

Mid-IR Laser Materials

MRS Fall Meeting, Boston, MA November 30, 1993





General background

Lamp-pumped laser materials

- 3- μm Er-doped lasers
- 2- μm Tm, Ho lasers

Diode-pumped laser materials

- 2- μm Tm and Tm, Ho lasers
- 3- μm Er-doped lasers*

Parametric oscillators

*Thanks to ARPA



RESEARCH
DIVISION

WHO CARES?

n Medicine:

- **Fiber-delivered laser surgery: knees, backs, arteries**
- **Mid-IR wavelengths are better at cutting cartilaginous tissue, plaque than 1- μ m Nd:YAG lasers**

n Laser radar

- **Wavelengths are in "eye-safe" region**
- **Aerosol sensing, gas detection with tuning of wavelengths, wind-sensing with coherent detection**

n IRCM



RESEARCH
DIVISION

RARE-EARTH-DOPED MID-IR LASERS: ISSUES

Tm, Ho and 1600-nm Er-doped lasers terminate on ground state of ion and are "3 1/2 level" systems

- **To minimize volumetric threshold, ion doping level must be kept low, ideally <1%**

Absorption transitions in visible and near-IR are spectrally narrow and weak

- **To improve optical pumping, need heavily doped samples**

Uh-oh

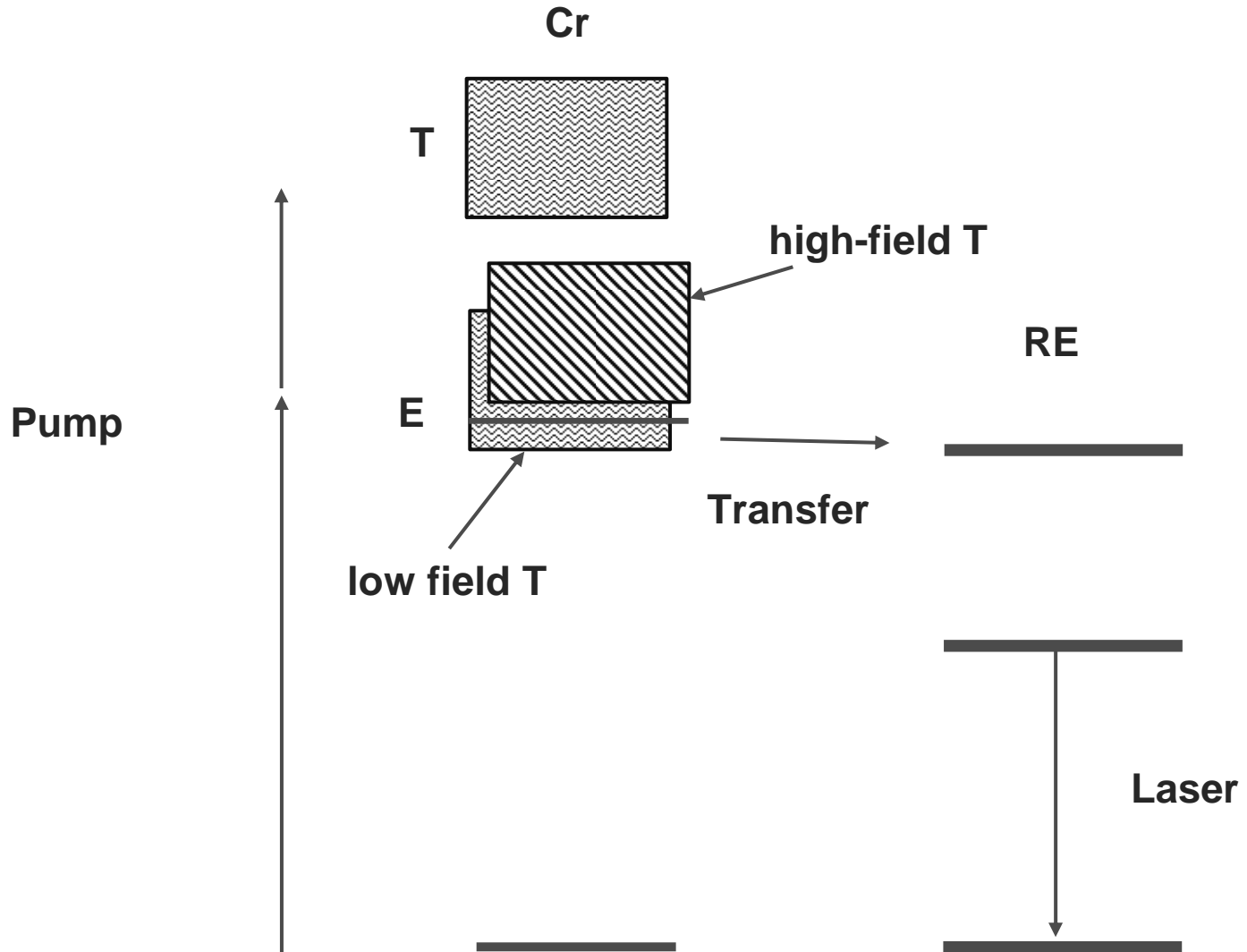
Conclusion: lamp pumping is difficult

Solution: need to find sensitizer-activator schemes



RESEARCH
DIVISION

GENERIC Cr SENSITIZER SCHEME





RESEARCH
DIVISION

Cr-SENSITIZED MID-IR LASERS: MATERIALS ISSUES

Any host material must be able to incorporate both trivalent rare earths and trivalent chromium - garnet structure works

For Er-doped, 3- μ m lasers, Cr sensitization works well only in low-field hosts such as gallium garnets - but they have poor thermal, mechanical properties compared to YAG, and Er:YAG systems are the present choice for high powers

For Tm,Ho-doped materials, Cr transfer works in one high-field material, YAG, and no other lamp-pumped material equals Cr,Tm,Ho:YAG in high-power performance

CTH:YAG has major limits due to upconversion; fluoride hosts have greatly reduced upconversion, but no Cr doping!



*RESEARCH
DIVISION*

DIODE-PUMPED MID-IR LASERS

Diode-pumping eliminates the need for sensitization, as the diode wavelength can be tuned directly to one of the RE absorption bands

- **Opens up selection of laser materials**
- **Upconversion effects can be reduced**

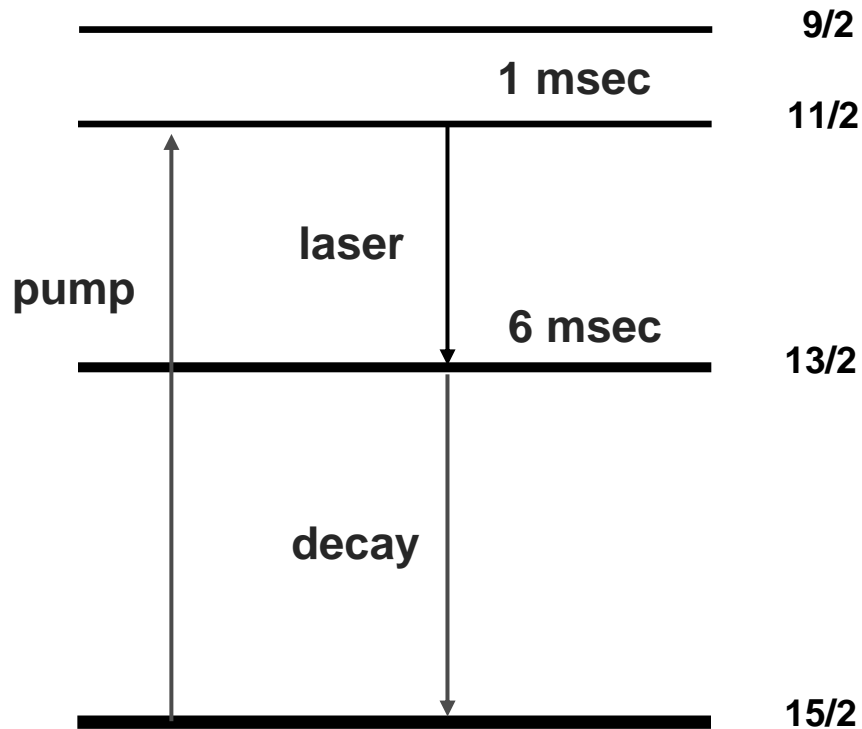
The high excitation densities obtained with diode-pumped systems make cw operation possible

- **Critical for operation of wind-sensing lidar**
- **New laser-based medical techniques may emerge**

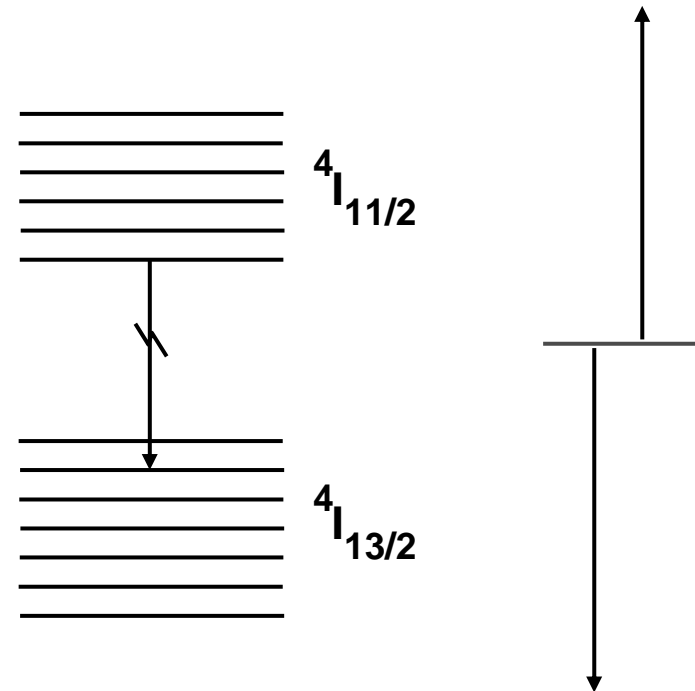


RESEARCH
DIVISION

HOW IS CW Er-LASER ACTION POSSIBLE AT 3 μm ?



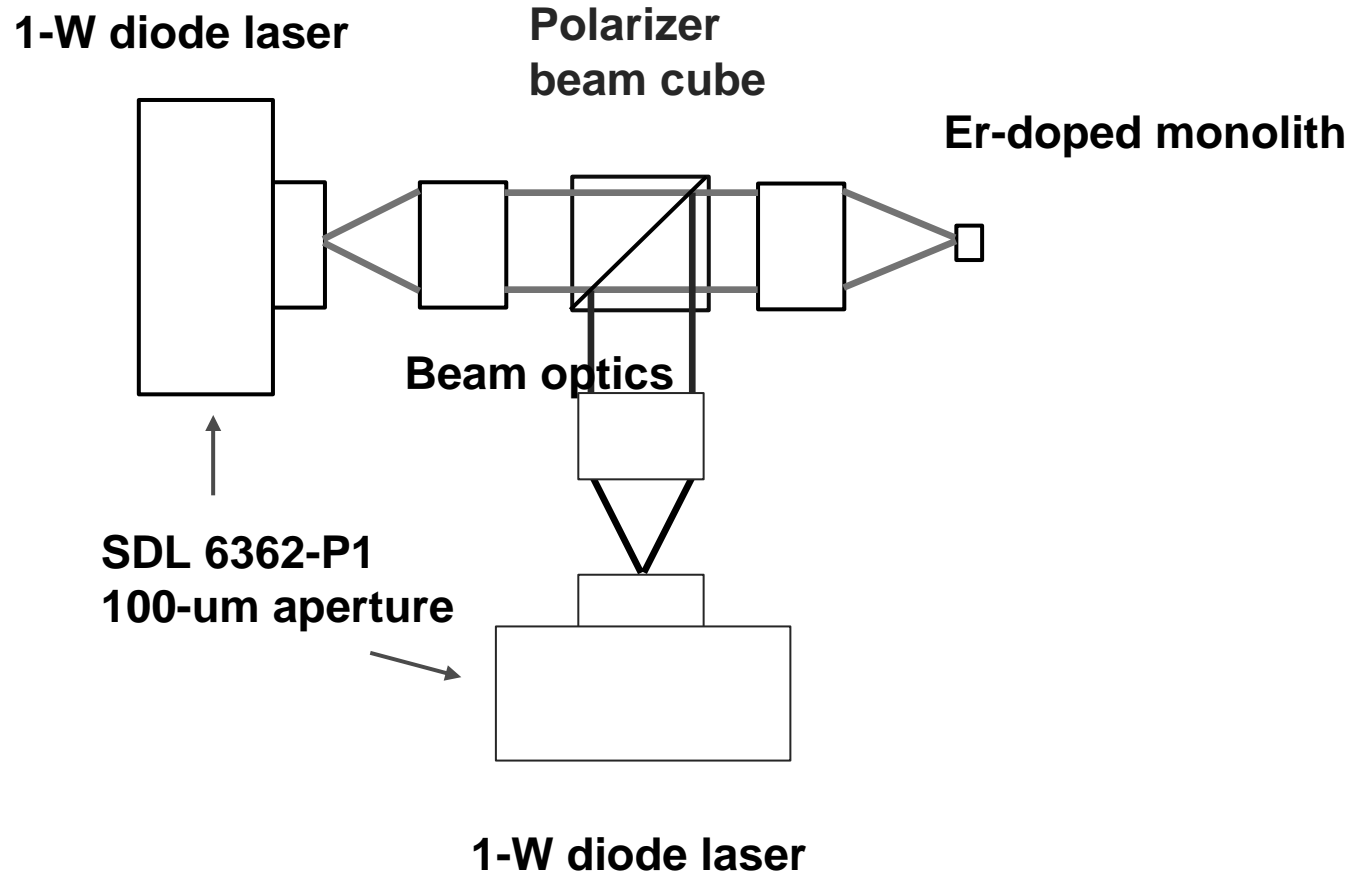
Answers:
Thermalization and upconversion





RESEARCH
DIVISION

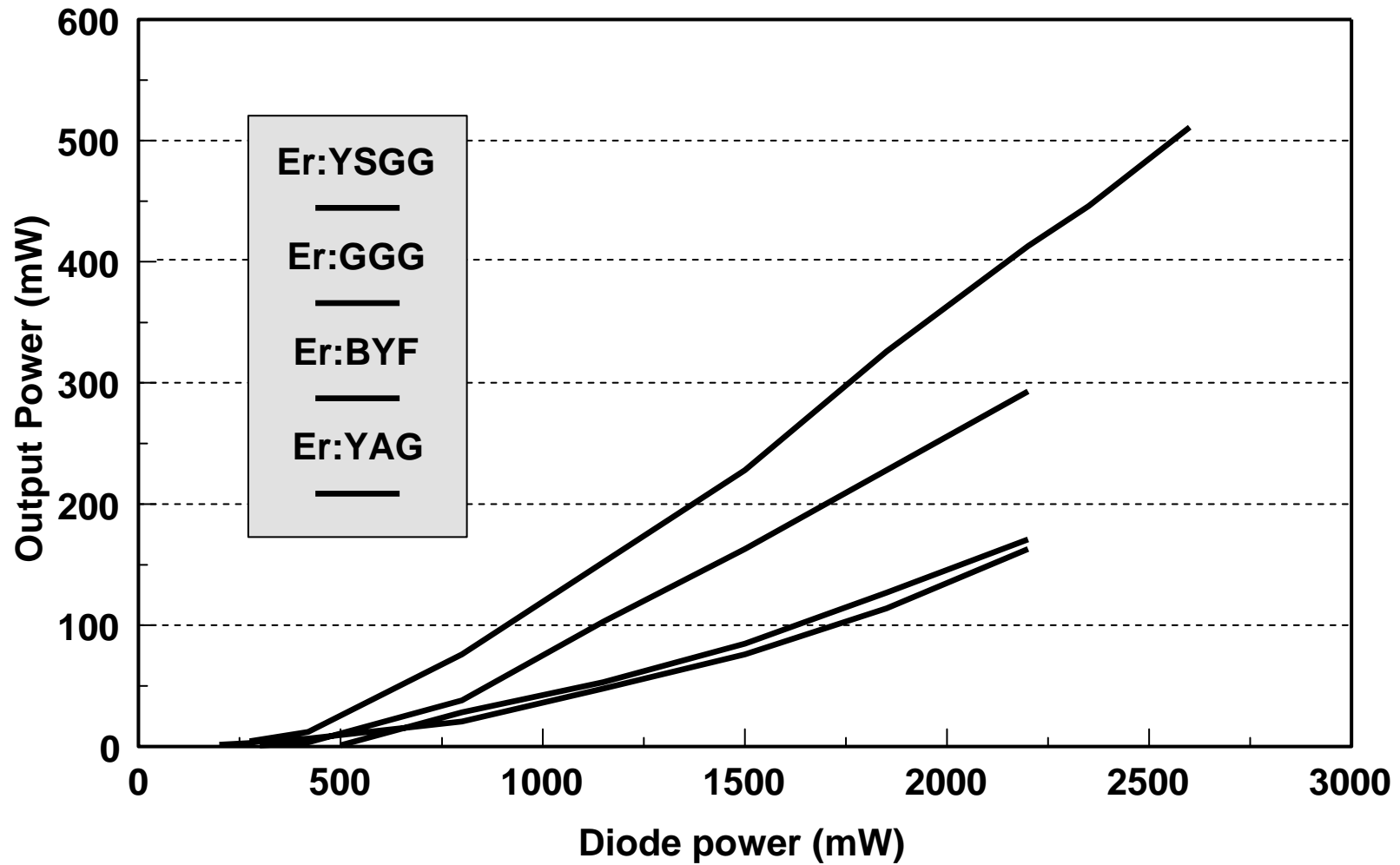
DOUBLE-DIODE PUMP SYSTEM





RESEARCH
DIVISION

INPUT-OUTPUT DATA FOR CW Er-DOPED LASERS - DOUBLE DIODE





Three -level laser

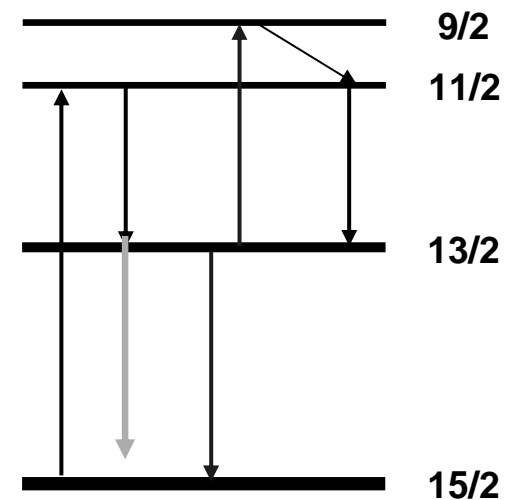
- *Low Er doping levels (0.5%)*

Upconversion is a problem

- *Find hosts with large Er-Er spacing*
- *Find hosts with minimal clustering?*

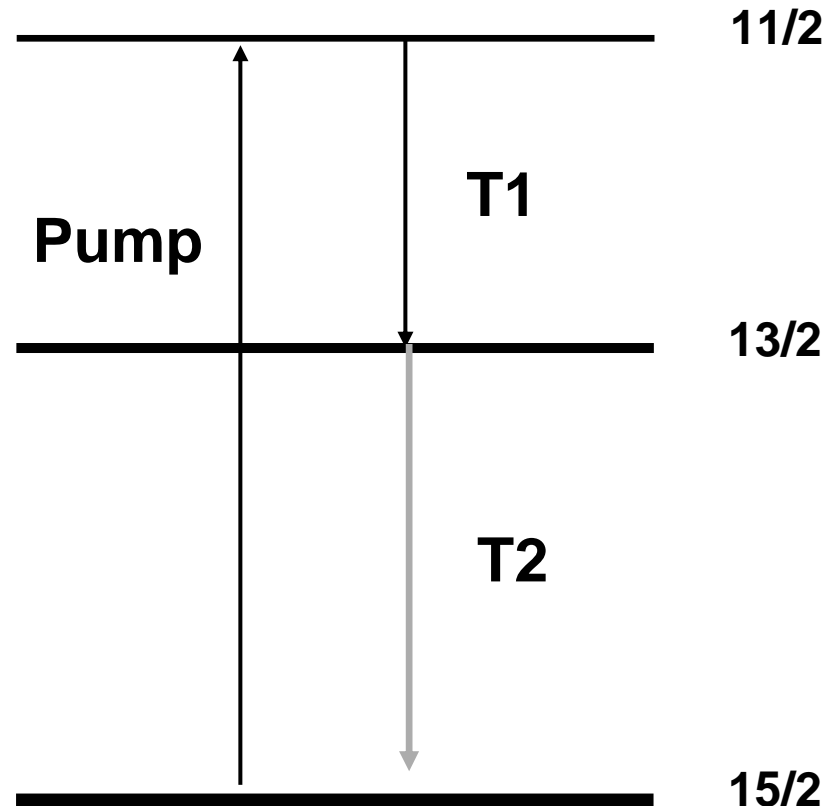
Efficient pumping at 970 nm

- *Minimize level lifetimes above 13/2*
- *Use Yb as sensitizer*





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





RESEARCH
DIVISION

DIODE-PUMPED MID-IR LASERS: MATERIALS

For Tm,Ho lasers fluoride crystals provide better cw performance than oxides due to lower phonon frequencies and resultant reduced upconversion - but thermo-mechanical properties limit average power

For Tm lasers YAG can provide high powers, but a material with a higher gain cross section with the same lower manifold splitting would be appreciated

For cw Er lasers at 3 μm materials limits have not yet been reached - but may soon

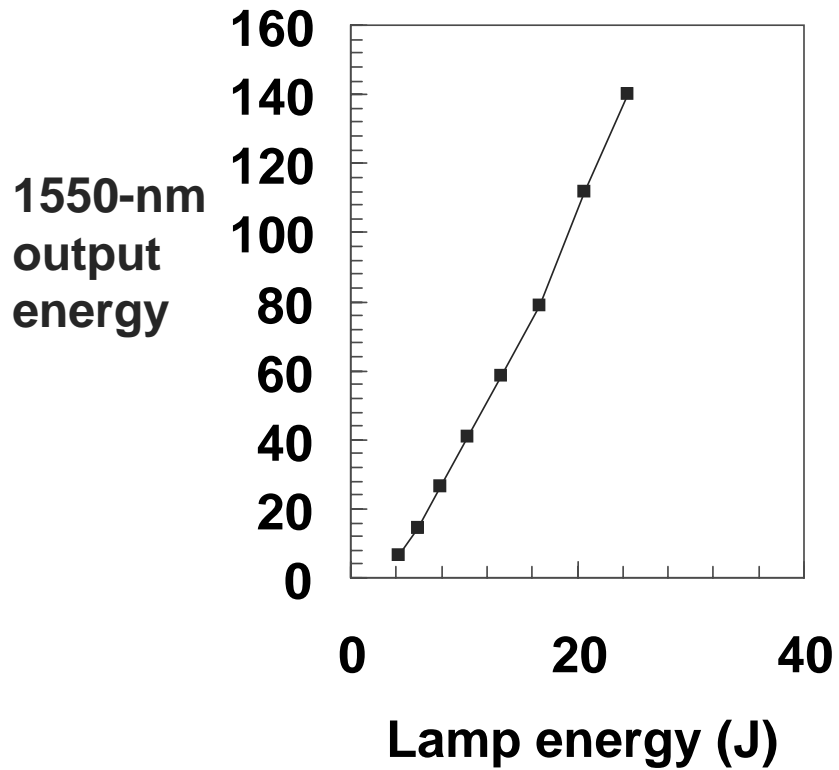
For cw Er lasers at 1.6 μm want high phonon frequencies, large crystal-field splitting of lower level, minimal ion-ion interaction, good thermal properties



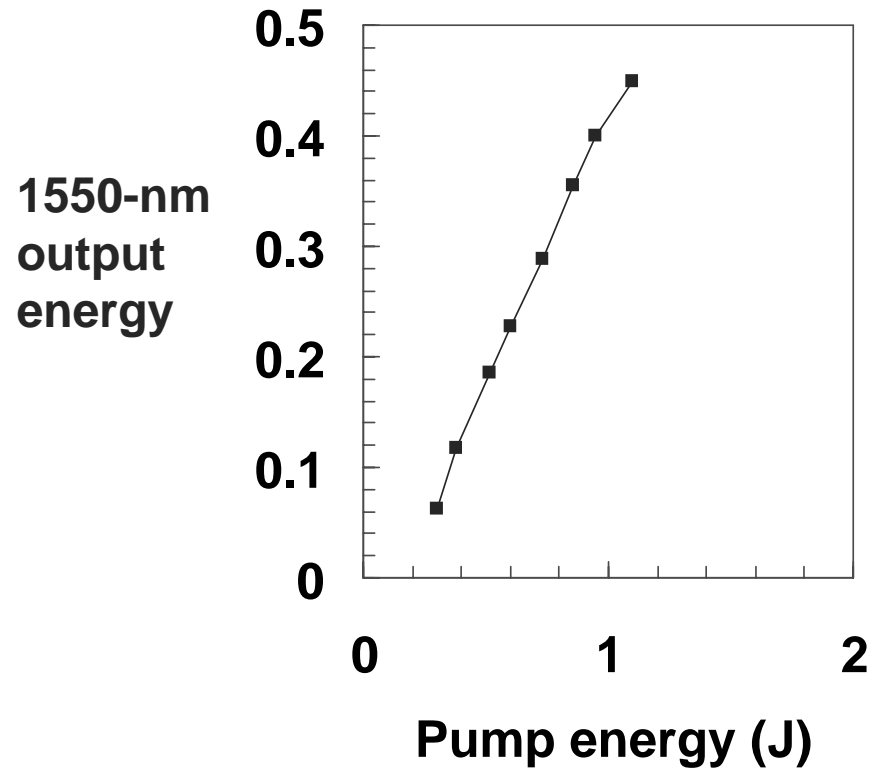
RESEARCH
DIVISION

PERFORMANCE OF HIGH-ENERGY, Nd-LASER-PUMPED OPOs (SEO IR&D)

Nd:YLF internal OPO



Nd:YAG osc-amp external OPO



Data at 10 Hz



RESEARCH
DIVISION

MID-IR OPO MATERIALS: ISSUES

**Candidate materials fall into two classes:
oxide insulators or semiconductors**

Current list includes:

- **KTP family (KTA, CTA, etc.)**
- **KNbO₃**
- **AgGaSe₂**
- **ZnGeP₂**
- **CdSe**

Issues:

**Growth of large, high-quality crystals
for all the materials**

**Characterization of thermo-optical,
thermo-mechanical for all**

De-poling for KNbO₃

**Impurity and defect-induced absorption
and scattering for all the
semiconductors**