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Toward Temperature Independent Er:glass Lasers

William Hageman and Michael Bass

College of Optics and Photonics – CREOL and FPCE
University of Central Florida

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
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Overview

- Background
- Experimental Setup
- Results
- Application to Laser Design
- Future Work
- Review

Background

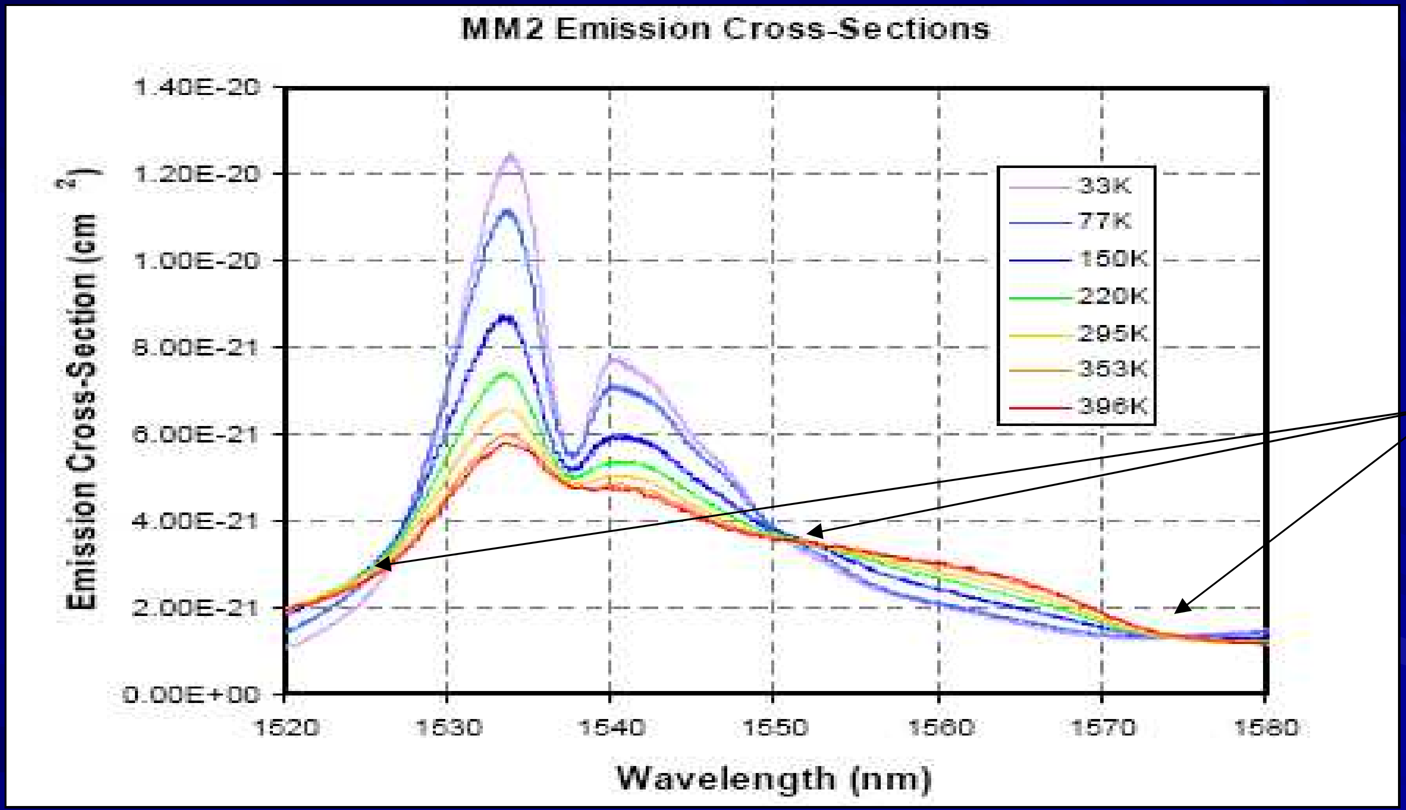
- Thermal Dependence in Laser Systems
  - Mechanical Misalignment due to Thermal Effects
  - Optical Distortion and thermo-optical properties of optical materials due to pumping induced temperature distribution (i.e. lensing due to dn/dT)
  - Variation in output energy due to temperature of gain material as a whole (**OUR FOCUS**)

Er:glass Systems

- Inherent "eyesafe" wavelength regime (1.53 – 1.55 µm) where 100x greater pulse energy is allowed for Class I rating.
- Useful in open beam applications such as range finding, target designation, and LIDAR where probability of accidental exposure to beam is high
- One drawback to production of Er:glass systems is a significant variability of laser output energy with change in ambient temperature.
- Improved passive athermalization of Er:glass systems would allow for reduced energy consumption and reduction of system weight.

Emission Cross-Section Behavior

- Earlier study has shown stimulated emission cross-section to be the driving factor in temperature dependence of Nd^{3+} laser systems. (M. Bass, L. Weichman, S. Vigil, and B. Brickeen, IEEE JOURNAL OF QUANTUM ELECTRONICS, VOL. 39, NO. 6, JUNE 2003)



- Spectroscopy of Er:glass shows temperature independent points in Er:glass emission cross section spectrum. (J. Koroshetz, B. Brickeen, S. Fahr, A. Rapaport, M. Bass, *Optics Express, Vol. 15, No. 18, (2007))*

Theory

Laser output can be described by simple relation:

$$E_{out} = \eta_{slope}(E_{in} - E_{th})$$

Using the basic laser rate equations and solving for steady state condition, relations can be found for η_{slope} and E_{th}:

Three Level System:	Four Level System:
$\eta_{slope} = \frac{(1-R)}{(1+R)} \frac{2(1-L_N)\eta}{(L-\ln(R))\gamma}$ $E_{th} = \frac{t_{pulse}h\nu}{\eta\tau}\left(\frac{L_N + (\gamma-1)}{1-L_N}\right)$	$\eta_{slope} = \frac{(1-R)}{(1+R)} \frac{2\eta}{(L-\ln(R))}$ $E_{th} = \frac{t_{pulse}L_N N_{tot} h\nu}{\eta\tau}$

Where: $L_N = \frac{L-\ln(R)}{2\sigma_{21}n_{tot}l}$

Theory

Output energy expression can be differentiated with respect to temperature (T):

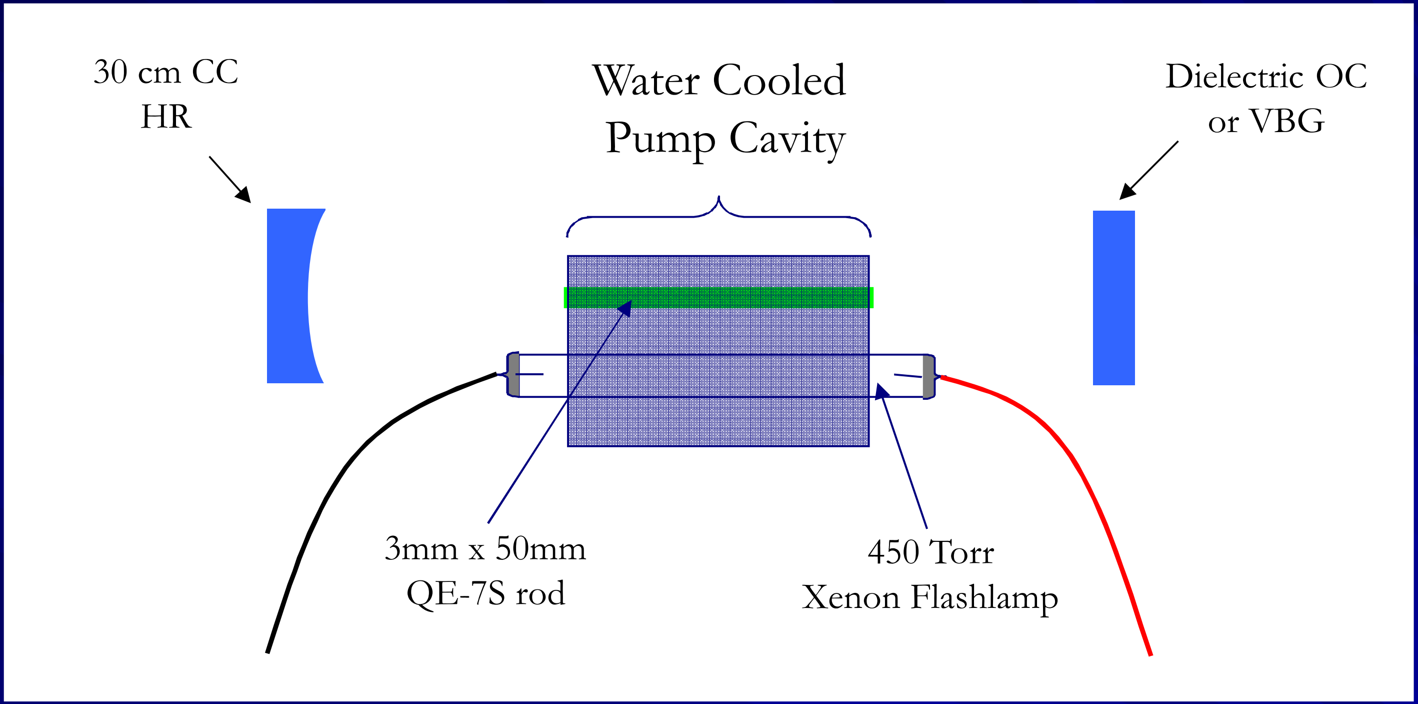
$$\frac{dE_{out}}{dT} = \left[\frac{d\eta_{slope}}{dT}\right]\left(E_{in} - E_{th}\right) - \eta_{slope}\left[\frac{dE_{th}}{dT}\right]$$

What variables in η_{slope} and E_{th} exhibit temperature dependence?

If the emission cross section only varies significantly with temperature as in Nd^{3+} case, then using a Volume Bragg Grating (VBG) to hold the emission wavelength to a value with athermal cross section should create a fully athermal laser output.

$$\frac{dE_{out}}{dT} = \left[\frac{d\eta_{slope}}{d\sigma}\cancelto{0}{\frac{d\sigma}{dT}}\right]\left(E_{in} - E_{th}\right) - \eta_{slope}\left[\frac{dE_{th}}{d\sigma}\cancelto{0}{\frac{d\sigma}{dT}}\right] = 0$$

Experimental Setup

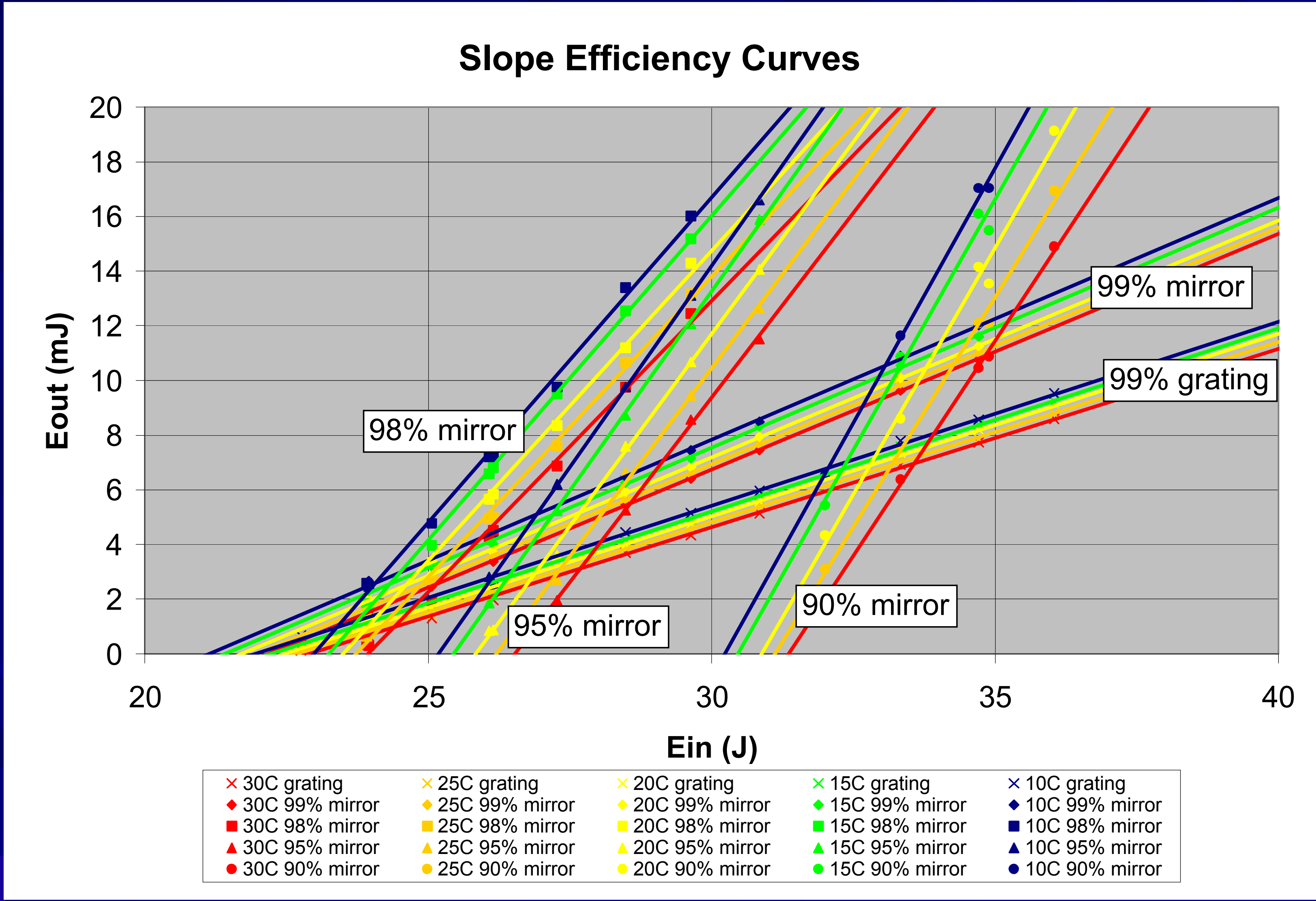


- Flashlamp driven, long pulsed system
- Water cooled QE-7S rod with 10°C - 30°C thermal range
- Thermally isolated end reflectors to avoid thermal misalignment of the system
- Low rep rate to ensure the rod is in thermal equilibrium before each shot.

Experimental Procedure

- Dielectric coated end reflectors were used as well as a VBG (R=0.989 @ 1552.75 nm, FWHM < 0.4 nm)
- Output measured from 10 - 30°C in 5°C increments
- Optimal alignment verified before and after each run to check for possible thermal alignment issues.
- Lamp fired with a repetition rate of only 0.02 Hz to ensure thermal equilibrium between rod and coolant.

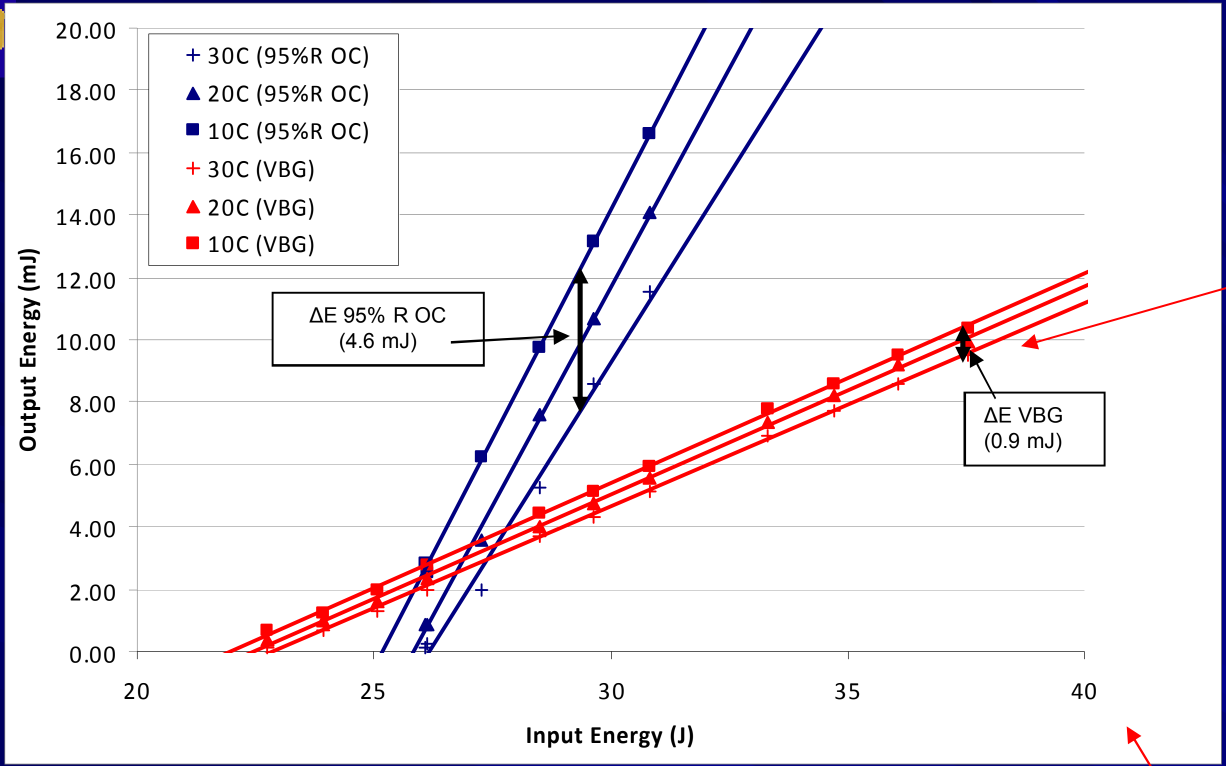
Experimental Results



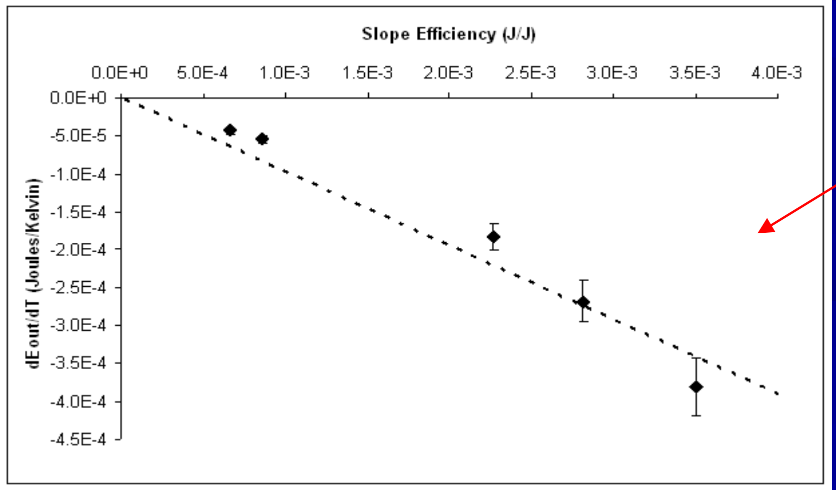
Experimental Summary

- Slope efficiency of a laser system is highly correlated to the sensitivity of the output to temperature.
  - Large slope efficiencies lead to large temperature dependence.

- Temperature dependent change in output energy is found in all cases… **even when the VBG is used to hold the emission cross section at an athermal wavelength**.
  - **More then just emission cross section is driving the temperature dependence of the system.**

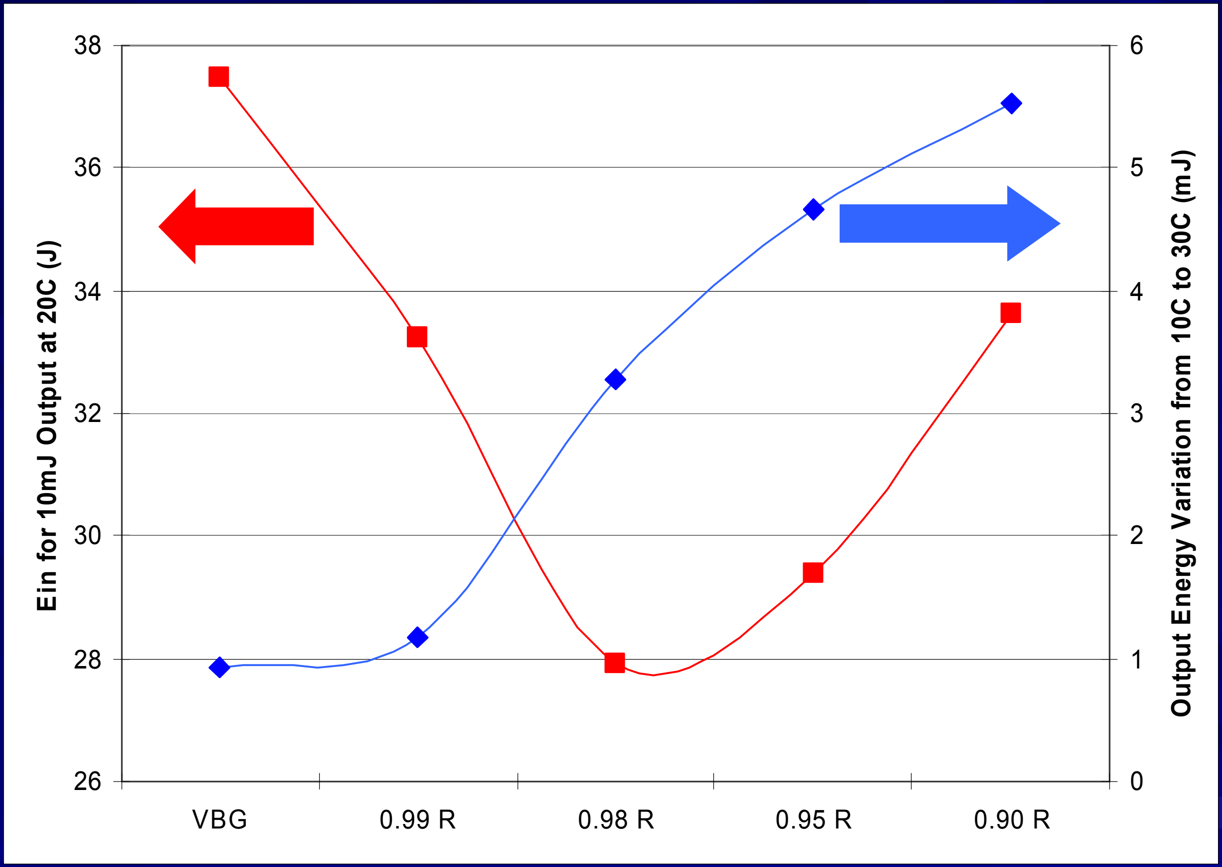


VBG end reflector still exhibits output energy variation even though much less.



Rate of change of output energy with temperature is roughly linearly related to slope efficiency.

Application to Design



Tradeoffs can be made in efficiency to increase thermal stability.

Example: A 20% drop from maximum efficiency can increase the temperature stability of the system by a factor of 3.

Future Work

•The potential still exists for a fully passively athermalized system.

•These experiments show that quantities other than the stimulated emission coefficient in the expressions for slope efficiency and threshold energy are temperature dependent.

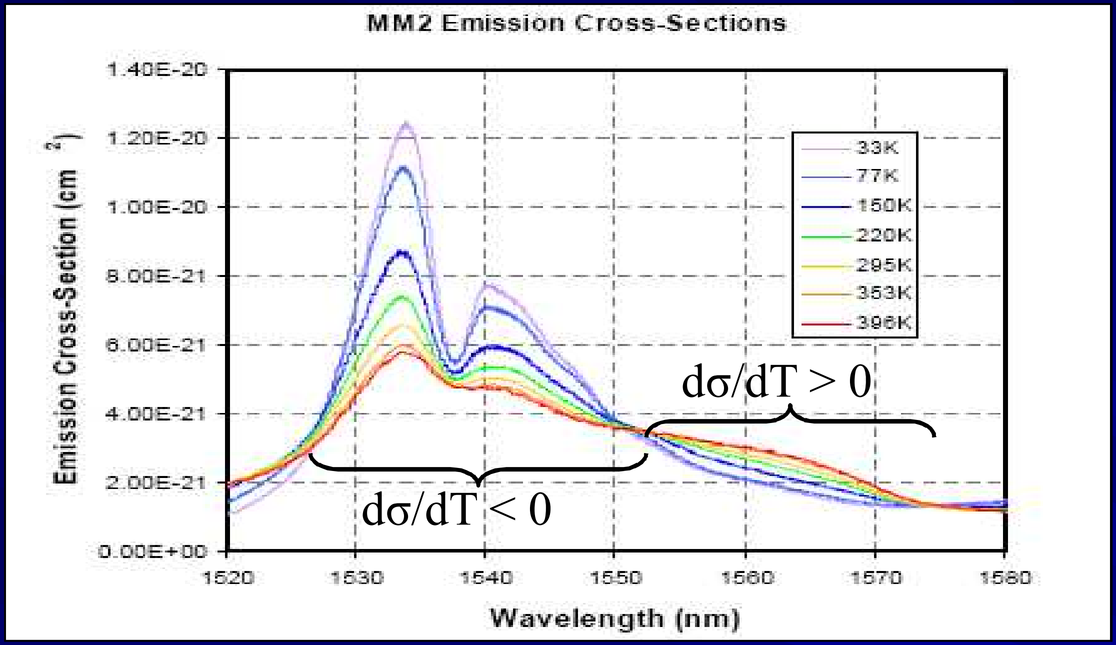
•Unlike previous work with Nd^{3+} systems, Er^{3+} is a quasi-three level system with more complicated thermal dependences.

•Experiments are on-going to determine the source of the additional temperature dependence

Leading candidates:

- **η** – pump efficiency
- **γ** – level degeneracy
- **L** – Loss

Future Work



The sign of dσ/dT can be selected using a VBG that is opposite in sign and magnitude to the output energy change caused by other temperature dependent variables.

dσ/dT can be used to correct for the effects of other temperature dependent system variables

$$\frac{dE_{out}}{dT}=\left[\frac{d\eta_{slope}}{d\sigma}\frac{d\sigma}{dT}+\frac{d\eta_{slope}}{d\eta}\frac{d\eta}{dT}+\frac{d\eta_{slope}}{d\gamma}\frac{d\gamma}{dT}+\frac{d\eta_{slope}}{dL}\frac{dL}{dT}\right](E_{in}-E_{th})-\eta_{slope}\left[\frac{dE_{th}}{d\sigma}\frac{d\sigma}{dT}+\frac{dE_{th}}{d\eta}\frac{d\eta}{dT}+\frac{dE_{th}}{d\gamma}\frac{d\gamma}{dT}+\frac{dE_{th}}{dL}\frac{dL}{dT}\right]$$

Summary

- System designers can trade efficiency for temperature independence in Er:glass systems
- The quasi three-level nature of Er:glass leads to more complicated temperature dependence than previously observed in four-level Nd^{3+} materials
- Using a VBG to hold the emission wavelength to an athermal point in the emission cross-section curve does not produce overall athermal behavior in the output energy of Er:glass lasers.
- It is possible to compensate for the temperature dependence of Er:glass output energy not arising from $d\sigma/dT$ by purposely introducing emission cross-section driven temperature dependence of the opposite sign.

Acknowledgements

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