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High Power Lasers for Advanced LIGO

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Objectives

- Investigate high power lasers for Advanced LIGO

- Build Deployable Lasers:

  - 10W for Gingin
  - 10W for TAMA
  - 50 - 100W for Gingin High Power Test Facility
  - 100W prototype for Adv LIGO concept test

Content

- High power laser requirements
- Design issues
- Review of approach
- Progress to date
- Optimum design recommendations
- Plan for future work

Advanced LIGO laser requirements

TEM_{oo} Power	≥ 180 W
Non TEM_{oo} Power	< 5 W
Frequency Noise	≤ 10 Hz/$\sqrt{\text{Hz}}$ (10 Hz)
Amplitude Noise	$\leq 2 \times 10^{-9}$ /$\sqrt{\text{Hz}}$ (10 Hz)
Beam Jitter	$\leq 2 \times 10^{-6}$ rad/$\sqrt{\text{Hz}}$ (100 Hz)
RF Intensity Noise	0.5 dB above shot noise at 25 MHz for 150 mW

Laser Design issues

Simultaneous achievement of high power, TEM_{00} and low noise:

- Getting to high power is (now) the easy part
  (eg/ TRW MOPA design → 25 kW)

- Excellent beam quality (egTEM_{00}) at high power is more elusive, and limited by thermo-optical properties of gain medium:
  - thermal wavefront distortion in MOPAs
  - loss of mode control in oscillators

- Low noise at high power requires well saturated gain everywhere to minimize ASE. Eg: use:
  - Zig-zag slab
  - oscillator matched to gain medium
  - unstable resonator (near flat top mode)

Design choices

Gain Medium Configuration:

Slabs: allow uniform pumping, cooling, zigzag propagation, saturation, efficiency

Rods: simple, power scaling limited by thermal effects gain/mode spatial mismatch

Pumping:

Side pumping: Simple extension of existing design. Pumping and cooling scaling together. Use fiber coupling to place gain where needed.

End pumping: Initially believed unattractive: fills whole crystal.

Optical Configuration:

Injection locked unstable resonator: optimum control of gain saturation, mode control, extraction efficiency

MOPA: simple, but offering less wavefront control

Design approach

- Our side-pumped, 5W injection locked slab design met or exceeded LIGO I requirements. Used for scaling to 10W

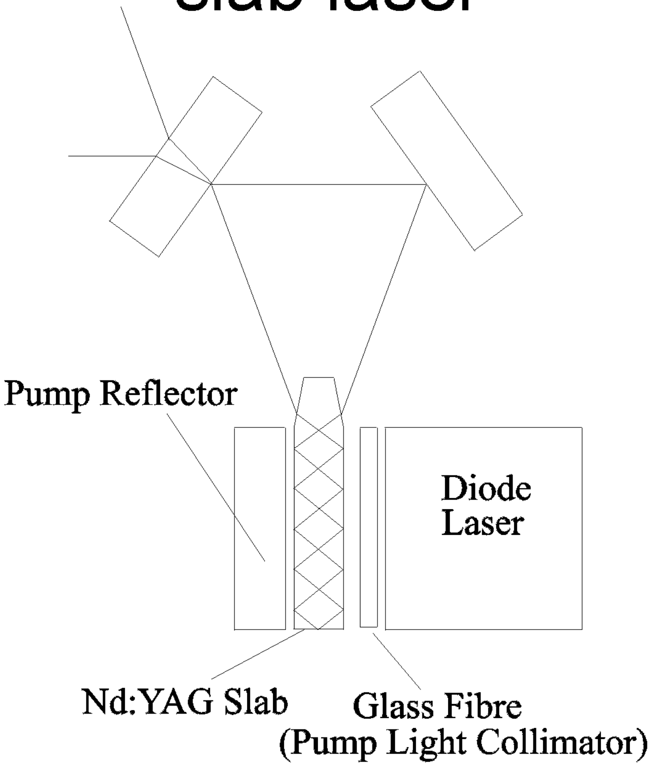
- Our power scaling concept, using stable-unstable injection locked resonator worked as expected in 30 W design verification laser tests

- Extended design to 100 W by
  - increasing gain to support larger magnification unstable resonator
  - increased pump/cooling heights to increase the mode size
  - using high power diode-lasers, and larger optical fibres

5 W Laser

- Relative Intensity Noise (RIN) meets LIGO I requirements
- Frequency noise when injection locked is limited by the frequency noise of the master laser

Co-planar folded slab laser



Top View

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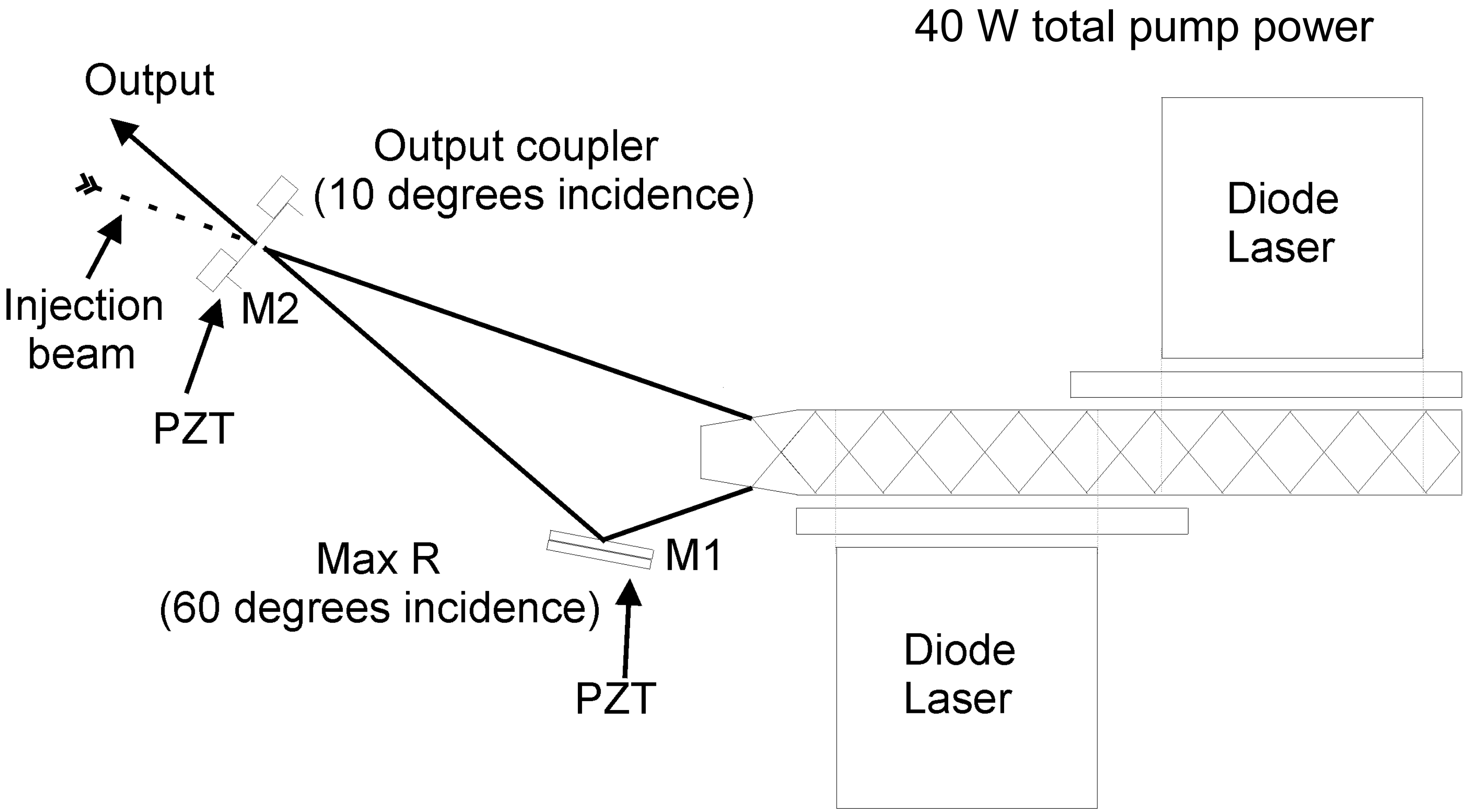
10 W Laser



40 W total pump power

Output

Output coupler
(10 degrees incidence)

Diode
Laser

Injection
beam

M2

PZT

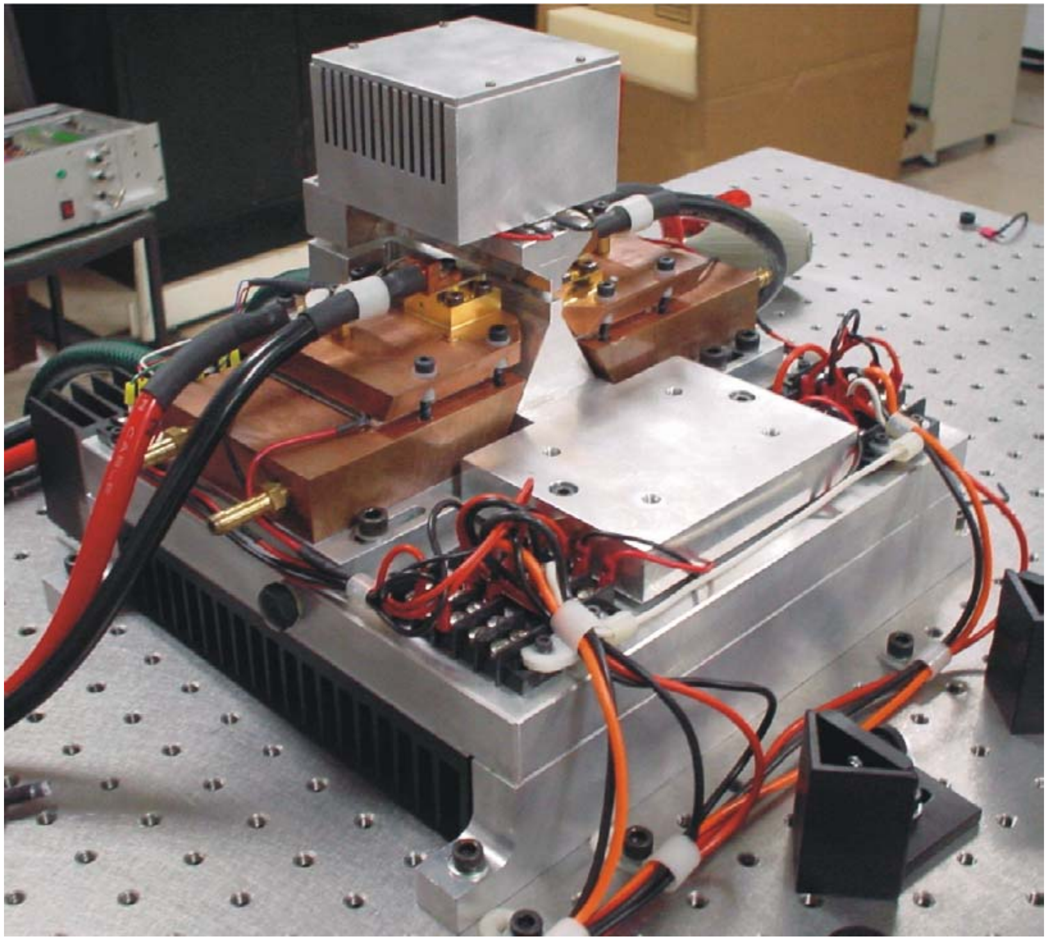
Max R
(60 degrees incidence)

M1

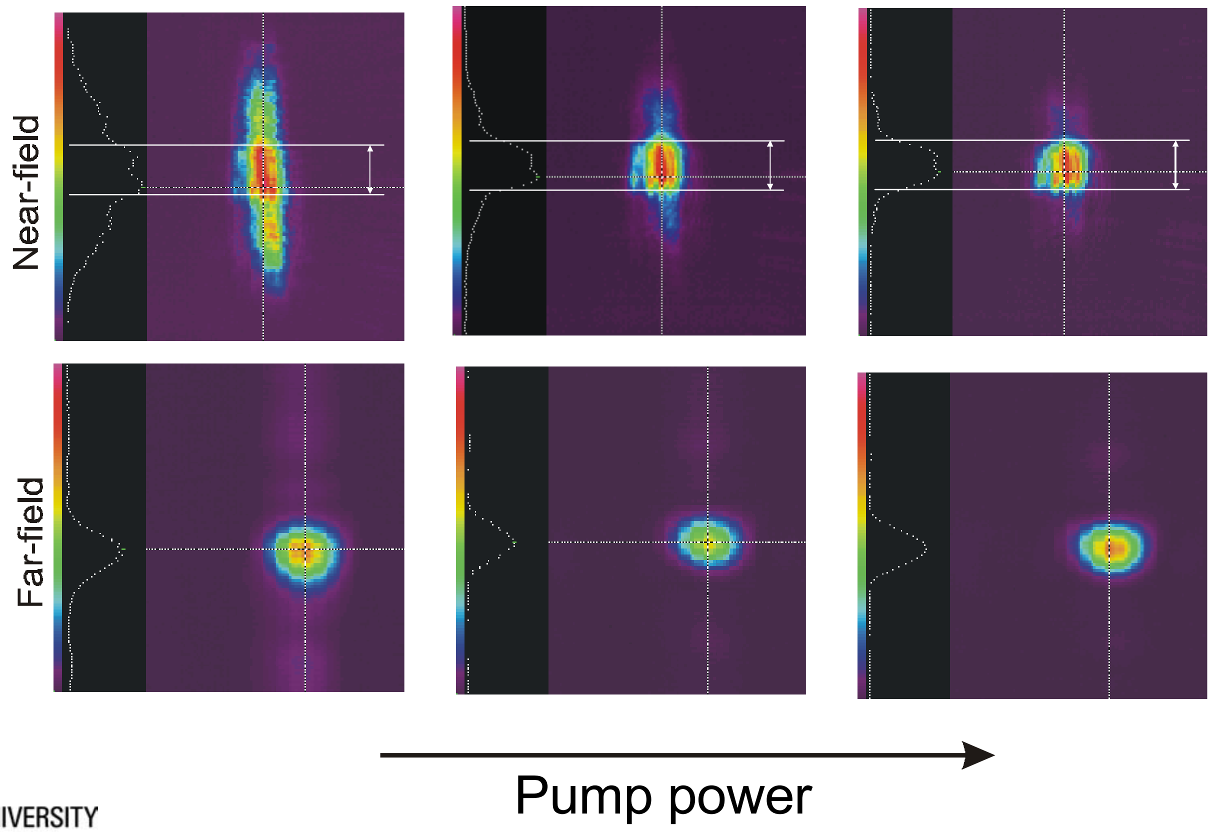
PZT

Diode
Laser

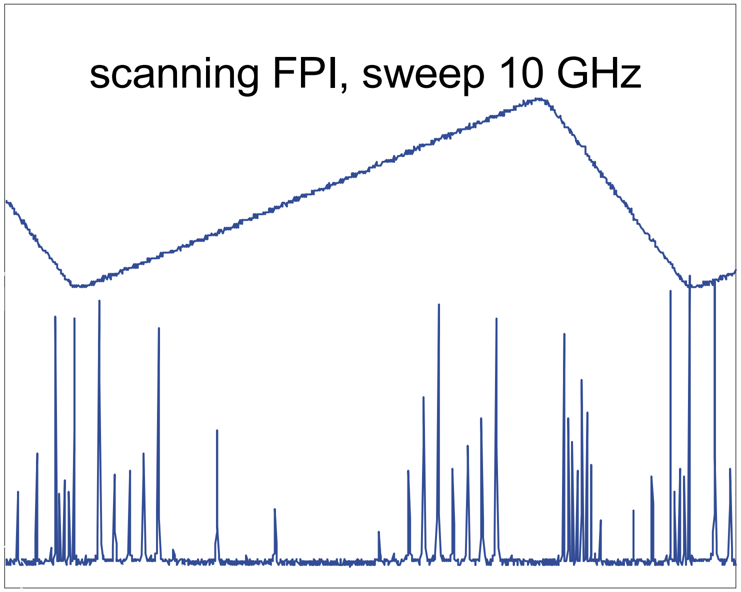
10 W Laser prototype



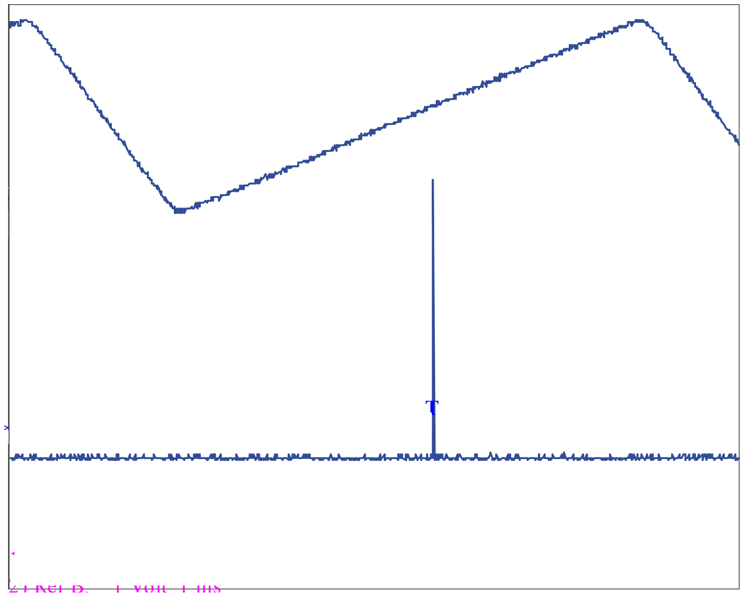
Measured near- and far-field beam profiles from unstable resonator



Stable-unstable laser injection locked

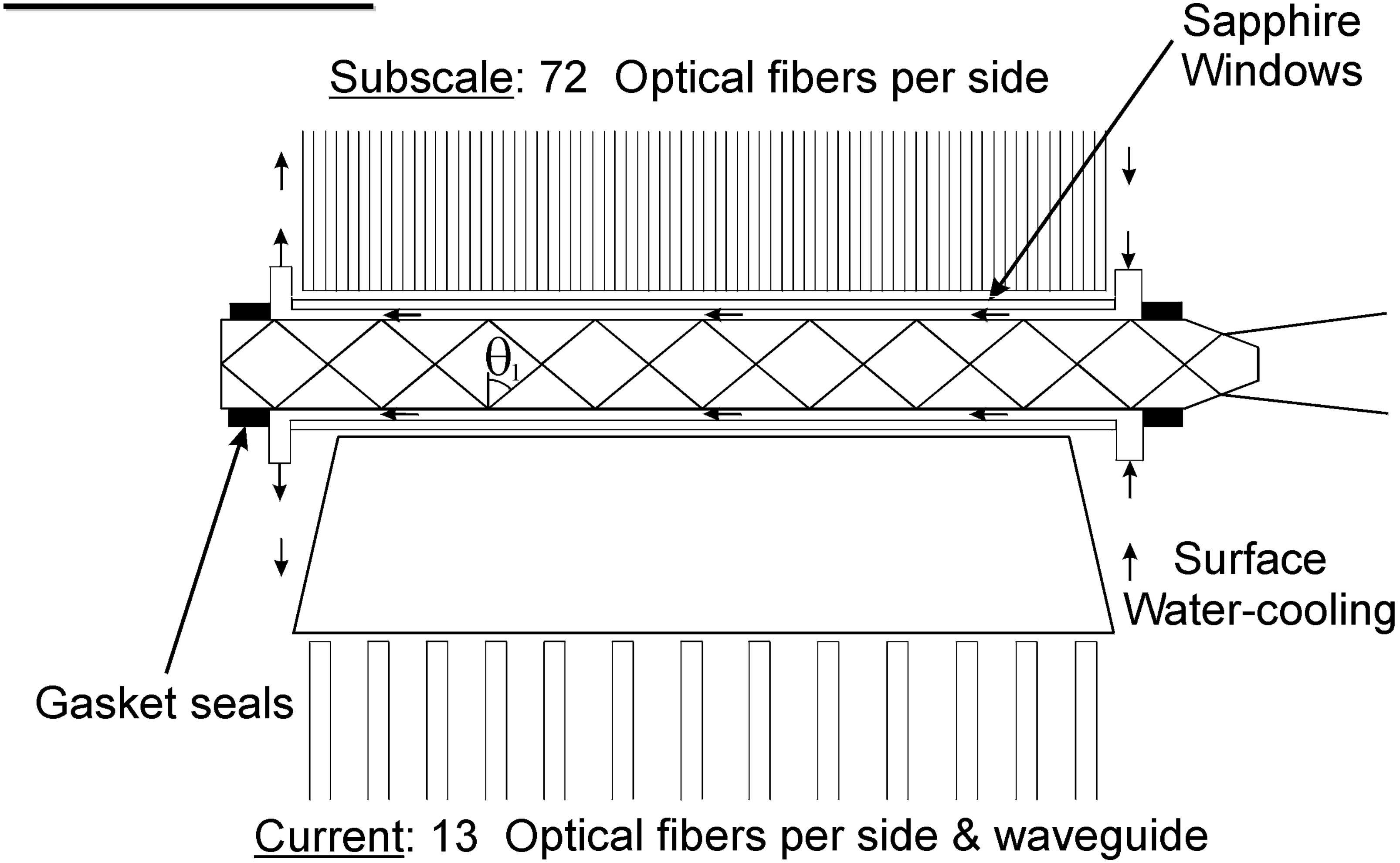


free-running slave



master laser on

100 W Laser



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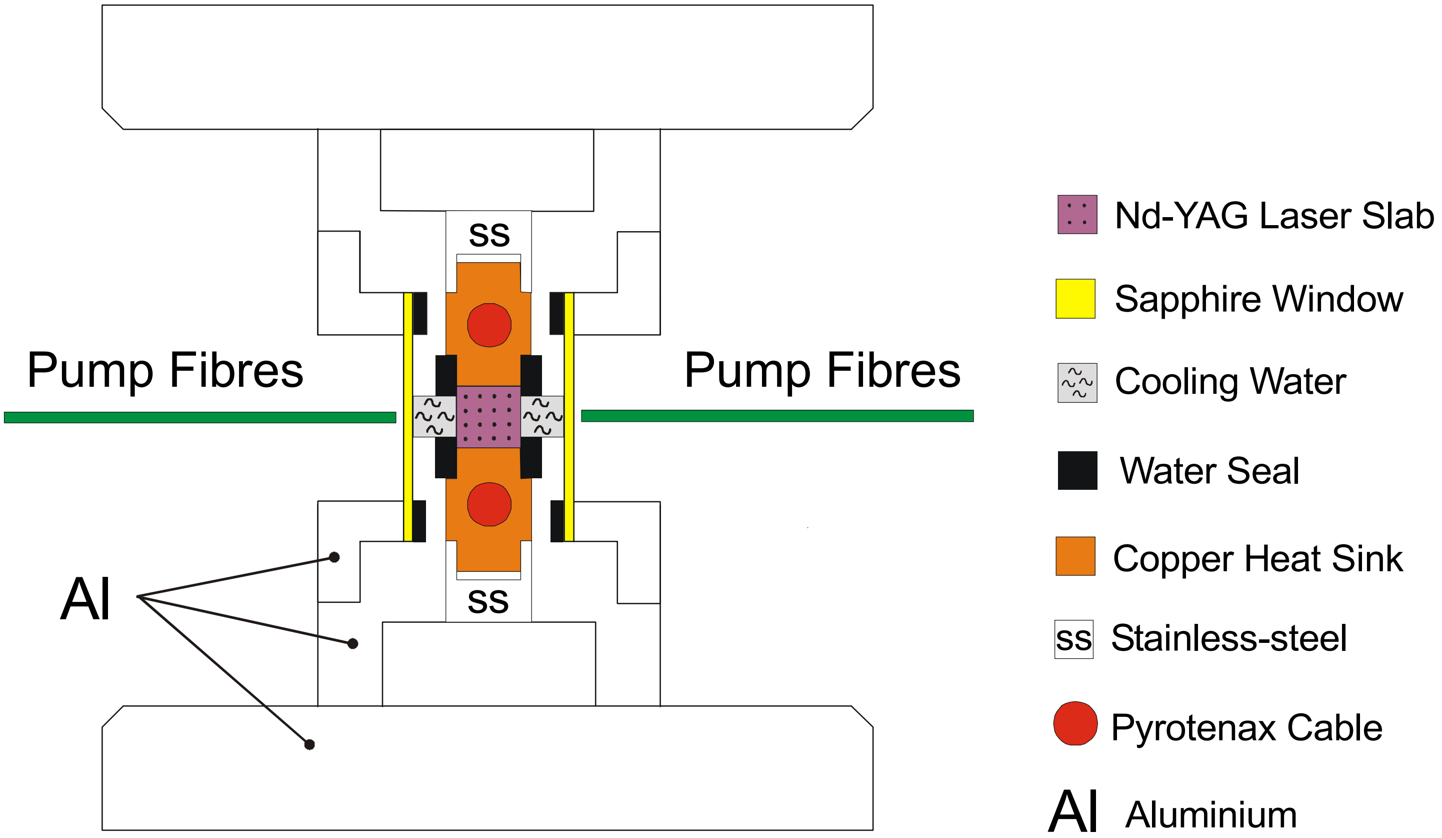
Side-pumped, side-cooled laser head



100 W laser head

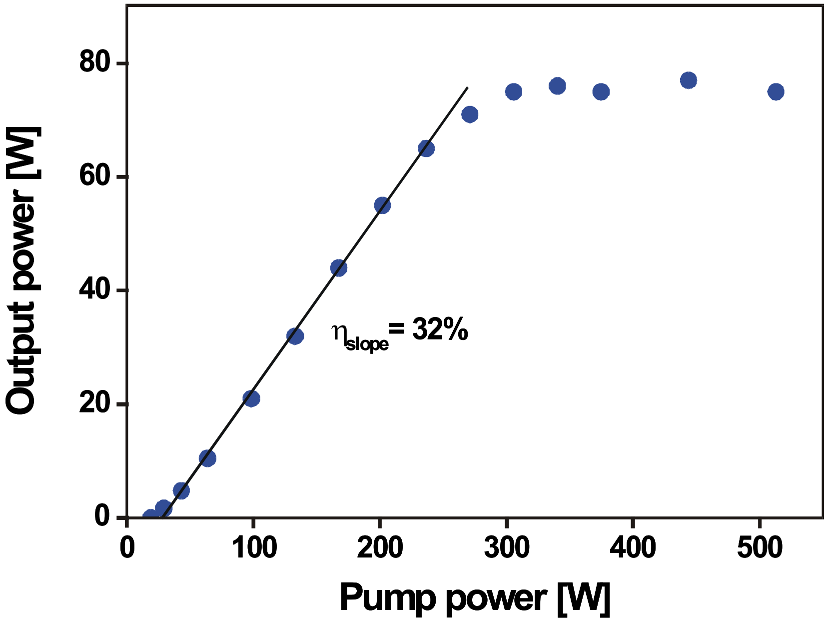
Power Scaling

Initial power roll-over observed due to:

(A) Thermal lensing
(B) Depolarization

Strategy for correction:

(A) Revised pump geometry
(B) New high quality crystals
  - orientation
  - polishing tolerance



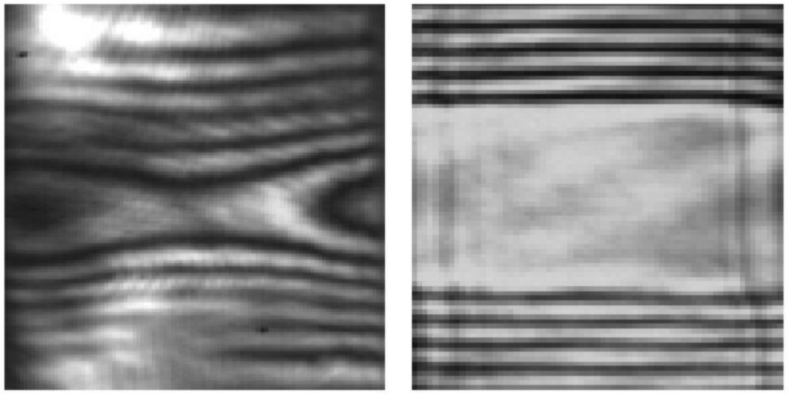
100 W Laser results

- **Laser head design difficult to scale to 100 W level**:
  - various laser engineering issues had to be solved:
    - laser crystal quality and orientation in boule
    - crystal cut and polish
    - pump nonuniformity, fiber degradation
  - vertical and horizontal thermal lenses can be controlled
  - larger diameter optical fibres couple to the diode-lasers without degrading SMA fibre connectors
  - planar waveguides reduce pump non-uniformity to acceptable levels
- **Laser power currently limited to ~ 80 W:**
  - birefringence in regions of strong thermal gradients outside pumped region degrades mode
  - continuing work on vertical thermal engineering
- **Use of single mode resonator requires more uniform gain medium**

Latest results: Homogeneous pumped region

Left: Horizontal negative pump power dependent thermal lens due to degrading optical fibre transmission (600 micron core) & non-homogeneous horizontal pump distribution (hot spots from optical fibres).

Right: Uniform pumped gain region. LZH optical fibres (800 micron core) and longer waveguides average pump distribution between fibres - **essentially no thermal lensing in pump region, 80W max.**



Old scheme New scheme

Lessons Learned: Optimum design

- Need excellent pumped gain uniformity:
  - -zigzag slab
  - -pump uniformity
  - -horizontal and horizontal thermal lens control

- Avoid large regions of varying temperature gradients to minimize effect of thermal birefringence on mode
- Achieve good overlap of mode and uniform gain region
- Side pumped slab gain design not easily scaled to 100W
- Need alternative, optimized gain medium configuration to demonstrate injection locked oscillator
- End pumped conduction cooled slab attractive alternative

- Retain unstable, supergaussian resonator for mode control and beam quality

New slab laser head design

Revised laser head designed to provide improved efficiency and thermal performance: similar to the TRW design shown:

Improvements

- End pumping
    - improved efficiency
    - more uniform slab power loading
- New pumping geometry
    - homogeneous pumping
    - minimal birefringence
- Improved robustness
    - Silicon Dioxide coatings (cooler slabs)

(TRW design)

New slabs currently being fabricated (due Aug/Sept)

Plan for future work

2003 - Finish 10 W lasers for Gingin and TAMA
- Assemble and test high power laser for Gingin
  - Continue work on current laser head
  - 100 W using new improved design (~Oct-Dec)
  - Worst case: 50 W backup, current laser head as is

2004-2009 - Proposed work:

"High power lasers and optical systems for advanced interferometry - an ACIGA project"

- Complete development of new laser head for 100 W
- Use laser in Gingin high power test facility experiments