THE UNIVERSITY OF ADELAIDE

Injection Locking for LIGO II

Progress Report on 100 W Adelaide Laser

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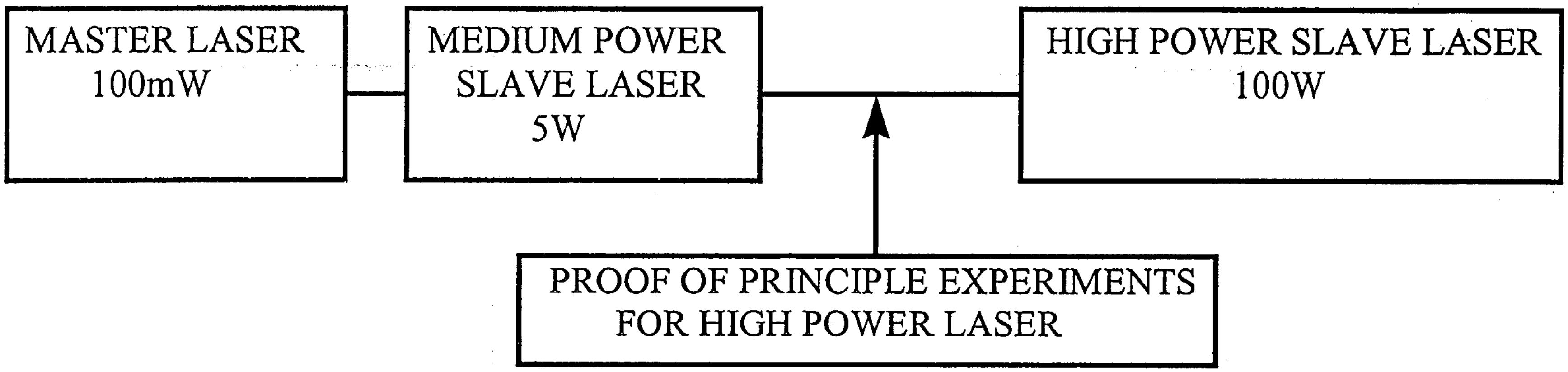
ACIGA / LIGO / Stanford collaboration

LSC Livingston meeting, March 2000

LIGO-G000143-00-D

High Power Laser Development for Advanced Long-Baseline Interferometers

- Strategy: USE A CHAIN OF INJECTION-LOCKED LASERS



- AN ADELAIDE-ACIGA/STANFORD/LIGO COLLABORATION
- HIGH POWER LASER USES A 'STABLE/UNSTABLE' LASER RESONATOR TO PRODUCE A LASER THAT IS EFFICIENT, INTRINSICALLY STABLE AND SCALABLE TO >100W

Contents

- Injection locking progress

  - 5 W laser, noise characteristics
  - 30 W design verification experiments
  - 100 W status

- Proposed continued work

  - 100 W laser characterization
  - Wavefront distortions in core optics

Injection Locking

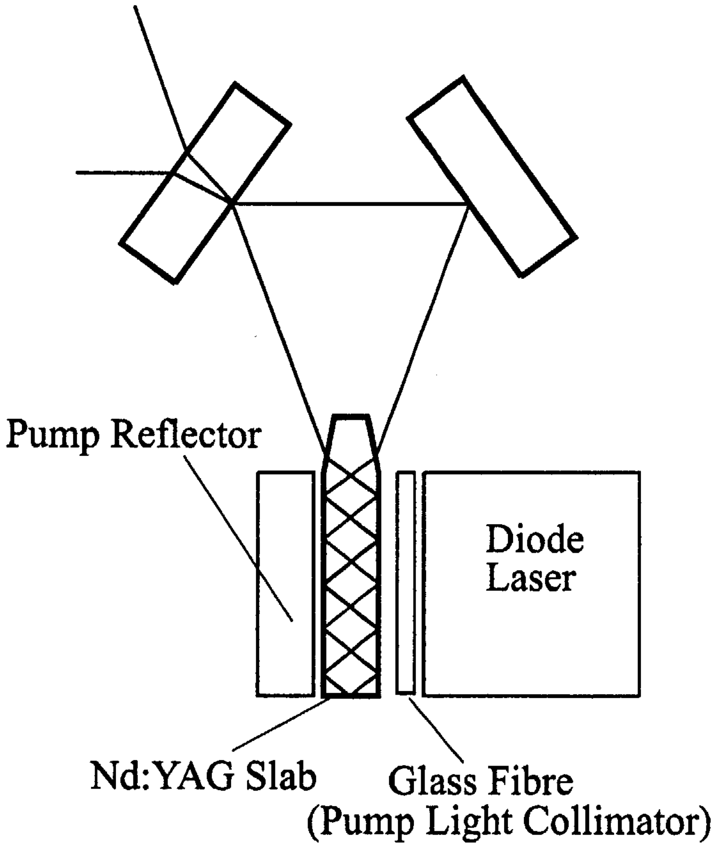
Advantages

- Minimum phase noise
- No ASE
- Saturated gain
- Optimally coupled resonator
- Mode matching
- Efficient
- Compact
- 2 or 3 stages for >100 W at PR mirror

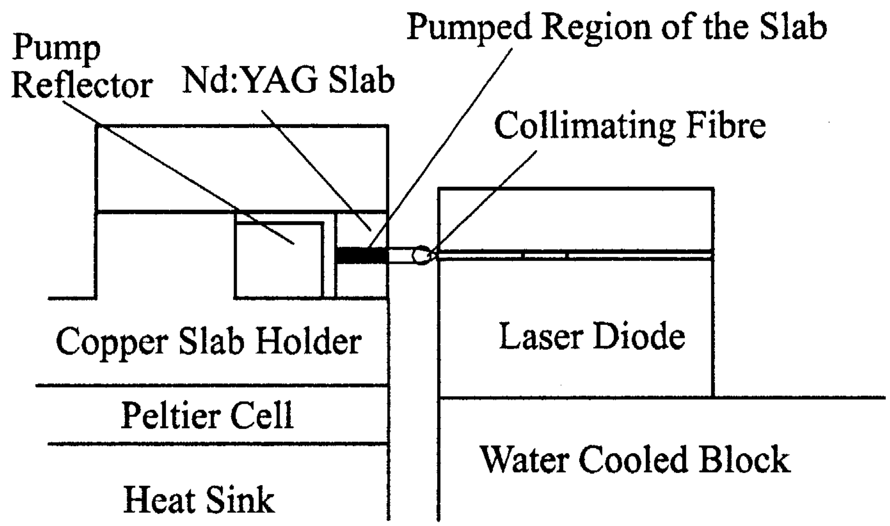
Issues

- Complexity of lock
- Reliability
- Robustness
- Experimental proof of all potential advantages

5w SLAVE LASER



Top View

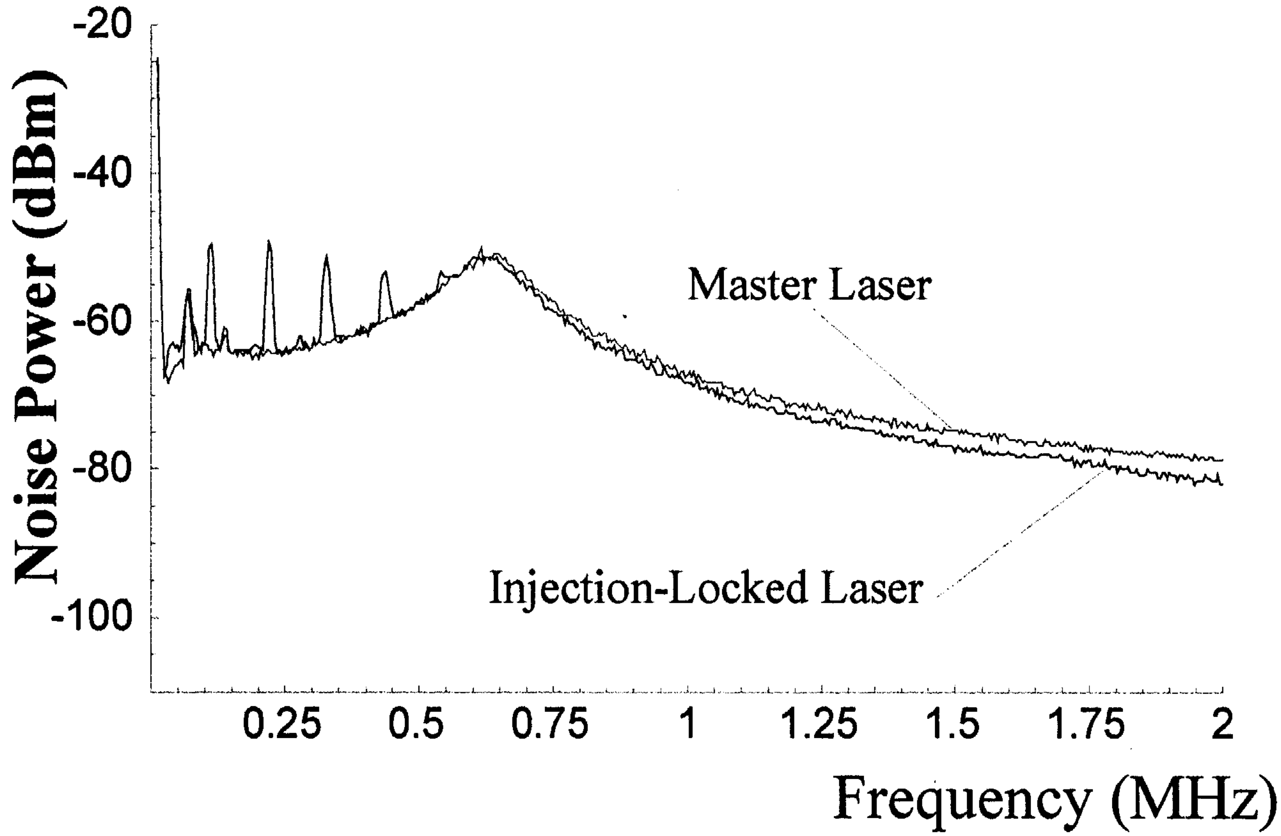


End View

Development of prototype injection-locked 5 W laser essentially completed

- long term injection-locking achieved using PDH servo
- frequency noise at audio frequencies is that of NPRO master laser
- frequency noise added by injection-locking $< 10^{-2}\ \mathrm{Hz}/\sqrt{\mathrm{Hz}}$ at 100 Hz
- RIN of $10^{-6}/\sqrt{\mathrm{Hz}}$ reduced to $10^{-7}/\sqrt{\mathrm{Hz}}$ at 100 Hz by feedback to pump diodes of slave laser
- measured RIN at 24.5 MHz and ~66 mW of detected power
- investigating a tilt-lock servo
- brass-board for ARI under construction

RF Relative Intensity Noise of injection-locked 5 W laser is less than that of NPRO master laser, in agreement with theory



RF RIN of injection-locked lasers

Using model of Ralph, Harb et al:

(Phys. Rev. A **54**, 4359 (1996); Phys. Rev. A **54**, 4370 (1996))

$$RIN_{il}^2(f) = \frac{2e}{I} + \frac{RIN_m^2(f)}{F_R}$$

$$F_R = 1 + \frac{\left(\omega_R^2 - \omega^2\right)^2}{\omega^2 \omega_{lock}^2} \approx 1 + \left(\frac{\omega}{\omega_{lock}}\right)^2 \quad \text{if } \omega >> \omega_R$$

RIN_{il} is relative intensity noise of injection-locked laser,

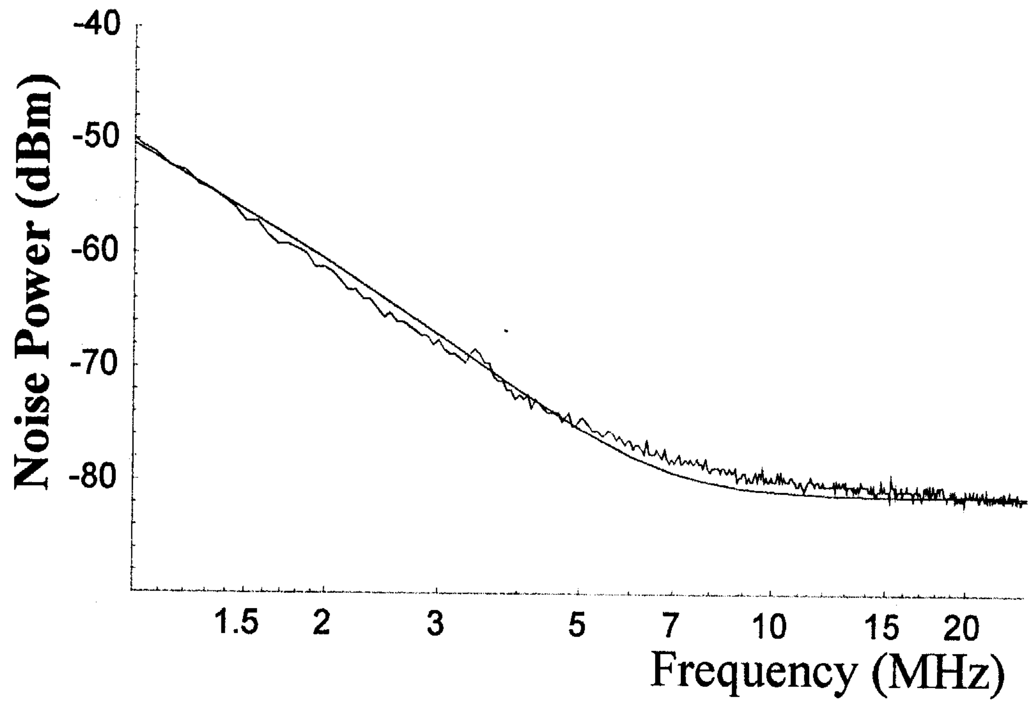
RIN_m is relative intensity noise of master laser,

ω_{lock} is injection-locking range,

ω_R is relaxation-oscillation frequency.

Injection-locking essentially meets the LIGO-I RF RIN specification

RIN of 5 W laser agrees with quantum mechanical model (I_{pc} = 46 mA)



RIN at 24.5 MHz inferred to be 1.006 times shot-noise limit for 600 mW of detected power.

Design verification experiments

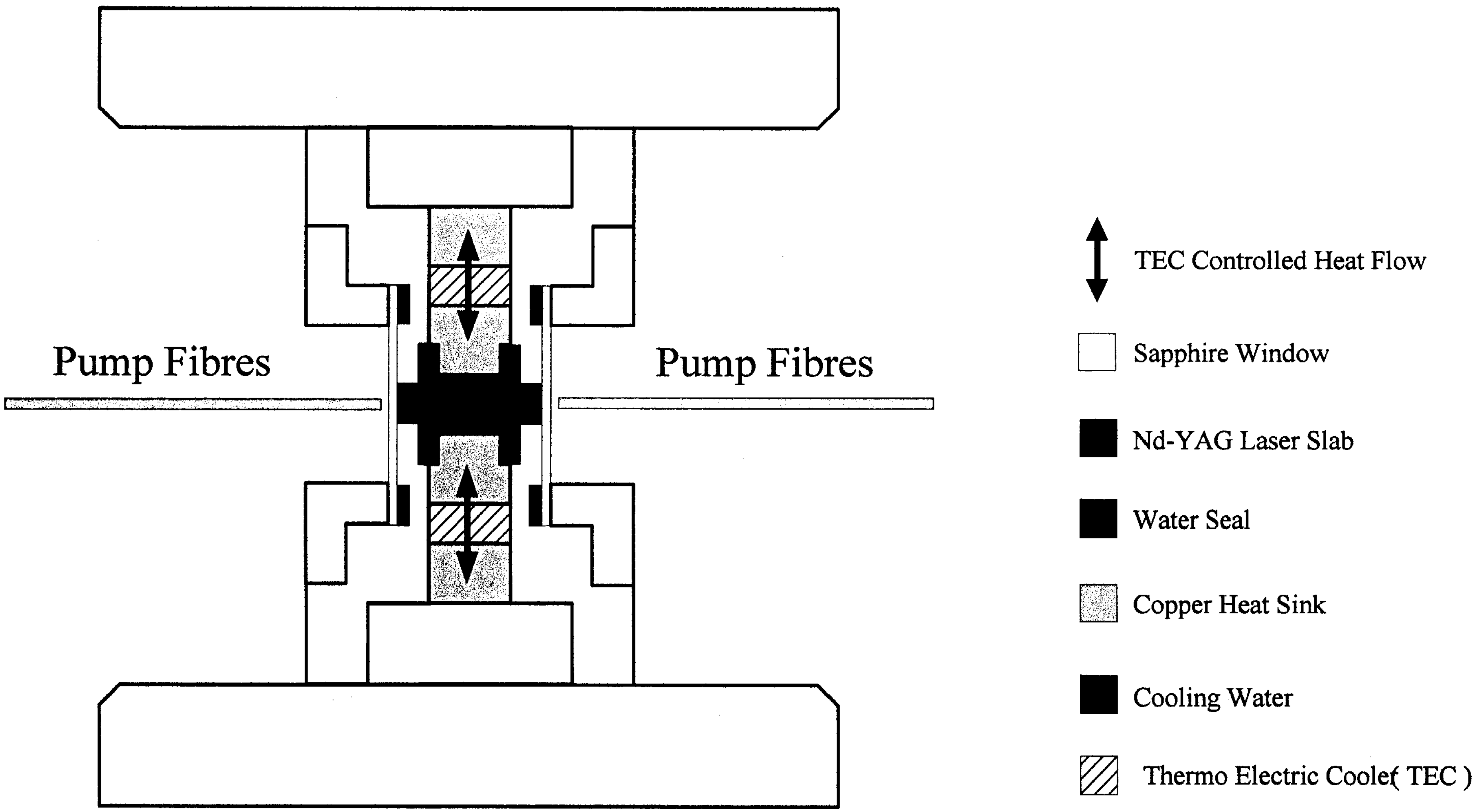
Laser:

- 30 W laser, 100 W fibre-coupled pump power, side-pumped, side-cooled slab
- standing wave stable-unstable resonator for maximum gain

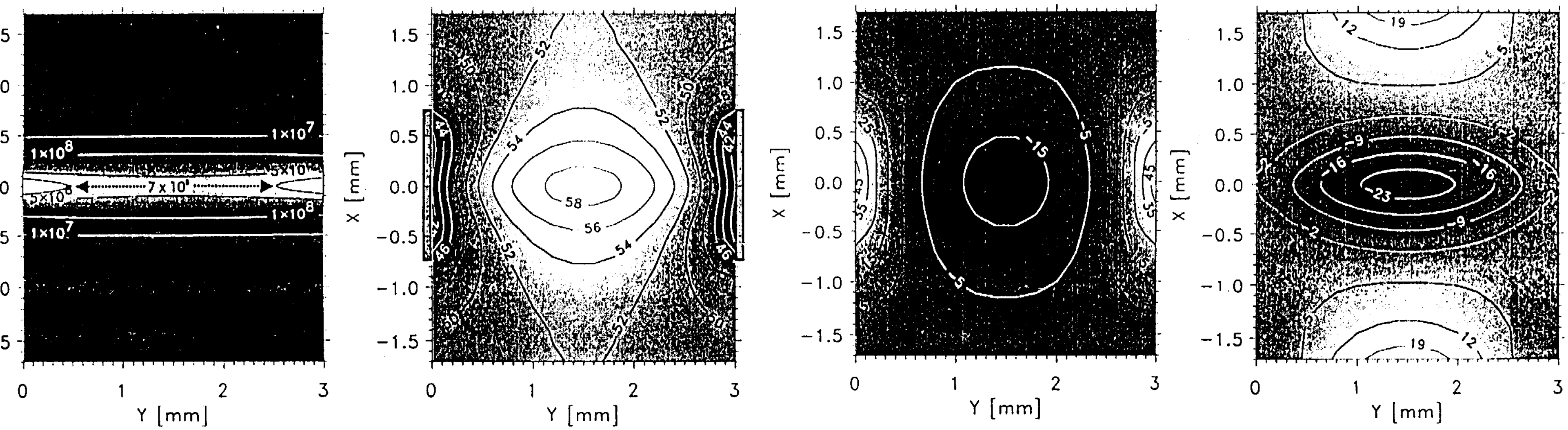
Objectives:

- Thermal control demonstration
- Stable-unstable resonator
- Injection locking of stable-unstable resonator

Schematic of Laser Head

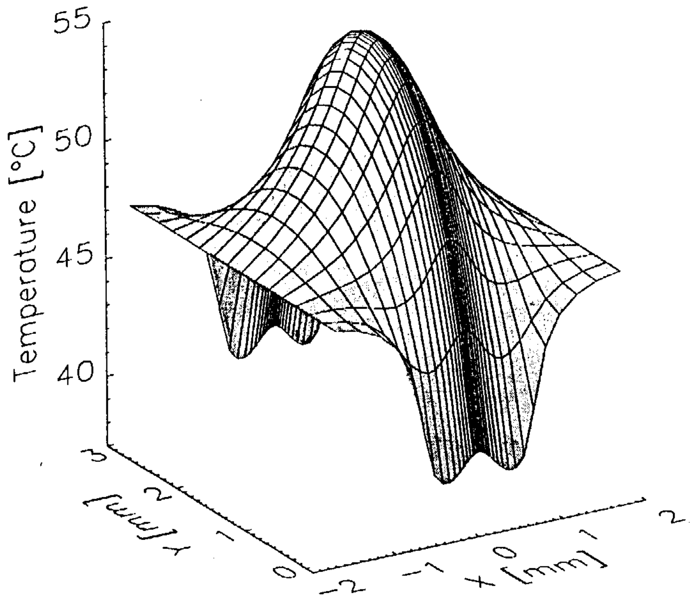


Thermal modelling of 30 W Nd:YAG slab.

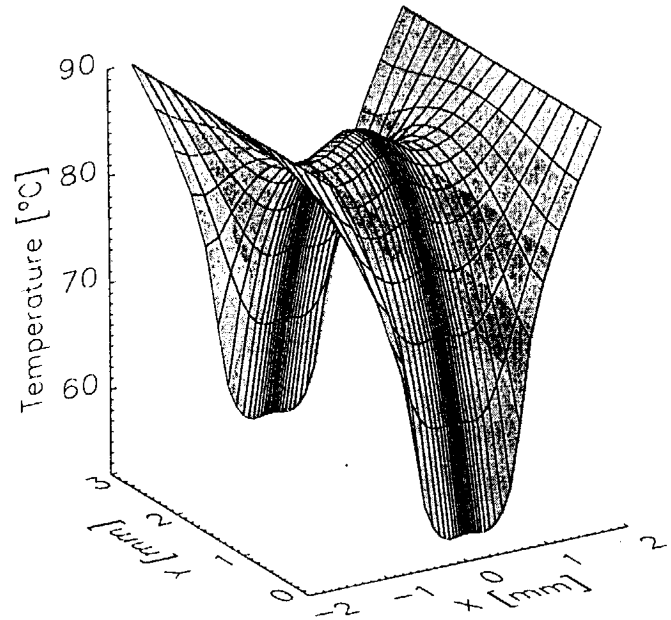


) heat generation [W/m^3]   (B) temperature [^{o}C]   (C) stress (x) [MPa]   (D) stress (y) [MPa]

Thermal modelling of the 30 W Nd:YAG slab - cooling & heating the bottom/top surfaces.

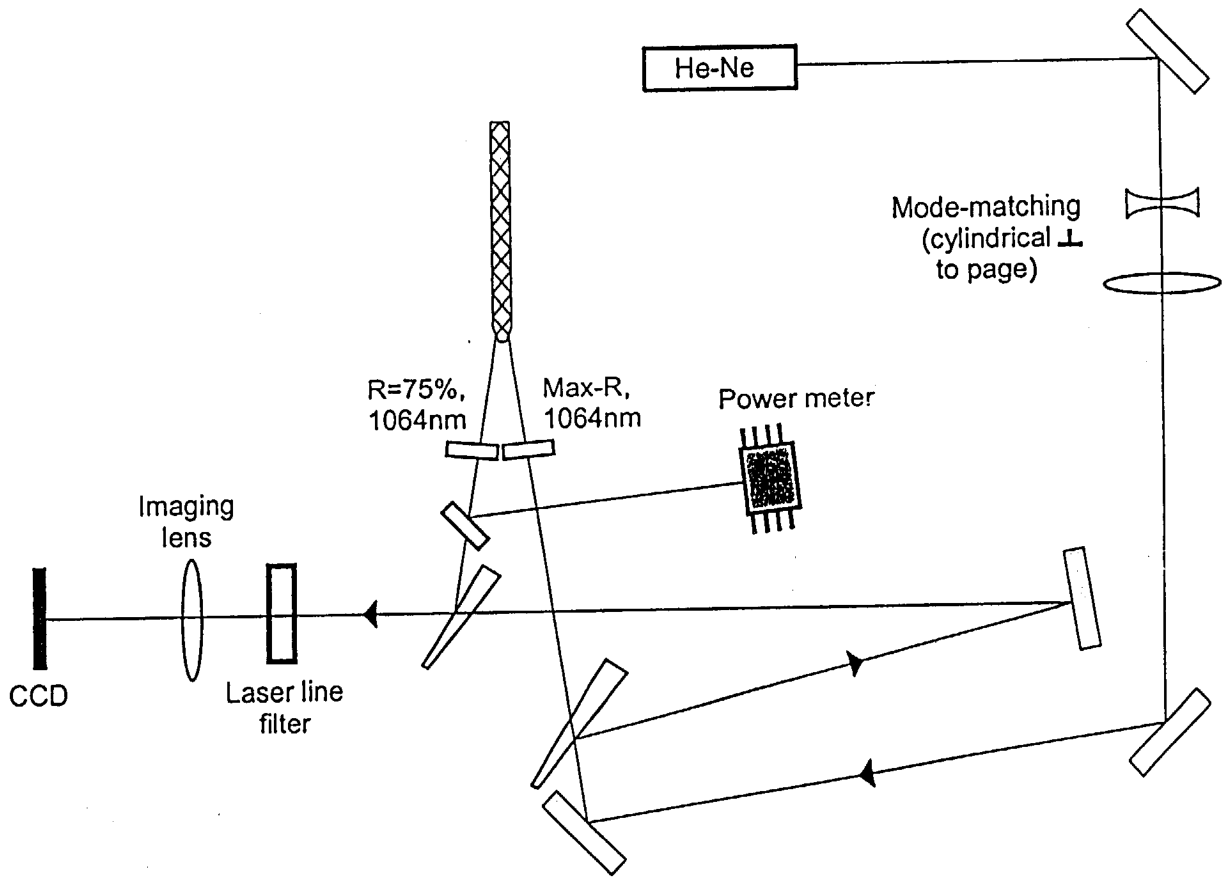


(A) bottom-top cooling

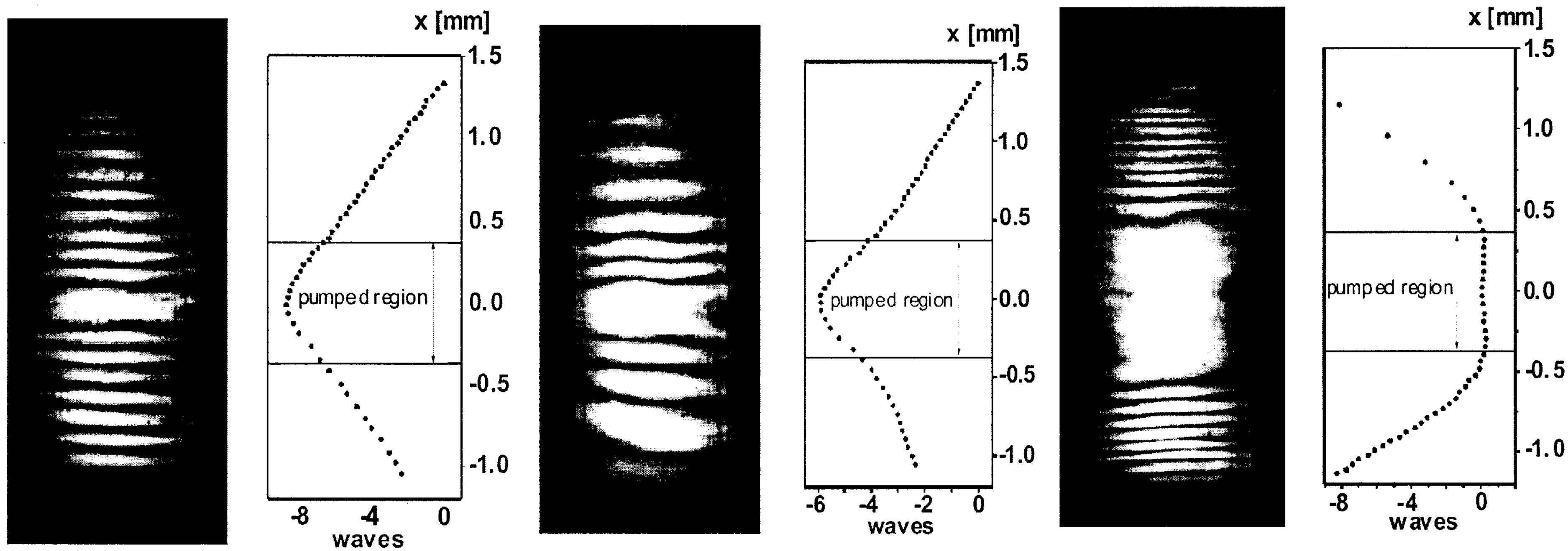


(B) bottom-top heating

Mach-zehnder interferometer used for thermal lens measurement



Thermal lens compensation using TEC's.



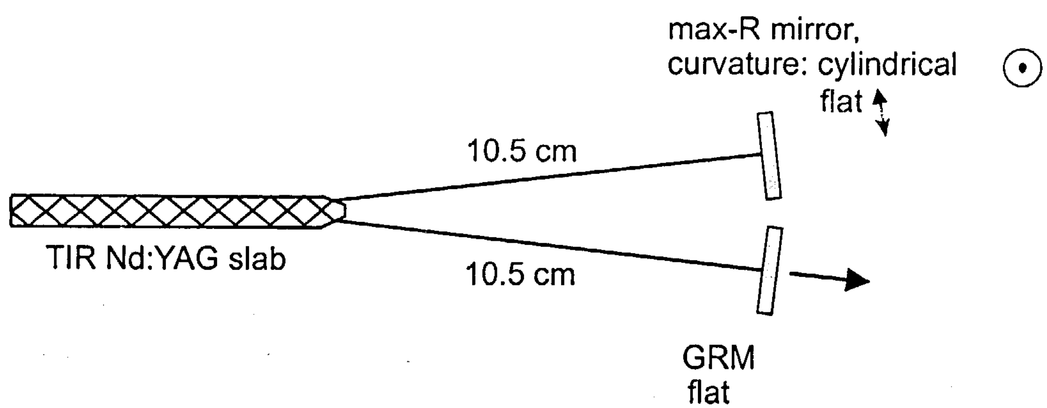
TEC I=+0.9 A

TEC I=0.0 A

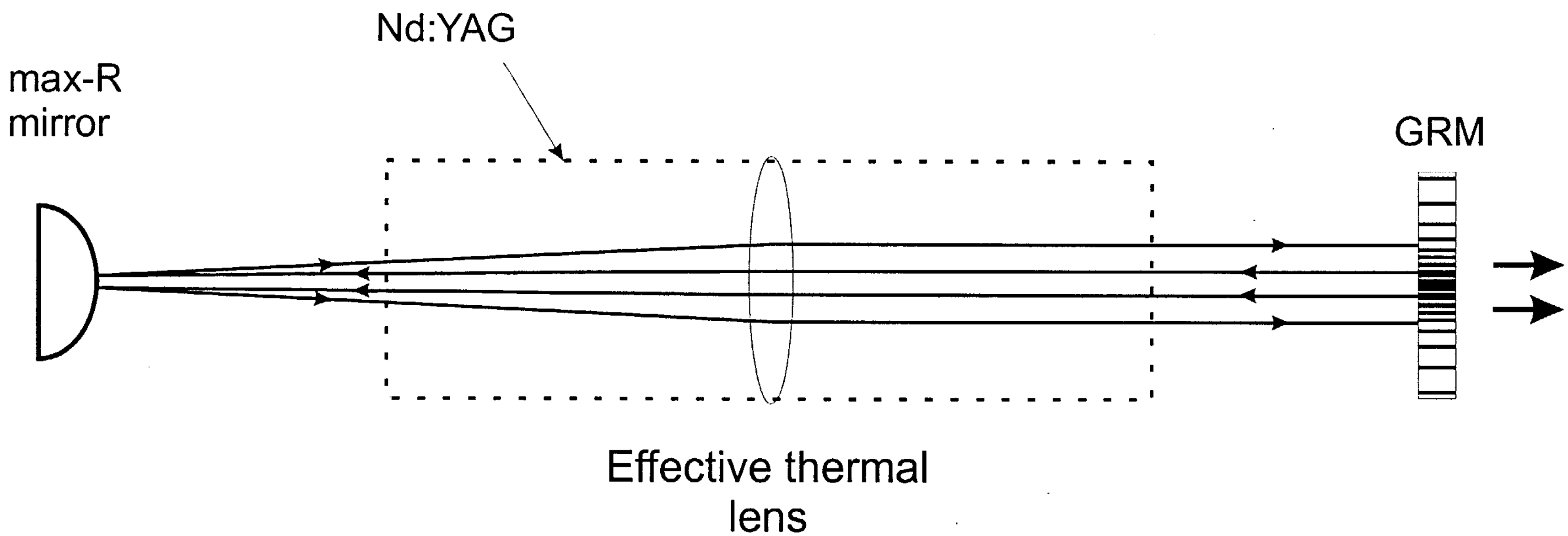
TEC I=-0.8,-0.85 A

Standing-wave stable-unstable resonator design

Features: Geometric magnification = 1.3
Standing-wave cavity
Armlength = 10.5 cm
GRM flat
Cylindrical max-R mirror radius = -15.26 cm
Thermal lens = 32 cm

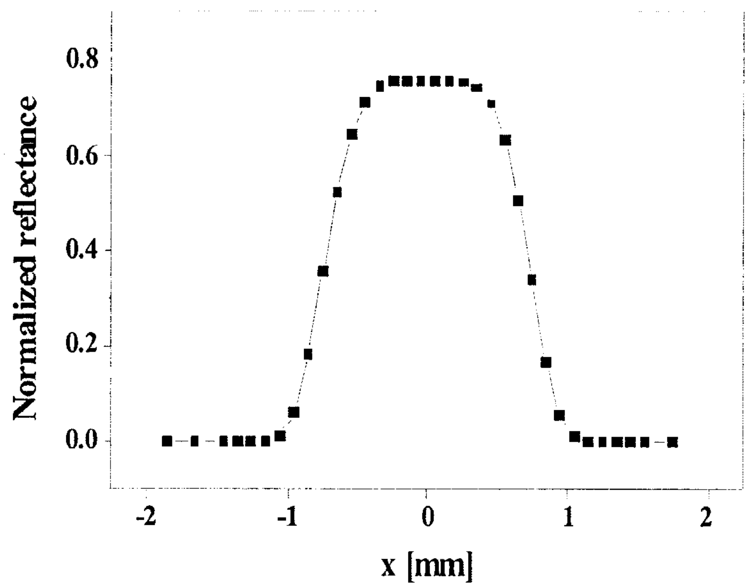


Standing-wave stable-unstable resonator (unstable plane)



GRM design

Measured GRM profile (manufactured by INO)



Features

GRM flat (no curvature)
AR coated on back
Strip reflectance profile
Supergaussian order $n = 5$
Peak reflectance, $R_o = 76\%$
Waist = 0.78 mm

Stable-Unstable Resonator

Status:

- Standing-wave stable-unstable resonator operating
- Initial results indicate:
  - large vertical mode
  - well behaved intensity profile
  - transition from stable to unstable resonator via thermal lens control
- Current setback:
  - cracked laser crystal

Plan for continuing device understanding experiments at 30 W

- Replacement laser crystal in house
- Building second generation laser head
- Use some of new diodes, 200 W pump, larger mode volume for initial detailed investigation of stable-unstable resonator
  - mode control
  - injection locking
  - operational by April 2000

100 W Laser

Status report:

- Thermomechanical analysis of 100 W laser slab complete
- 520 W of diode-lasers have been delivered and tested
- All power supplies and thermal control of diode-lasers complete
- Laser head design / manufacture in progress
- Laser crystal to be ordered March 2000
- Laser optics on order
- Lasing by July 2000

Adelaide / ACIGA / LIGO / Stanford
Proposal for continued work

ARC 2001-2004

Objectives:

Full characterization of 100 W laser technology

- Injection locked ring oscillator
  - Long-term stability, reliability
  - Characterization of intensity and frequency noise
  - Assess robustness of lock
- Backup: Regenerative amplifier, or multipass MOPA

Use 100 W laser to investigate wavefront distortions due to absorption in fused silica, sapphire test masses

High-power wavefront distortions

Proposed work
2002-2004

While testing high-power laser, use it in a realistic environment to investigate effect of high power on optical components

- Subscale table top experiments in Adelaide
  - 100 mm optics
  - 1 m Fabry-Perot, $2\omega_o = 10$ mm, $F = 10^3$
  - Characterize wavefront (Hartmann, Interferometers)
  - Insert optic in F. P. for transmission distortions
  - Develop diagnostics
- Full scale optics at ACIGA research interferometer

Concluding Remarks

Injection locking of 100 W laser is a viable and attractive approach

- All experimental results to date support design approach
    - 5 W complete, results excellent
    - 30 W device under experimentation, results encouraging so far
    - 100 W design / construction in progress
- 100 W injection locking by Nov-Dec 2000
- Continued high power experiments proposed

Note 1, Linda Turner, 05/17/00 10:38:28 AM
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