



MEDIUM POWER STABLE LASERS FOR HIGH PRECISION METROLOGY

by

David Ottaway

Thesis submitted for the degree of

Doctor of Philosophy

in

The University of Adelaide

(Department of Physics and Mathematical Physics)

December, 1998

Abstract

Medium power (5-10W) single frequency lasers with low intensity and frequency noise, plus good beam quality are required for a range of high precision metrology applications. Examples of such applications include laser interferometric detection of gravitational waves and long range vibrometry. In this thesis I will describe the development of a compact and efficient, single frequency, injection-locked, 5 W Nd:YAG laser. The laser output is close to diffraction limited with M^2 values of 1.0 and 1.2 in the horizontal and vertical planes respectively.

The slave laser is a diode pumped slab laser based on the co-planar pumped folded zig-zag slab laser geometry. The slab is side pumped using a single twenty watt laser diode array collimated by a Doric fibre lens. The slab is transversely cooled using Peltier cells that are air cooled.

We use injection-locking to force single frequency operation and to transfer the frequency stability of the monolithic Non Planar Ring Oscillator (NPRO) master laser to the output of our slave laser. The inherent stability of the slave laser allows injection-locking for periods of up to 30 s without the use of servo control. We achieve long term injection-locking by controlling the slave laser resonator using a Pound Drever Hall frequency control servo system.

A heterodyne technique is used to study the phase fidelity of our injection-locked laser compared to that of our master laser. We show that the slave laser contribution to the frequency noise of our injection-locked laser is negligible compared with the frequency noise of the free running master laser. This is in good agreement with theory.

The relative intensity noise of the injection-locked slave has also been measured and is less than $10^{-5} / \sqrt{Hz}$ at low frequencies. Further intensity noise reduction, in excess of an order of magnitude at low frequencies, has been achieved by electronic feedback to the slave laser pump source (a high power multi-emitter diode linear array). The laser is shot-noise limited above 5 MHz for 6 mA of detected photocurrent.

Contents

1	Introduction	3
1.1	Multi-watt single frequency solid-state lasers	4
1.2	Interferometric Detection of Gravitational Waves	10
1.3	Field Based Laser Vibrometry	13
1.4	Introduction to Control Theory	15
2	The Slave Laser	19
2.1	Introduction	19
2.2	Diode and Slab Temperature Control	24
2.3	Slab Laser Loss and Gain Measurements	33
2.3.1	Crystal Loss Measurements	33
2.3.2	Small Signal Gain Measurements	36
2.3.3	Optimum Output Coupling.	36
2.4	Efficiency and Mode Confinement	38
2.5	Slab Interferograms	42
2.6	Ring Resonator Results	47
3	Injection Locking of the Slave Laser	51
3.1	Introduction	51
3.2	Theory of Injection Locking	52
3.3	Passive Injection Locking Performance	57
3.3.1	Mode Matching and Alignment	57
3.3.2	Master and Slave Temperature Matching	60
3.4	Injection Locking Servo Design	61
3.4.1	The Discriminator	61

3.4.2	The Actuator	63
3.4.3	High Voltage Amplifier	70
3.4.4	Pre-Amp Design and Loop Gain	70
3.5	Slave Laser Frequency Noise	73
4	Frequency and Intensity Noise Measurements	79
4.1	Introduction	79
4.2	Theory of Frequency Noise Reduction by Injection-Locking	80
4.3	Frequency Noise due to the Slave Resonator	82
4.4	Intensity Noise	84
4.4.1	Measurement of Intensity Noise	88
4.5	Intensity Noise Reduction	90
5	Conclusions and Further Work	97
A	Mathematical Derivations of Formulae	101
A.1	Sensitivity of the Wheastone Bridge Temperature Sensor	101
A.2	Ring Laser as a Regenerative Amplifier	102
A.3	Mode Matching	104
A.4	Sensitivity of Pound-Drever-Hall Error Signal	106
A.5	Sensitivity of the AOM beatnote experiment	108
B	Circuit Diagrams	111
B.1	Pre-Amp for Temperature Control of the Slab	111
B.2	Power Amp in the temperature controller of the slab	111
B.3	Pre-Amp for the Frequency Servo for the Slave Laser	111
B.4	Transimpedance Photo-diode Circuit	114
B.5	Intensity Noise Suppression Pre-Amp	114
C	Publications	117