ACIGA LASER TECHNOLOGY
10W AND 100W

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South Australia
LSC March 2005, G050207-00-Z

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- 10 W laser for Gingin and for TAMA 300
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GWI Laser Requirements

- Gravitational wave interferometers (GWI's) require high power CW lasers that produce a single frequency TEM_{00} mode

<u>High power laser requirements:</u>

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

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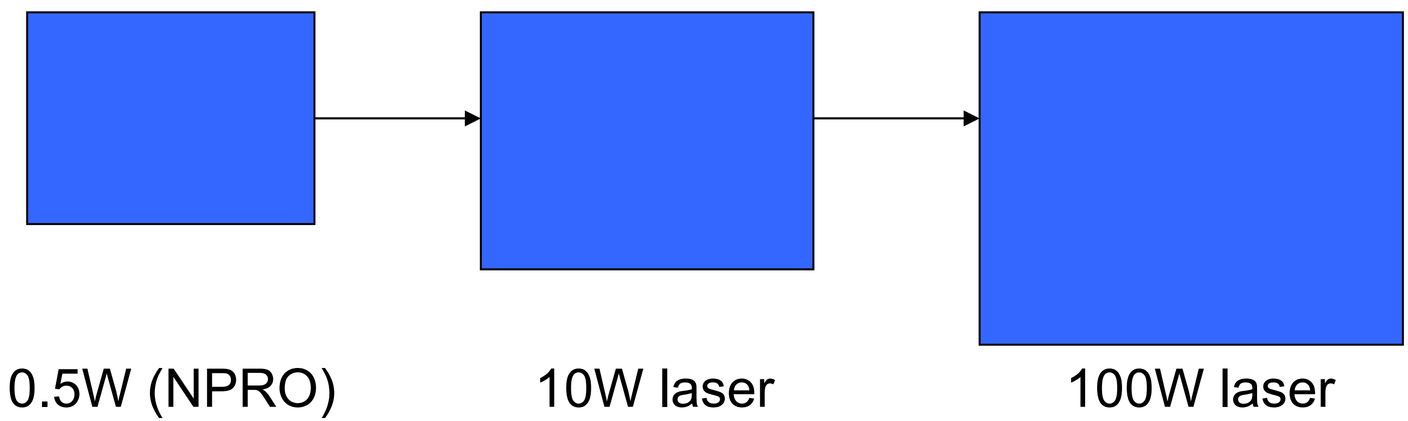
Adelaide High Power Laser Approach for GWI's

Strategy to achieve GWI high power laser requirements:

→ Injection-locked chain of lasers



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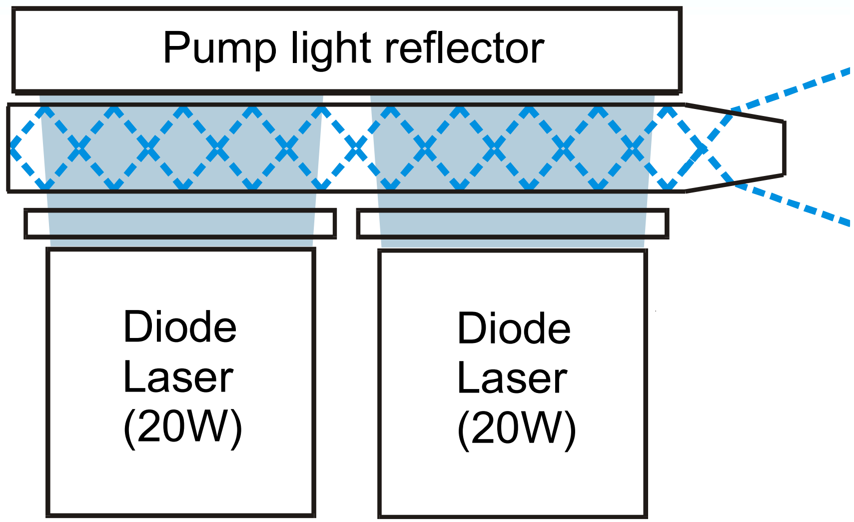
Gain Medium for 10W Slave Laser

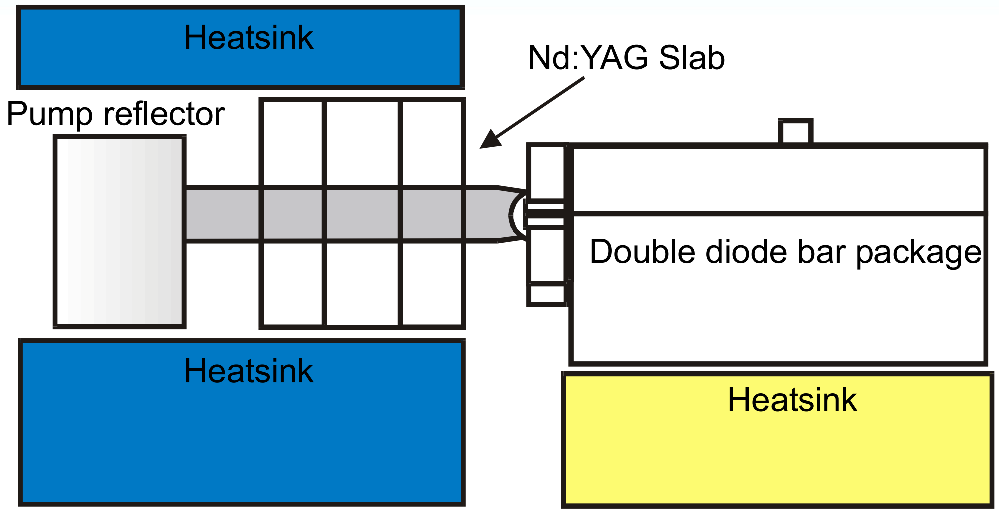


(Diode power derated for increased lifetime)

- Coplanar folded zigzag slab (CPFS) *
- Side pumped using fast-axis collimated diode bars

*J. Richards and A. McInnes, *Opt. Lett.* **20**, (1995), 371.

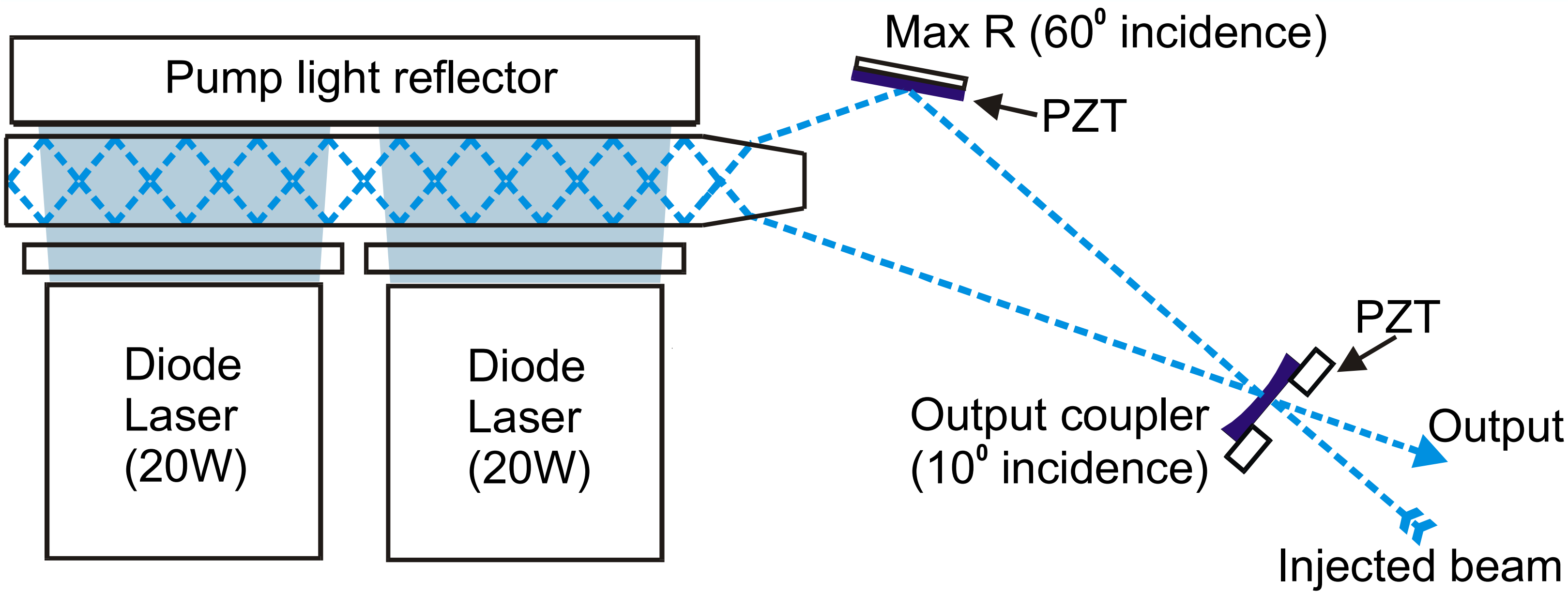
Gain Medium for 10W Slave Laser



- Top and bottom cooled
- Mounted on a single air-cooled base

→ Compact laser with increased portability and reliability

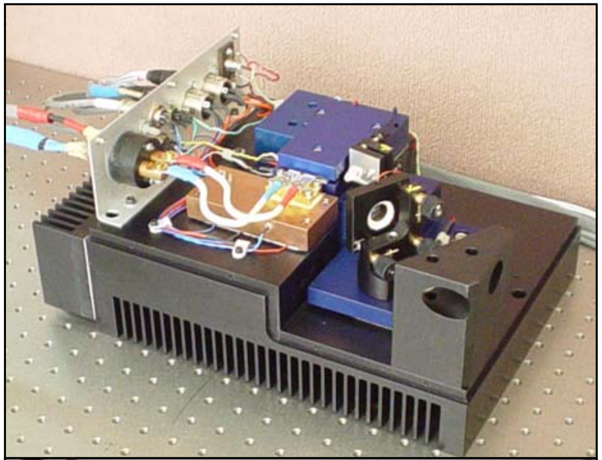
Travelling-Wave Resonator

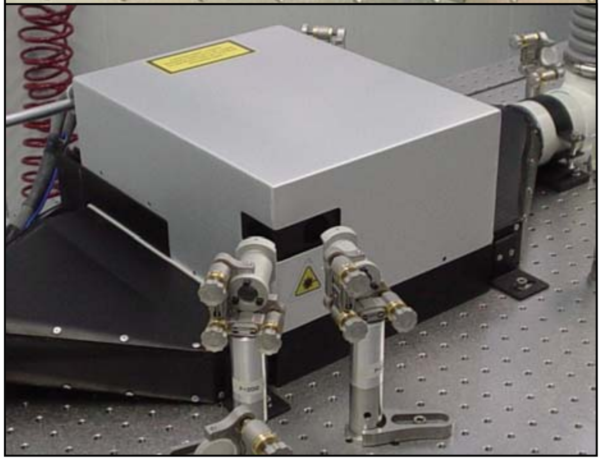


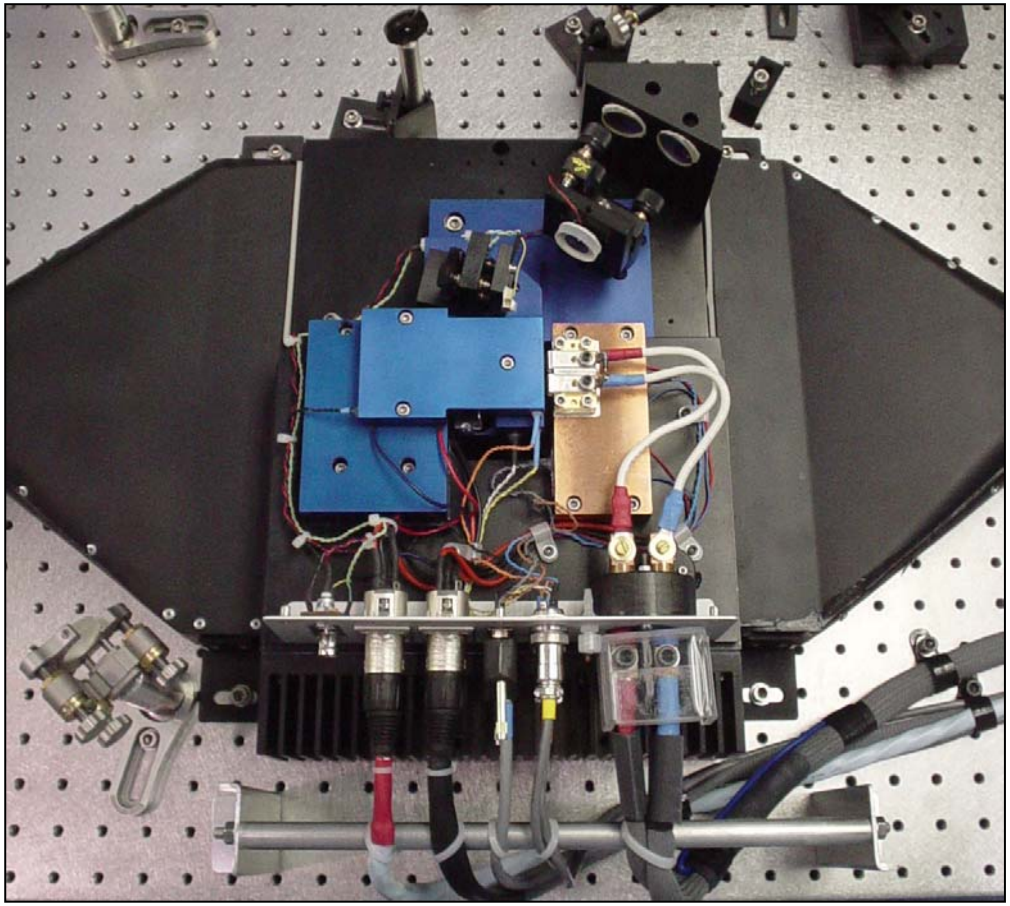
Injection locking servo control system:

Low bandwidth, high dynamic range PZT plus high bandwidth, low dynamic range PZT together provide sufficient bandwidth and dynamic range.

10W Slave Laser







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Control and Confinement of Mode

- Astigmatic thermal lensing in the pumped slab: $f_{vertical}$ ~ 6-8cm
  $f_{horizontal}$ ~ 2-3m
- Vertical (cooling) plane
  - mode confinement provided primarily by strong thermal lensing
  - mode control achieved by matching the laser mode to the pumped region
- Horizontal plane
  - mode confinement by residual curvature of the slab sides, very weak thermal lens and mirror curvature
  - higher order mode rejection by apertures formed by Brewster entrance/exit windows

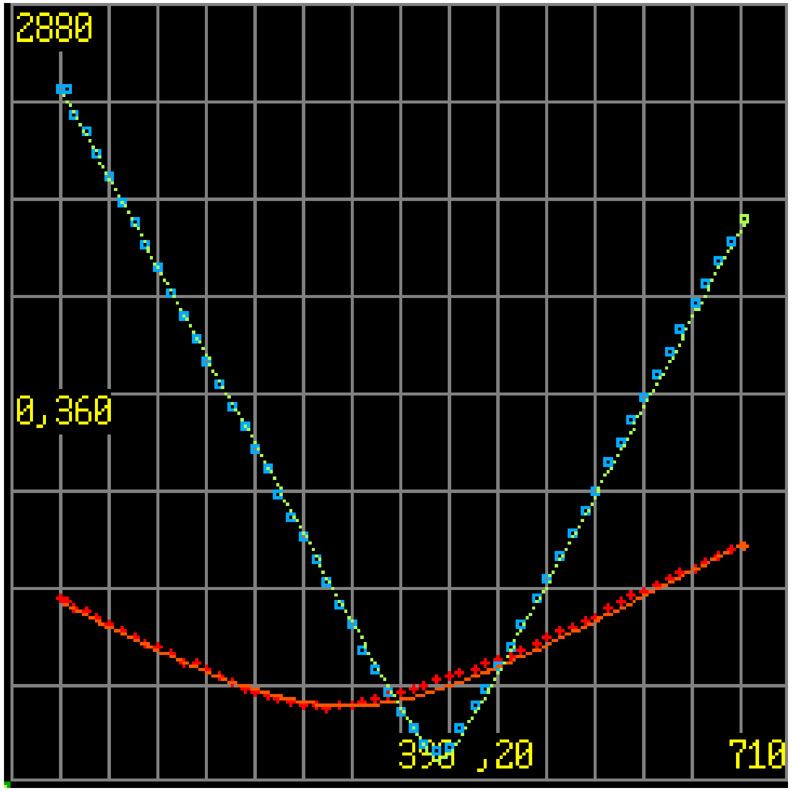
Careful adjustment of cavity length and pump power achieves an excellent fundamental mode, in both horizontal and vertical planes.

Travelling-Wave Results

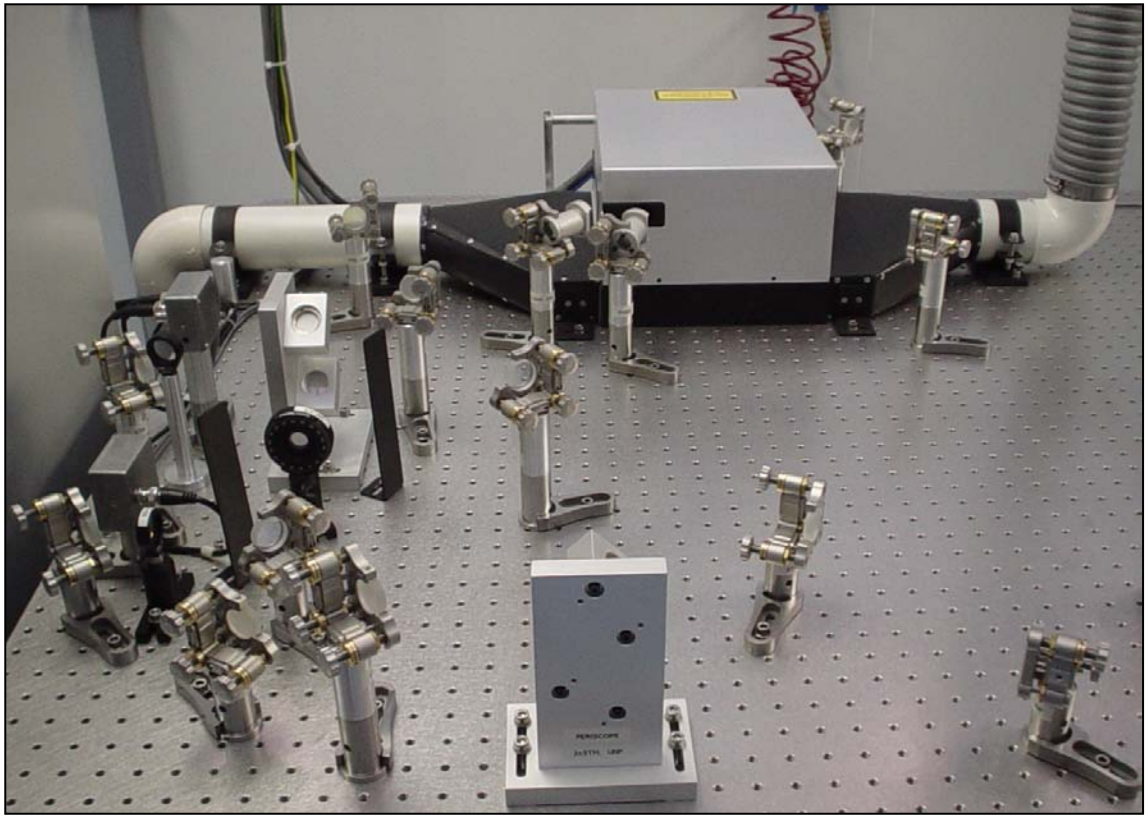
Using 90% reflective, 5.00m concave output coupler

- **$M^2_{horizontal}$ < 1.1**
- **$M^2_{vertical}$ < 1.1**
- **Output power = 9.8 W (32W pump power)**

Measured using Spiricon M^2 Beam Analyser



ACIGA Laser Locking Setup



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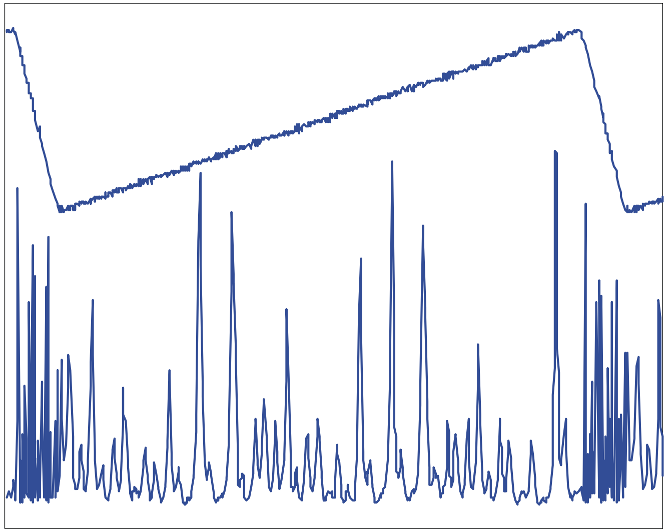
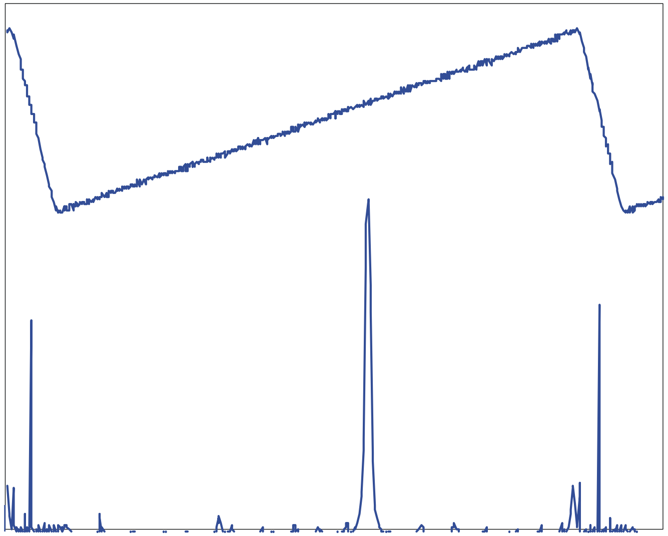
Laser Injection-Locked for hours



Multi- longitudinal mode operation of free-running slave laser



Injection-locked slave with 100% reverse-wave suppression

(Traces measured using a scanning Fabry-Perot cavity (10GHz FSR))

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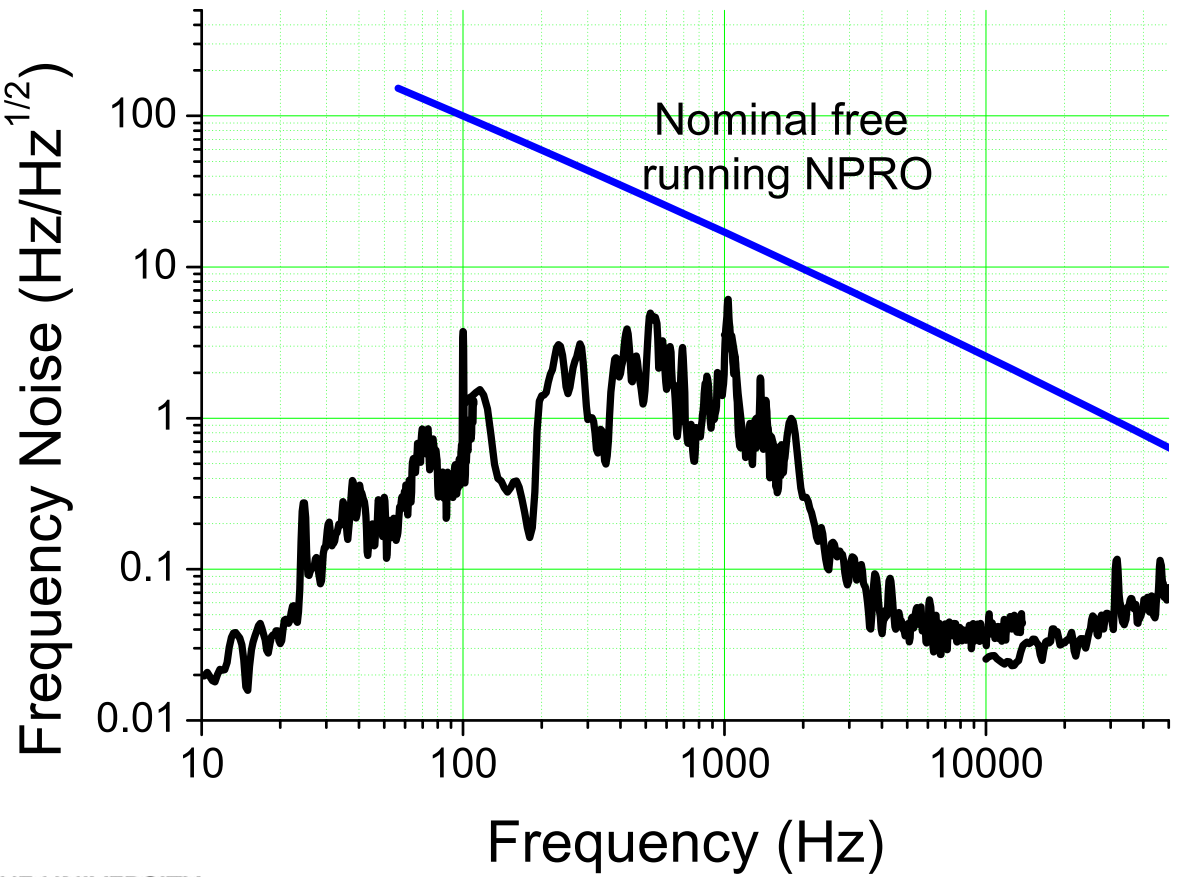
Preliminary Frequency Noise Measurements



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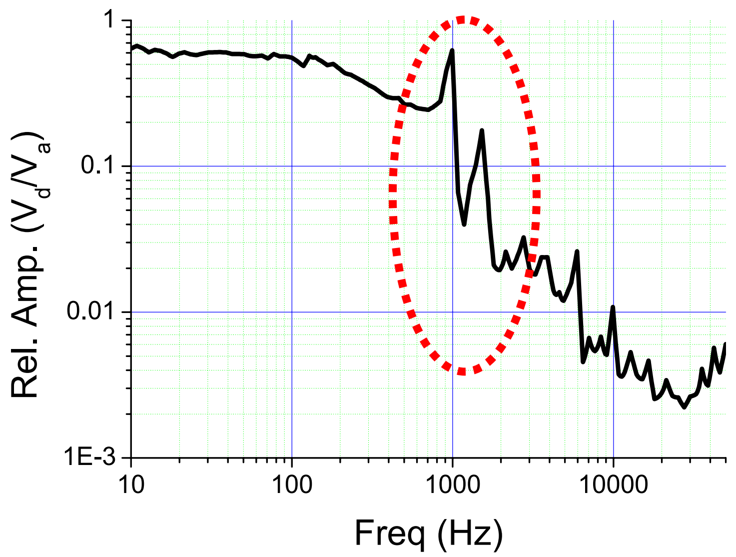
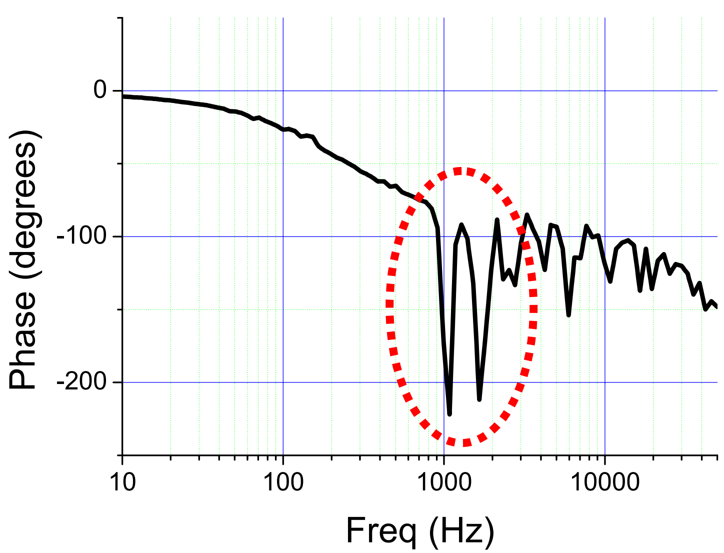
Current ACIGA Laser Mirror Mounts

- ACIGA Output Coupler (HD) transfer function
  - resonances lower than expected, leading to increased frequency noise and limited locking bandwidth





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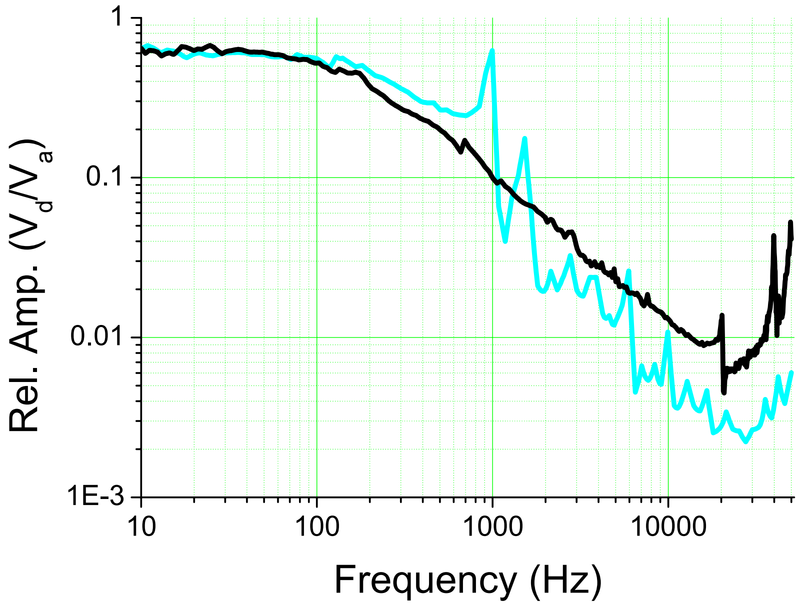
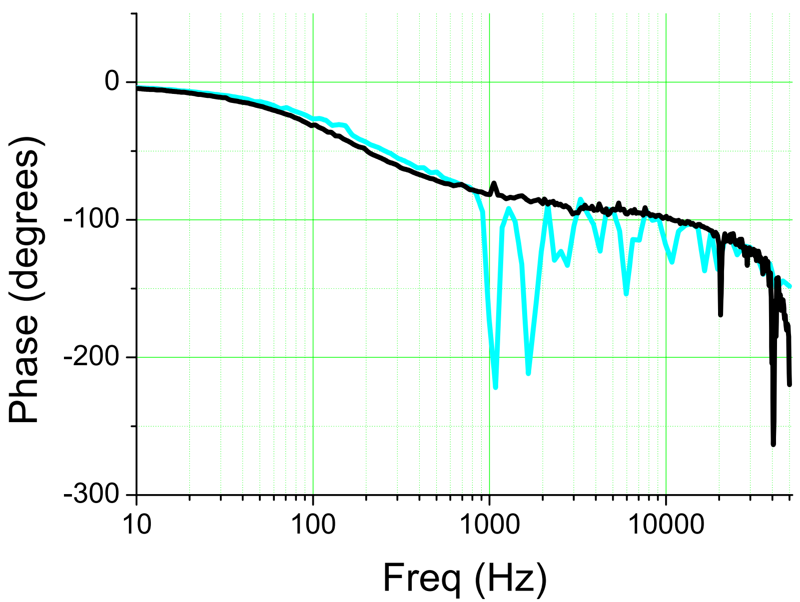
Improved Mirror Mounts for ACIGA Laser

- To improve the injection-locking bandwidth, we have:
  - reduced the output coupler mass
  - improved bonding technique





New 100 W Laser

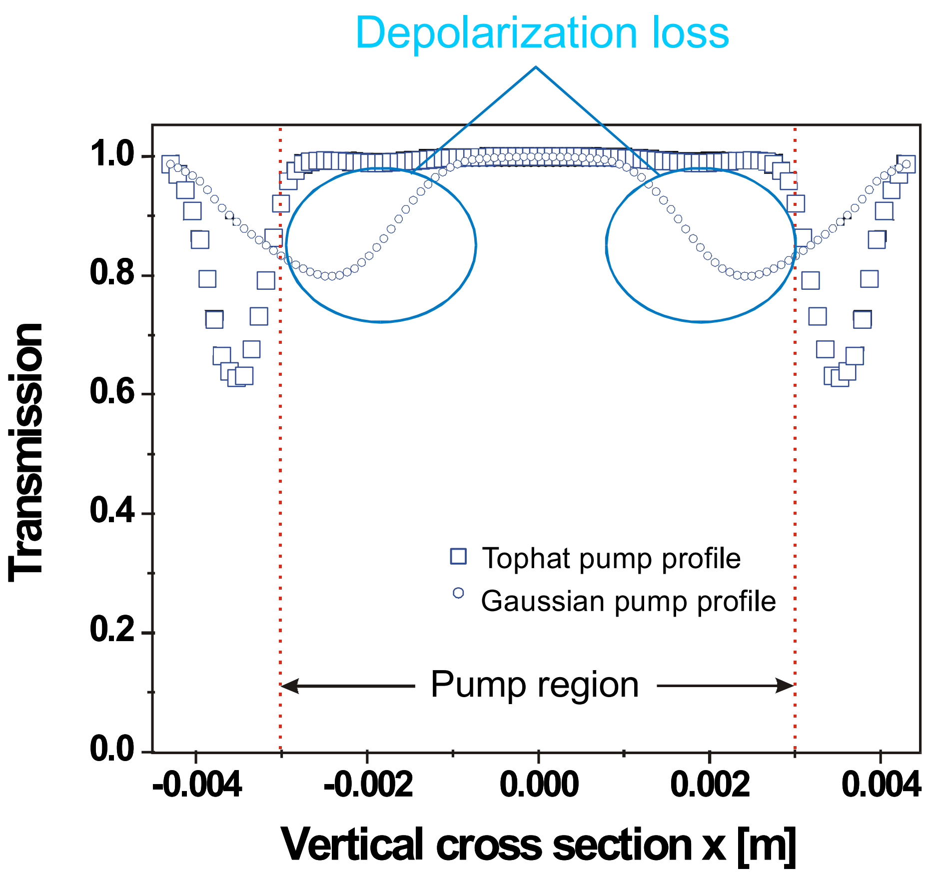
Extension of previous approach:

- Injection locked oscillator
- Unstable Resonator
- Zigzag slab

New Features:

- End pumping
- Birefringence control by defined gain medium
- Improved pump uniformity across wavefront
- Robust
- Scalable to very high power (kW)

Effect of pump profile on depolarization loss



(Birefringence modeling: M. Ostemeyer)

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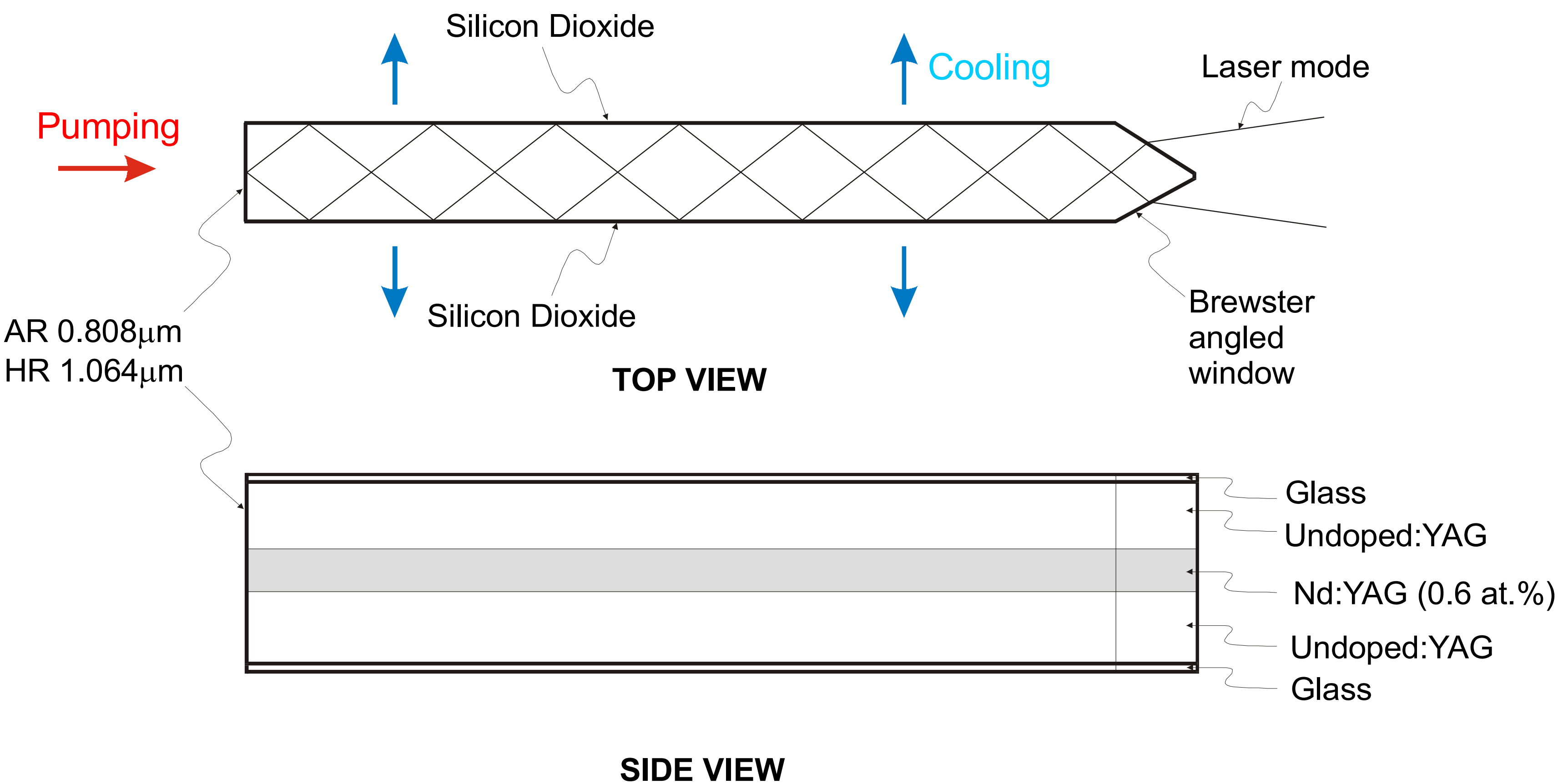
New design advantages

- **Tophat pump distribution** – minimum birefringence
- **Good absorption efficiency** due to quasi end-pumping
- **More uniform power loading** within slab due to double-clad structure transporting pump light along slab before absorption
- **No hard-edged apertures** in vertical direction
- **Large pump input aperture and acceptance angle** accommodates real divergent pump sources
- **Insensitive to pump beam-quality** due to mixing of pump light in slab
- Undoped YAG layers produce **reduced thermally induced stress**
- **Conduction-cooled**

Composite end-pumped, side-cooled folded zigzag slab



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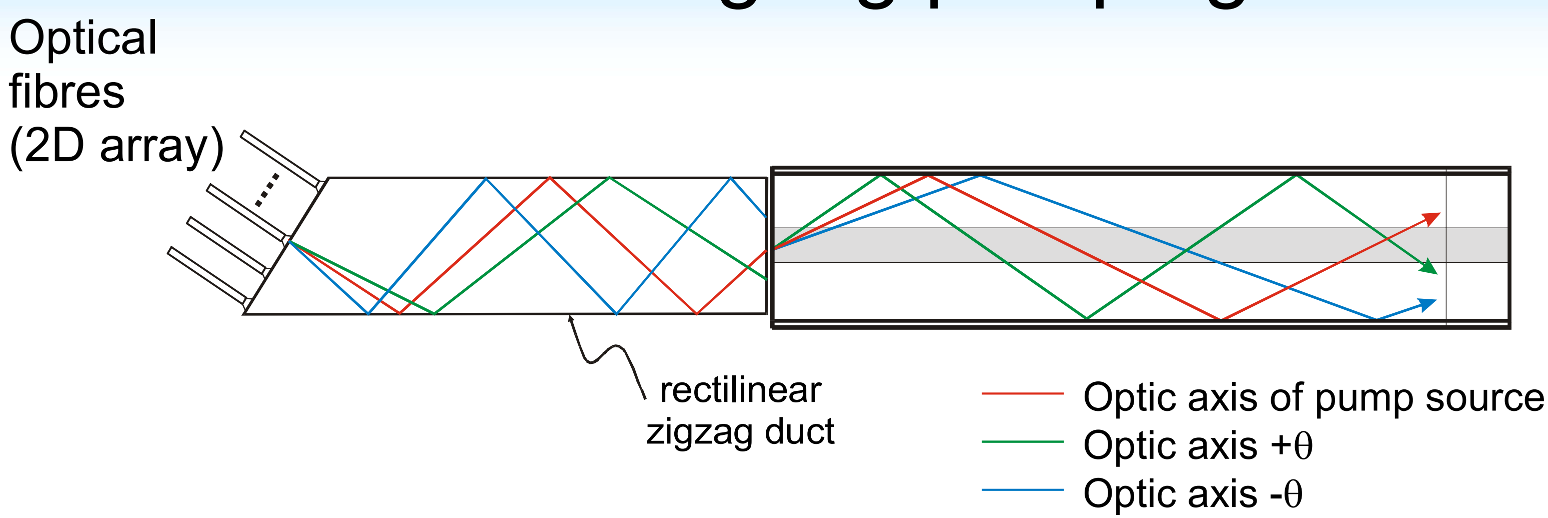
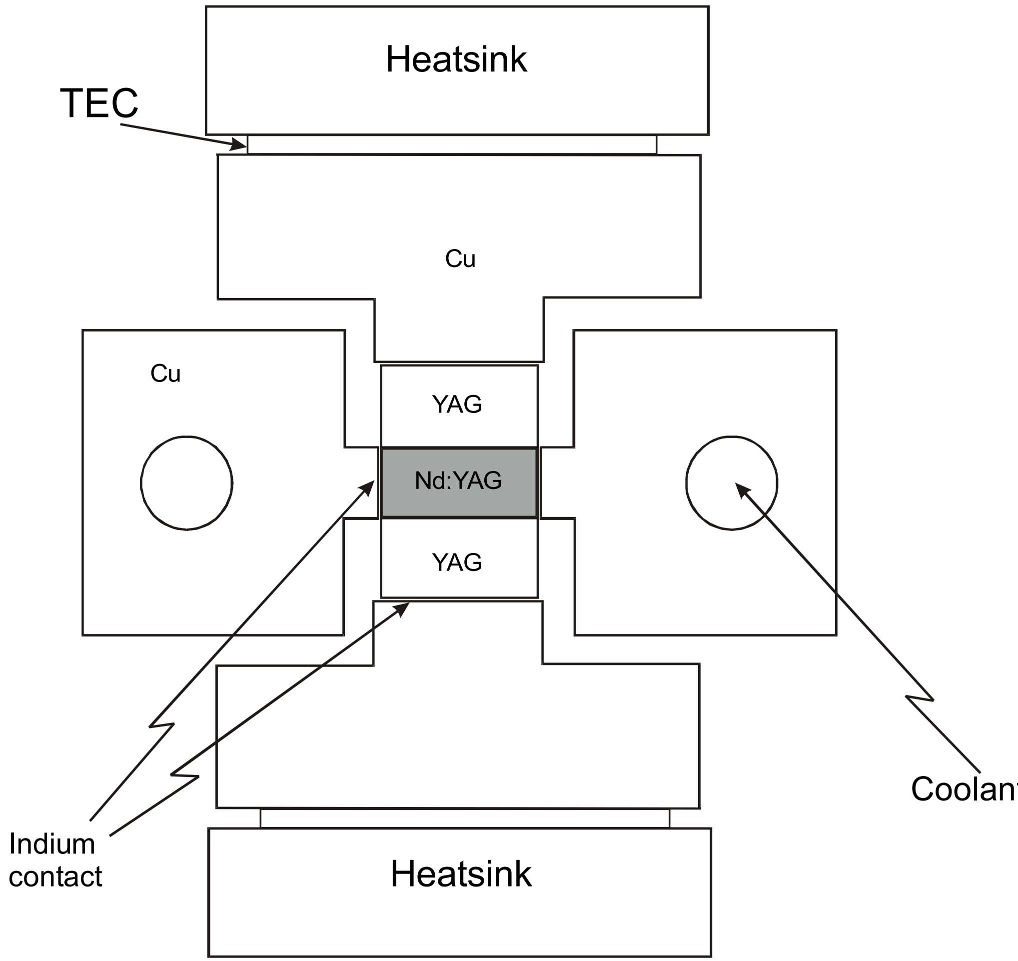
Off-axis zigzag pumping

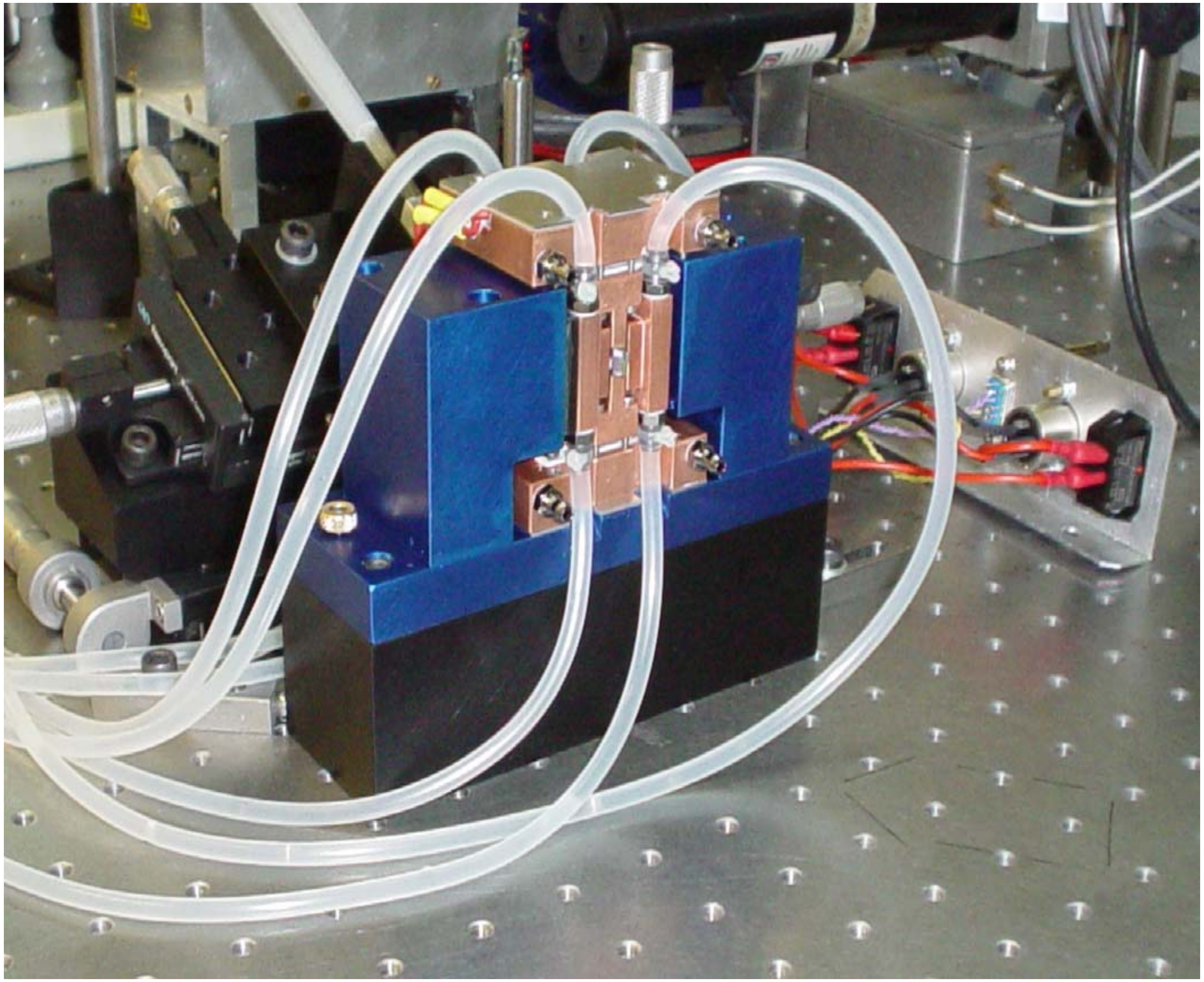


- Rectilinear zigzag duct allows pumping at normal incidence and homogenizes pump light prior to slab entry
- Can replace pump fibers by collimated bar-stack-array and use non-imaging lens duct
- Scalable by increasing pump power, height of doped and undoped region (scaling direction is orthogonal to cooling/laser zigzag mode plane)

End view of conduction-cooled laser head



New 100W Laser Head



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Stable-unstable resonator

- A stable-unstable resonator will be used
  - Stable in the plane of the zigzag and confined by the Brewster angled windows
  - Unstable in the plane orthogonal to the zigzag. Unstable resonators can operate with large modes (to allow for power scaling), and do not require mode confinement apertures for good beam quality
- The composite slab is used in a traveling wave resonator to allow injection-locking

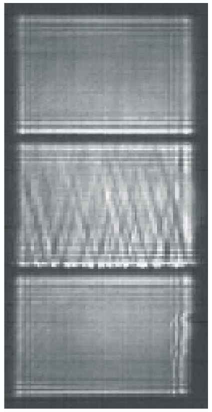
100W Laser Design

Design features for GWI Laser:

- Single laser head with simple, robust resonator, good alignment stability
  - Repeatable turn-on stability
- Thermal lens control, less sensitive to pump power
- Vary laser power by varying pump power: not point design
- Efficient cooling: less water, less vibrations, less noise
- Design does not pump through cooling water:
  - less pump noise

While we have not proven all this yet, preliminary measurements on faulty laser crystal support these design aims.

Laser active material



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100W Laser Status

using faulty crystal

Thermal properties of design have been verified experimentally:

- horizontal and vertical thermal lens controlled
- heat is efficiently removed from laser crystal

Robust engineering, coatings: reproducible laser behavior

Pump efficiency verified: ~ 90% pump power absorption

(35W measured out with 155W pump)

Replacement slabs fabricated, polished & Coated:

→ delivery expected March 2005.