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

Contents

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 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 km are reported and compared to results from a boundary layer radar.

Statement of Originality

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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.

α	...	Absorption coefficient
α_{bl}	...	Bulk loss coefficient
α_{ext}	...	Extinction coefficient
α_{te}	...	Linear coefficient of thermal expansion
β	...	Backscatter coefficient
δ	...	Optical loss due to crystal
δ_{rt}	...	Round-trip loss
η	...	Overall system efficiency
η_{α}	...	Fraction of incident pump light absorbed
η_{qd}	...	Quantum defect
η_{St}	...	Storage efficiency
θ_1	...	TIR angle
θ_{exit}	...	Beam exit angle out of slab
θ_n	...	Slab nose angle
θ_{sep}	...	Beam exit separation angle
κ_{tc}	...	Thermal conductivity
λ	...	Wavelength
λ_{abs}	...	Absorption wavelength
λ_e	...	Emission wavelength
μ_P	...	Material Poisson ratio
ν_d	...	Doppler shift

ν_{LO}	...	Frequency of the local oscillator radiation
ν_{sig}	...	Frequency of the signal radiation
ρ	...	Density
σ_a	...	Absorption cross section
σ_e	...	Stimulated emission cross section
σ_f	...	Surface fracture stress
τ	...	Output pulse FWHM length
τ_{Er}	...	Er fluorescence lifetime
υ_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
$\Delta\upsilon_r$	...	LOS velocity resolution
Δf_p	...	Fourier transform spectral width
Δ R	...	Range resolution
ΔT	...	Temperature difference
ΔT_{PBT}	...	Pulse build-up time
ΔV	...	Change in voltage
a_r	...	Aperture radius
A_λ	...	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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