ACIGA LASER DEVELOPMENT

10W AND 100W

David Hosken, Damien Mudge, Peter Veitch,
and Jesper Munch

The University of Adelaide
South Australia

Gingin Oct. 05

LIGO-G050523-00-Z

Adelaide Laser Approach for GWI's

Use proven laser architecture, scalable to high power:

- **slab lasers for efficiency, ease of cooling and manufacture**
- **unstable resonators for power scaling and mode control**

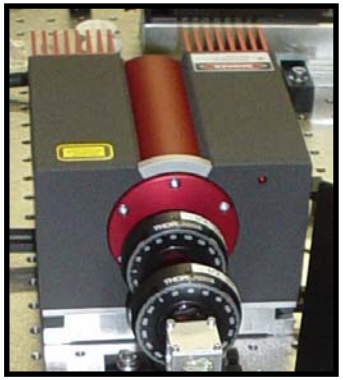
Use optimum approach for minimizing noise:

- **injection-locked resonators**

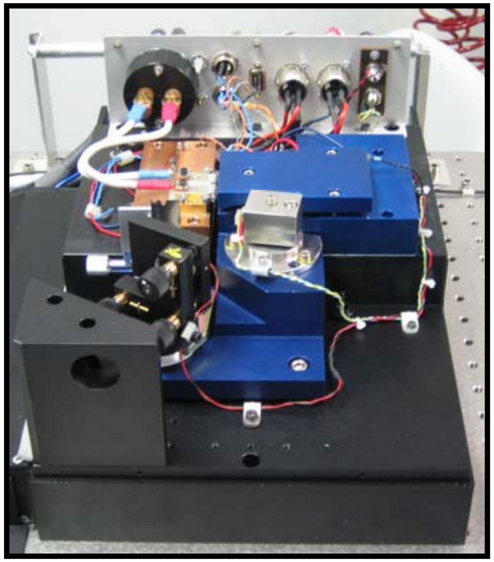
Use novel composite gain media configurations for optimum mode control:

- **composite ceramic Nd:YAG slabs**
- **optimized end pumping**

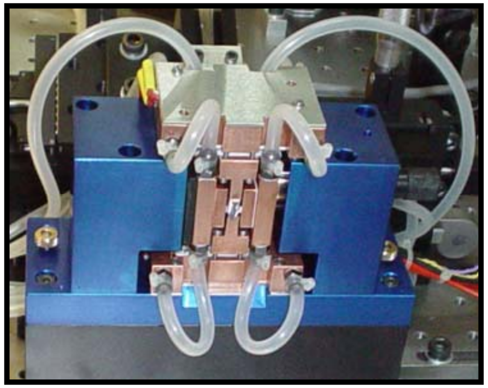
High Power Laser Strategy: Injection-locked chain



0.5W (NPRO)



10W laser



100W laser

10W lasers for TAMA 300 and the ACIGA HOPTF

THE UNIVERSITY OF ADELAIDE AUSTRALIA

Contents

- 10W Nd:YAG laser for Gingin HOPTF and TAMA 300
- 100W Nd:YAG laser for Gingin HOPTF and ….

10W Laser Requirements

- 10W, TEM_{oo}
- RIN and frequency noise superior to LIGO I requirements

RIN $< 10^{-5} \times (100 / f)^2 /\sqrt{Hz}$ (40Hz -100Hz)

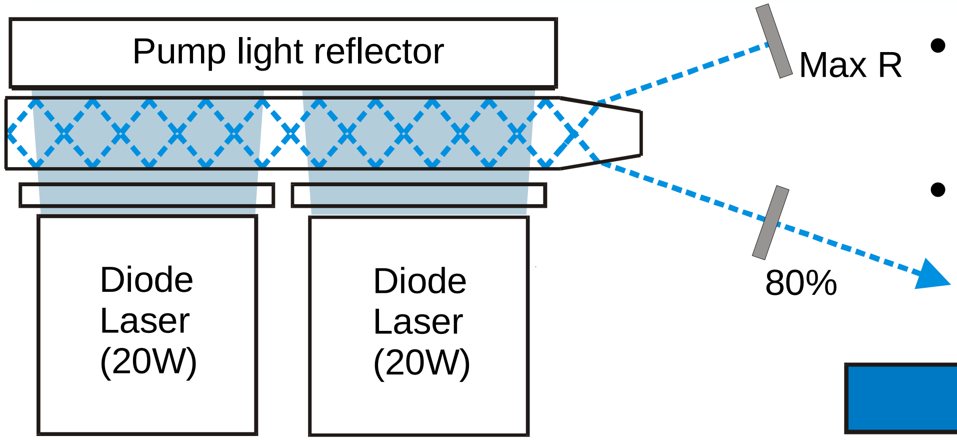
$< 10^{-5} /\sqrt{Hz}$ (100Hz -10kHz)

< 1.01 x Shot noise for 600mW at 150MHz

Frequency noise < NPRO frequency noise

THE UNIVERSITY OF ADELAIDE AUSTRALIA

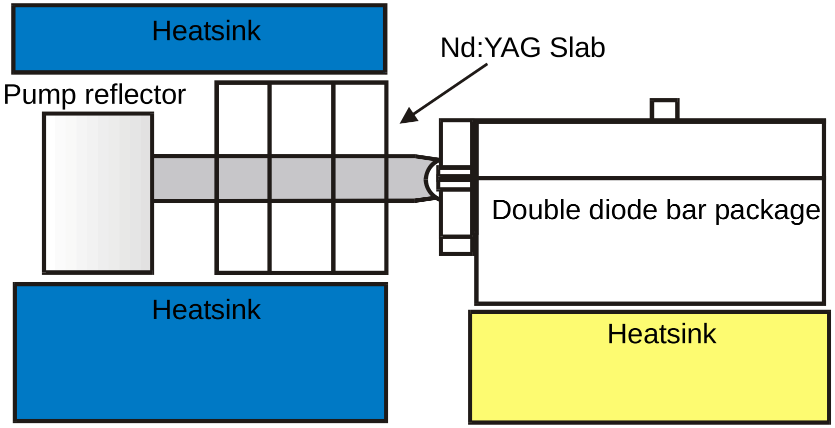
Gain Medium for 10W Slave Laser



(Diode power derated for increased lifetime)

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

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

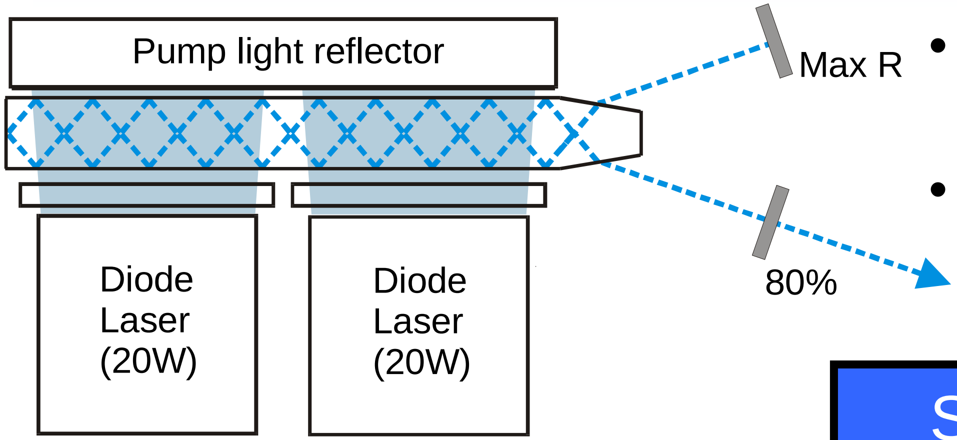


→ Compact laser with increased portability and reliability

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

THE UNIVERSITY OF ADELAIDE AUSTRALIA

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

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

Standing-Wave Result:

Multimode power = 15.9W
(40W pump power)

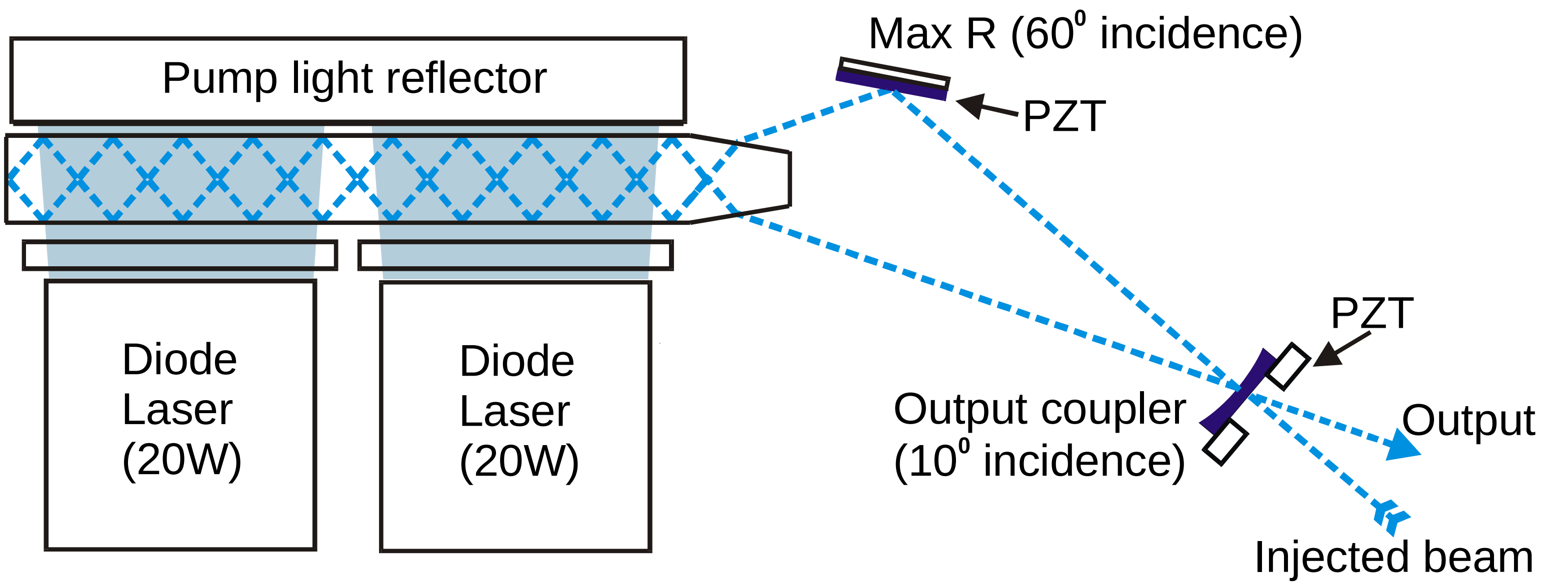
Multimode slope efficiency = 45%

→ Compact laser with increased portability and reliability

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

THE UNIVERSITY OF ADELAIDE AUSTRALIA

Travelling-Wave Resonator



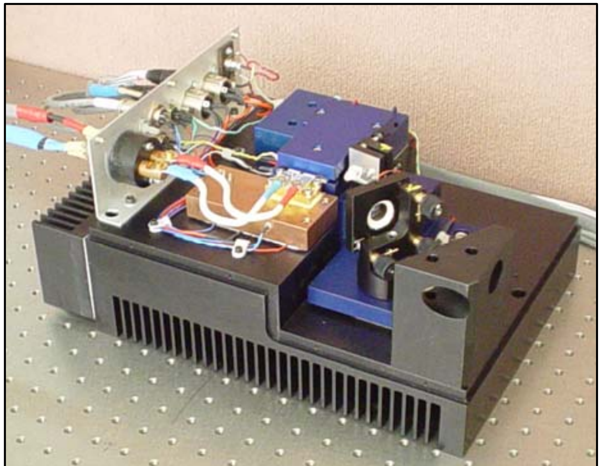
Injection locking PDH servo control system:

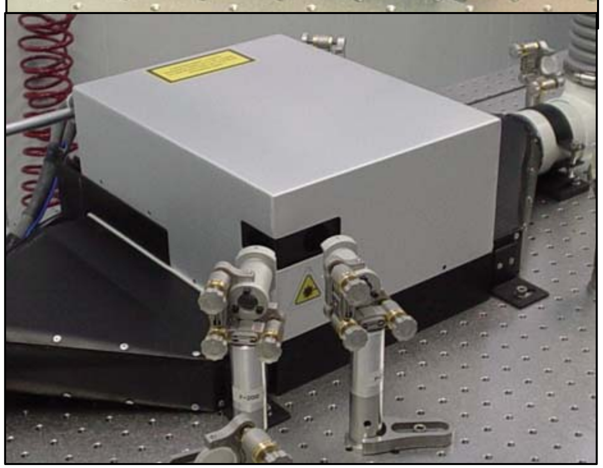
- low bandwidth, high dynamic range PZT, and
- high bandwidth, low dynamic range PZT

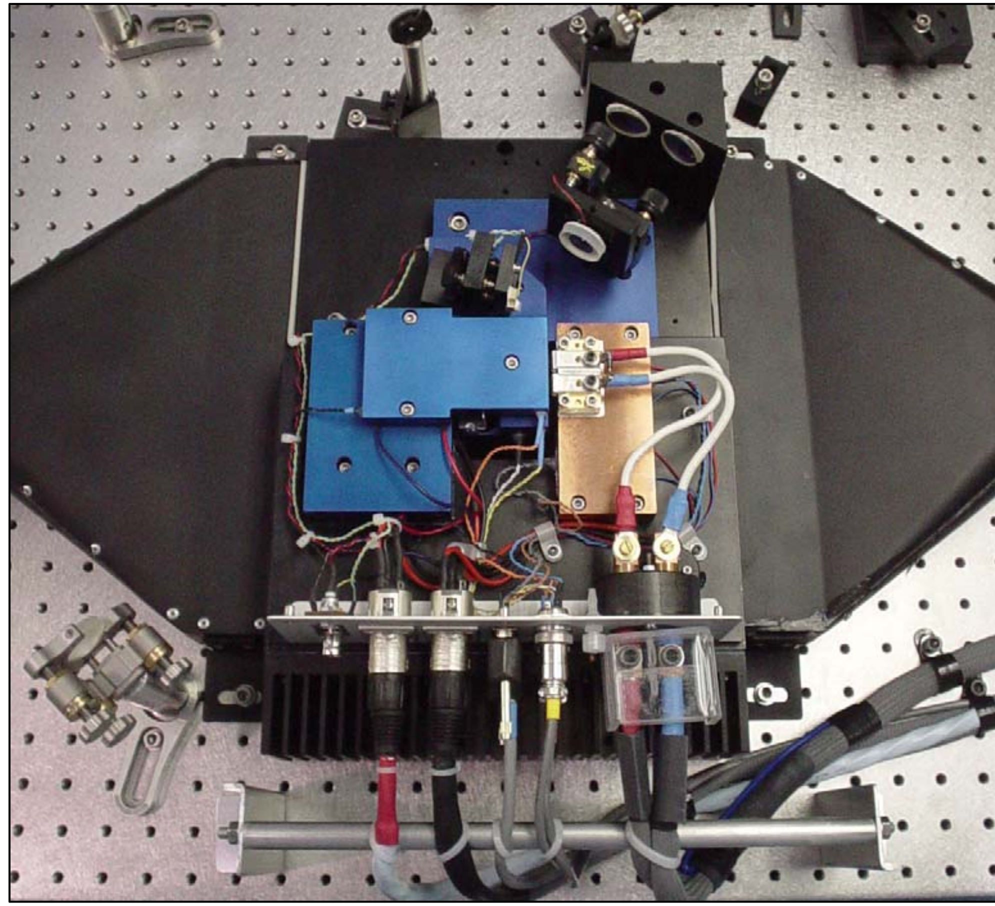
$\rightarrow$ sufficient bandwidth and dynamic range.

THE UNIVERSITY OF ADELAIDE AUSTRALIA

10W Slave Laser







THE UNIVERSITY OF ADELAIDE AUSTRALIA

Mode Control and Confinement

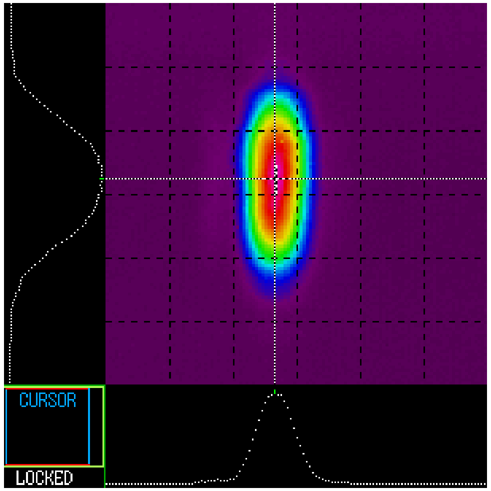
- Astigmatic thermal lensing in the pumped slab: $f_{vertical}$ ~ 6-8cm
  $f_{horizontal}$ ~ 2-3m
- Vertical (cooling) plane
  - mode confinement provided primarily by strong thermal lensing
  - mode control achieved by matching the laser mode to the pumped region
- Horizontal plane
  - mode confinement 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

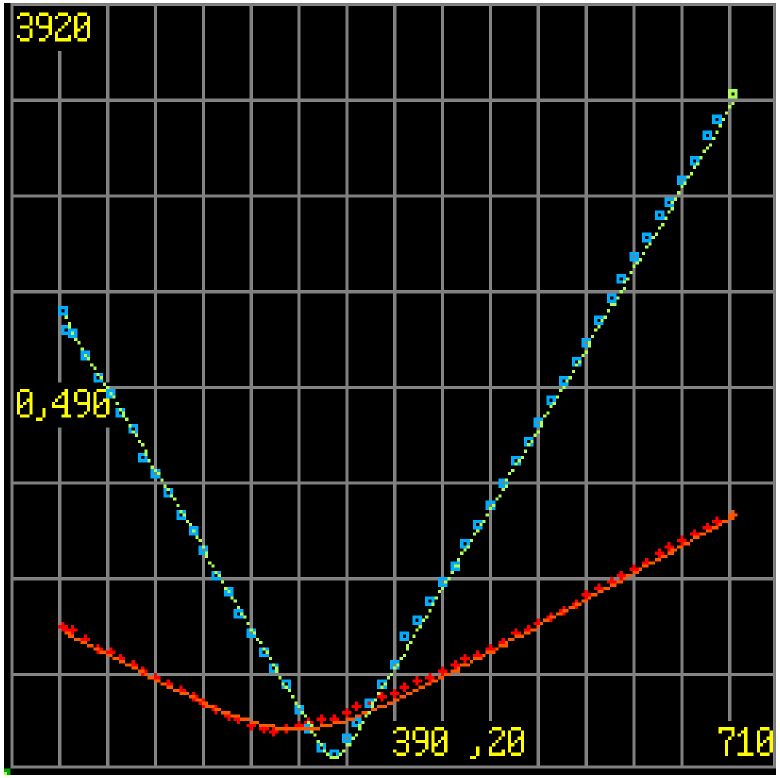
Careful adjustment of cavity length and pump power achieves an excellent fundamental mode, in both horizontal and vertical planes.

10W Beam Diffraction-Limited

Using 90% reflective, 5.00m concave output coupler:

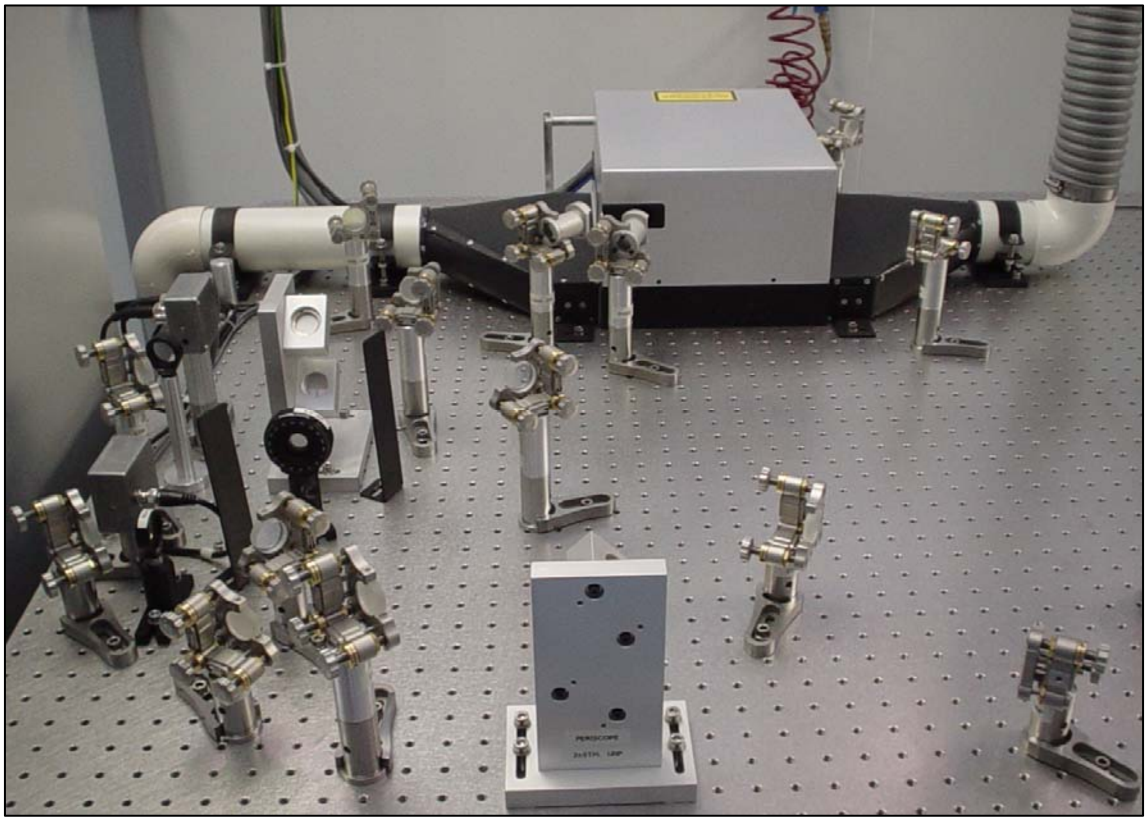
- **$M^2_{horizontal}$ < 1.05**
- **$M^2_{vertical}$ < 1.05**
- **Output power = 11 W**





Measured using Spiricon M² Beam Analyser

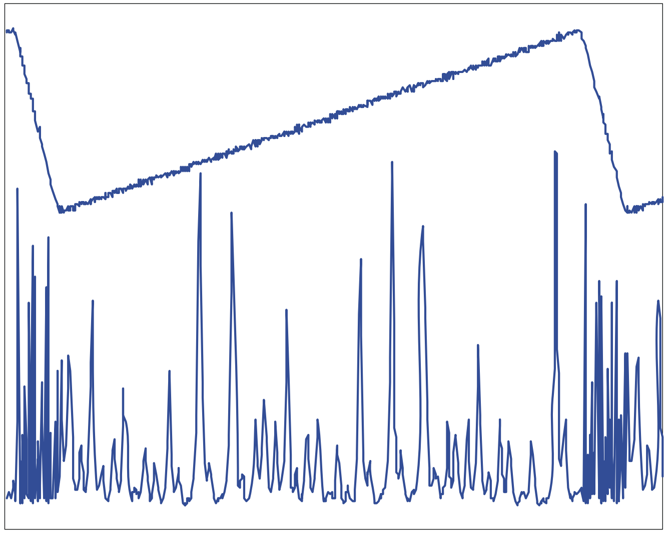
HOPTF Injection-Locking Setup



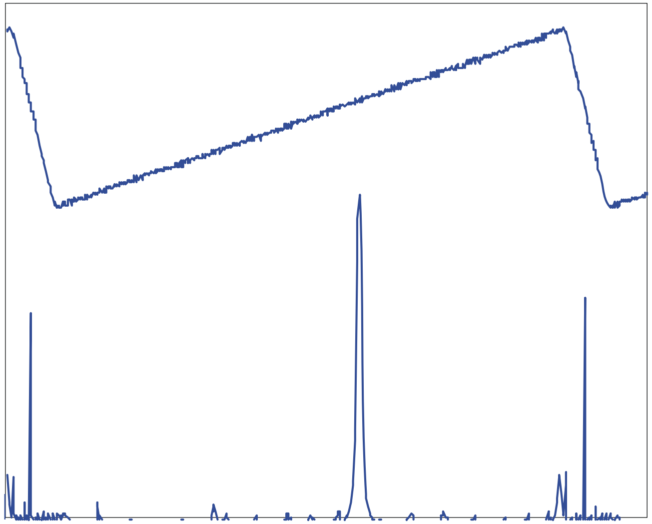
THE UNIVERSITY
OF ADELAIDE
AUSTRALIA

SUB CRUCE LUMEN

Long-Term Injection Locking Demonstrated



Multi- longitudinal mode operation of free-running slave laser



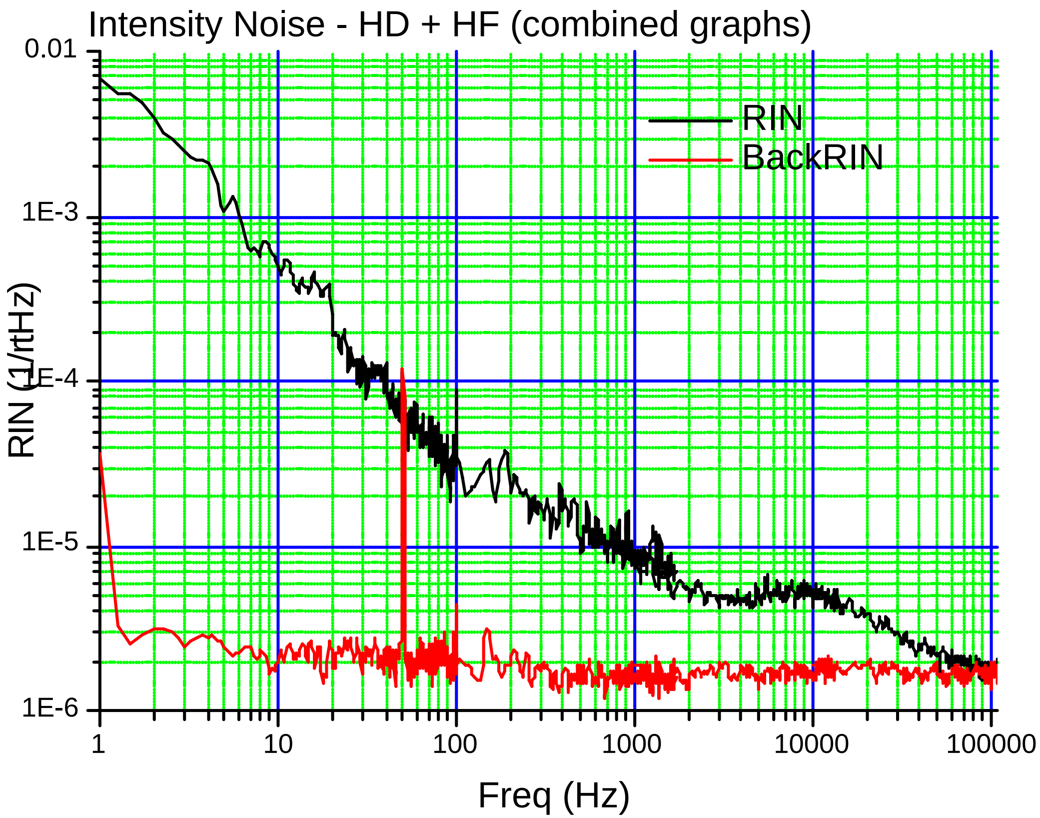
Injection-locked slave with 100% reverse-wave suppression

THE UNIVERSITY OF ADELAIDE AUSTRALIA

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

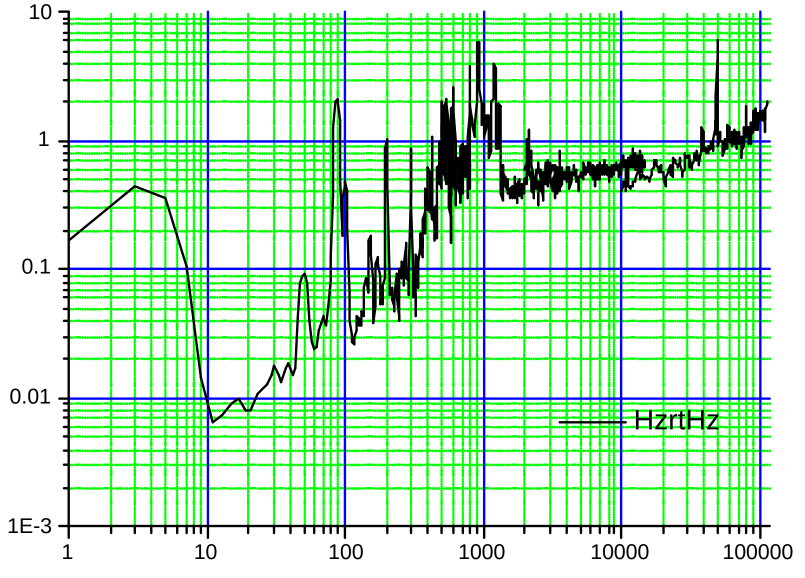
Gingin Oct. 2005

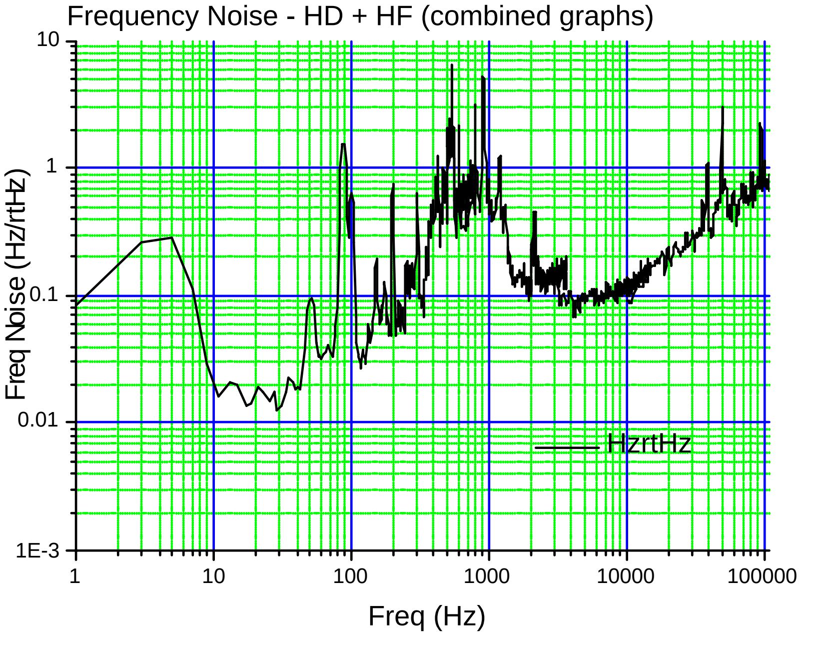
Intensity Noise Meets Requirements



THE UNIVERSITY OF ADELAIDE AUSTRALIA

Frequency Noise Meets Requirements





THE UNIVERSITY OF ADELAIDE AUSTRALIA

New 100W Laser

Extension of previous approach:

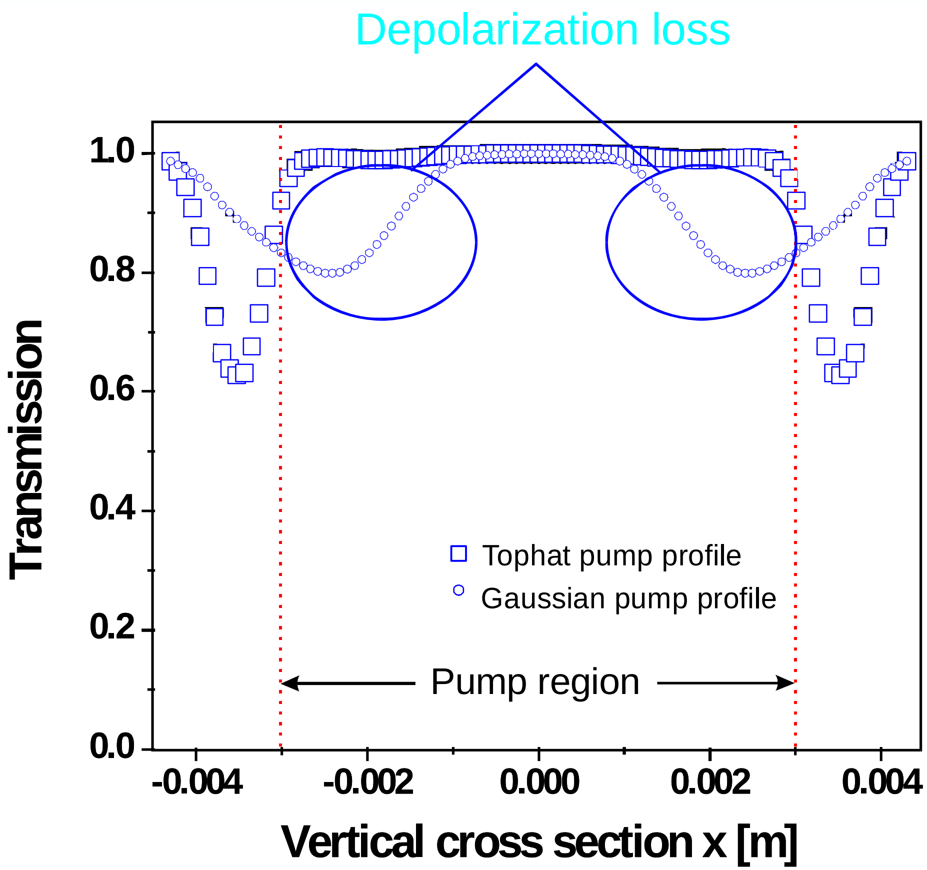
- Injection locked oscillator
- Unstable Resonator
- Zigzag slab

New Features:

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

THE UNIVERSITY OF ADELAIDE AUSTRALIA

Pump Profile Effects Depolarization Loss

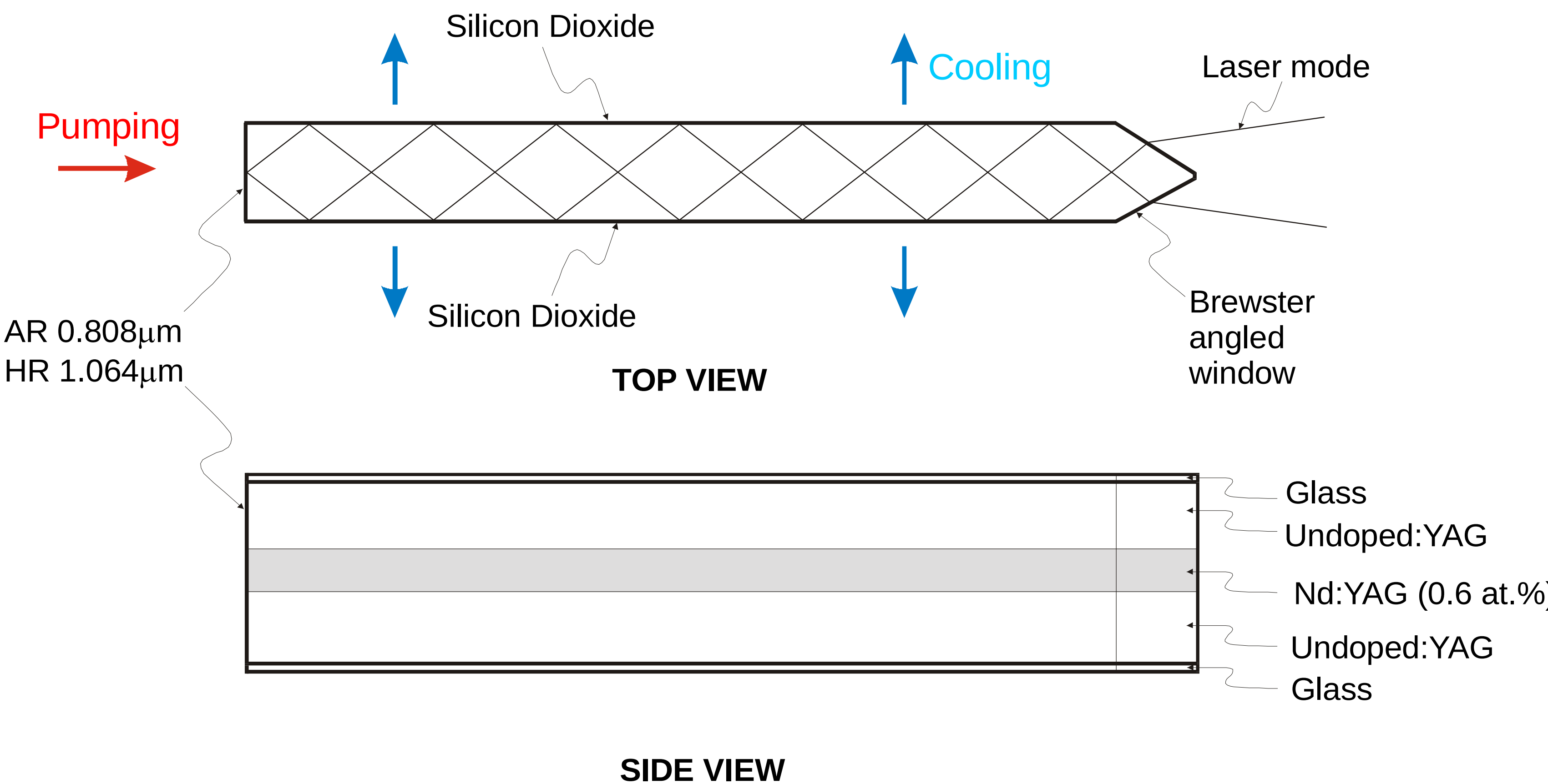


(Birefringence modeling: M. Ostemeyer)

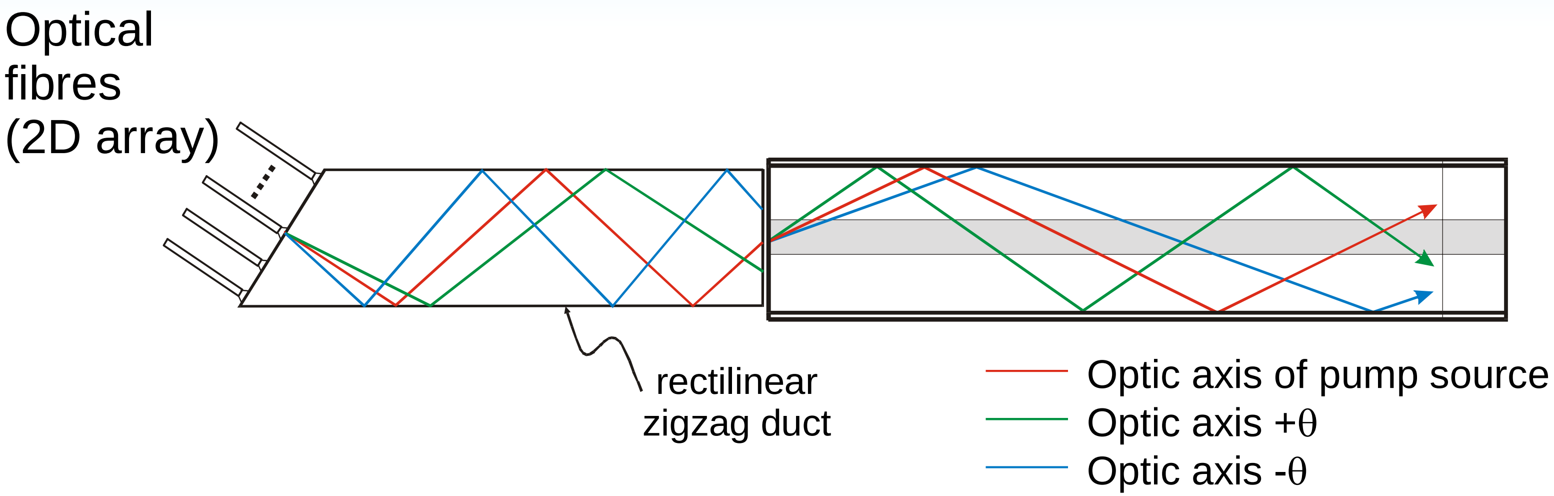
THE UNIVERSITY OF ADELAIDE AUSTRALIA

Gingin Oct. 2005

Composite End-Pumped, Side-Cooled Folded Zigzag Slab



Slab is Off-Axis Zigzag End Pumped

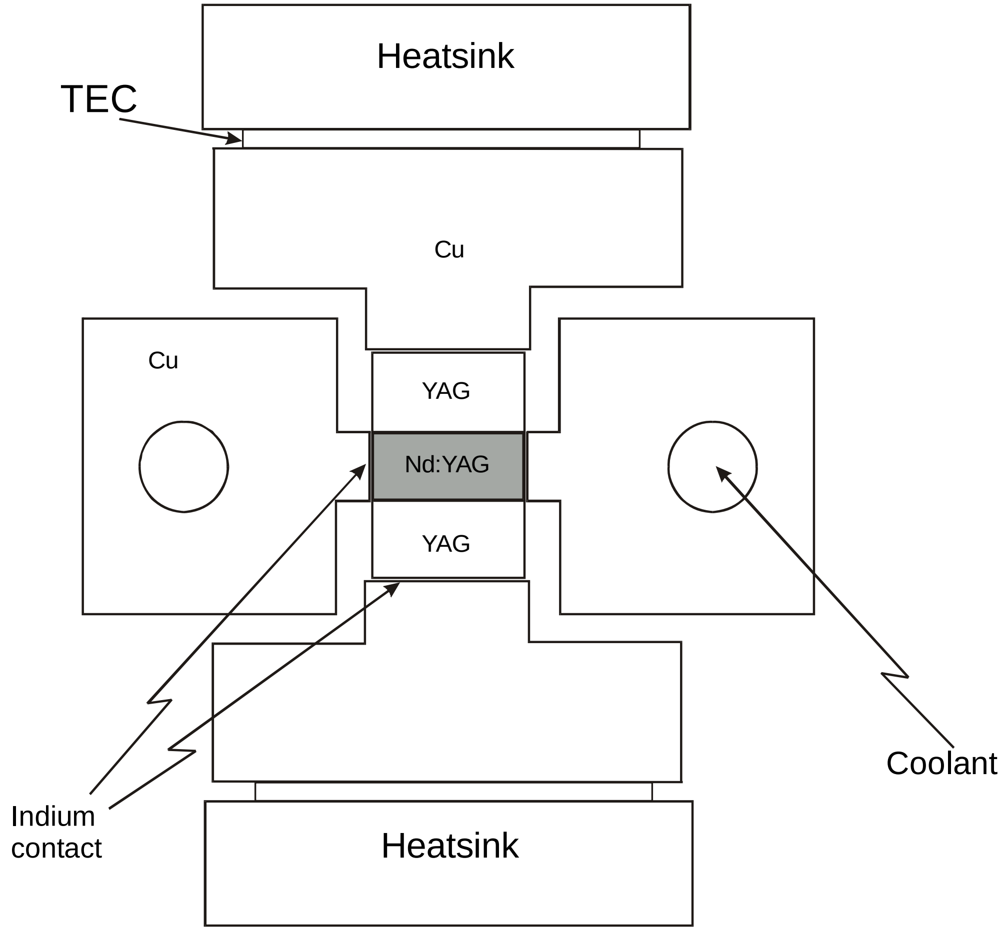


- Rectilinear zigzag duct allows pumping at normal incidence and homogenizes pump light prior to slab entry
- Can replace pump fibers by collimated bar-stack-array
- Scalable by increasing pump power, height of doped and undoped region (scaling direction is orthogonal to cooling/laser zigzag mode plane)

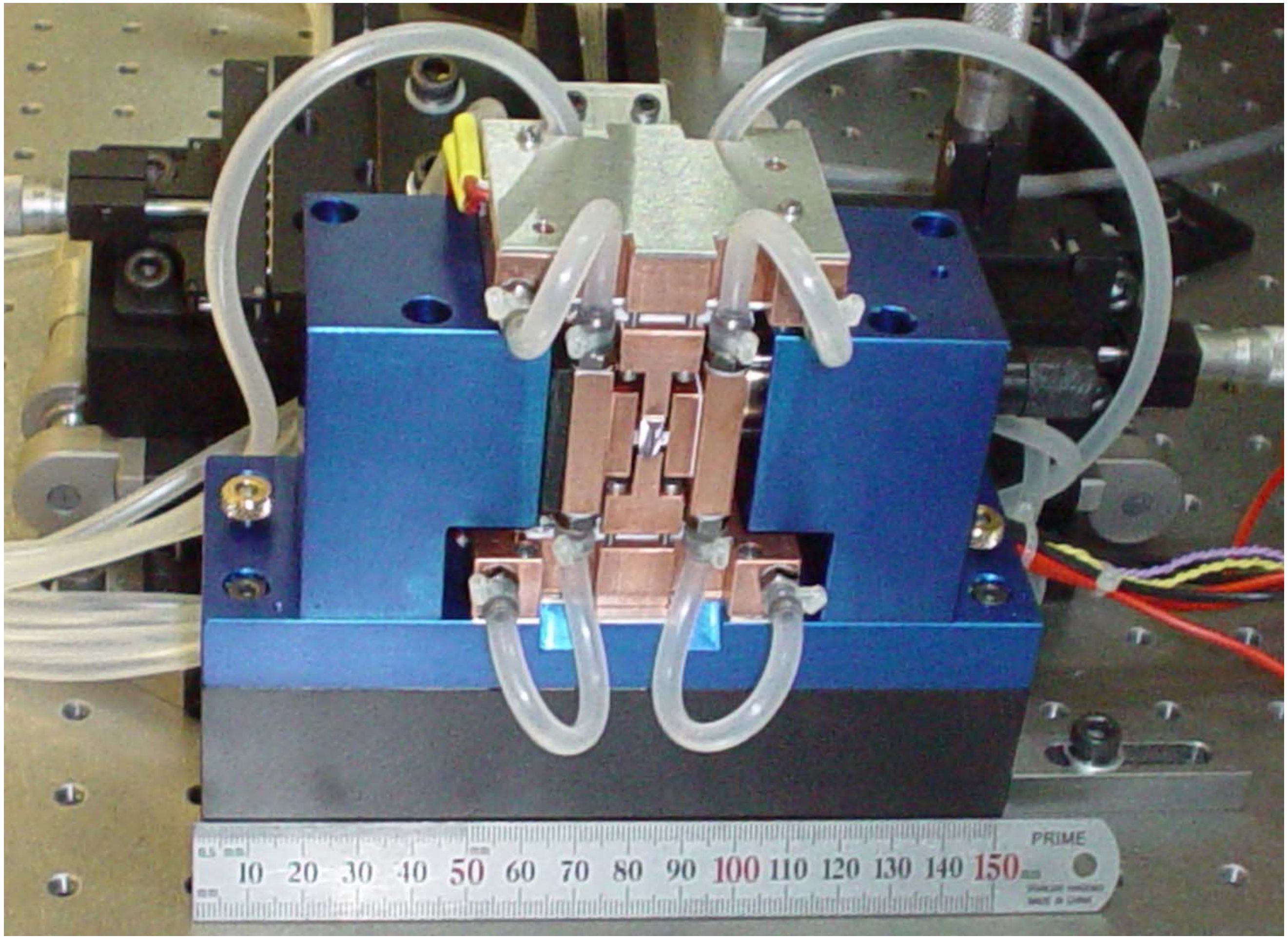
Advantages of New Design

- **Top-hat 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**
- **Scalable to high power**

End View of Laser Head

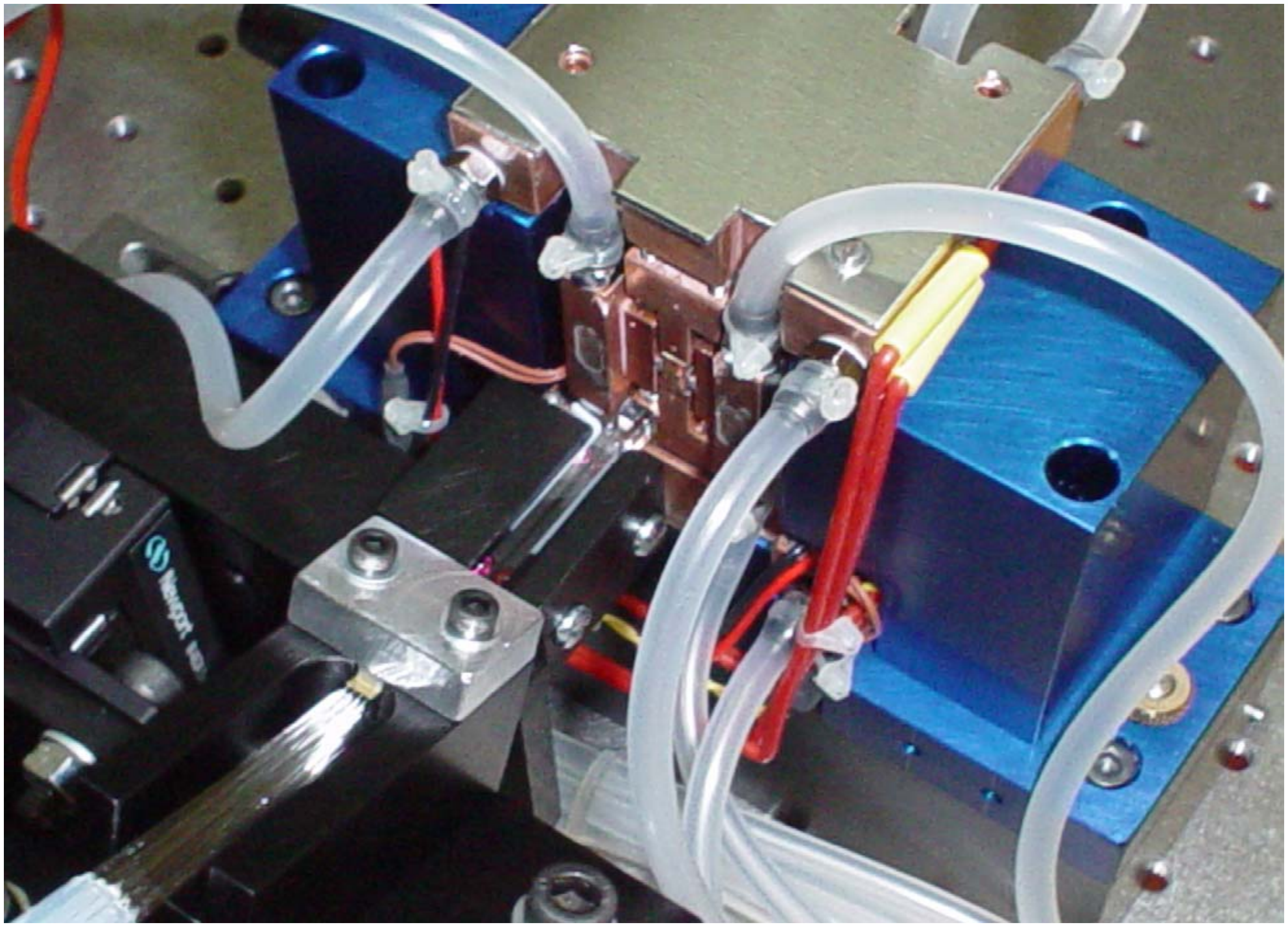


New 100W Laser Head



THE UNIVERSITY
OF ADELAIDE
AUSTRALIA

End-Pumping of New 100W Laser Head



THE UNIVERSITY OF ADELAIDE
AUSTRALIA

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 Features

- Single laser head with simple, compact resonator, good alignment 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
- No cooling water in contact with gain medium
- Scalable to high power

100W Laser Status

- **50W output from 200W pump** - using standing wave laser
- **~30% slope efficiency**
- **minimal wavefront distortion** (measured using Mach-Zehnder interferometer)
- **not point design** - reducing pump power by disconnecting pump fibre does not change thermal lensing significantly
- **good pump absorption** ~ 90% absorption

Conclusion

Developed injection-locked air-cooled 10W Nd:YAG slab laser

- slab gain medium provides mode control and discrimination
- robust
- output diffraction limited,
- noise meets LIGO 1 specifications
- installed at TAMA and Gingin HOPTF

High power Nd:YAG slab laser

- initial testing very encouraging: 50W demonstrated
- previously demonstrated unstable resonator and injection locking
- composite end-pumped zigzag slab architecture

  $\rightarrow$ not point design

  $\rightarrow$ scalable to high power

Next:

- increase pump power for HPL
- test ceramic Nd:YAG composite slabs

THE UNIVERSITY OF ADELAIDE AUSTRALIA