MOPA Progress at Stanford

Slabs and Fibers

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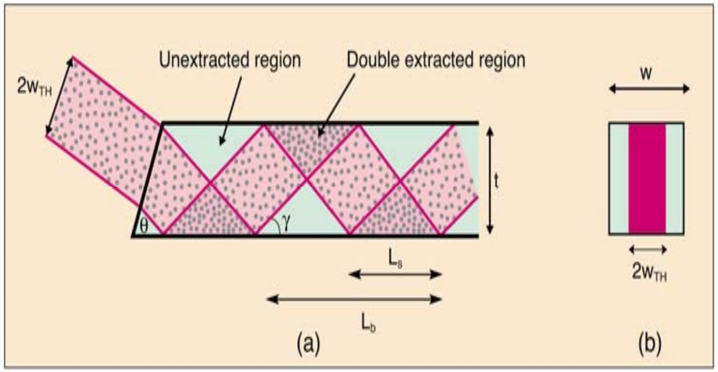
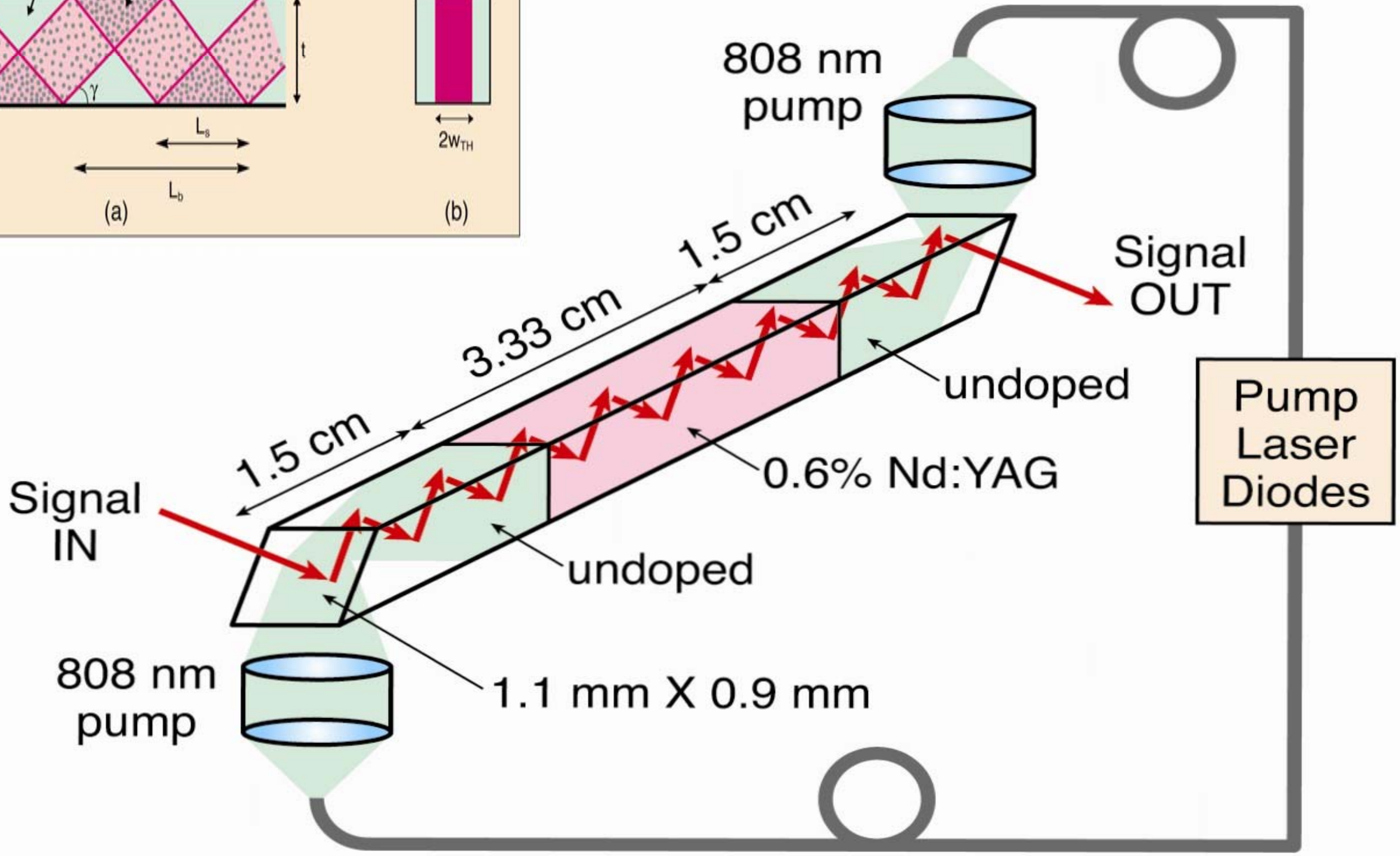
End-Pumped Slab Research

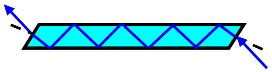
- Review Shally Saraf’s work / Our Architecture
- What’s been happening lately
- Current Slab Amplifier Testbed
- Slab Status / Recent Results
- Our Future Plans

End Pumped Slab Layout



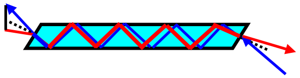


Results of Shally's MOPA experiment



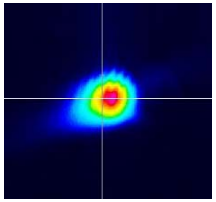
❑ Single Pass Power Output ~ 65 W

- –Depolarization ~ 1.5%.
- –P-P intensity fluctuations < 2%
- –$M^2 < 1.08$

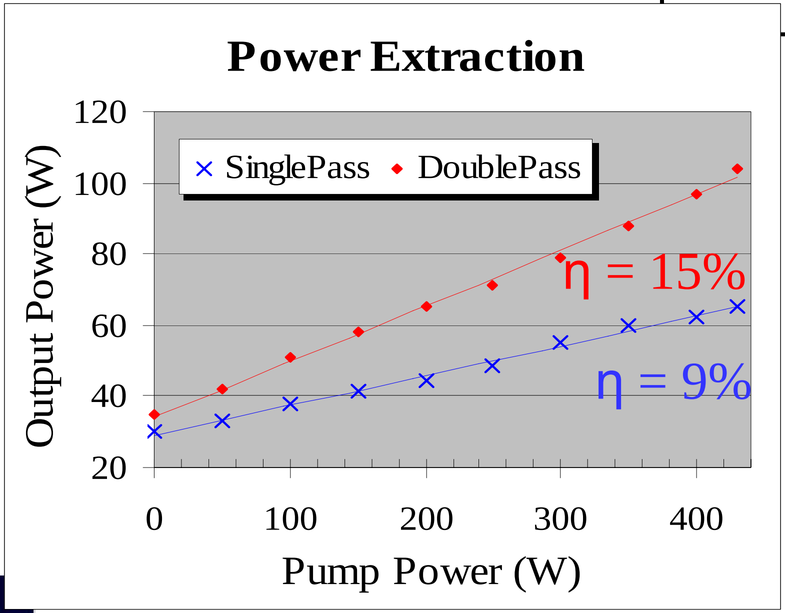


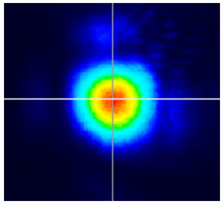
✓ Double Pass Power Output ~ <u>104 W</u>

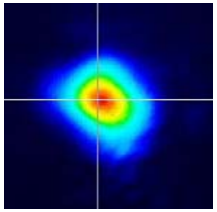
- –Angular multiplexing avoids Faraday rotator.
- –Depolarization < 3%.
- –P-P intensity fluctuations < 2%
- –$M^2 < 1.09$



COLD SLAB



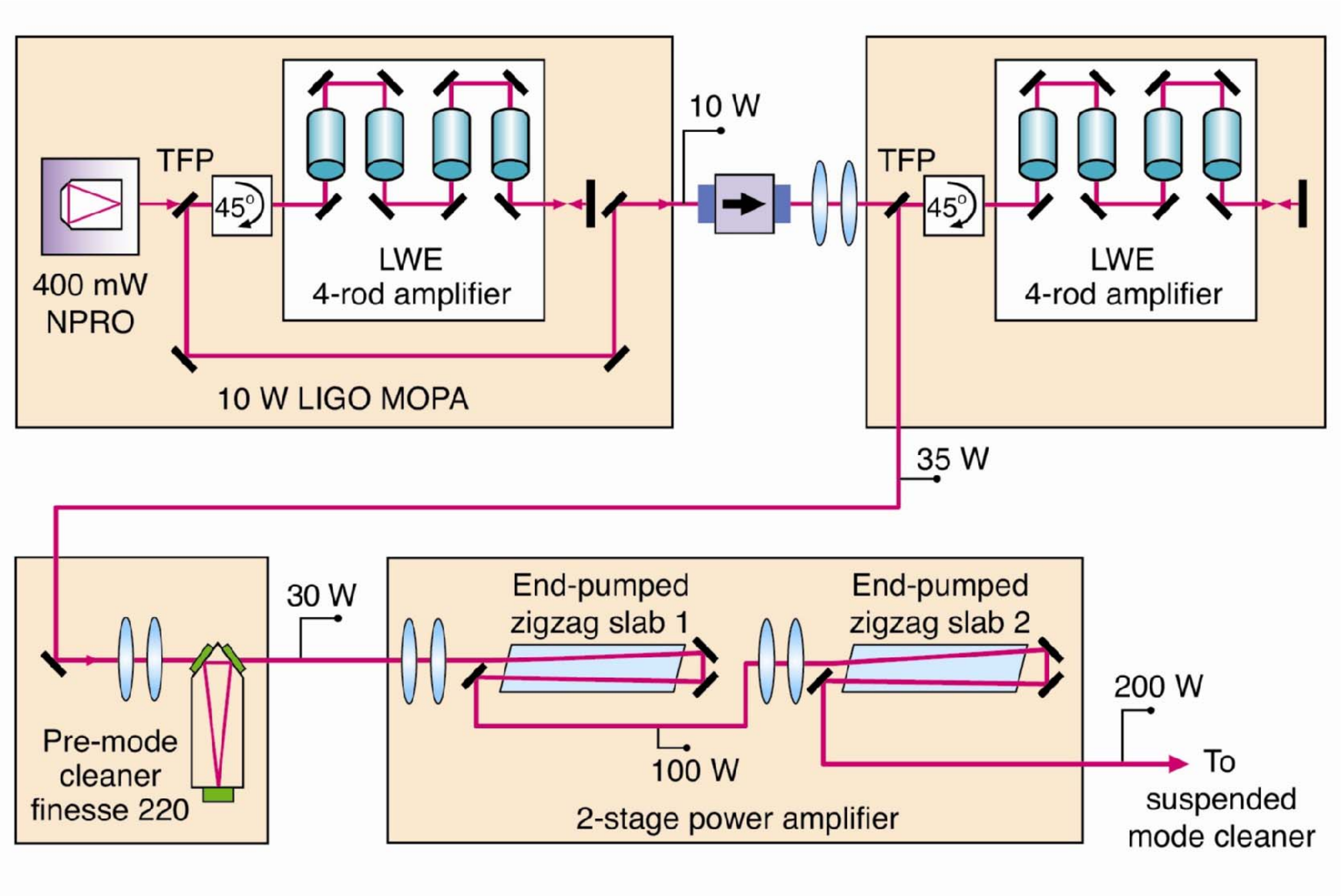




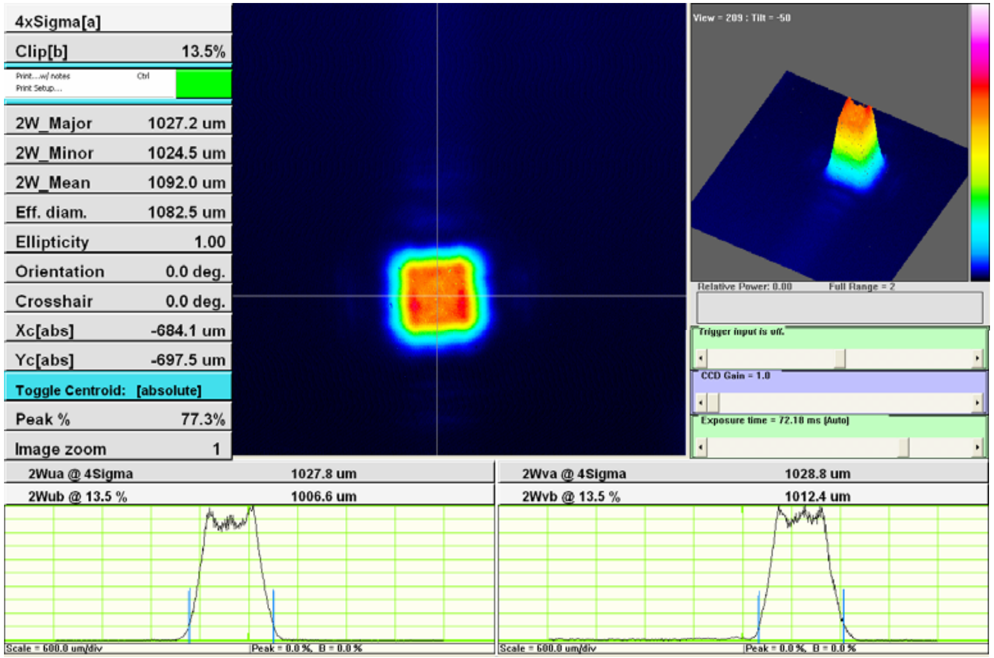
Saraf, et.al.,

2003

The Hope

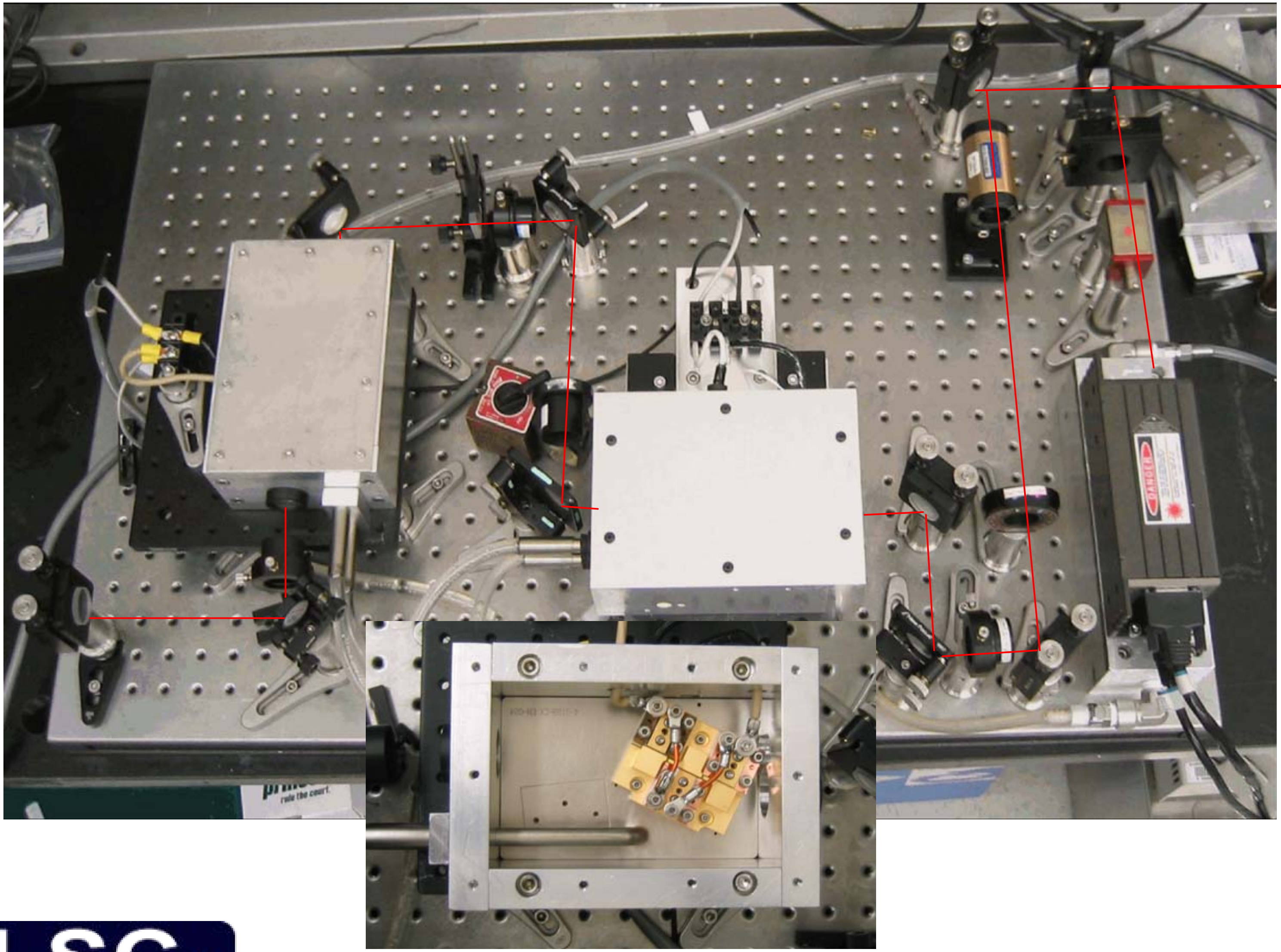

10 W
TFP
45°
LWE
4-rod amplifier
400 mW
NPRO
10 W LIGO MOPA
TFP
45°
LWE
4-rod amplifier
35 W
30 W
End-pumped
zigzag slab 1
End-pumped
zigzag slab 2
200 W
Pre-mode
cleaner
finesse 220
100 W
2-stage power amplifier
To
suspended
mode cleaner

Building Tools for Moving Forward



Patrick Lu's Gaussian-to-Super Gaussian beam converter
Fejer Group uses laser for SHG
Amber thermally loads Mode-Cleaners
Pumps are shared with other research groups

Planning Ahead



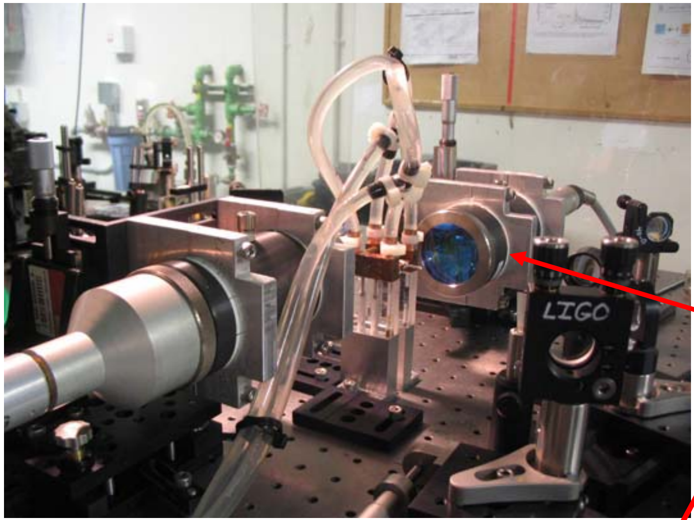
6W

M^2=1

(no B.S)

Suitable replacement for "LIGO box" in case we need it.

Packaging Improvements



Then

(2002)

Good power

Reliable,

But not stabilized at 808nm

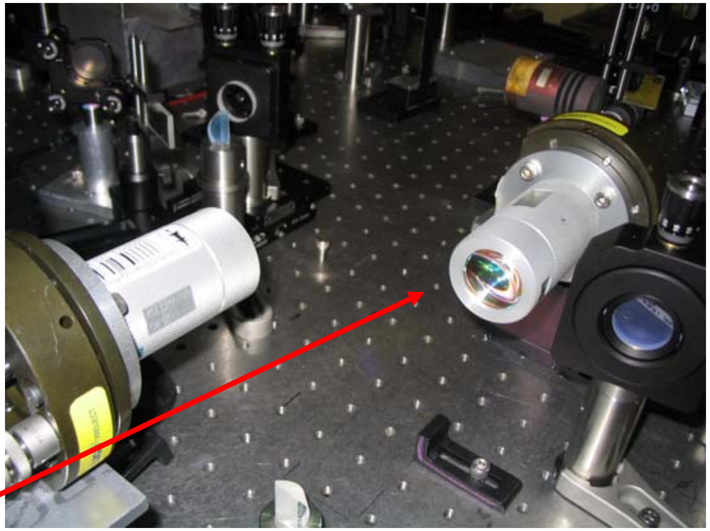
Now

Much smaller

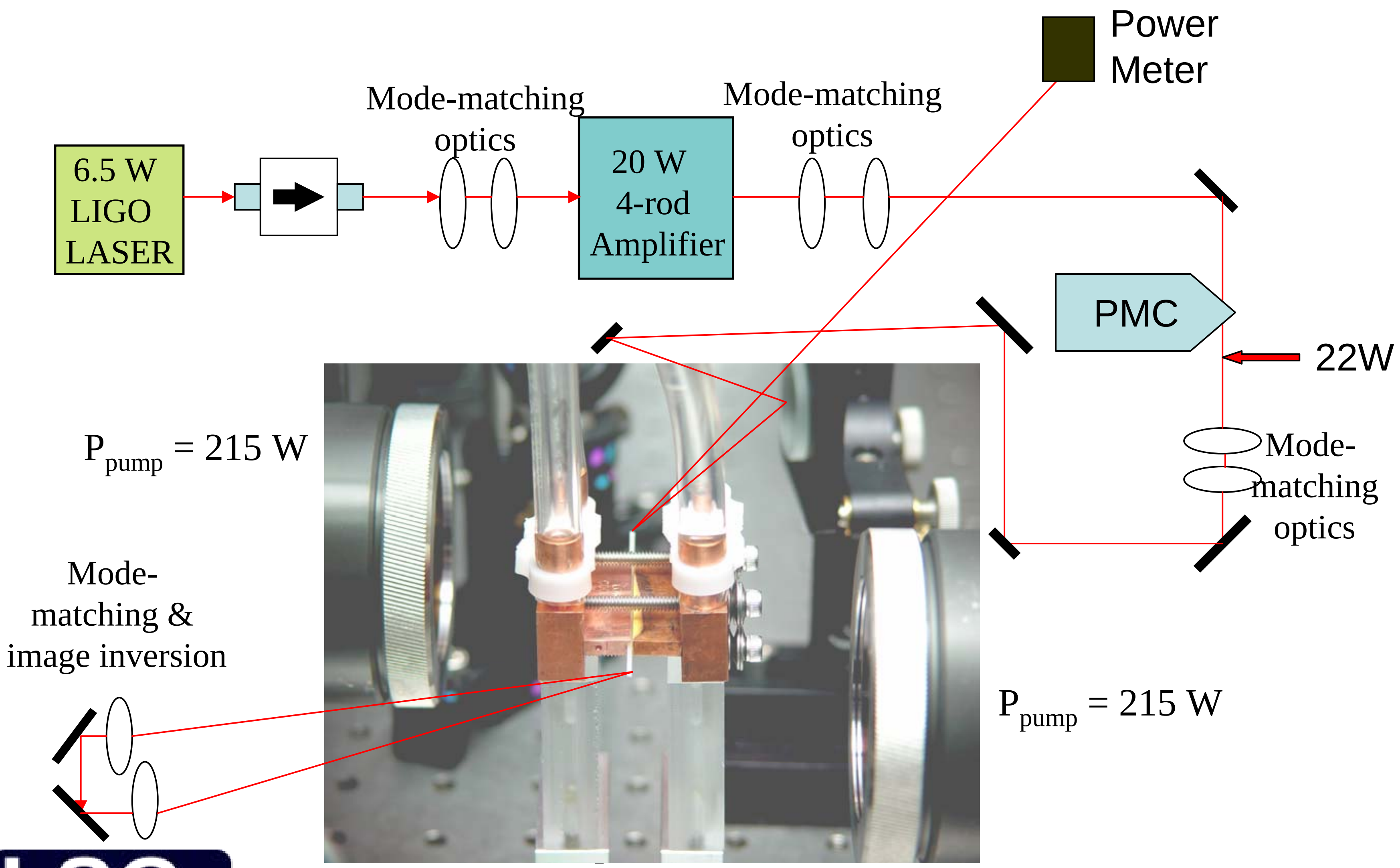
110v

Easily movable

Stll not stabilized



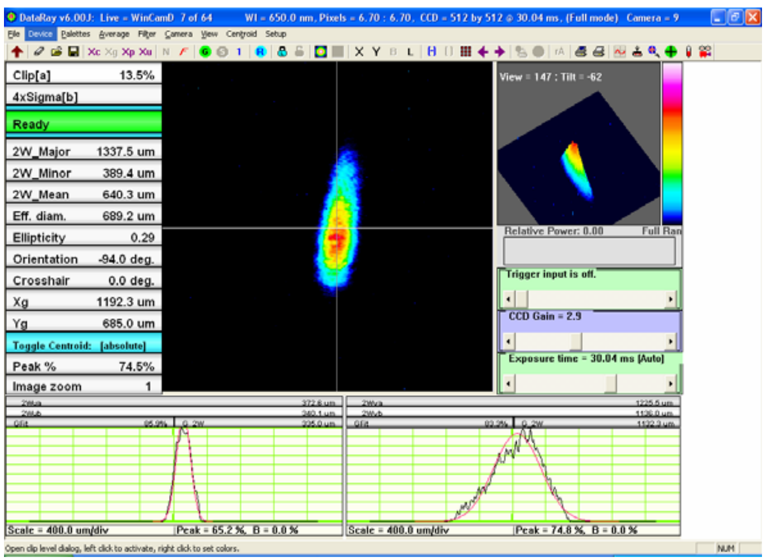
Setup for MOPA experiment



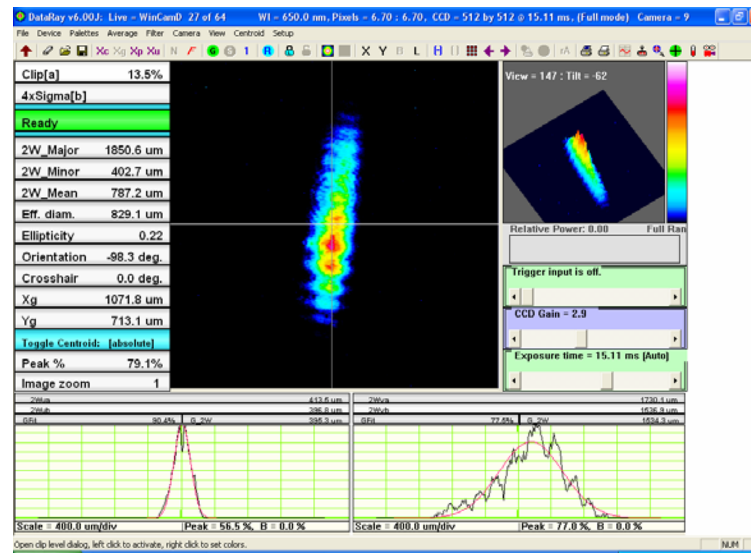
end pumped slab

Re-creating the past is difficult

- Shally had used a spot size of 300*u*m at slab center
- Our attempt to re-create showed tremendous thermal lensing and much lower extraction (only 17W at P_{pump}=400W)

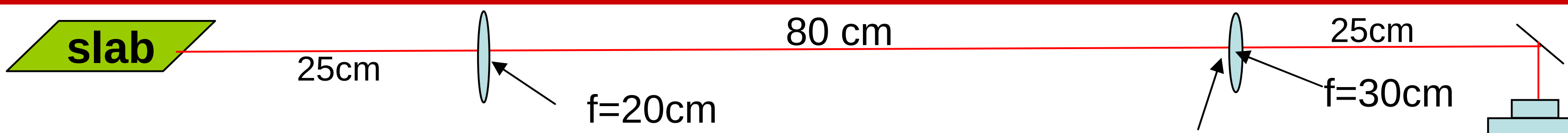


275um spot at slab center (cold pass)

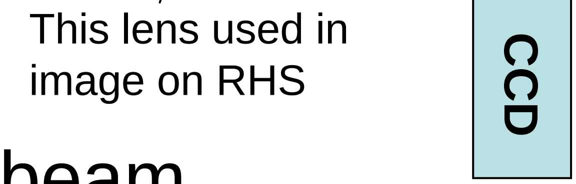


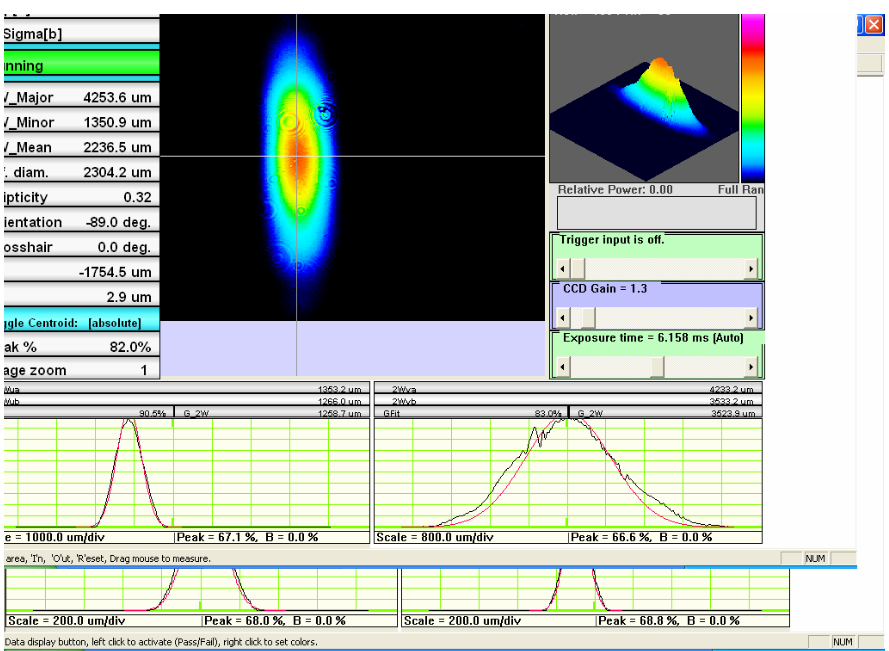
Same spot pumped by 200W /side

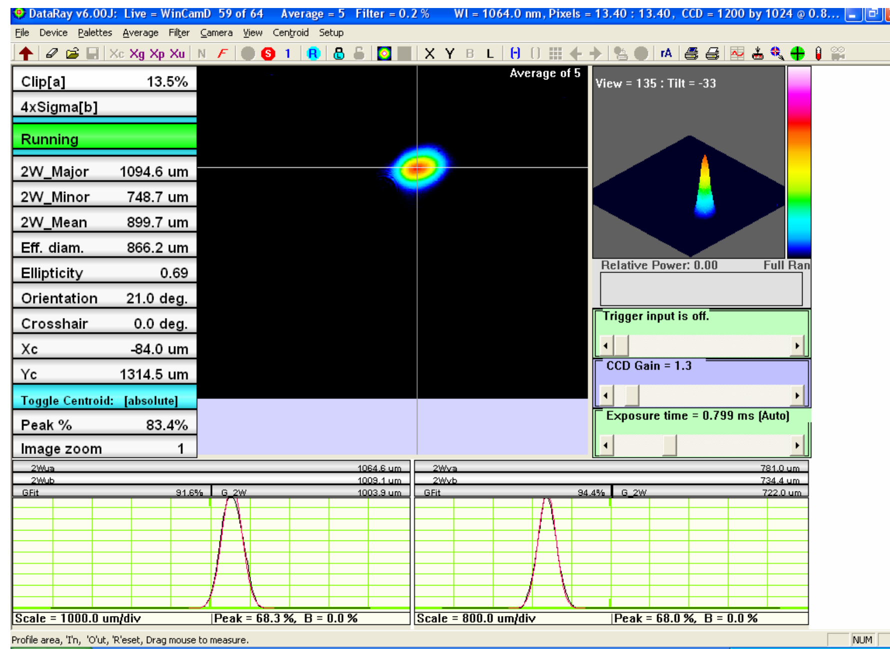
Days of Manipulation + Luck + a New Slab=



- 62W Single-pass beam
- Double pass resulted in 80W beam







Oddities / Hope / Future Slabs

- We did manage to extract 42W in a single-pass (60W double pass)
  - Spot size of 120*u*m
  - Previously spot size was 300*u*m
- Next slab tested only offered 25W/pass (as of now)
- Second slab amplifier shows similar behavior (g_0l matches that of 1st setup)
- We are ready to continue double-passing 2 slabs as soon as they are available

Fibers

High Power Fiber Research

- Overview and advantages of fiber amplifiers
- Numerical modeling and simulation
- Experimental setup and results
- Vision of the future
- Future Work

Fiber Laser Sources for High Power

Advantages	Disadvantages
Highly efficient due to excellent overlap of the pump with signal	Nonlinear effects can limit output power
Long absorption length allows smaller heat dissipation per unit length	Glasses tend to have lower thermal conductivity than crystals
Guiding nature can help ensure transverse mode quality of beam	

Single Mode Fiber Amplifier Challenges

- Coupling pump into fiber
  - Single mode fiber coupled diode laser pumps are limited to ~ 1 W

Solution: Couple multimode pumps

- Nonlinear effects
  - Undesirable nonlinear effects (SRS, SBS) scale approximately with product of interaction length and average intensity

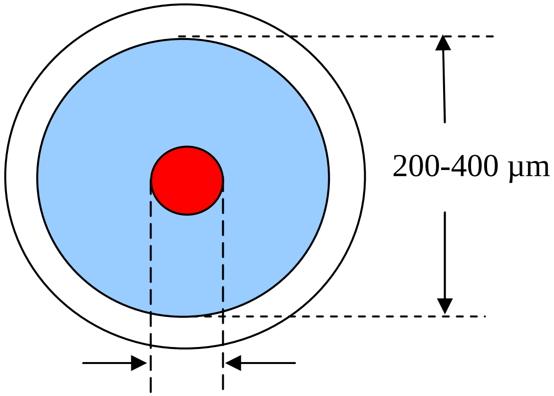
Solution: Increase core area

Large Mode Area Double Clad Fiber

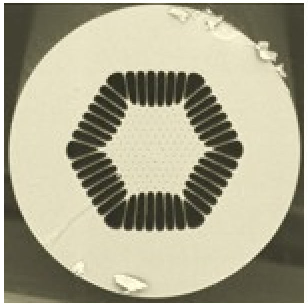
- Inner cladding permits multimode pumps to be coupled into fiber
- Large mode area decreases average intensity in fiber

Maintain spatial mode by employing differential bending losses

LMA Fiber Types

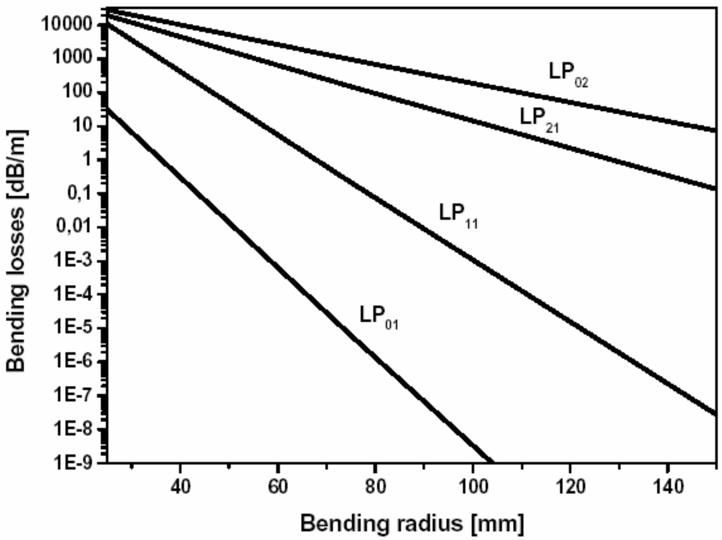


Standard LMA Fiber



-Crystal-Fiber LMA fiber

Holey LMA Fiber



J. Limpert et al., Photonics West 2003

Fiber Amplifier Modeling

$$\frac{d\vec{S}_{\nu}(z)}{dz} = \left(\vec{\vec{g}}_{\nu}(z) + \vec{\vec{b}}_{\nu}(z) + \vec{\vec{l}}_{\nu}(z) \right) \vec{S}_{\nu}(z) + \vec{E}_{\nu}(z)$$

Birefringence tensor

Spontaneous emission factor

Stokes vector components

Mueller Gain Matrix

Background loss

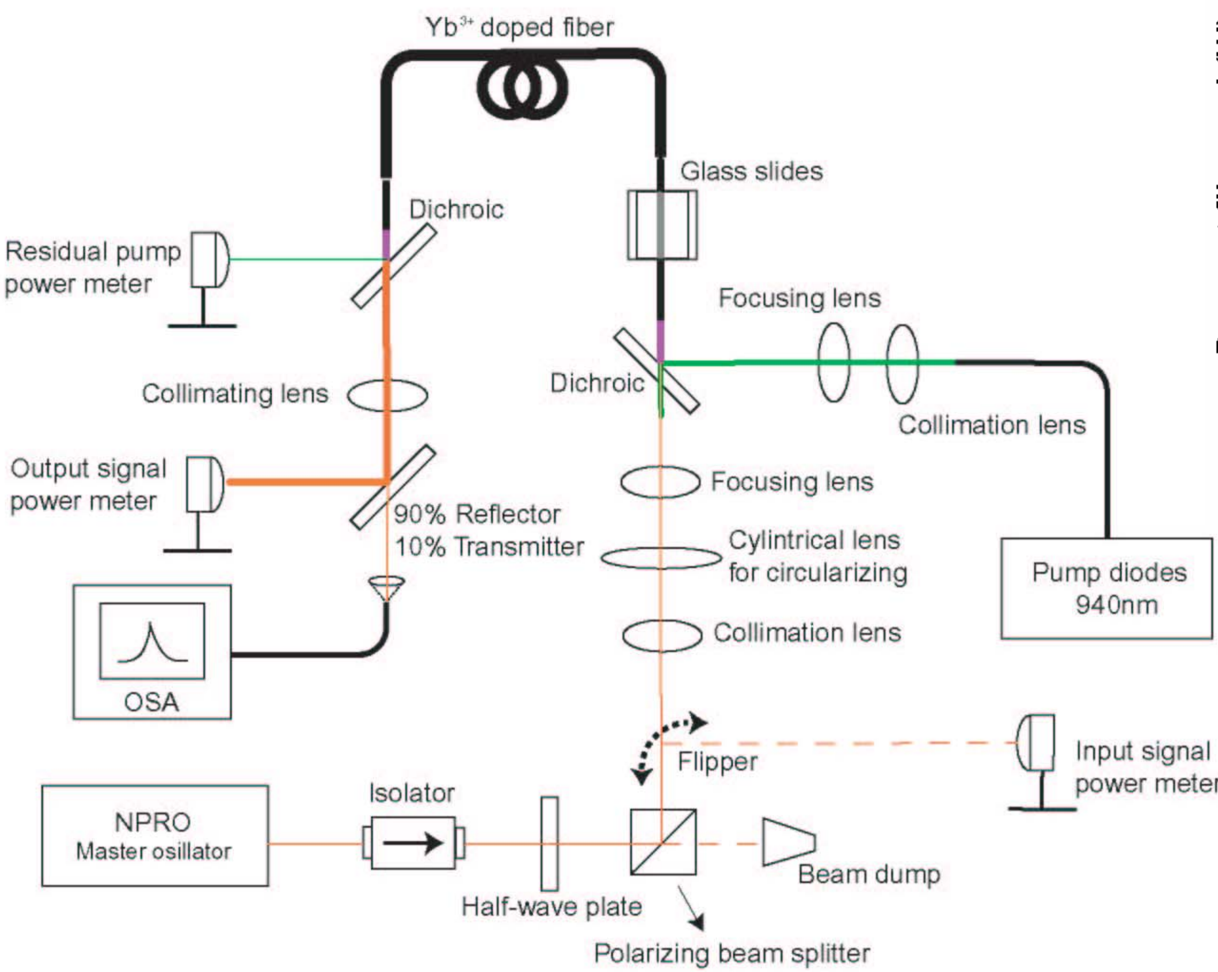
* Wagener et al., JLT 1998

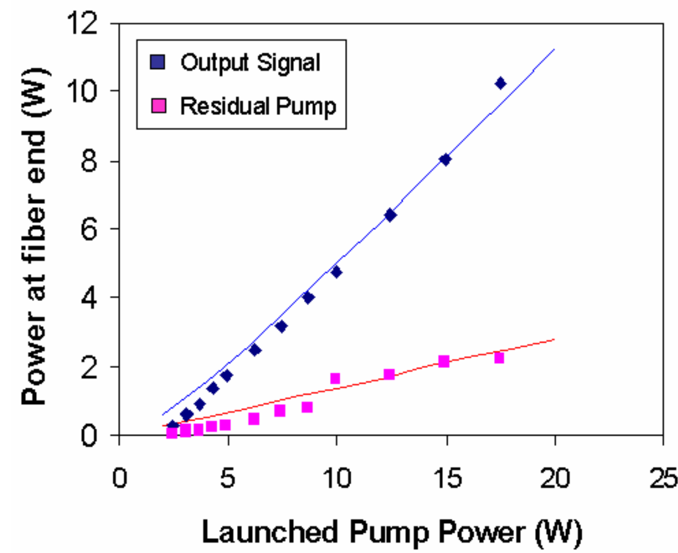
Software predicts amplifier and laser output power versus pump power, fiber length, ion doping, etc.

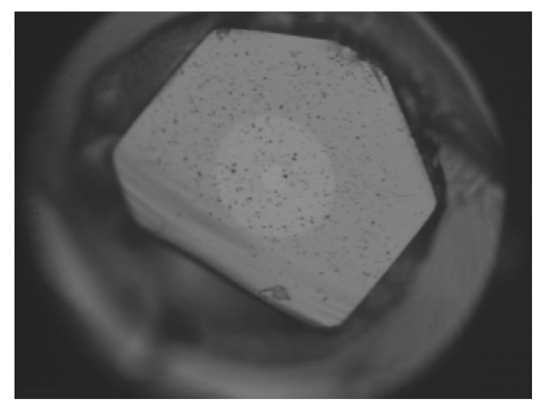
Code also calculates

- ASE power and spectrum
- Polarization properties
- Nonlinear effects
- Fiber temperature profile

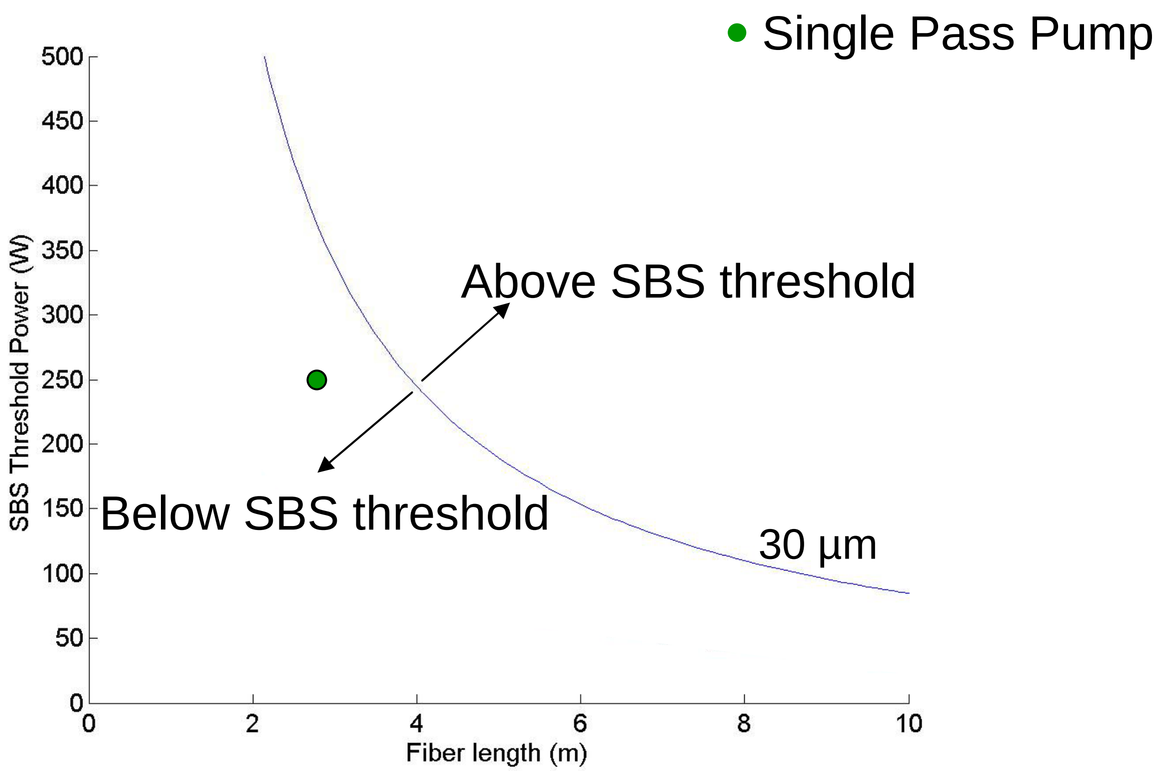
Model Verification





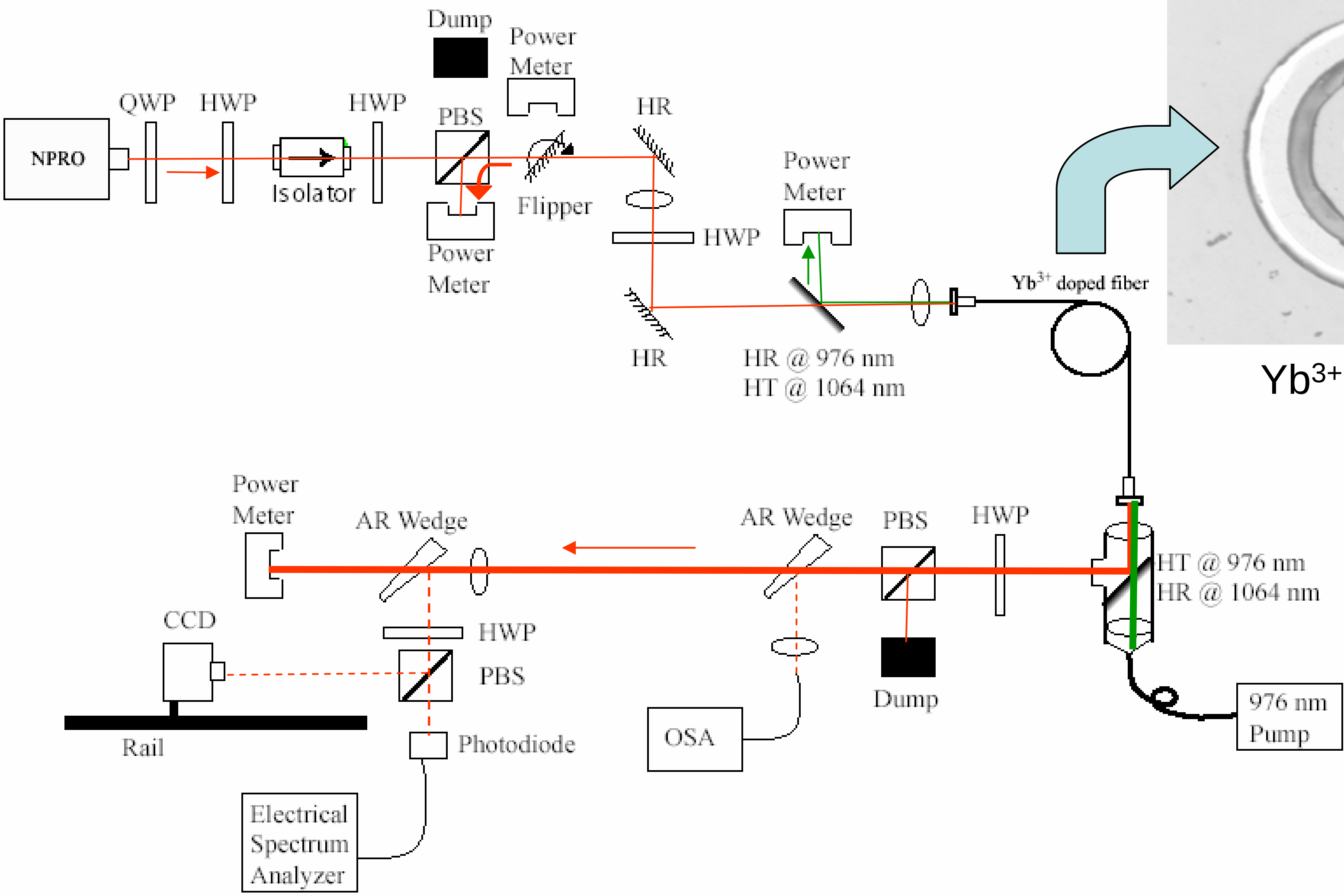


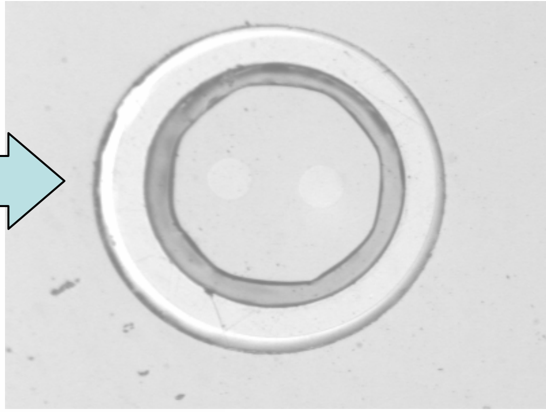
SBS avoidance



Single pass pump design is below the Brillouin threshold

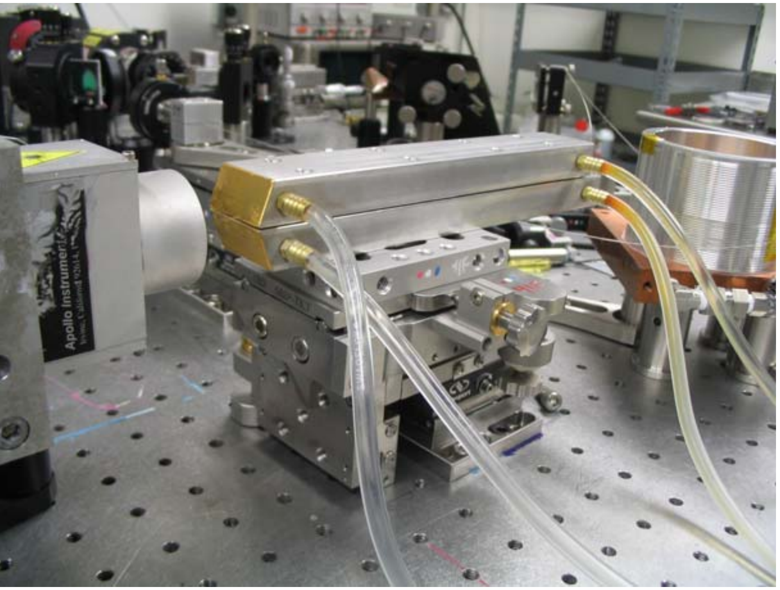
High Power Fiber Amplifier Setup

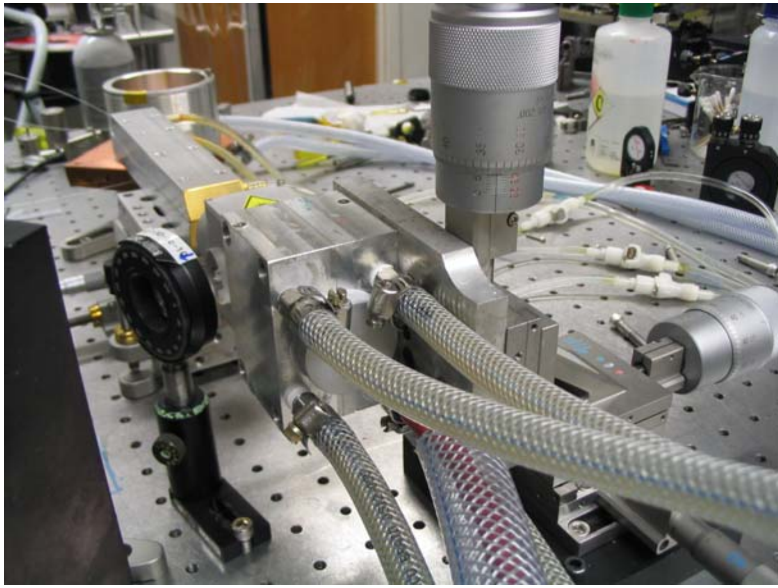


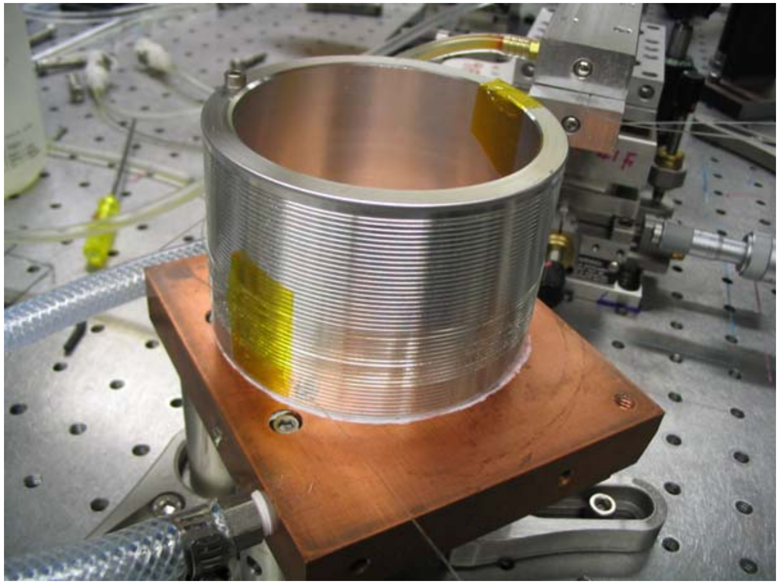


Yb^{3+} doped fiber

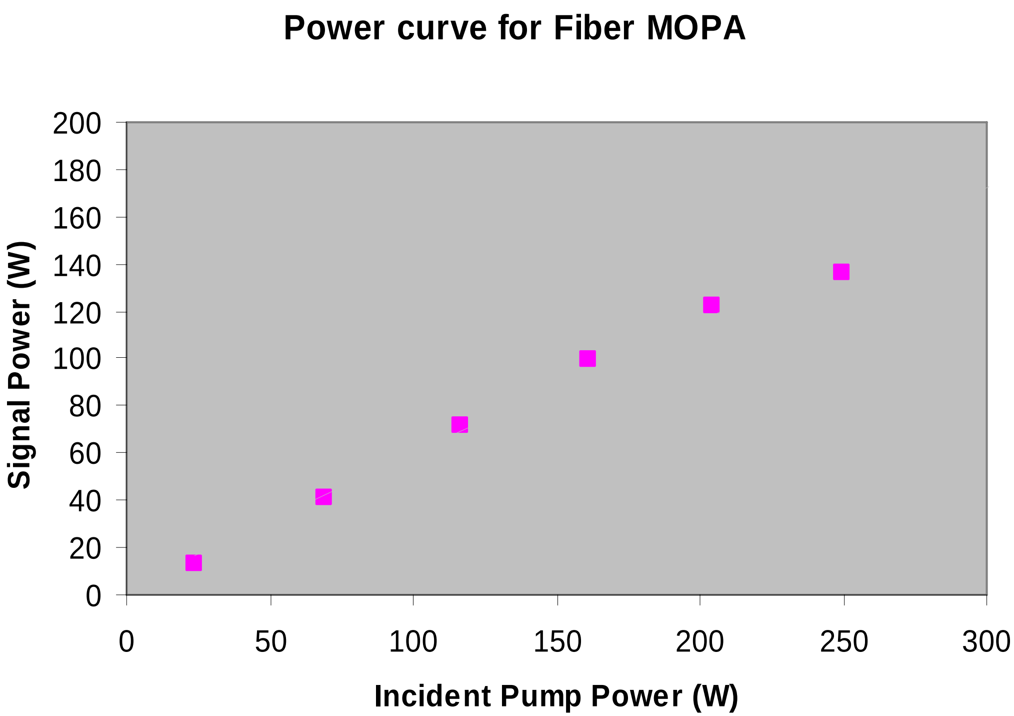
Fiber Experimental Setup Photos

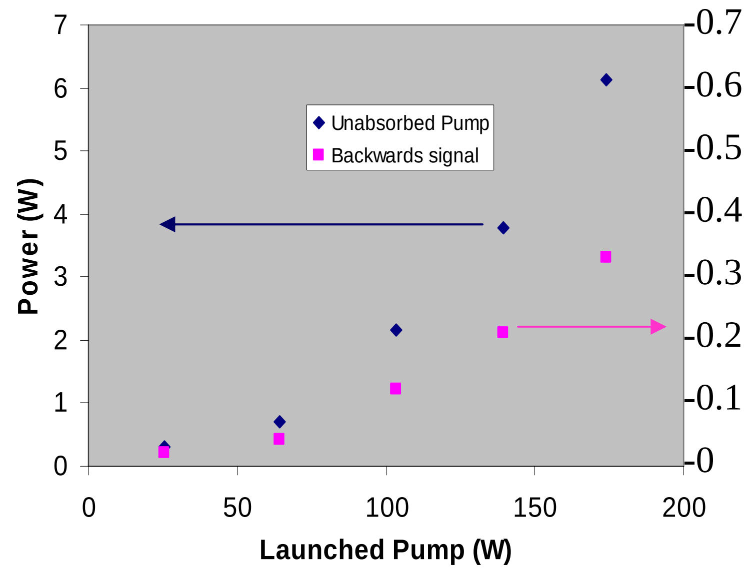






High Power Fiber Amplifier Results (1)



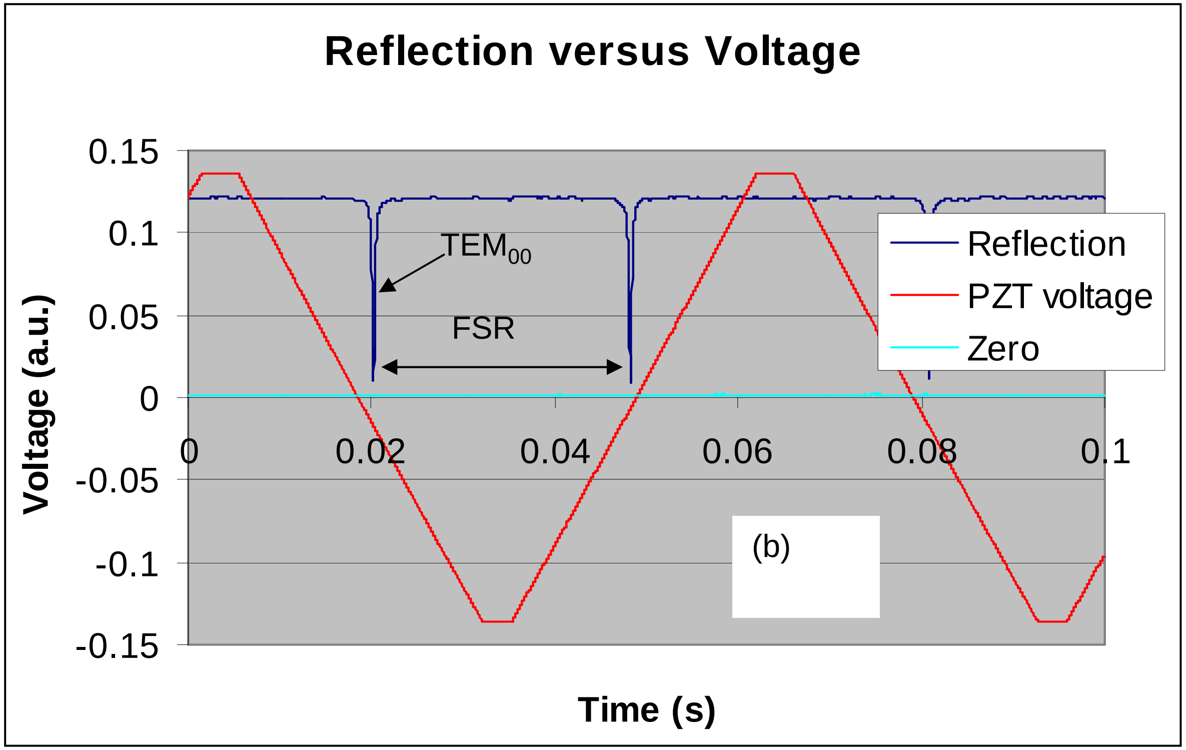


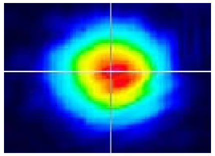
- 136W of output power
- No sign of SBS at the highest power level

Mode was very touchy to the environment

Best polarization ratio was 18:1

High Power Fiber Amplifier Results (2)



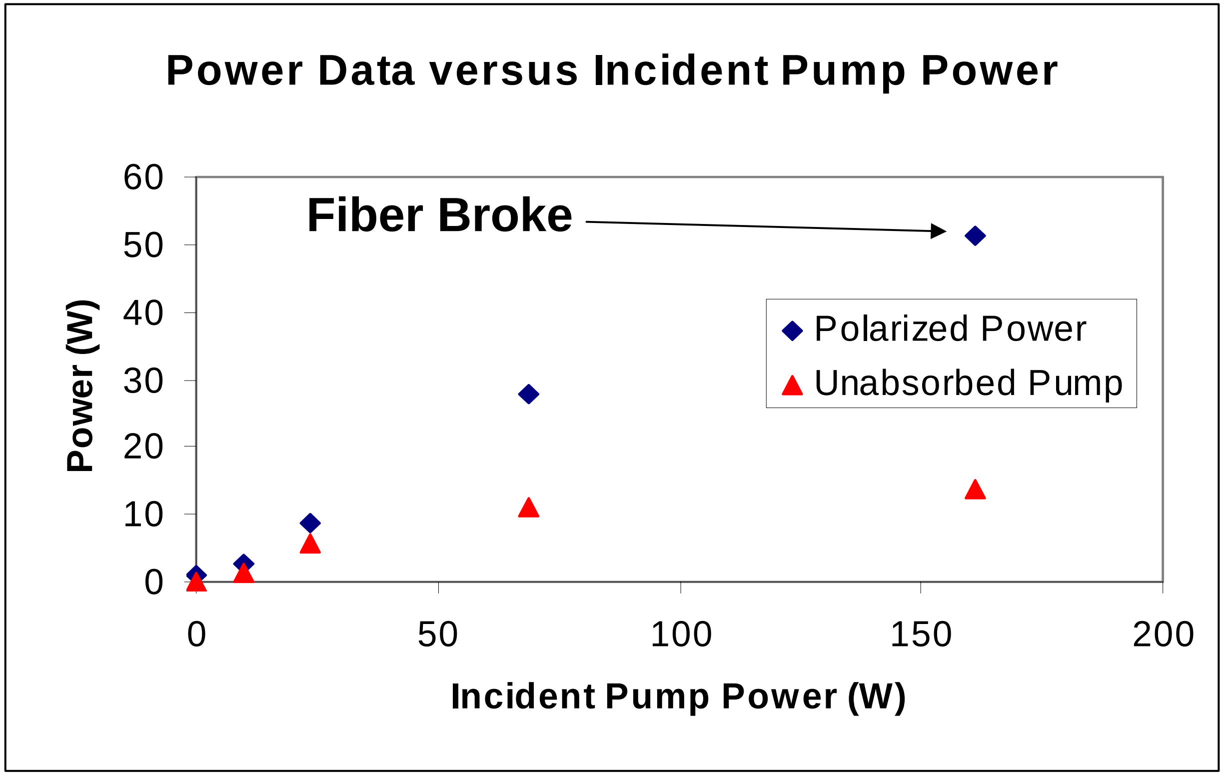


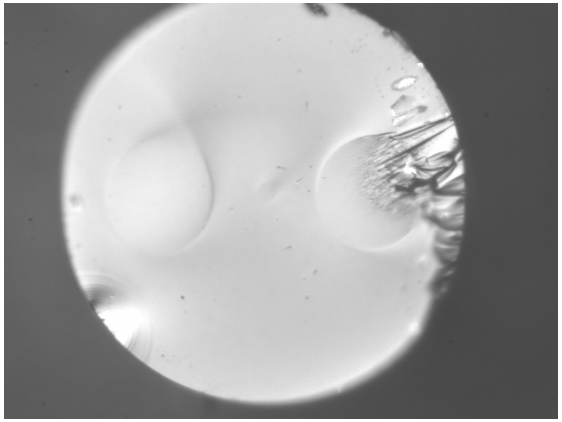
$M^2 < 1.05$

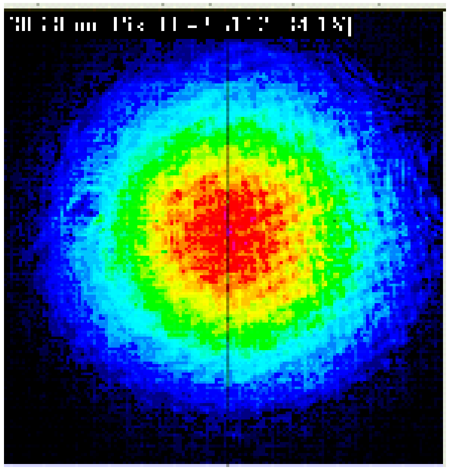
Analysis of mode cleaner reflection spectrum indicates that less than 1.5% of the output power is contained in the higher order modes at 10 W level

Improving Output Characteristics

- Alternate fiber from another vendor (Liekki)





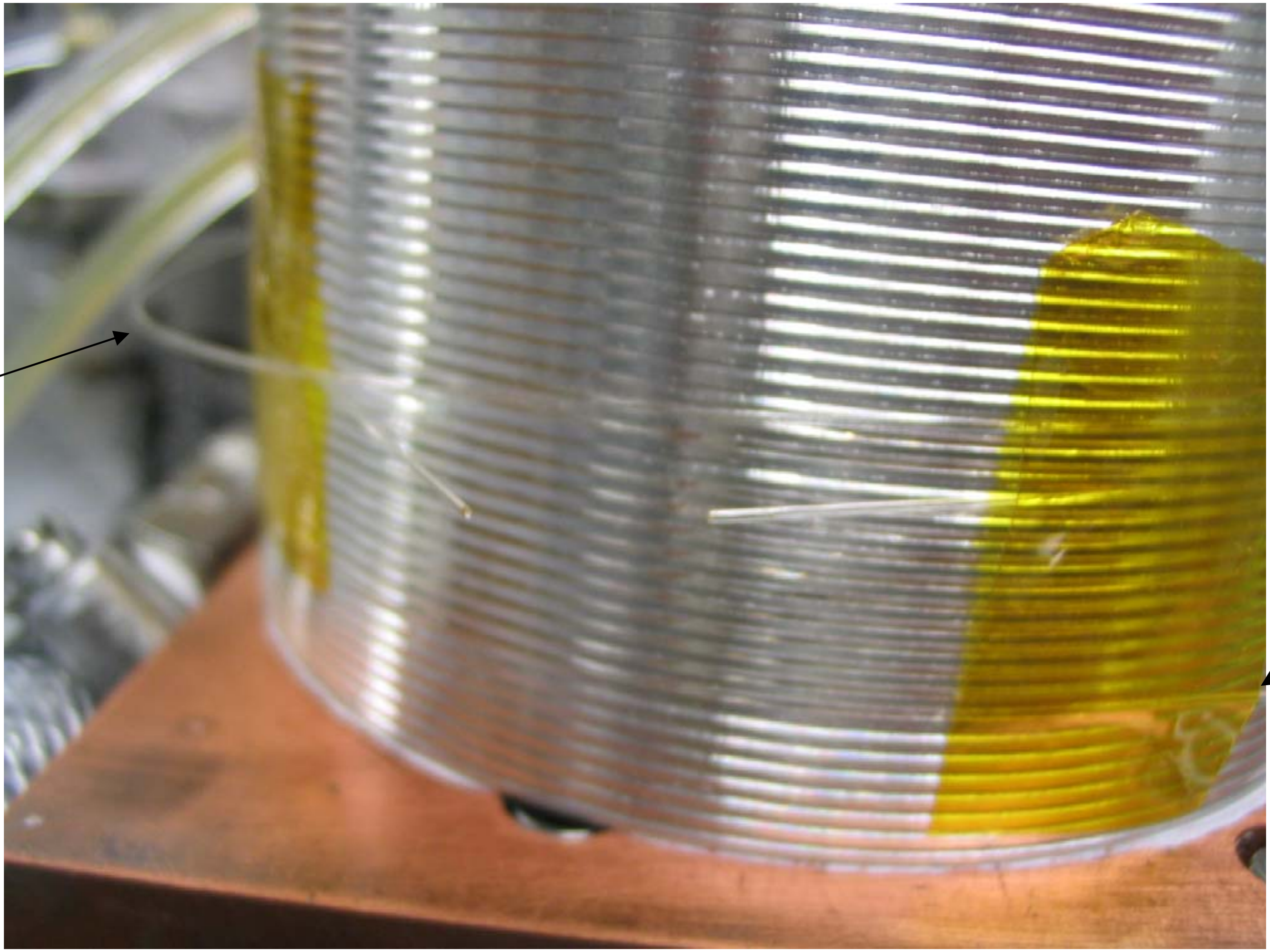


Beam at 3.5 mm diameter

- **Polarization ratio > 150:1 and was stable**
- **Mode is very stable to perturbations**

Zooming in On Damage

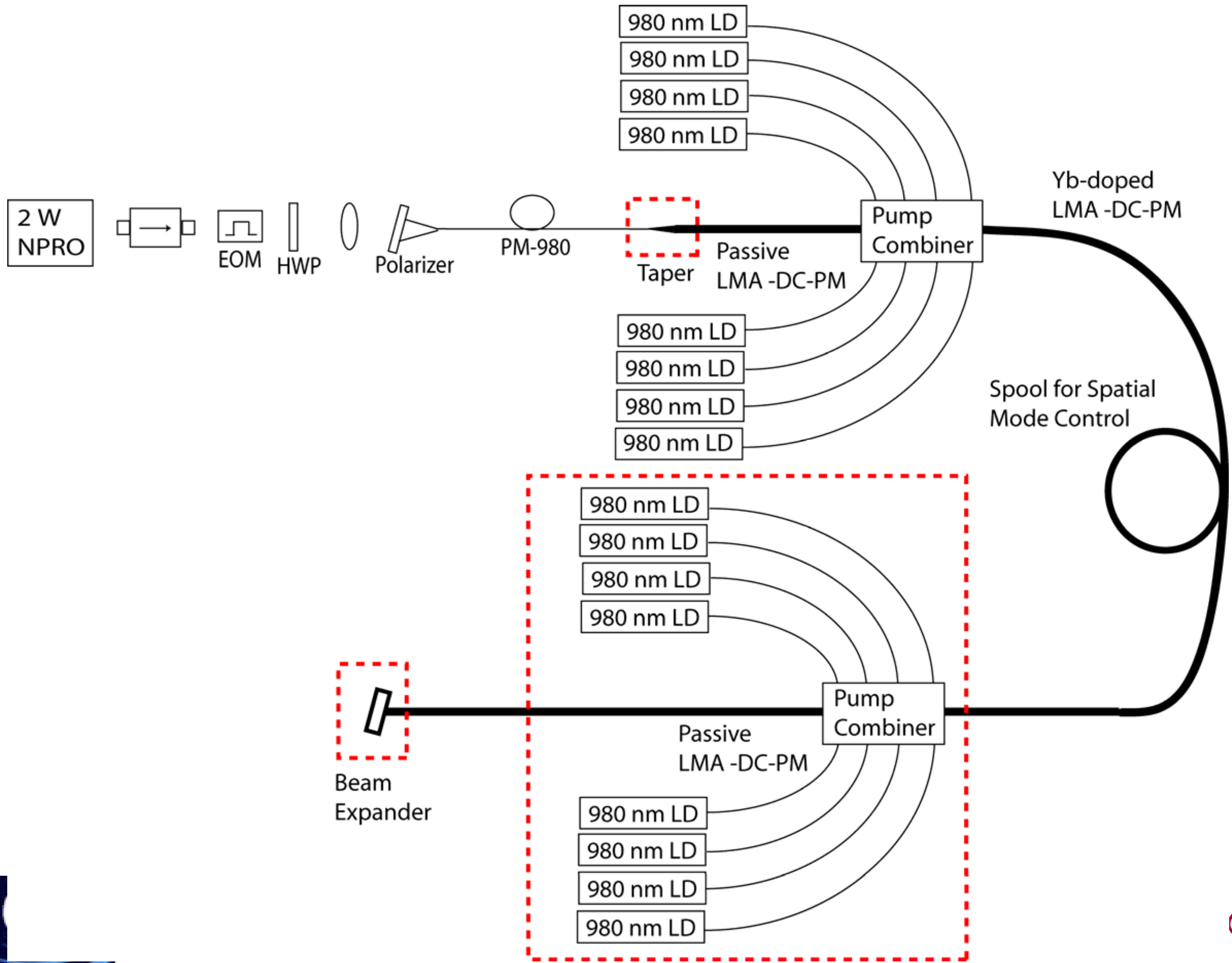
Signal end



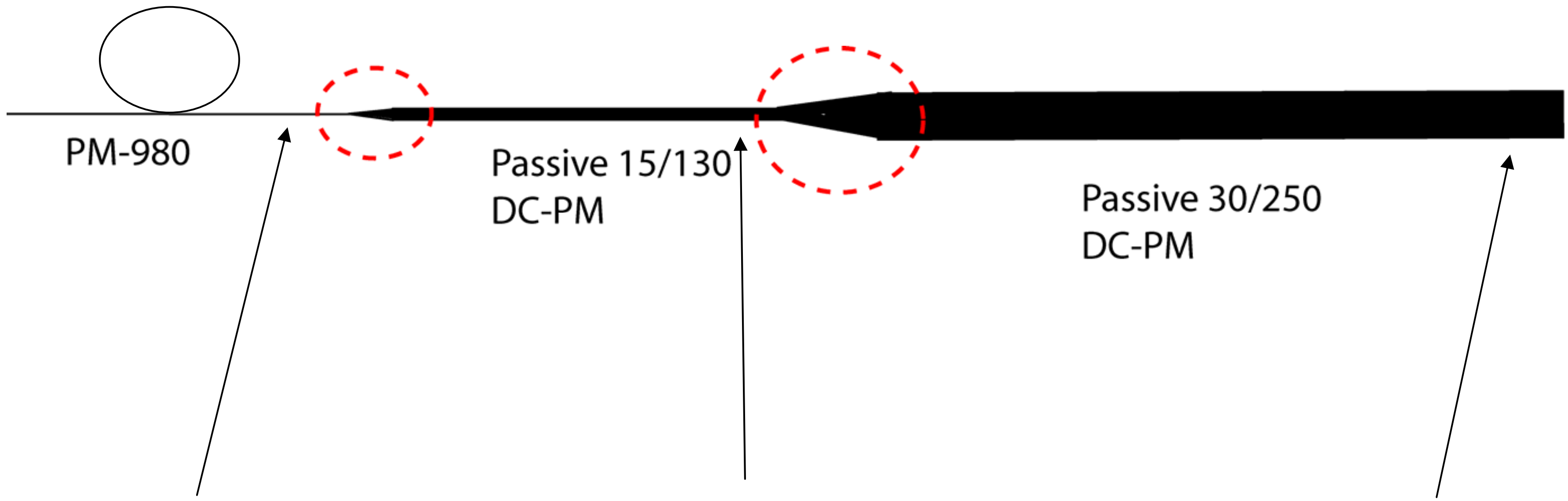
Pump end

Broken fiber due to too tight spooling and poor thermal contact

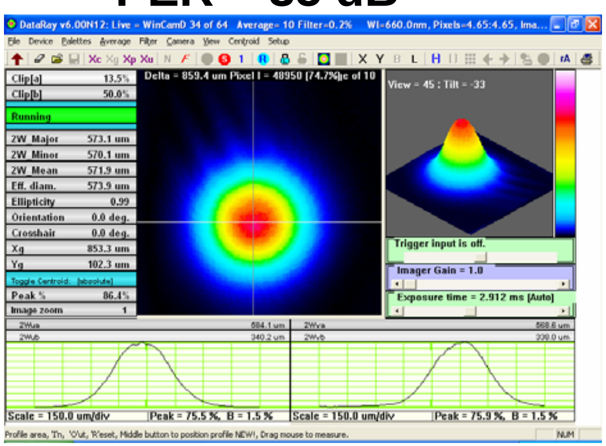
Vision of the Future



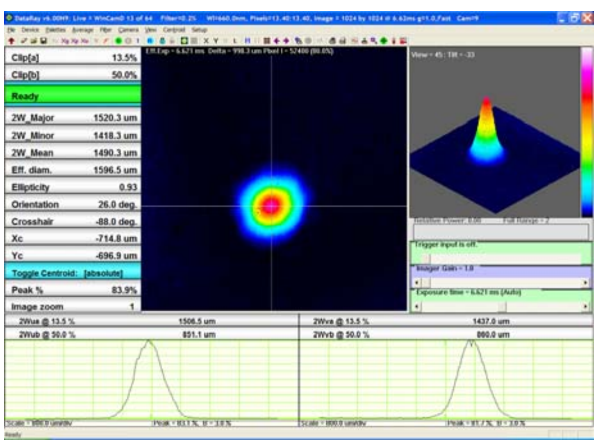
Increasing Reliability – Tapers



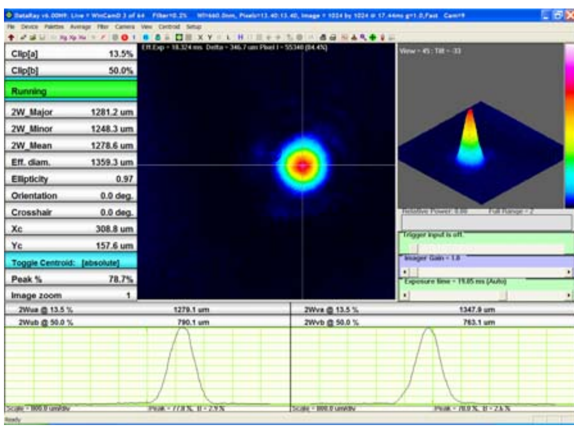
PER = 35 dB



PER = 26 dB



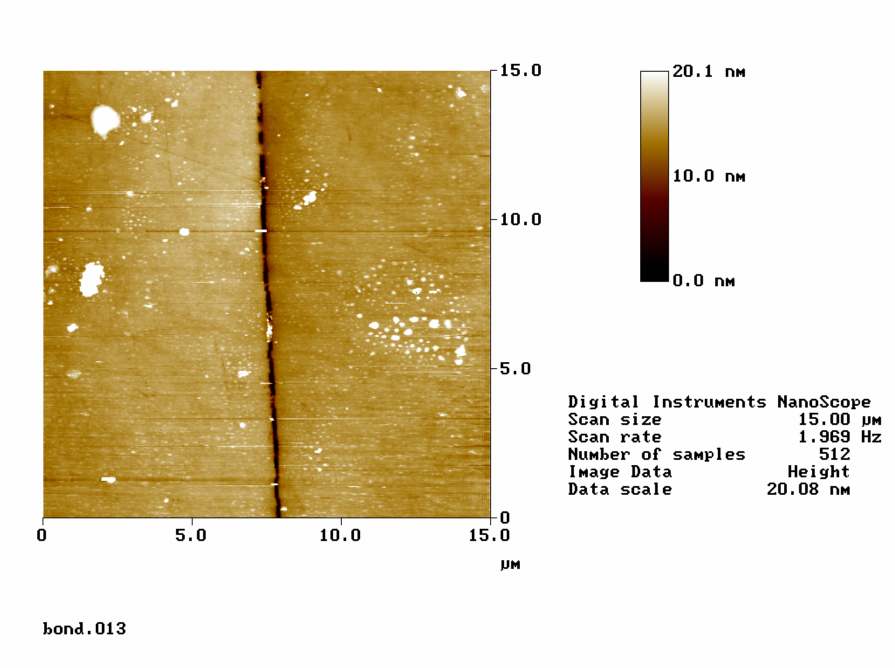
PER = 23 dB



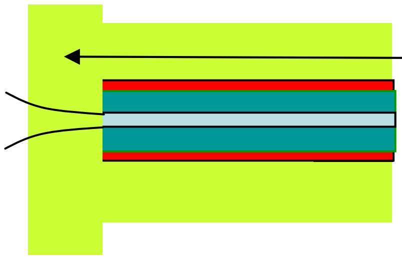
Unfortunately, shaped inner cladding of active fiber prevented final taper from being realized with Yb fiber

Increasing Reliability -- Silicate Bonding

- No high temperature processes
- Bond is as strong as substrate in silica/silica bonds
- Low optical absorption

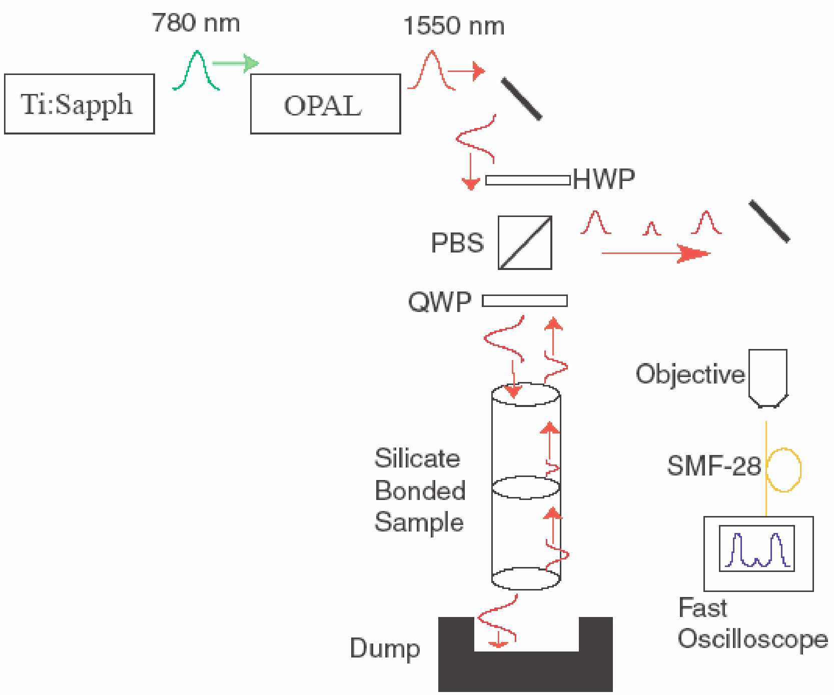


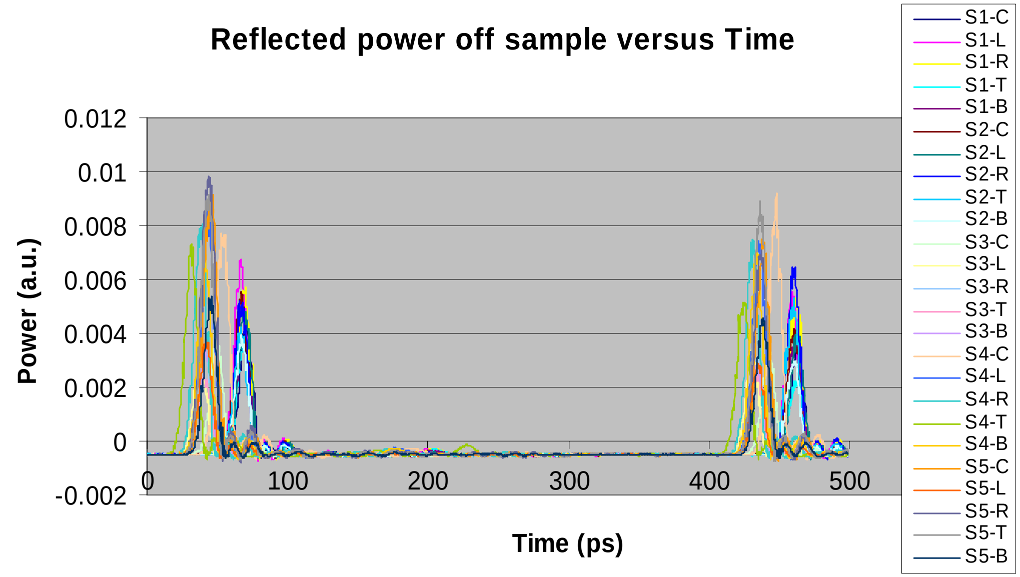
Courtesy of Sheila Rowan



Fiber in capillary bonded to optical flat

Measured Silicate Bond Properties





- Reflection is under -28 dB (measurement limited by photodiode ringing)
- Bond can withstand intensities > 1 GW/cm^2
- Mechanically strong (hand-test)

Future Work

- **Continue characterizing Liekki gain fibers**
- **Machine new mounts for fiber laser to increase stability**
- **Obtain 150 W of output power**
- **Characterize fiber amplifier output**
- **Manufacture/obtain taper and compare free space noise amplifier properties to tapered input properties**
- **Look at new material systems which may offer lower SPONTANEOUS Brillouin scattering noise (i.e. phosphates)**