Eye-safe Er:YAG Lasers for Coherent Remote Sensing

by

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Contents

Abstract

Multi-watt lasers with an output wavelength in the eye-safe band are required for many remote sensing applications, including Doppler or coherent laser radars (CLR's). Er:YAG lasers at 1617 nm or 1645 nm operating on the $^4I_{13/2}$ to $^4I_{15/2}$ transition can potentially satisfy this need. Although this transition has been known for many years, the development of diode pumping makes these lasers practical.

Doppler wind-field mapping requires single frequency, diffraction limited pulses at a high pulse repetition frequency (PRF) to provide a spatially dense array of samples, allow signal averaging with minimal loss of temporal resolution and to minimize the time required to scan an extended volume. Pulses with energies >few mJ and pulse durations of >100 ns are essential for these measurements. Such requirements can be satisfied by continuous-wave (CW) pumping of a Q-switched free-space laser.

In this thesis I describe the design and development of a single frequency, continuous wave, Er:YAG laser at 1645 nm that uses resonant pumping at 1470 nm. With an intra-cavity polarizer and uncoated etalon, it produces up to 30 mW in a narrow line-width, single frequency, plane polarized, diffraction limited, TEM_{00} output. The laser is suitable as a master oscillator of a CLR.

I also describe the development and characterization of an efficient high power Er:YAG laser that is resonantly pumped using CW laser diodes at 1470 nm. For CW lasing, it emits 6.1 W at 1645 nm with a slope efficiency of 40%, the highest efficiency reported for an Er:YAG laser that is pumped in this manner. In Q-switched operation, the laser produces diffraction-limited pulses with an average

power of 2.5 W at 2 kHz PRF, and thus is suitable as the slave oscillator of a CLR. To our knowledge this is the first Q-switched Er:YAG laser resonantly pumped by CW laser diodes.

This thesis also presents an experimental investigation of the observed reduction in the average output power of Q-switched Er:YAG lasers at low PRF. The experimental results are compared with the predictions of a theoretical model developed using rate equations so the primary causes can be determined, and thus could be minimized in a future design.

Statement of Originality

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

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"Call to me and I will answer you and tell you great and unsearchable things you do not know." – Jeremiah 33:3

Nick Chang, August 2012

List of Symbols

η_{abs}	Pump absorption fraction
η_{eff}	Pump delivery efficiency
η_{mode}	Mode overlap efficiency
η_{slope}	Slope efficiency
γ	Gain coefficient
λ	Wavelength
σ_{al}	Effective absorption cross section of the laser wavelength
σ_{ap}	Effective absorption cross section of the pump wavelength
σ_{el}	Effective emission cross section of the laser wavelength
σ_{ep}	Effective emission cross section of the pump wavelength
σ_l	Absorption cross section for the laser transition
σ_p	Absorption cross section for the pump transition
τ_s	Upper state storage lifetime
$\triangle_l$	Laser inversion density
$\triangle_l^z$	Laser inversion density per unit area (Rod-integrated)
$\triangle_p$	Pump inversion density
$\triangle_p^z$	Pump inversion density per unit area (Rod-integrated)
A_p	Pump cross section area
C_{up}	Upconversion rate
f_{lens}	Effective focal length of the thermal lens
F_c	Cavity finesse
f_l	Fractional Boltzmann population of the laser transition
f_p	Fractional Boltzmann population of the pump transition

G	Round trip gain of the laser
h_s	Gain medium height
I_l	Laser intensity
I_p	Pump intensity
L_{cav}	One-way cavity loss
l_s	Gain medium length
M^2	Beam propagation factor
N_2^z	Excited manifold density per unit area (Rod-integrated)
N_2^{Total}	Total excited upper-state (N2) population
N_t	Doping cencentration per unit volume
$P_{av(\text{CW})}$	Average power in CW operation
P_{cav}	Laser intra-cavity power
P_{out}	Output power
P_p	Pump power
P_{th}	Threshold power
r_0	Radius of the waist
R^t_{laser}	De-excitation rate via lasing
R_{oc}	Reflectivity of the output coupler
R^t_{pump}	Pump excitation rate
R_p	Reflectivity of the coating for double pass pumping
r_p	Radus of the pump
r_s	Radius of the gain medium
t_{scatter}	Backscatter time
v_l	Frequency of the laser wavelength
V_{pump}	Volume pumped by the pump light
v_p	Frequency of the pump wavelength
W_{ij}	Radiative decay rate from level i to level j

w_s	Gain medium width
AOM	Acousto-optic modulator
AR	Anti-reflection
BD	Beam diameter
CPFS	Coplanar folded slab
CW	Continuous wave
DA	Full divergence angle
DI	Deionized
EDFL	Erbium doped fibre laser
EO	Electro-optic
ESA	Excited state absorption
ETU	Energy-transfer-upconversion
FSR	Free spectral range
FWHM	Full width half maximum
GSD	Ground-state depletion
LIDAR	Light detection and ranging
MP	Multi-phonon
NA	Numerical aperture
OSA	Optical spectrum analyzer
PBSC	Polarization beam splitter cube
PRF	Pulse repetition rate
QWP	Quarter-wave plate
RTP	Rubidium Titanyle Phosphate
TEC	Thermo-electic cooler
TFP	Thin film polarizer
YAG	Yttrium aluminum garnet

List of Figures

List of Tables