

DEVELOPMENT AND TESTING  
OF AN Er:Yb:GLASS  
COHERENT LASER RADAR  
FOR WIND FIELD MAPPING

by

Matthew C. Heintze

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For my family

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# Abstract

Doppler or coherent laser radars (CLR's) can measure range-resolved velocities of distant hard and diffuse targets. Critical applications include wind shear and wake vortex detection, clear air turbulence warning, wind field mapping, and pollution dispersion monitoring. To monitor these at different geographic locations in the atmosphere in real time requires a system with high temporal resolution. A laser transmitter that provides eye-safe, transform-limited energetic pulses with good beam quality and a sensitive transceiver is suitable for such applications.

In this thesis I describe the development of an eye-safe coherent laser radar that has a range resolution of 75 m with single-shot velocity resolution of  $\sim 1.5 \text{ ms}^{-1}$ . I also present measurements of atmospheric wind speeds using this laser.

The laser source is a travelling-wave oscillator that uses a conduction-cooled, Coplanar Pumped Folded Slab (CPFS) with an Er:Yb:phosphate glass gain medium that is side pumped using fast-axis collimated laser diodes. The laser uses polarisation-controlled outcoupling and is injection-seeded to produce eye-safe, transform-limited long duration Q-switched pulses at a frequency close to that of the master laser. This thesis describes the complete characterisation and development of that laser.

It also describes the design and development of the monostatic heterodyne receiver used to detect backscattered returns from targets. Measurements validating the performance of the CLR using stationary and moving hard targets are reported. The thesis also presents initial measurements of atmospheric wind speeds using the CLR. Reproducible range-resolved single-pulse measurements to  $\geq 2 \text{ km}$  are reported and compared to results from a boundary layer radar.



# Statement of Originality

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

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Supervisors: Prof. Jesper Munch and A/Prof. Peter J. Veitch



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# List of Symbols

Throughout this thesis, several symbols will be used repeatedly to represent specific quantities or parameters. The following is a list of these symbols and short descriptions for the readers convenience. This list is not exhaustive but every effort has been made to maintain conformity of symbols used here. Wherever possible standard symbols and notation have been used which appear in most laser texts.

$\alpha$	...	Absorption coefficient
$\alpha_{bl}$	...	Bulk loss coefficient
$\alpha_{ext}$	...	Extinction coefficient
$\alpha_{te}$	...	Linear coefficient of thermal expansion
$\beta$	...	Backscatter coefficient
$\delta$	...	Optical loss due to crystal
$\delta_{rt}$	...	Round-trip loss
$\eta$	...	Overall system efficiency
$\eta_{\alpha}$	...	Fraction of incident pump light absorbed
$\eta_{qd}$	...	Quantum defect
$\eta_{st}$	...	Storage efficiency
$\theta_1$	...	TIR angle
$\theta_{exit}$	...	Beam exit angle out of slab
$\theta_n$	...	Slab nose angle
$\theta_{sep}$	...	Beam exit separation angle
$\kappa_{tc}$	...	Thermal conductivity
$\lambda$	...	Wavelength
$\lambda_{abs}$	...	Absorption wavelength
$\lambda_e$	...	Emission wavelength
$\mu_P$	...	Material Poisson ratio
$\nu_d$	...	Doppler shift

$\nu_{LO}$	...	Frequency of the local oscillator radiation
$\nu_{sig}$	...	Frequency of the signal radiation
$\rho$	...	Density
$\sigma_a$	...	Absorption cross section
$\sigma_e$	...	Stimulated emission cross section
$\sigma_f$	...	Surface fracture stress
$\tau$	...	Output pulse FWHM length
$\tau_{Er}$	...	Er fluorescence lifetime
$v_r$	...	LOS velocity
$\phi_{LO}(t)$	...	Phase of the local oscillator radiation
$\phi_{sig}(t)$	...	Phase of the signal radiation
$\Delta\nu$	...	Change in frequency
$\Delta\nu_d$	...	Doppler shift uncertainty
$\Delta\nu_r$	...	LOS velocity resolution
$\Delta f_p$	...	Fourier transform spectral width
$\Delta R$	...	Range resolution
$\Delta T$	...	Temperature difference
$\Delta T_{PBT}$	...	Pulse build-up time
$\Delta V$	...	Change in voltage
$a_r$	...	Aperture radius
$A_\lambda$	...	Absorbance
$A_{eff}$	...	Effective aperture
$A_t$	...	Telescope collection area
$c$	...	Speed of light
$dn/dt$	...	Change in refractive index with temperature
$E$	...	Young's modulus
$E_{LO}$	...	Electric field of the local oscillator radiation
$E_{sig}$	...	Electric field of the signal radiation
$f_i$	...	Focal length of object i
$f_{th}$	...	Thermal lens focal length
$g_o$	...	Small signal gain coefficient
$G$	...	Gain factor
$G_o$	...	Single pass small signal gain factor
$h$	...	Height of gain medium
$h_p$	...	Height of the pumped region
$h\nu$	...	Photon energy
$h\nu_p$	...	Pump photon energy

$I_{fl}(t)$	...	Fluorescent emission intensity
$I_o$	...	Incident optical intensity
$I_s$	...	Saturation intensity
$loss_{\text{bulk}}$	...	Bulk scatter loss
$loss_{\text{perTIR}}$	...	Loss per TIR bounce
$loss_{\text{TIRscatter}}$	...	Surface scatter loss
$l_g$	...	Total mode pathlength in the gain region
$l_p$	...	Pumped length of gain medium
$l_s$	...	Parallel side length of gain medium
$M^2$	...	Beam quality factor
$M_h^2$	...	Beam quality factor (horizontal direction)
$M_v^2$	...	Beam quality factor (vertical direction)
$M_s$	...	Material constant
$n$	...	Index of refraction
$nb$	...	Number of TIR bounces
$N_o$	...	Total number of ions
$N_j$	...	Number of ions per unit volume for energy level $j$
$P$	...	Round-trip optical length
$P_{bs}$	...	Backscattered power
$P_L$	...	Slave laser transmitted power
$P_{LO}$	...	Power of the local oscillator radiation
$P_o$	...	Incident power
$P_p$	...	Absorbed pump light
$P_{sig}$	...	Power of the signal radiation
$P(z)$	...	Power at position $z$
$Q$	...	Heat absorbed per unit volume
$R$	...	Range
$R_{OC,i}$	...	Reflection percentage of output coupler $i$
$R_{opt}$	...	Optimum output coupling reflection
$R_{OC,tot}$	...	Total output coupling reflection percentage
$R_{pd}$	...	Responsivity of the photodiodes
$R_s$	...	Thermal shock resistance
$t$	...	Time
$t_{pump}$	...	Pump pulse duration
$t_r$	...	Cavity round-trip time
$T_a$	...	Average temperature of the pumped region of the slab
$V$	...	Volume of the pumped region

$V_{applied}$	...	Applied voltage
$V_{1/2}$	...	Half-wave voltage
$w_m$	...	Gaussian beam radius
$w_p$	...	Width of the pumped region
A/D	...	Analog-to-digital
AoI	...	Angle of incidence
AOM	...	Acousto-optic modulator
BAW	...	Brewster-angled wedge
BBO	...	Beta barium borate
CCD	...	Charge coupled device
CLR	...	Coherent laser radar
CPFS	...	Coplanar-pumped folded slab
Er	...	Erbium
ESA	...	Excited state absorption
ETE	...	Energy transfer efficiency
FFT	...	Fast Fourier transform
FSR	...	Free spectral range
FW	...	Forward-wave
FWHM	...	Full width half maximum
HWP	...	Half-wave plate
LOS	...	Line of sight
MPE	...	Maximum permissible exposure
MZ	...	Mach-Zehnder
PBSC	...	Polarising beam splitter cube
PBL	...	Planetary boundary layer
PRF	...	Pulse repetition frequency
PZT	...	Piezoelectric transducer
QWP	...	Quarter-wave plate
RW	...	Reverse-wave
SNR	...	Signal to noise ratio
T/R	...	Transmit/receive
TEC	...	Thermoelectric cooler
TIR	...	Total internal reflection
Yb	...	Ytterbium

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