-GAIN ENERGY DENSITY



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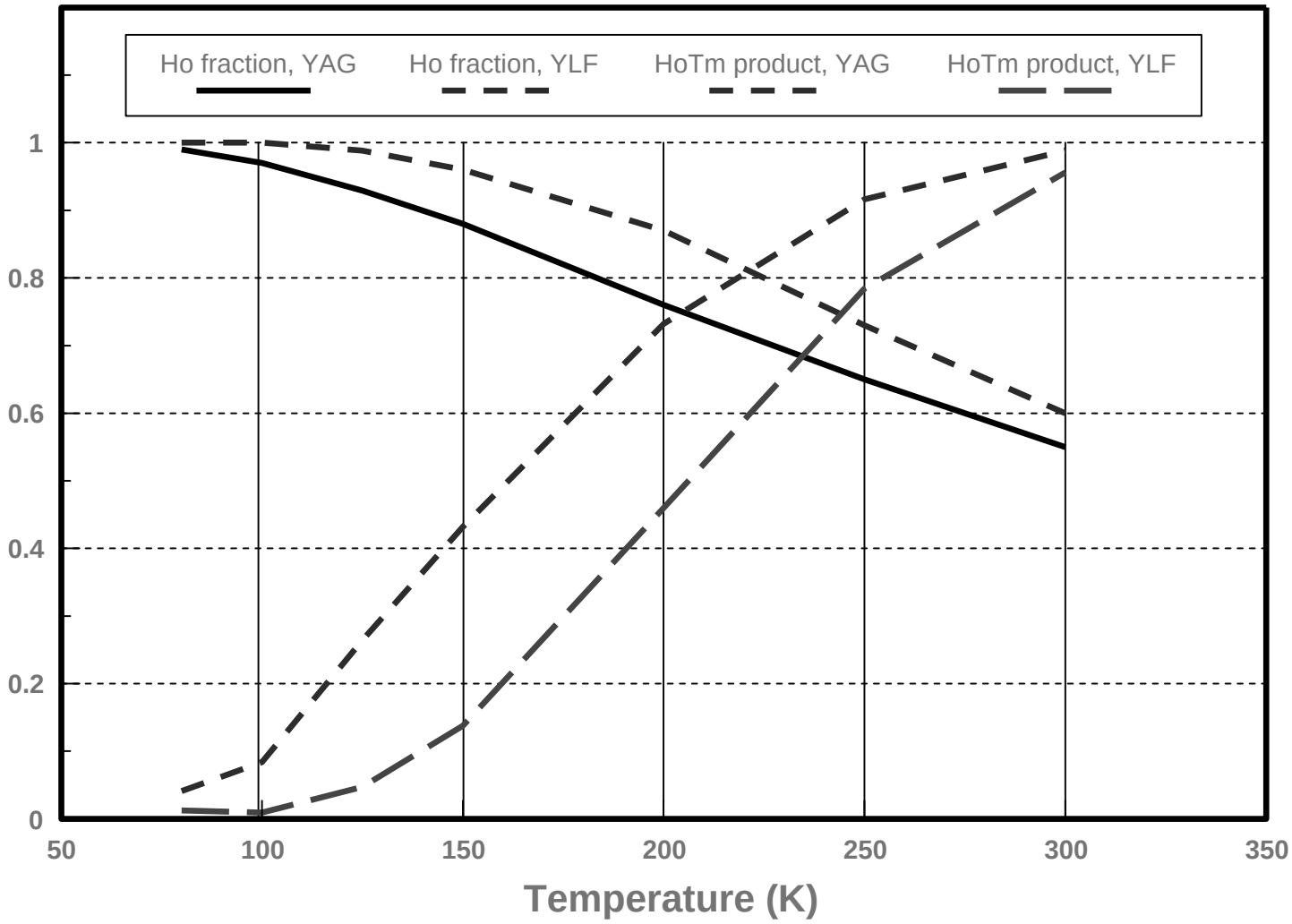
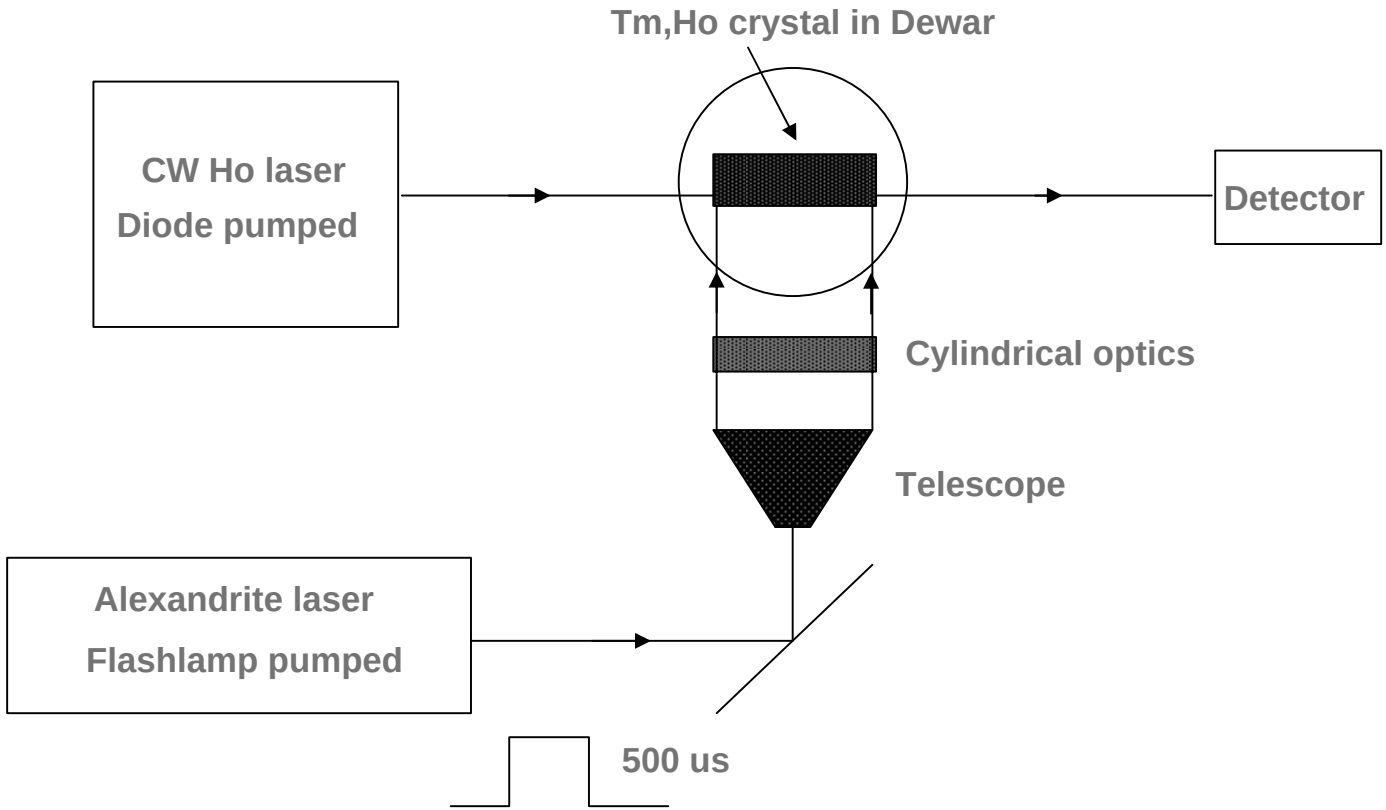
[Tm][Ho] PRODUCT - Ho FRACTIONAL ENERGY



Tm,Ho GAIN-PROBE EXPERIMENT



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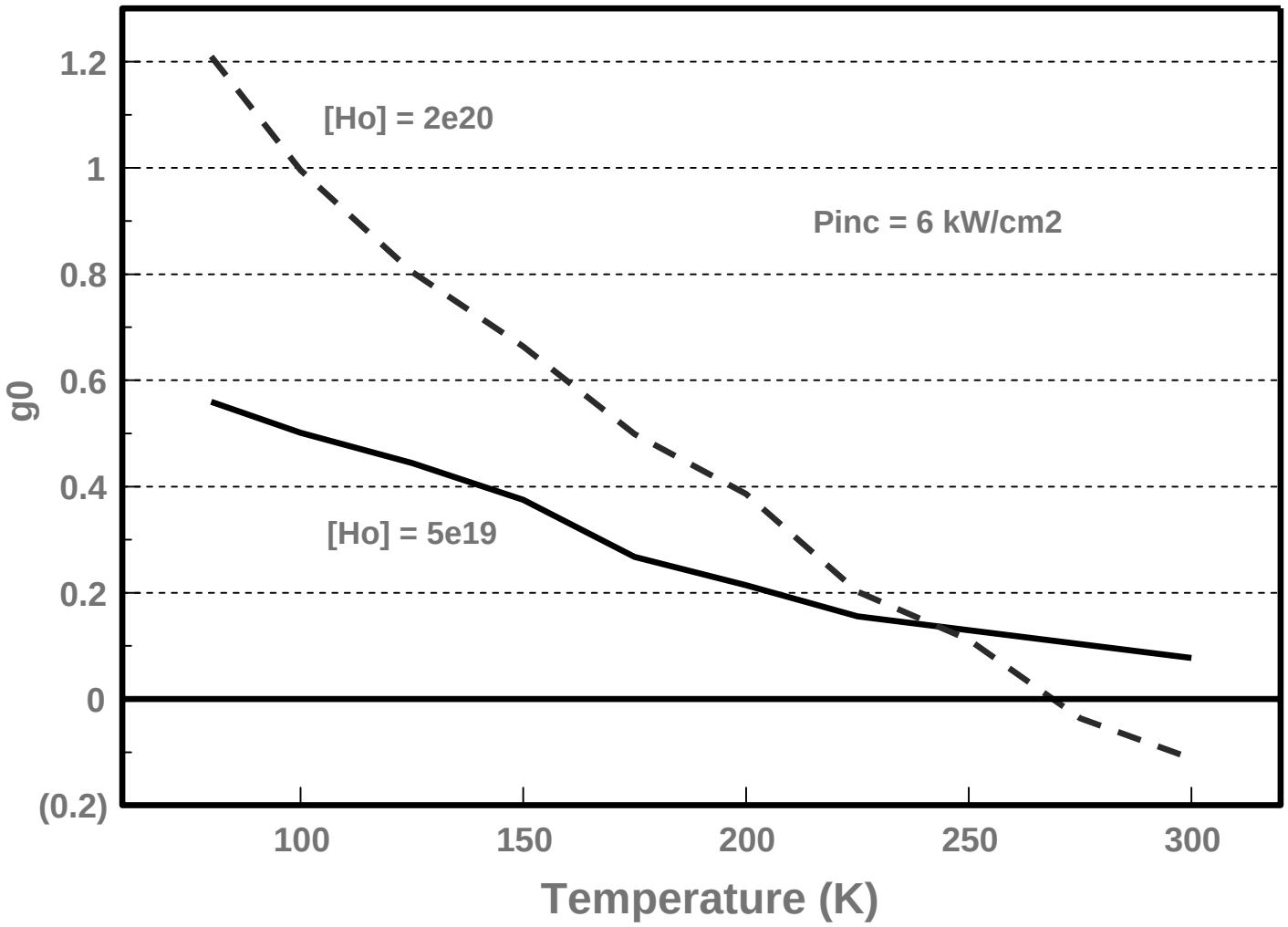
GAIN COEFFICIENT VS TEMPERATURE TWO Ho CONCENTRATIONS IN YAG



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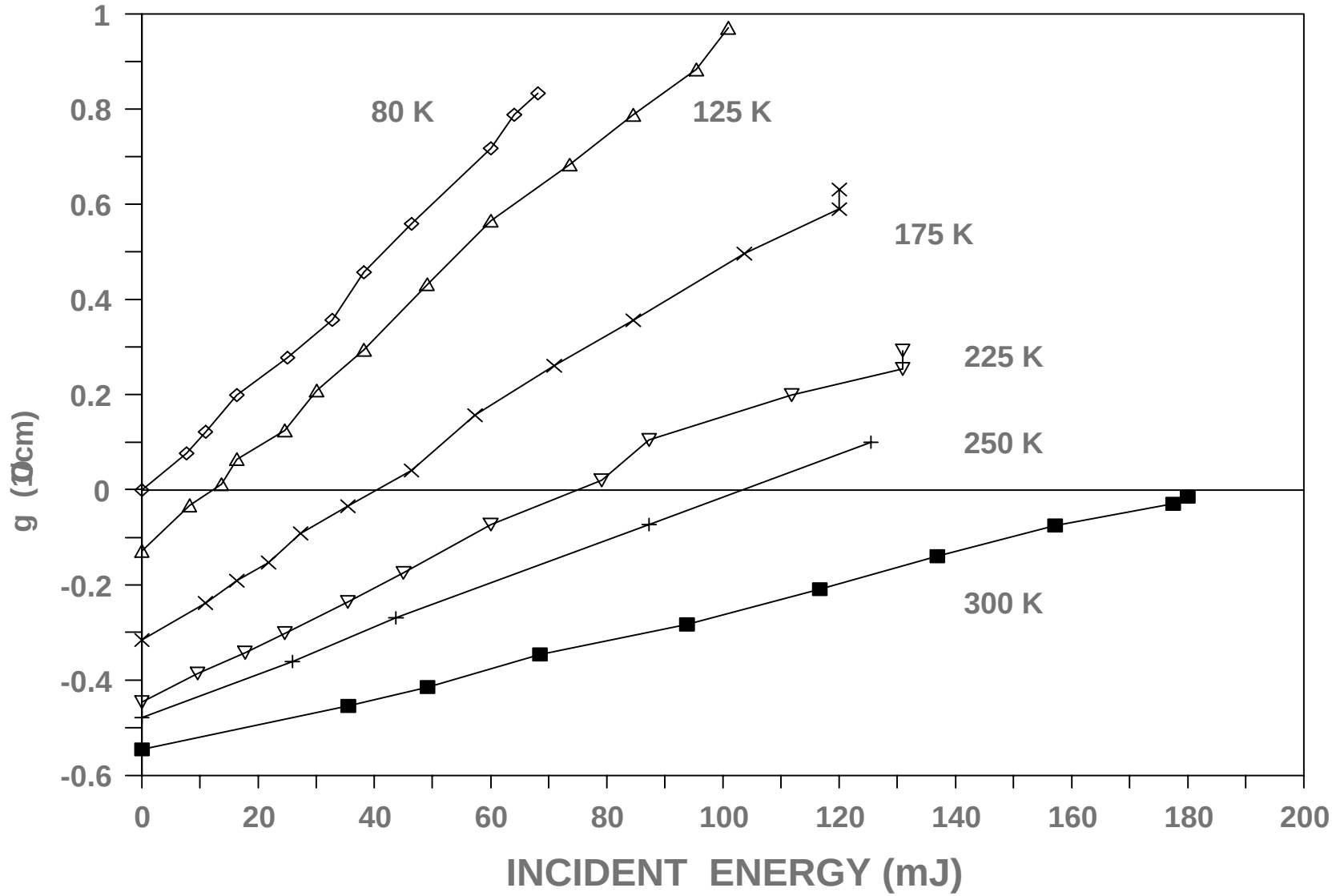
Tm,Ho:YLF GAIN VS. PUMP ENERGY FOR DIFFERENT TEMPERATURES



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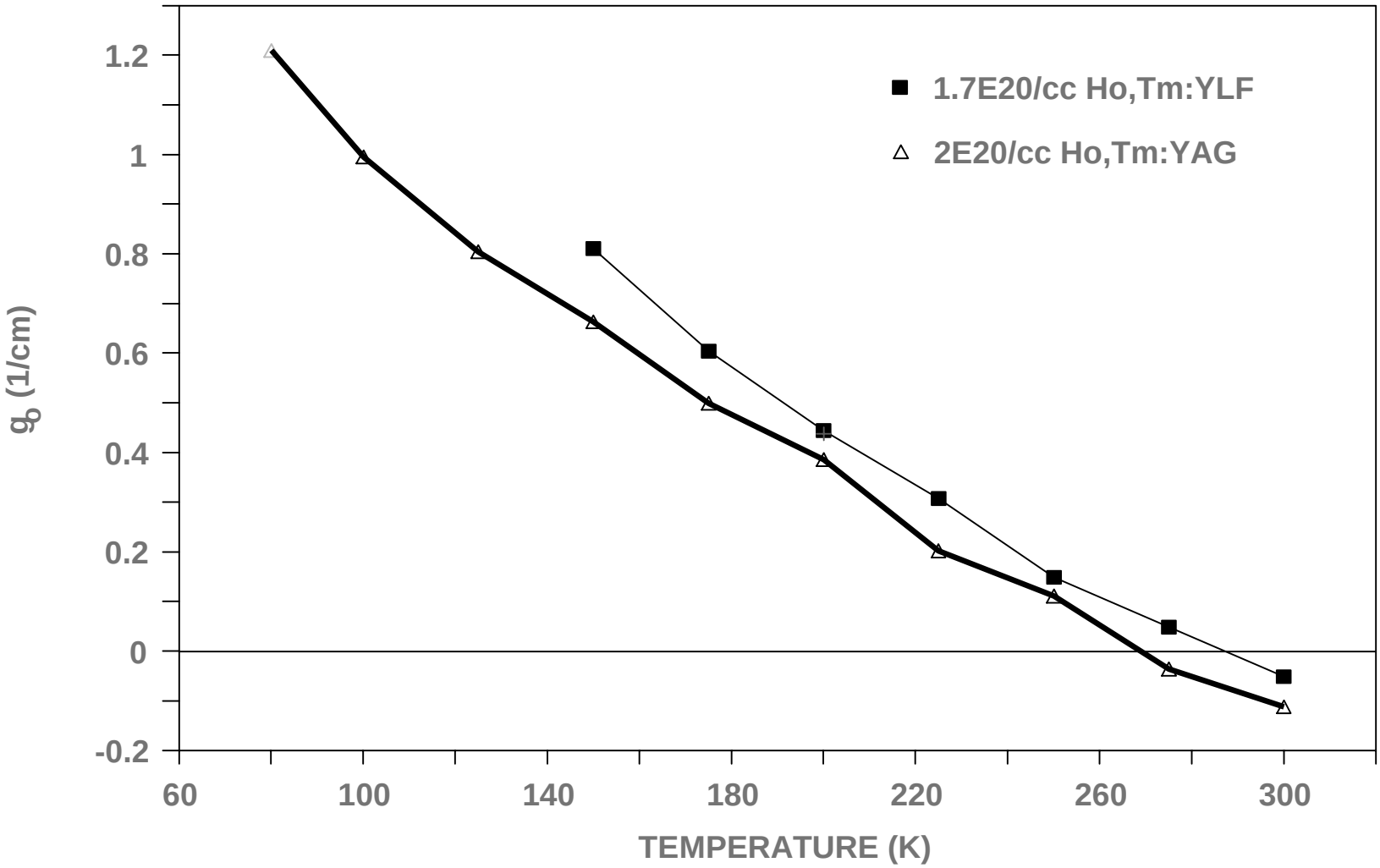
COMPARISON OF GAIN IN YAG AND YLF HIGH Ho CONCENTRATIONS



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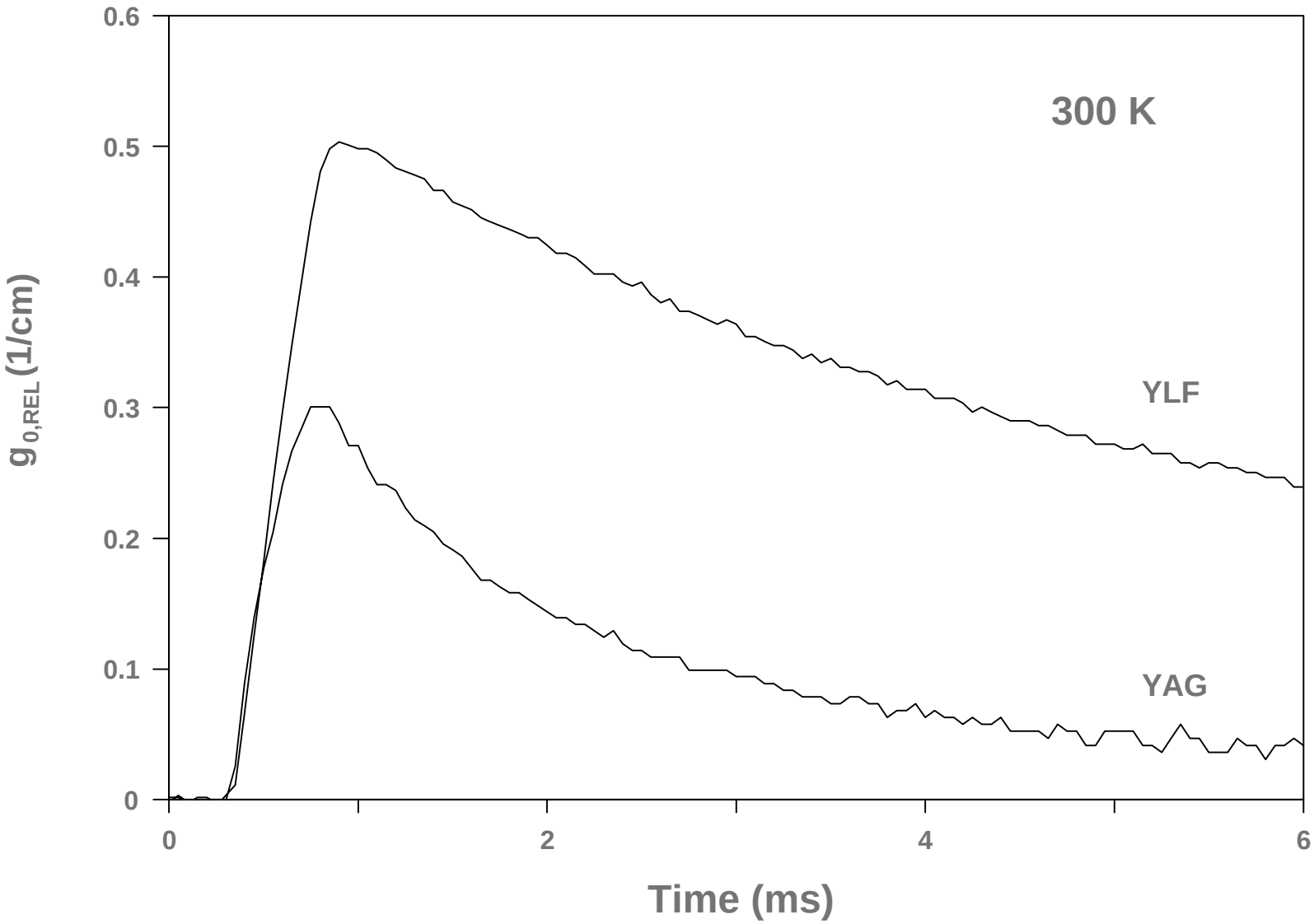
GAIN DECAY: YAG vs. YLF
HIGH Ho CONCENTRATIONS



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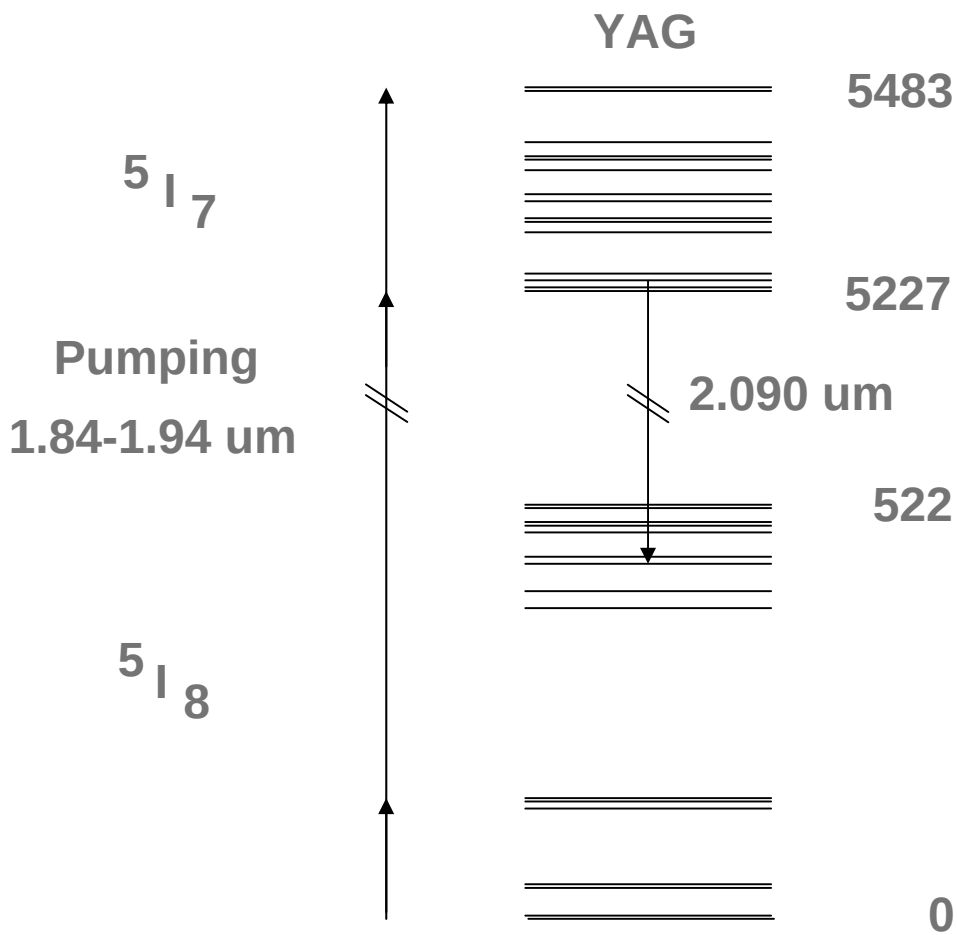
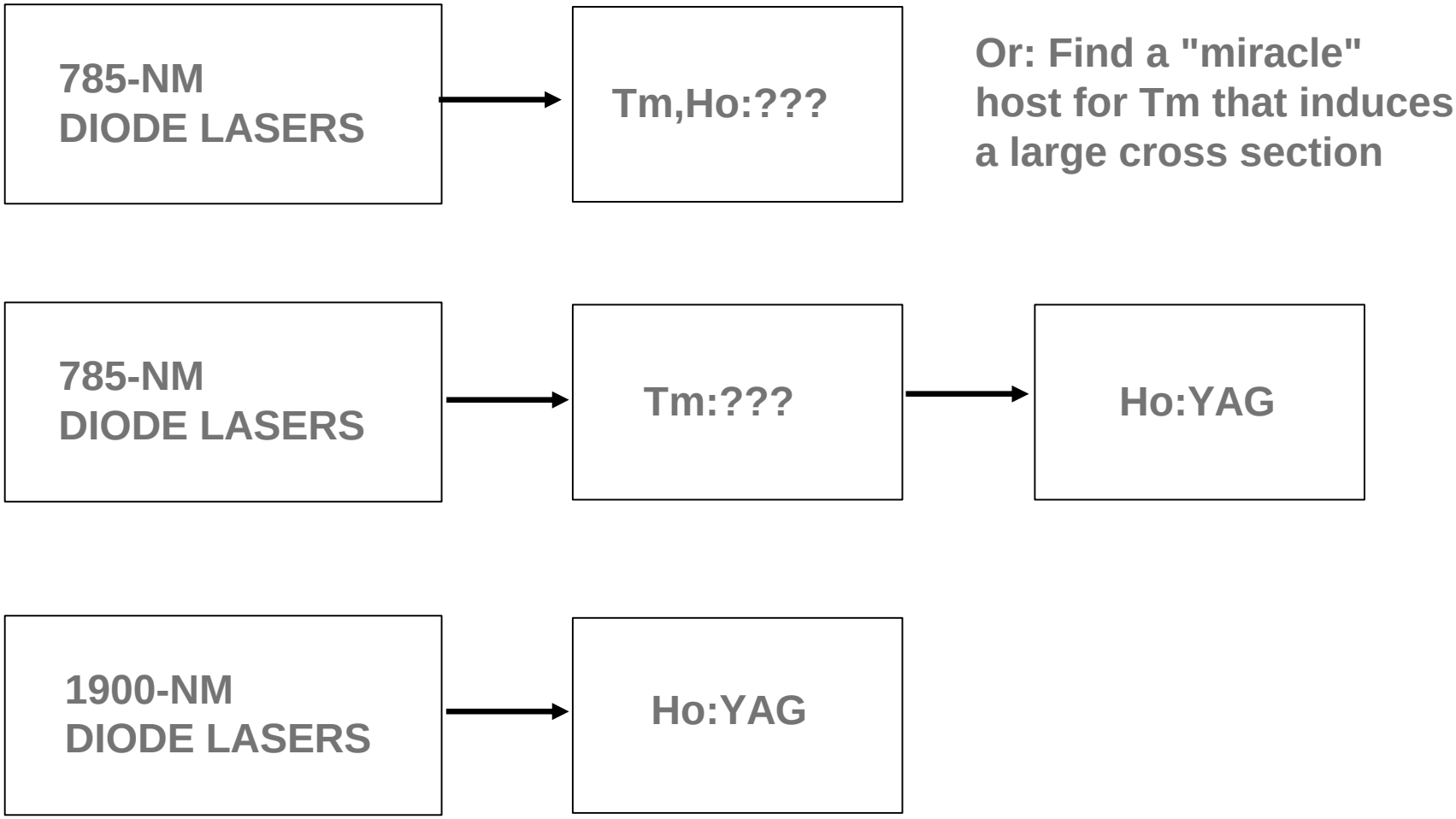
Ho:YAG RESONANT PUMPING



PUMPING OPTIONS



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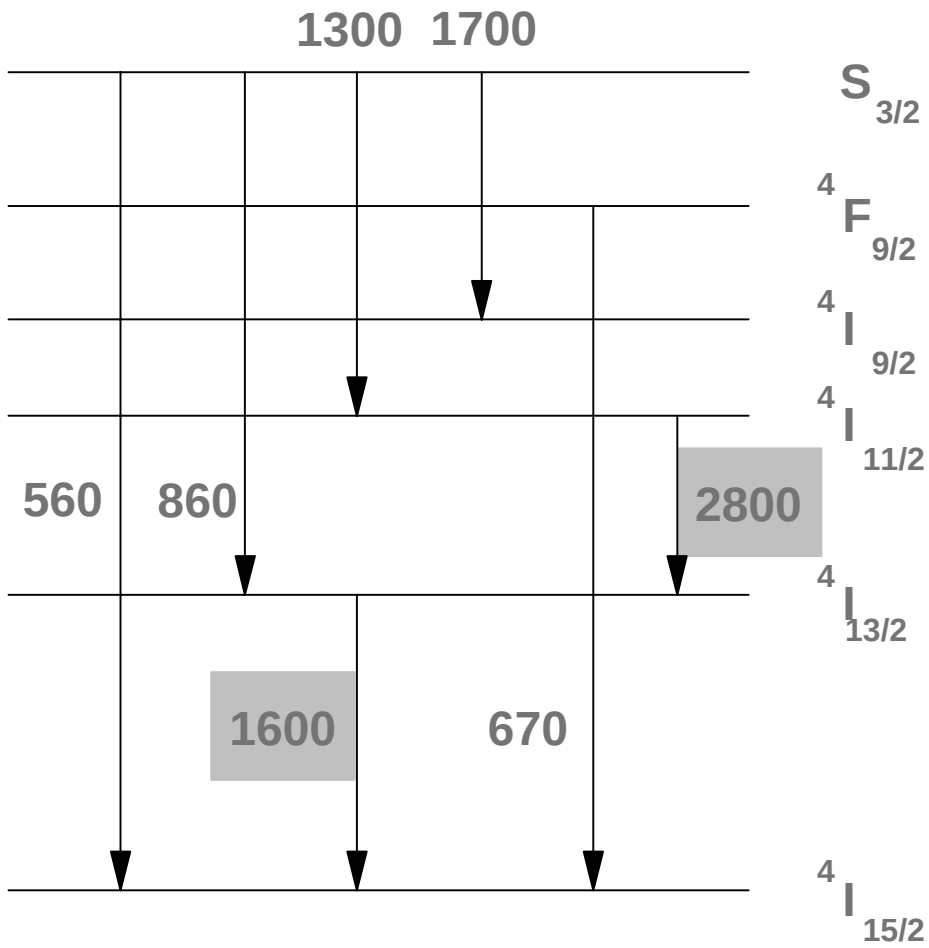
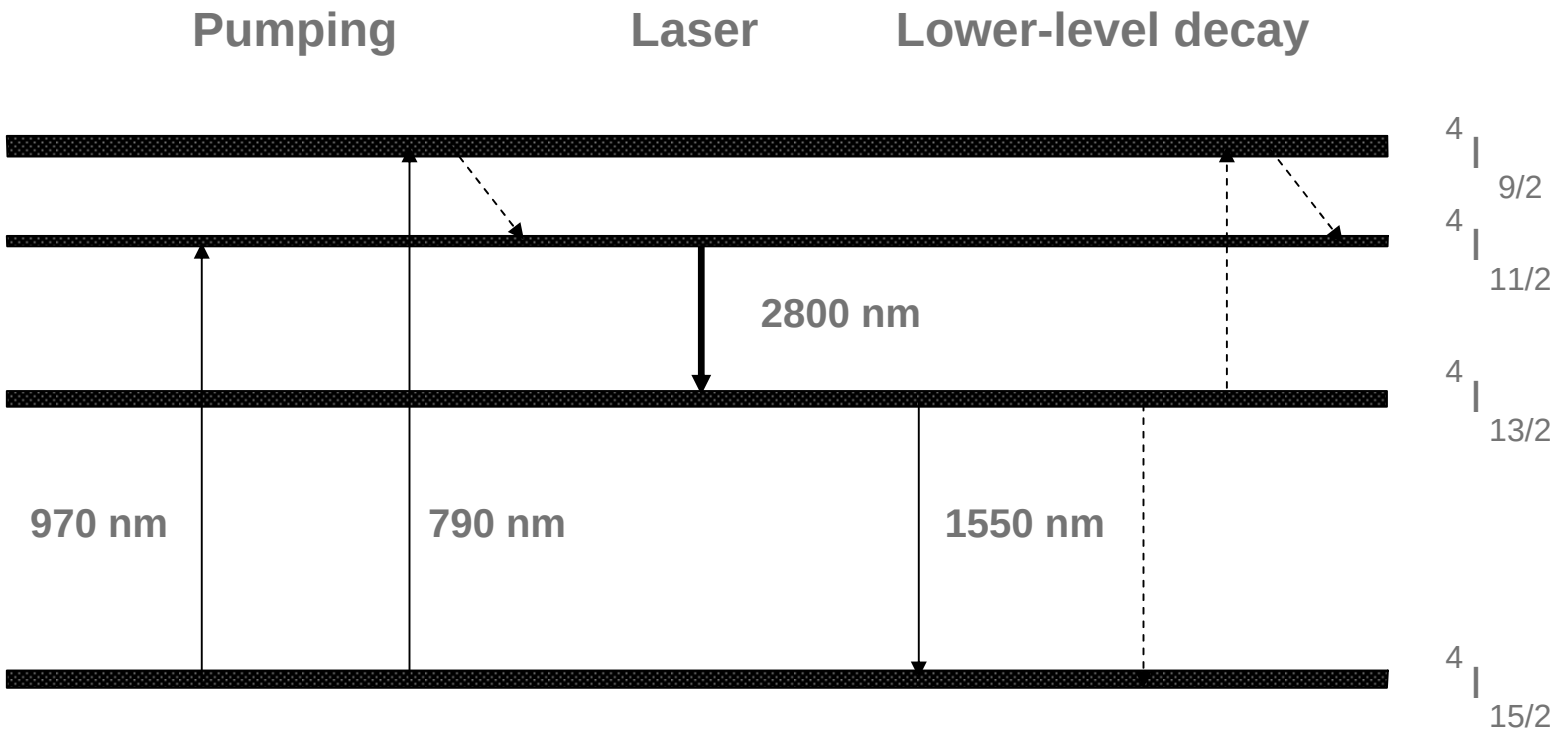
Er ION - LASER TRANSITIONS



Er LASERS - PUMPING AND LASER CYCLES



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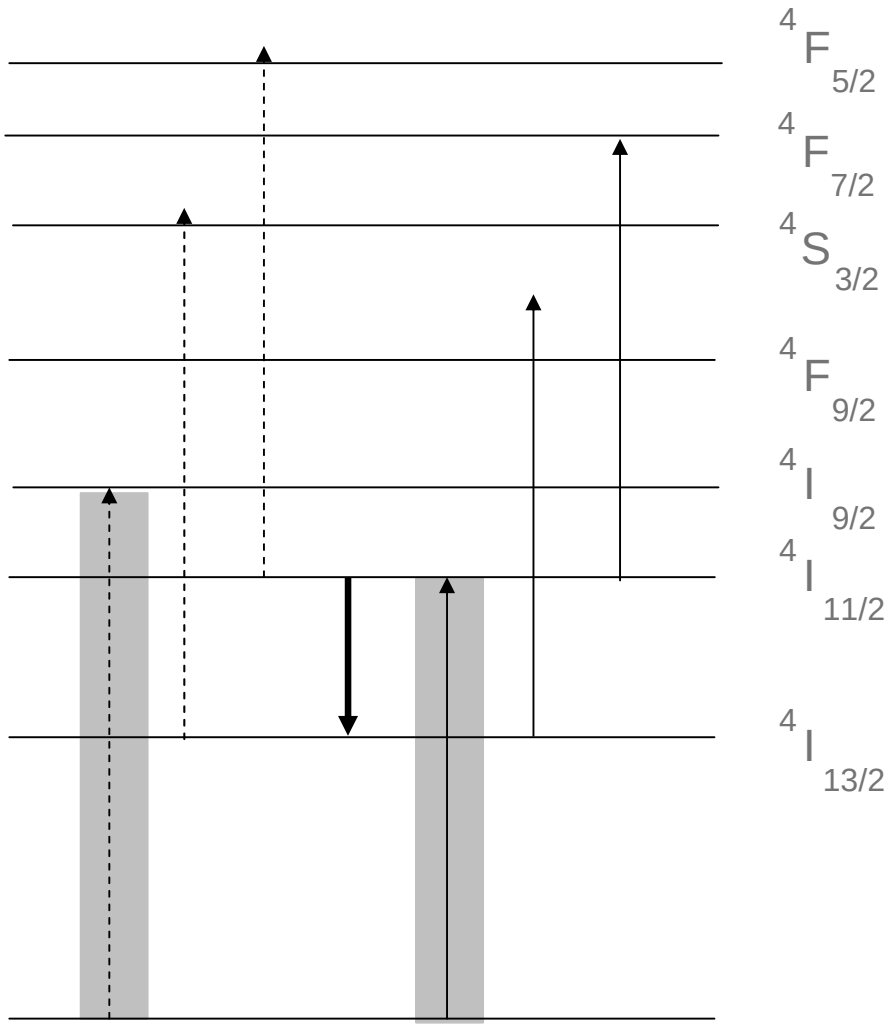
Er ION - DIODE PUMPING TRANSITIONS

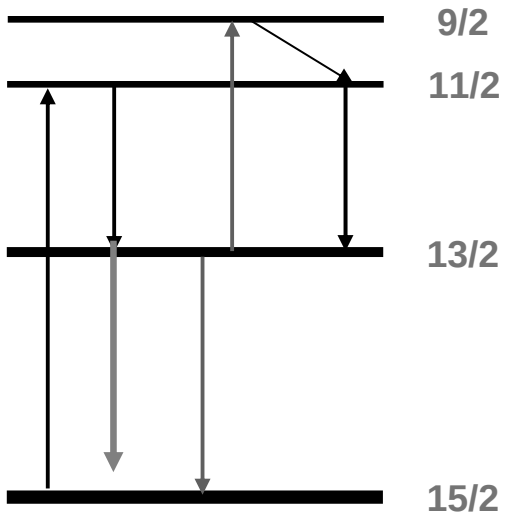
790 nm pump

970 nm pump



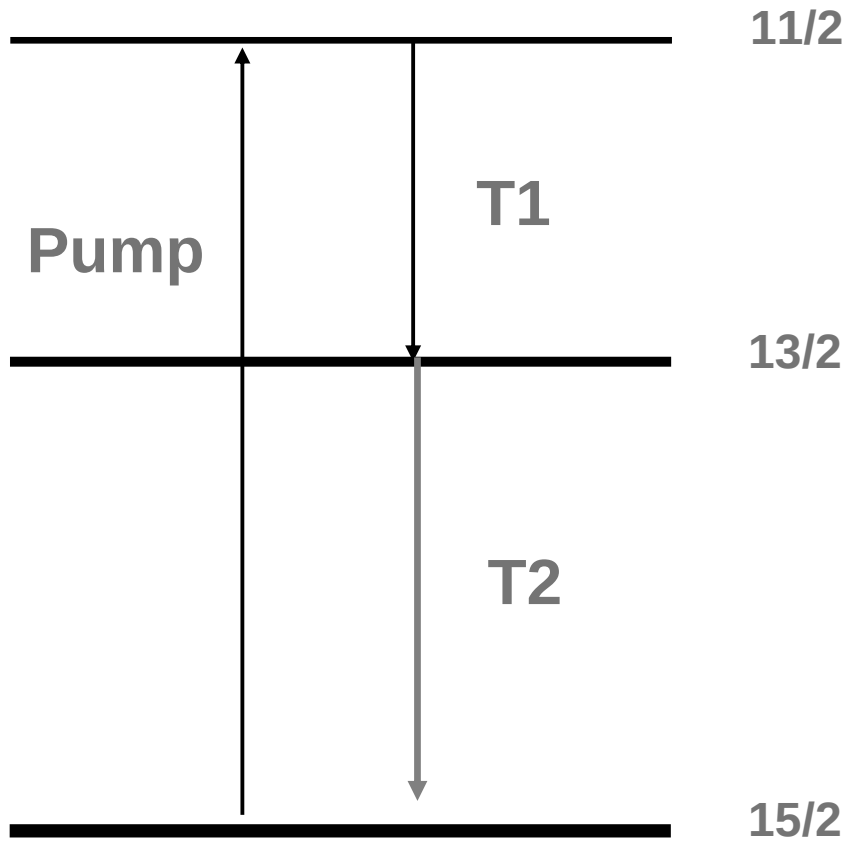
Er-DOPED 1600-nm-WAVELENGTH LASERS

- **Three -level laser**
  - *Low Er doping levels (0.5%)*
- **Upconversion**
  - *Find hosts with large Er-Er spacing*
  - *Find hosts with minimal clustering?*
- **Efficient pumping at 970 nm**
  - *Minimize level lifetimes above 13/2*
  - *Use Yb as sensitizer*

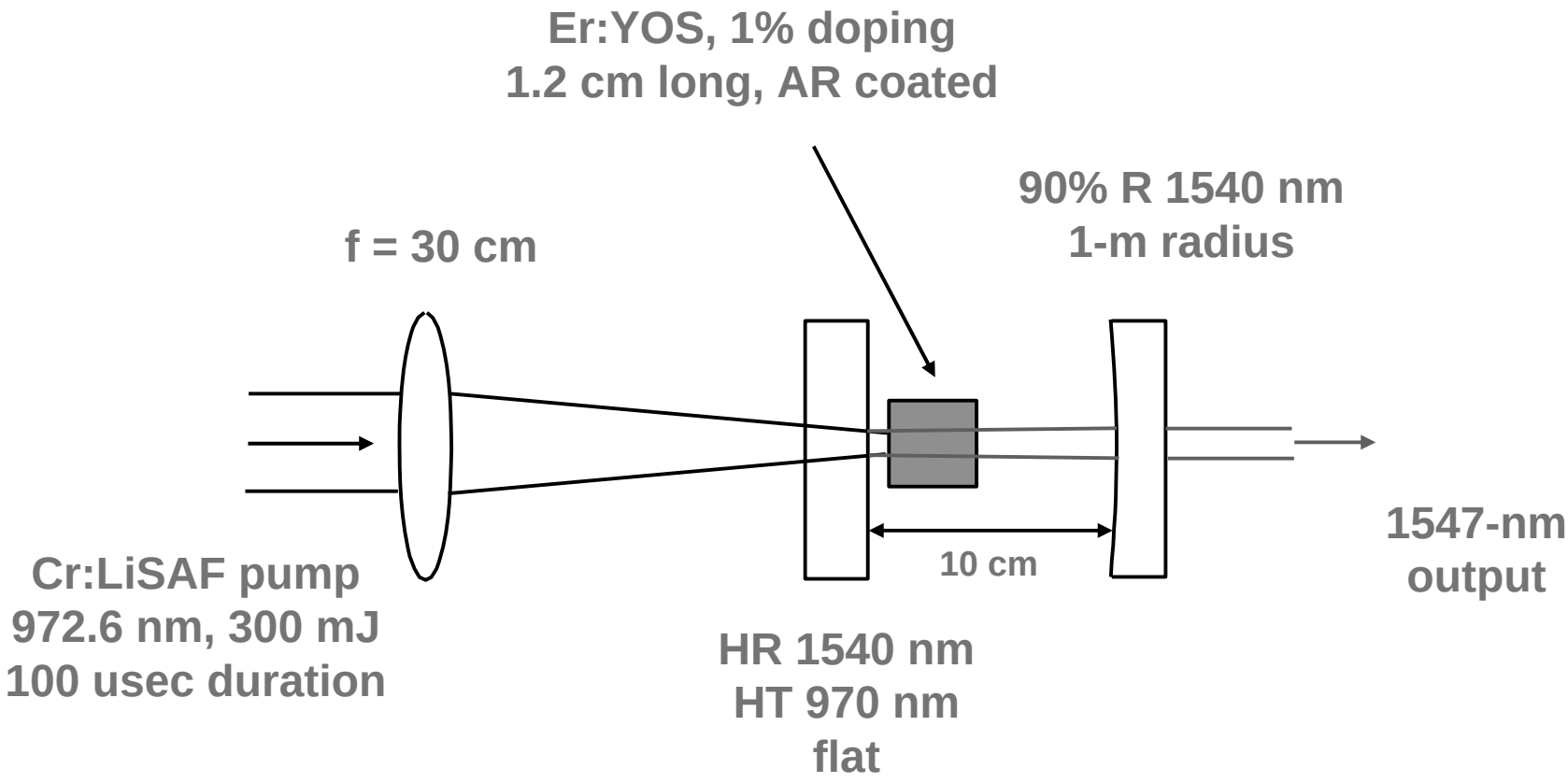


1600-nm LASER CANDIDATES: DYNAMICS

- **T1:**
  - **Er:YAG, 120 usec**
  - **Er:YOS, 43 usec**
  - **Er:YVO4, 57 usec**
  - **Er:glass (not observed)**
- **T2:**
  - **Er:YAG, 7.3 msec**
  - **Er:YOS, 12.7 msec**
  - **Er:YVO4, 6.2 msec**
  - **Er:glass, 8.3 msec**



Er:YOS LASER SCHEMATIC



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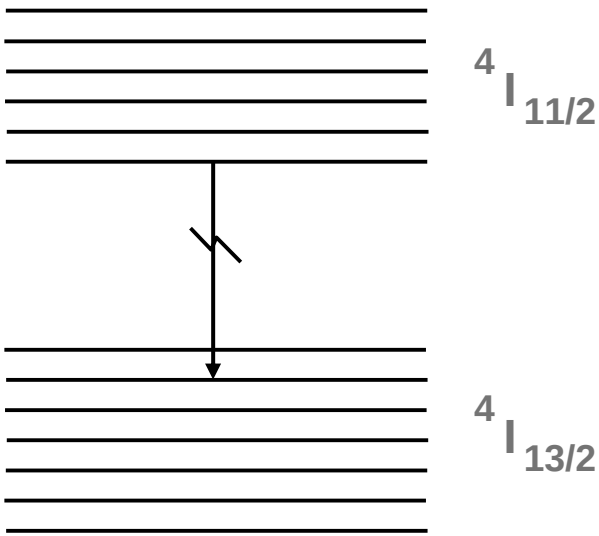
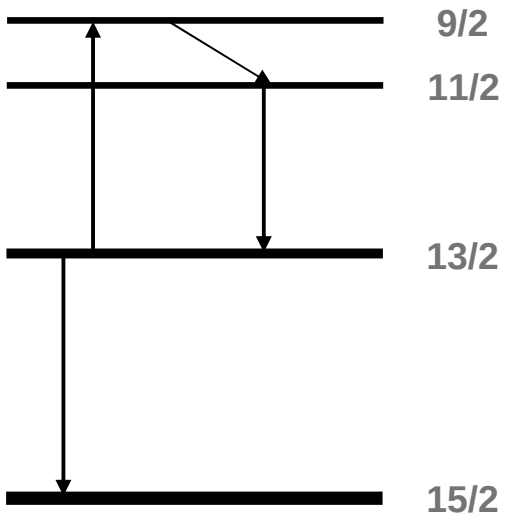
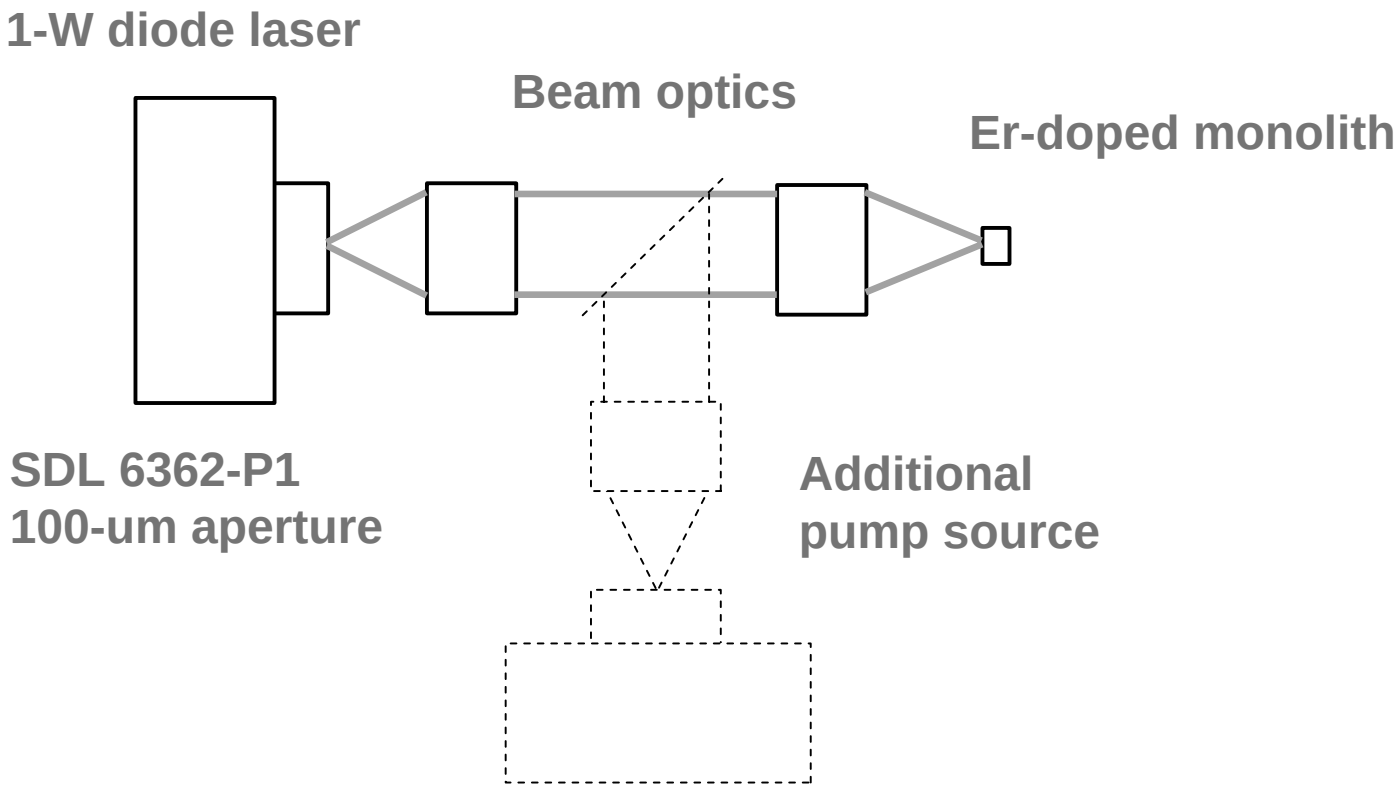
HOW IS CW Er-LASER ACTION POSSIBLE?

- Lower level is really a manifold
- Laser terminates on high-lying level in manifold
- Upconversion depletes lower level and repumps upper level





"HIGH-POWER" CW Er-DOPED LASERS



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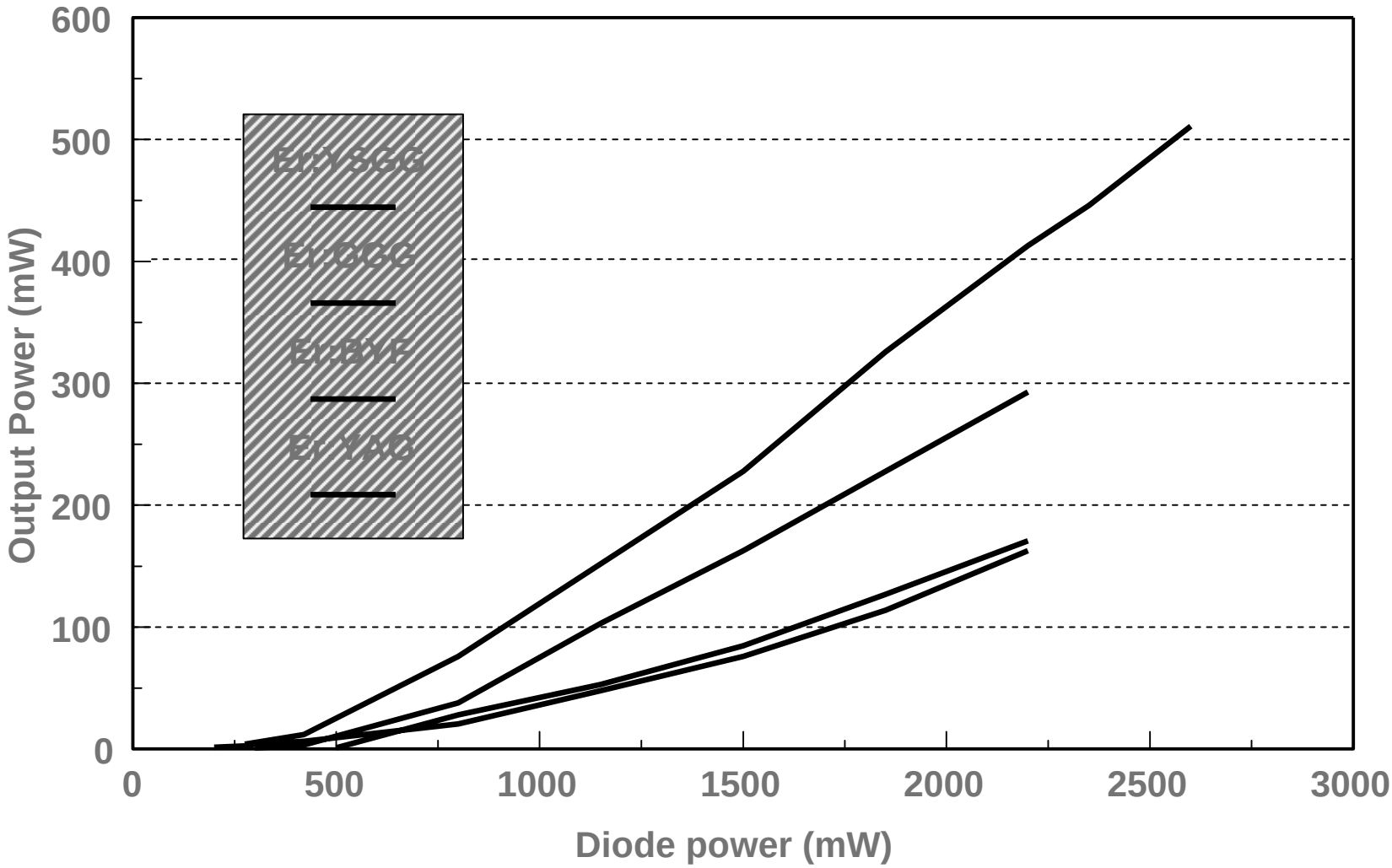
INPUT-OUTPUT DATA FOR CW Er-DOPED LASERS



For data storage only

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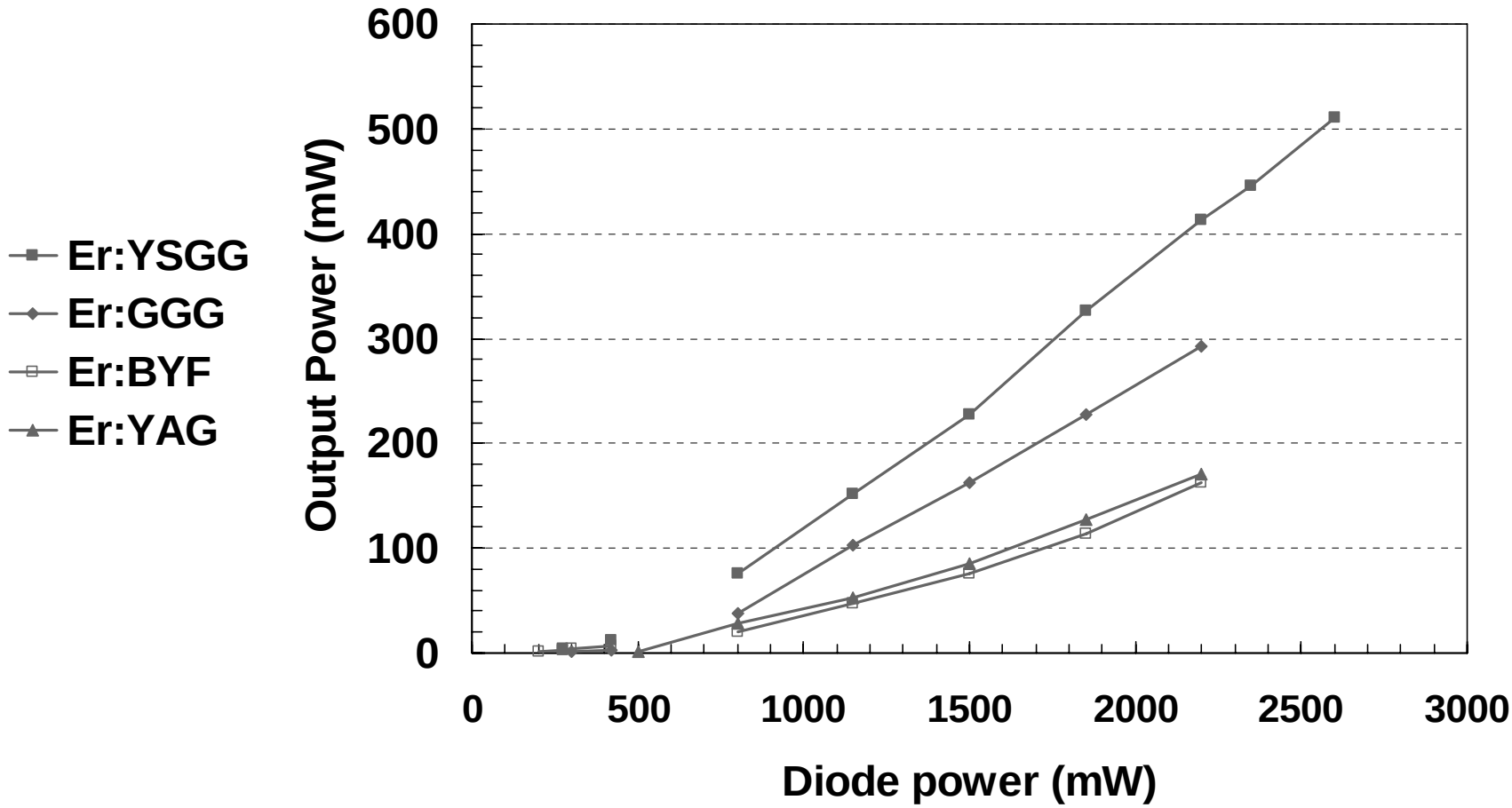
INPUT-OUTPUT DATA FOR CW Er-DOPED LASERS



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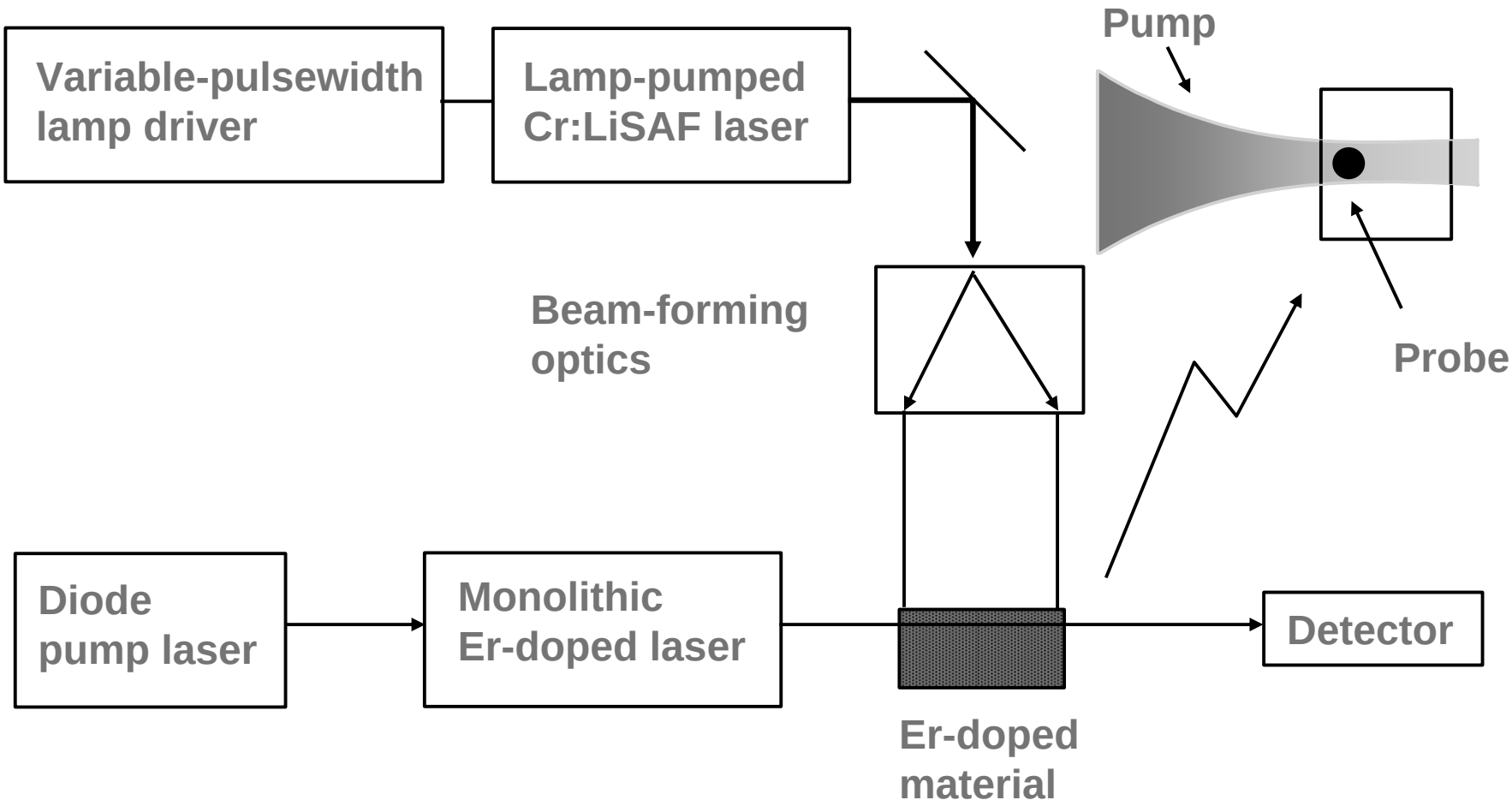
GAIN PROBE - BLOCK DIAGRAM



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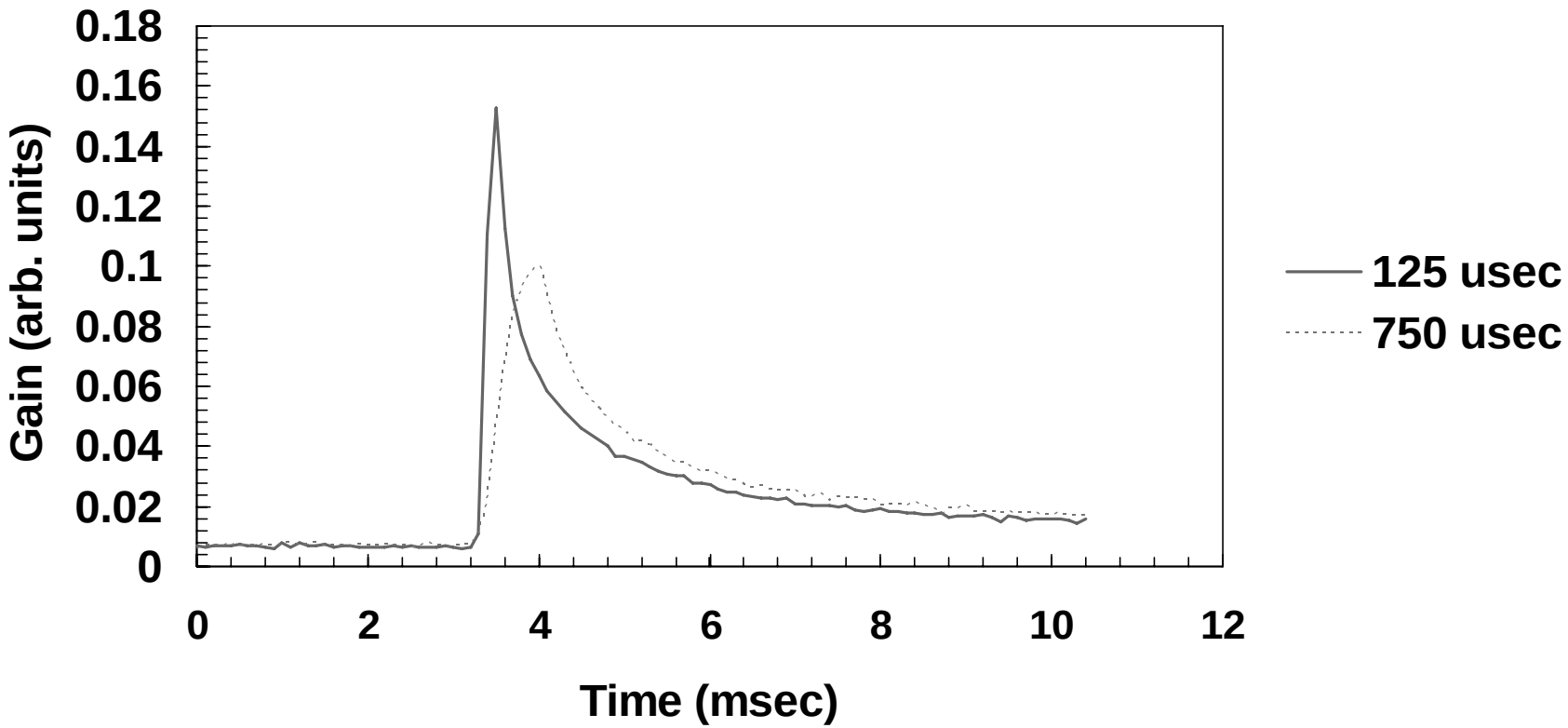
GAIN DYNAMICS - Er:YSGG, 500 mJ PUMP



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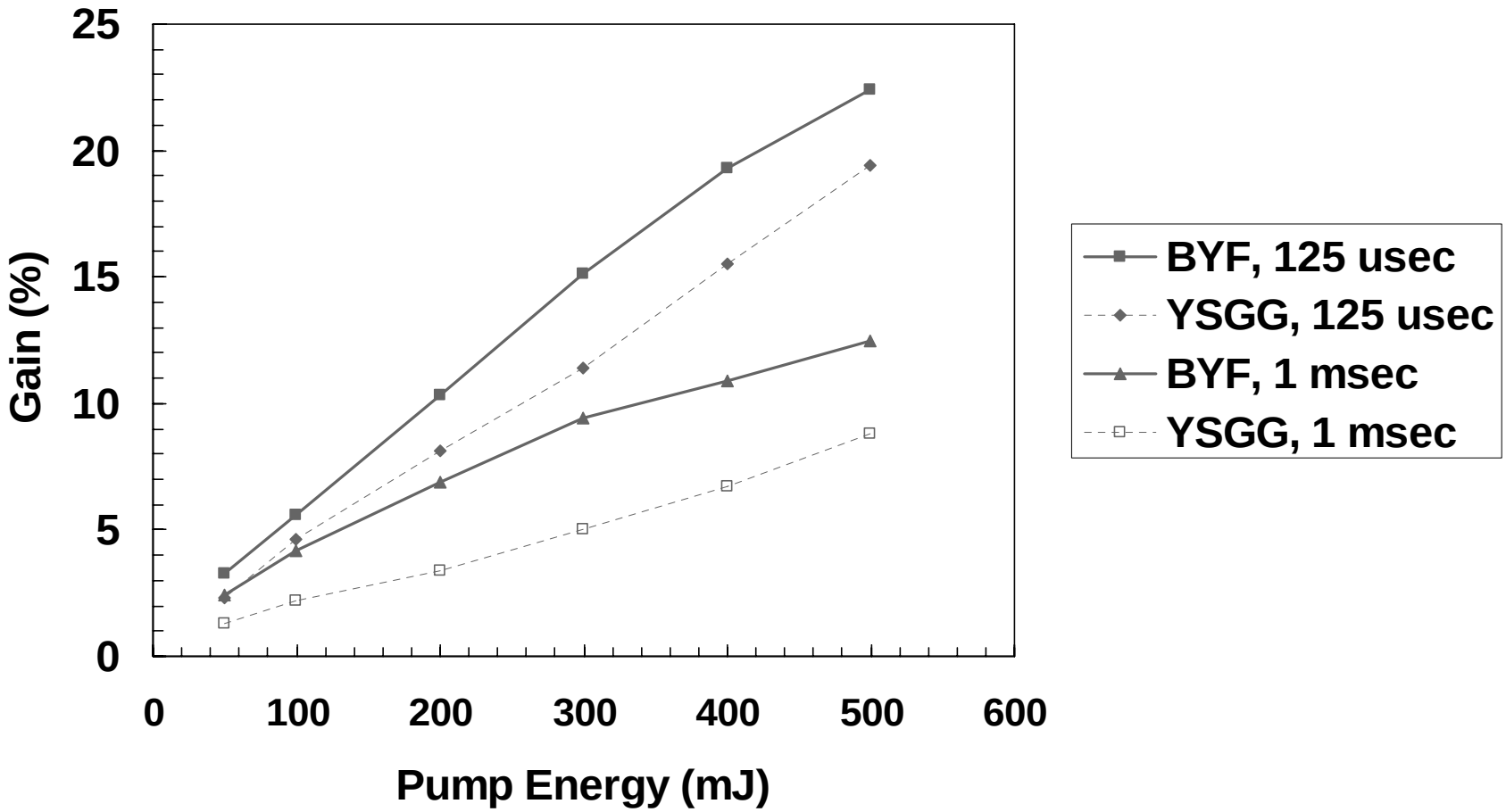
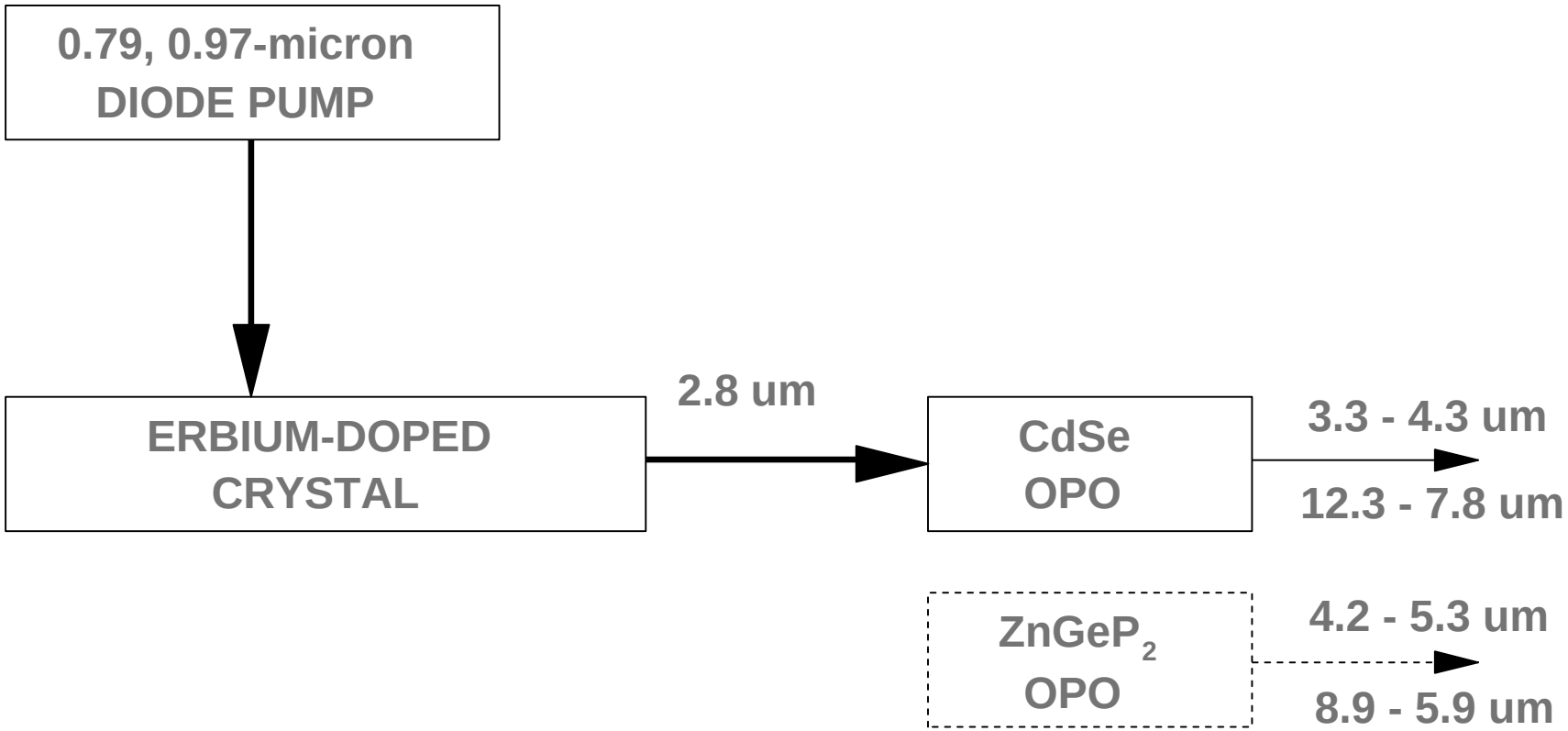
GAIN VS. PUMP ENERGY - Er:YSGG AND Er:BYF



Er-LASER-BASED OPO



APPLICATIONS

- Coherent lidar for wind sensing
  - Air speed
  - Wake vortices
  - Ballistic winds
  - Clear-air turbulence
  - Global wind patterns
- Dial source
  - Direct, with limited tuning
  - OPO-shifted for entire mid-IR
- IRCM
- Medical?