Stanford Gravitational Wave Group

Edge-Pumped Slab Amplifier Development

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University of Florida at Gainesville

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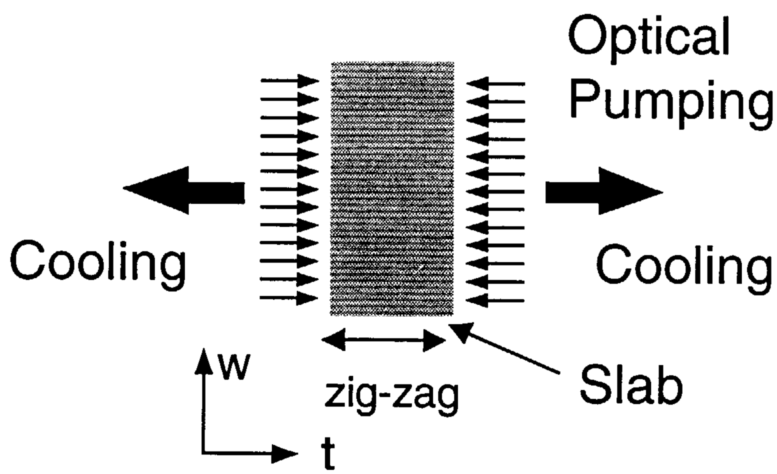
Outline

- **Edge-pumped Slab Laser Development**
  - Edge-Pumping Geometry
  - 1:1 Slab Results
  - Slab Temperature - Thermal Population Loss
  - 3:1 Slab - Design and Preliminary Results
- **Amplifier Research**
  - Predicted Amplifier Performance
  - Wavelength Temperature Tuning
- **Summary and Conclusions**
- **6 Month Research Plan for 10 W LIGO Master Oscillator**

Face-Pumping vs. Edge-Pumping

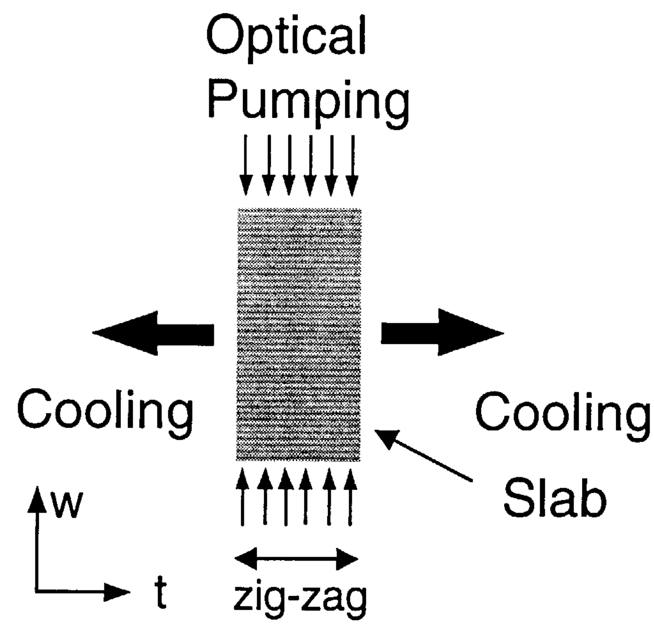


Face - Pumped

Cooling Face = Pumping Face

Stress Fracture α (w/ t)

Pump Absorption depends on t



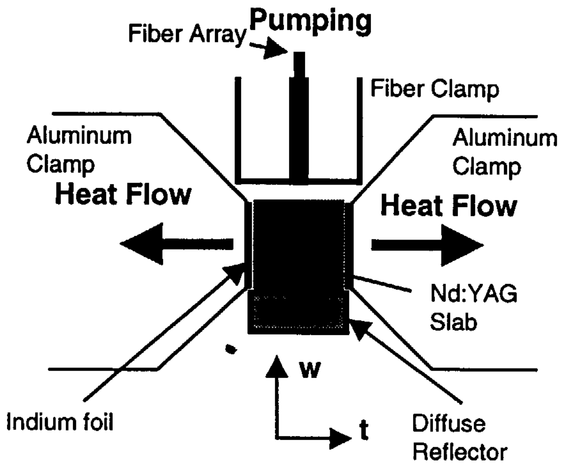
Edge - Pumped

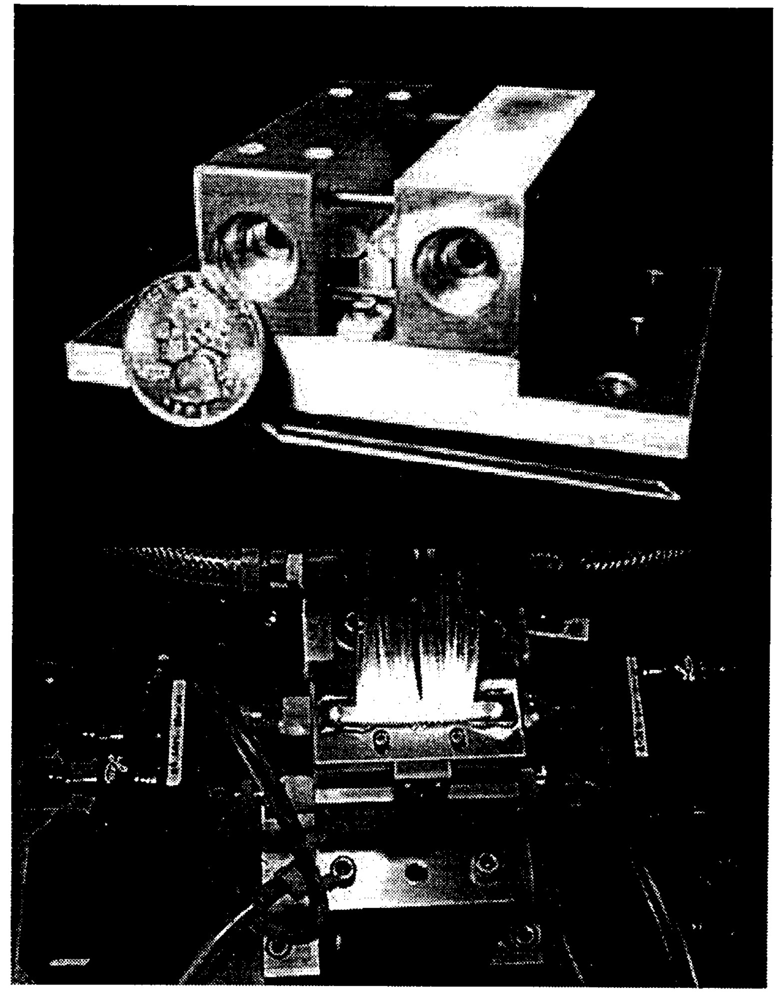
Cooling Face $\neq$ Pumping Face

Stress Fracture α (w/ t)

Pump Absorption depends on w

Edge-Pumped, Conduction-Cooled Slab Laser Design

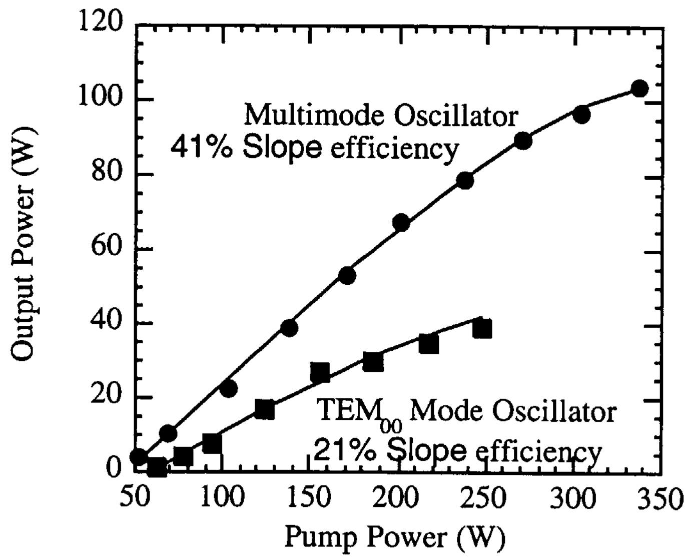




Advantages	Disadvantages
• Conduction-cooled • Separate pumping and cooling interfaces • Pump absorption and thermal characteristics both proportional to w	• TIR interface is also conduction cooling interface • Small thermal gradient in pumping direction

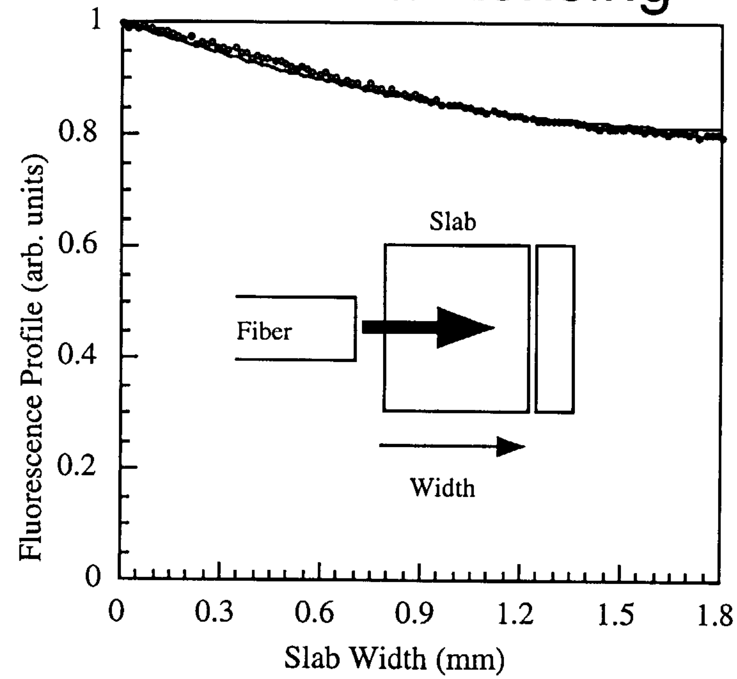
1:1 Slab Laser Results

Output Power



- 85 % pump absorption
- 5% Single pass loss
- 65 C average temperature increase

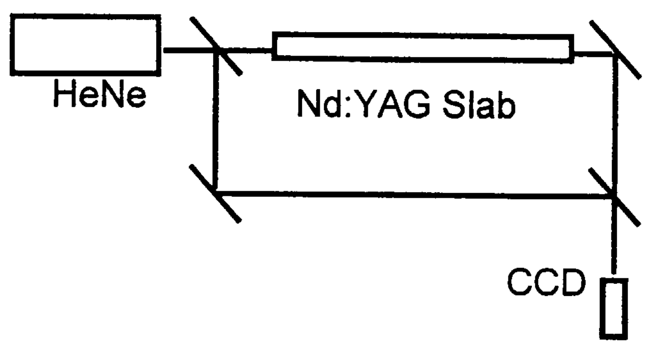
Thermal Lensing



- Thermal lens focal length longer than 0.5 m for all pump powers, both axis

Slab Average Temperature

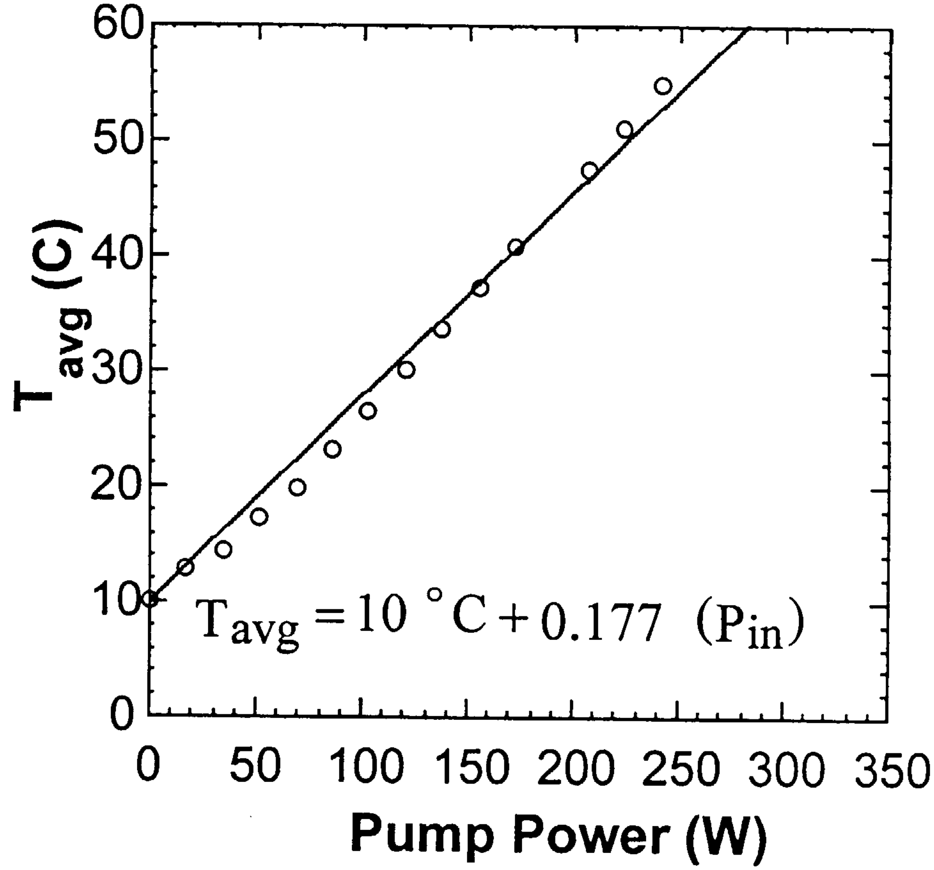
Average Temperature Measurement



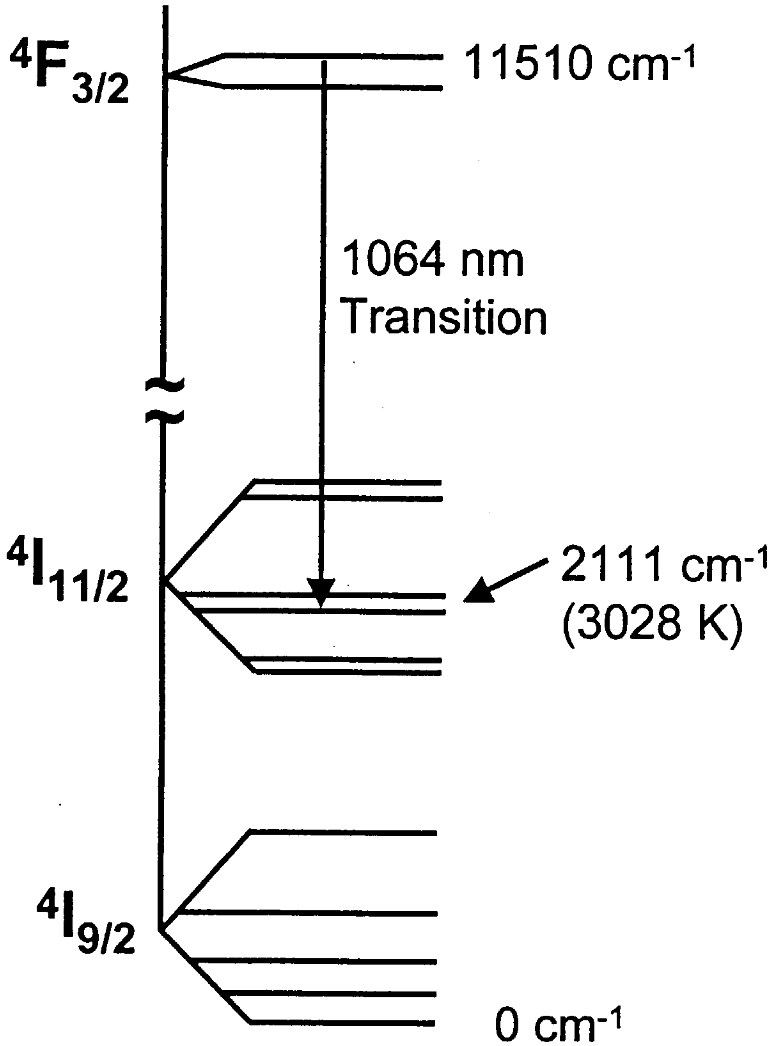
$$T_{avg} = T_c + \Delta T$$

$$\Delta T = \frac{\lambda \,\#\text{Fringes}}{\Delta OPL\left(\alpha(T), \frac{dn(T)}{dT}\right)}$$

$$\Delta T = P_{in}\,\eta_{heat}\left[\theta_{LaserHead} + \theta_{Coolant}\right]$$



Thermal Population Absorption Loss

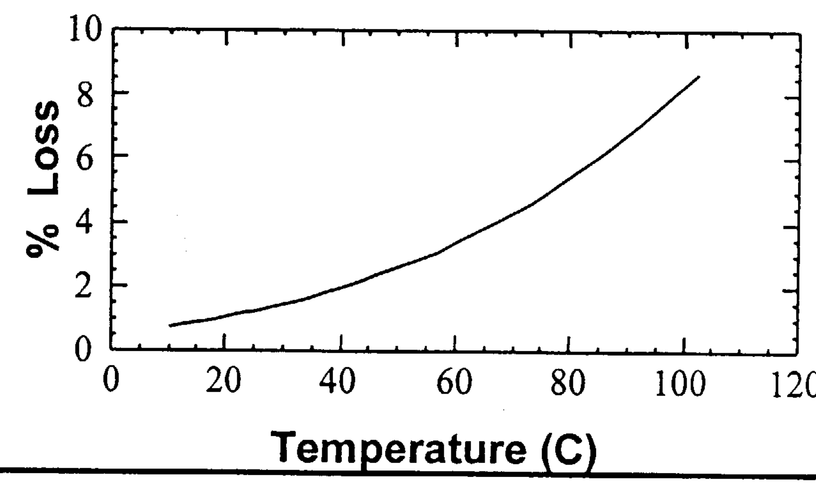


Boltzman Population Distribution

$$f_l = \frac{N_{2111}}{N_{total}} = \frac{\exp\left(\frac{-\Delta E_{2111}}{kT}\right)}{\sum_i \exp\left(\frac{-\Delta E_i}{kT}\right)}$$

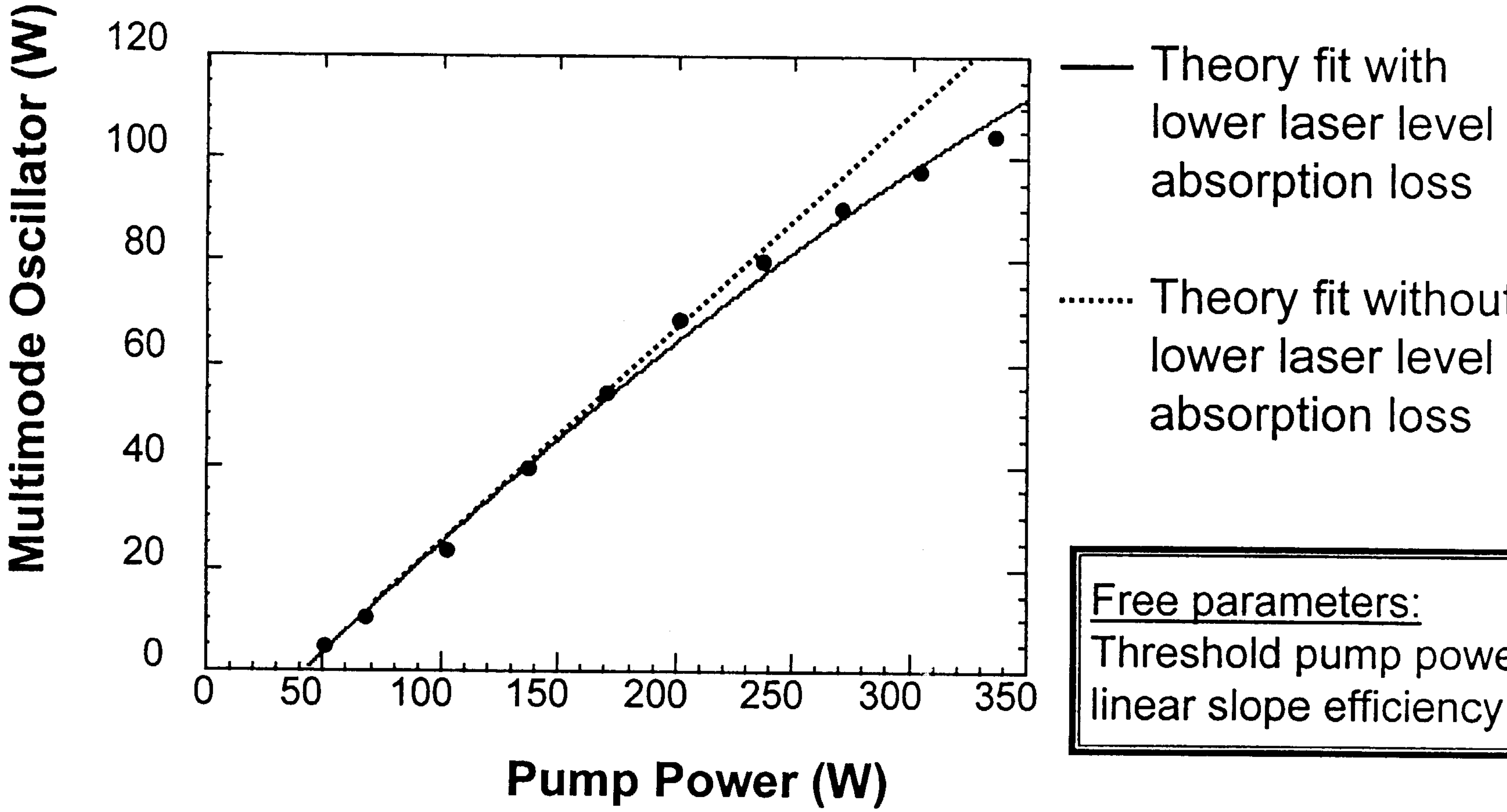
Single-Pass Percent Loss

$$L_{abs} = 1 - \exp(-\sigma \; N_{total} \, f_l \, l \;)$$



Stanford High Power Laser Lab

Laser Oscillator Model - Thermal Absorption Loss



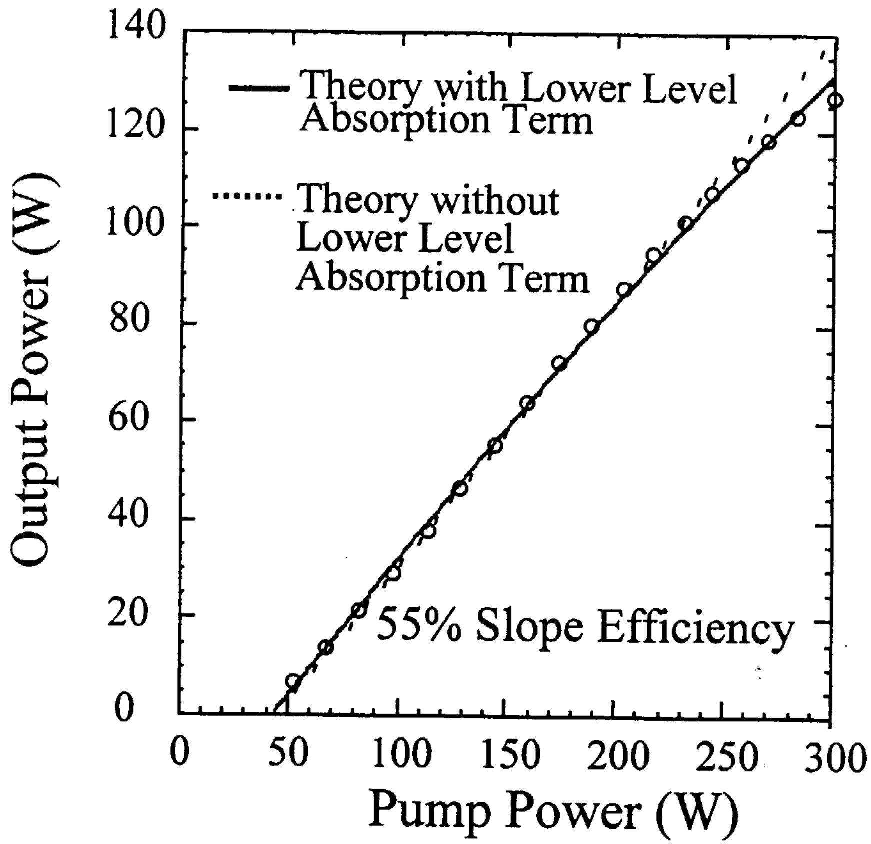
Free parameters:
Threshold pump power
linear slope efficiency

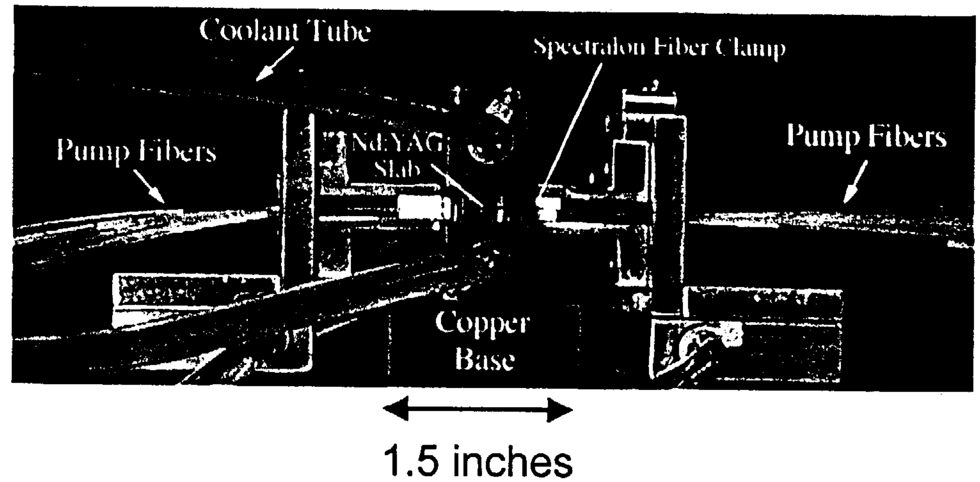
Edge-Pumped Laser Design Improvements

Problem	Primary Effect	Solutions
• High loss at TIR	• Lowers slope efficiency	• "Super-polished" slabs, • Fewer TIRs
• High average temperature (> 60 C)	• Increased slab loss due lower laser level absorption • Master Oscillator Power Amplifier gain mismatch	• Reduce laser head thermal resistance • Increase slab aspect (w/t), • - 40 C coolant, • Improve metal-coolant heat transfer
• One-sided pumping	• Asymmetric thermal profile in non zig-zag plane	• Two-sided pumping

Preliminary Results*

3:1 Nd:YAG Multimode Oscillator Results



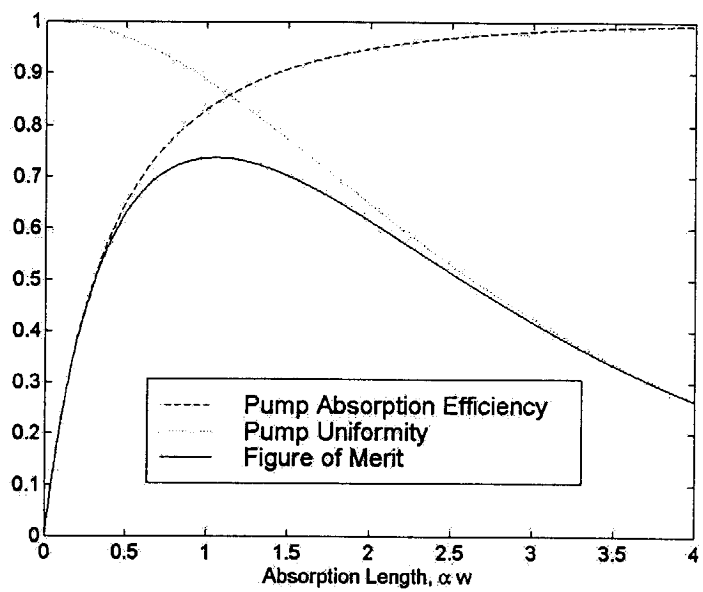


95% Pump Absorption Efficiency

- **Nd:YAG Slab**
  - 1% Doped Nd:YAG
  - 1.5 x 4.5 x 38.9 mm w/ Brewster end faces
  - SiO_2 Coating for low loss TIR
  - **1.5 % single-pass loss**

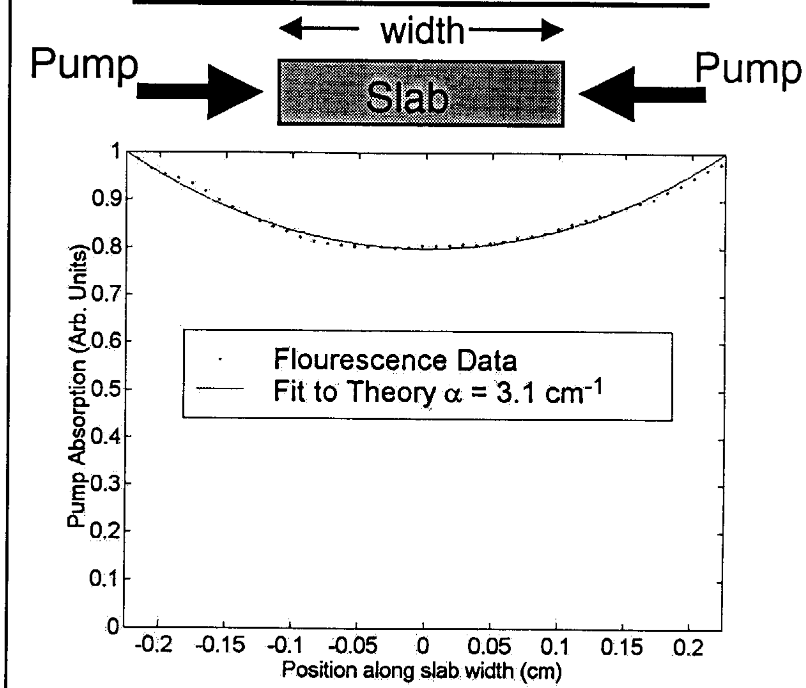
Preliminary Results*
3:1 Nd:YAG Thermal Lensing Results

Pumping Uniformity



- Design Point : α w = 1.35
- 4.5 mm Slab Width
- 3.0 cm^{-1} Absorption Coefficient, α,

Fluorescence Profile



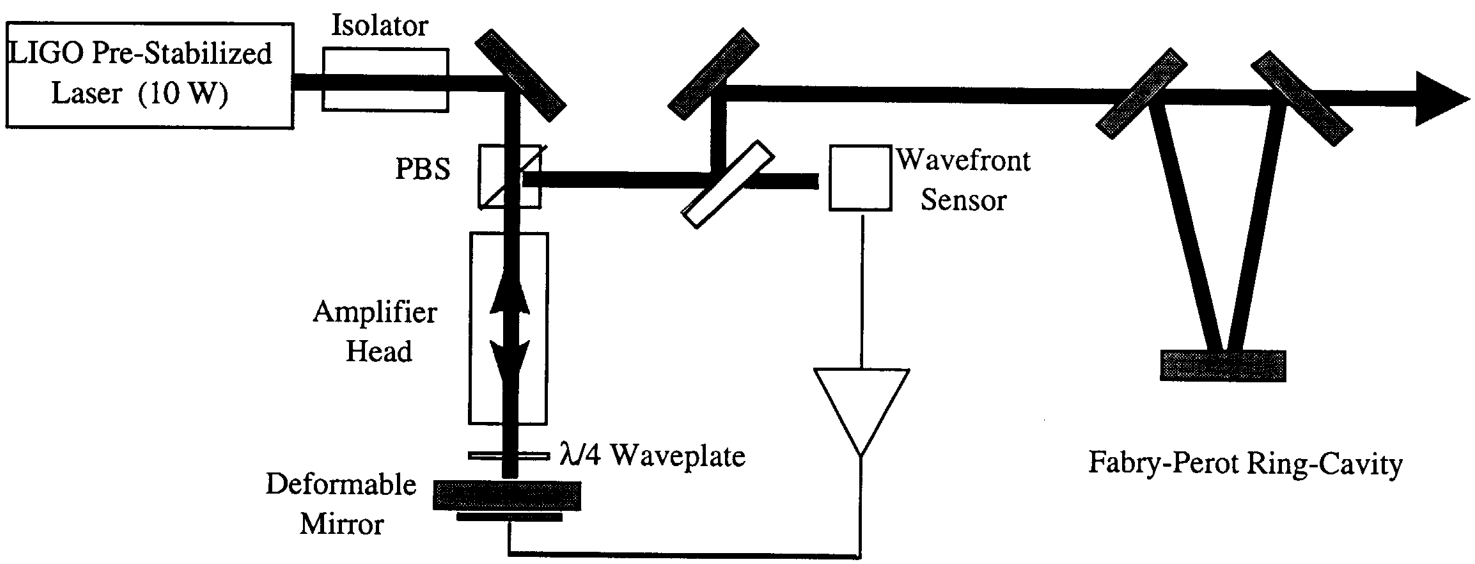
Measured Thermal Lens (full pump)

f_{width} = - 42 cm

$f_{thickness}$ = 52 cm

Stanford's LIGO II MOPA Amplifier Module Design

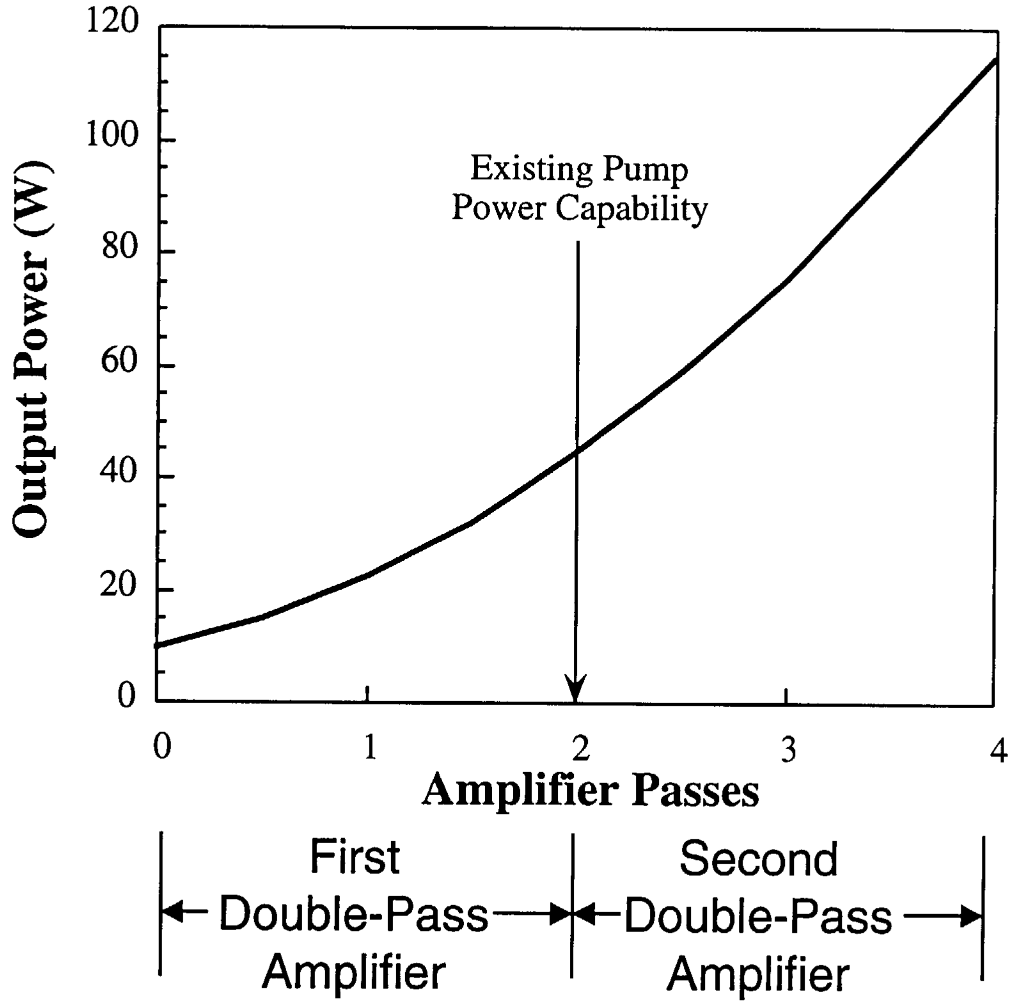
High Power Master-Oscillator Power-Amplifier



- Modular, easy to scale
- Coherence Control
- Spatial Mode Control
- Soft Failure Mode

- **Amplifier Power Noise**
- Extraction Efficiency
- Mode Distortion

Predicted Amplifier Power

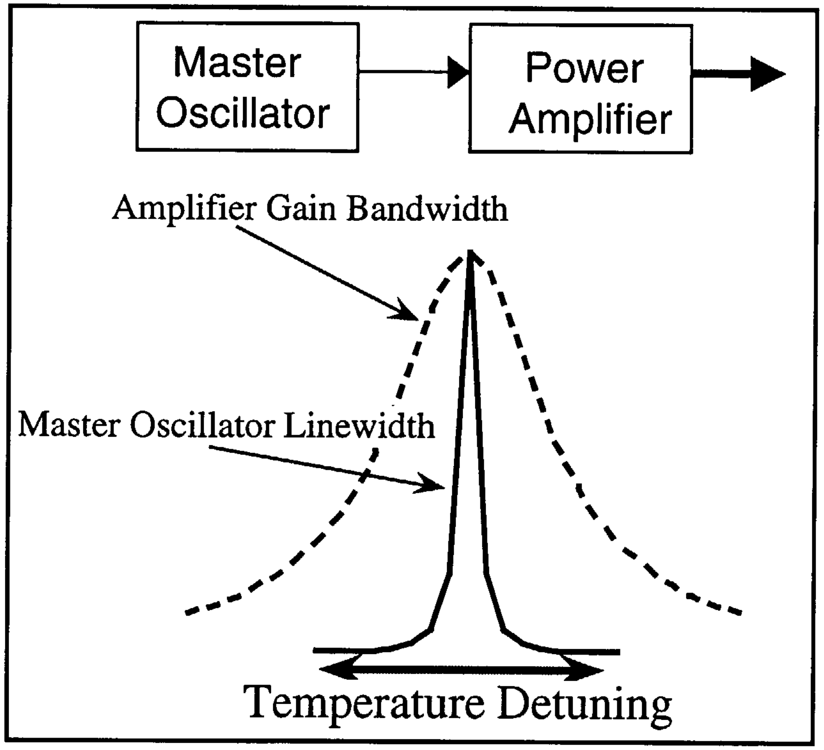


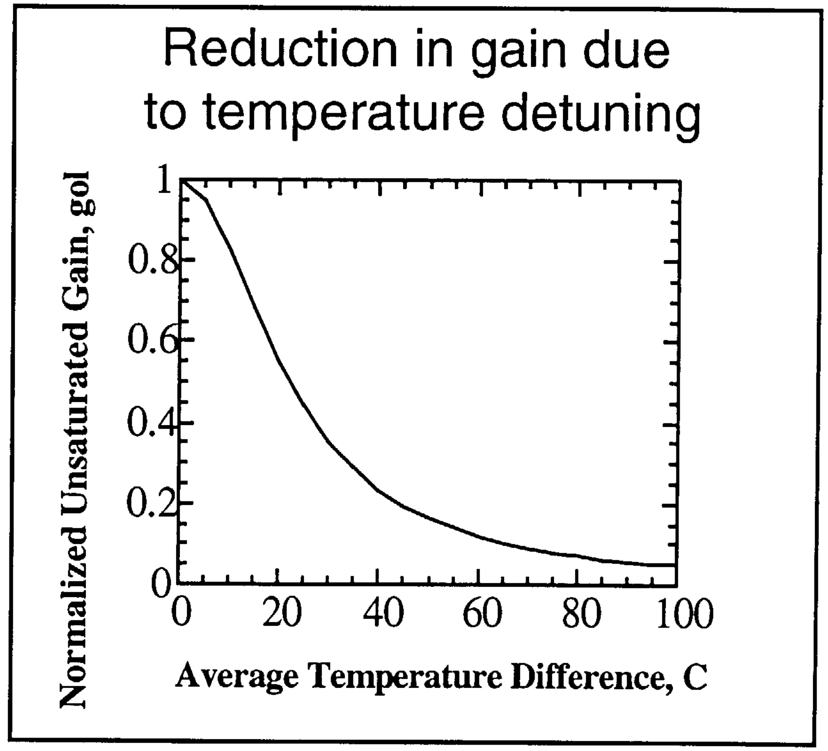
<u>Master Oscillator</u>
- 10 W LIGO Laser

<u>Amplifier</u>
- Edge-Pumped
- Conduction-Cooled
- Double-Pass
- 300 W Fiber-Coupled Laser Diode Arrays

Average Temperature Amplifier Detuning

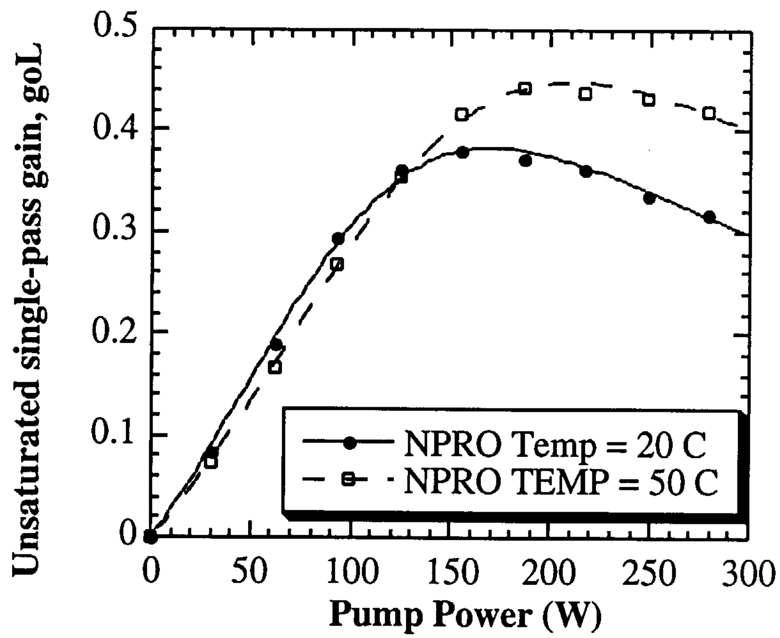
Wavelength Temperature Tuning 4.5×10^{-3} nm/C
Amplifier Gain Linewidth 0.2 nm





Temperature Detuning in Single-Pass Amplifier

Unsaturated single-pass gain
as a function of master oscillator (NPRO) temperature



Gain rollover due to master oscillator and power amplifier temperature detuning!

Summary and Conclusions

- **Conduction-cooled, edge-pumped slab multimode oscillator**
  - Slope efficiency has increased from 30 % to 55% since 6/98
  - Output power has increased from 40 W to 127 W since 6/98
- **Average Temperature Effects**
  - Thermal population absorption loss
  - Oscillator/amplifier wavelength detuning
- **Ready for 40 W MOPA System Characterization**

High Power Laser Research Proposal

- **Phase 1 - 40 W MOPA System Characterization**
  - Power Scaling (1 month)
  - Amplitude Noise - Saturated Amplifier (1.5 months)
  - Frequency Noise - Free Running (2 weeks)
  - Spatial Beam Control (3 weeks)
    - Beam Wiggle, Spatial Beam Distortion
  - 40 W Mode Cleaner (3 weeks)
  - Second Harmonic Generation - LBO, PPLT, PPLN (2 weeks)
  - Thermal Distortions in System Components (2 weeks)
    - Modulators, isolators, etc.
- **Phase 2**
  - 100 W MOPA - Diode Budget Dependent
  - Adaptive Optics MOPA Demonstration