The V3+: YAG Passive Q-switched end-pumping Nd: YAG Microlaser's design and characteristics

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Abstract

Q-switched A passively Q-switched (V3+:YAG) diode pumped solid state laser system with a characteristic study has been developed, and it emits light at a wavelength of 1342 nm. a saturable absorber (V3+:YAG, T0 = 97%) and an active laser component (Nd3+:YAG). The output coupler has a 95 percent reflectivity at 1342 nm and was installed on the V3+-doped portion of the microchip resonator, which is made up of dielectric mirrors that were directly printed on the monolith surfaces. The Q-switched microchip laser was put to the test using a pulsed laser diode. Its output parameters, including energy, peak power, and pulse width, were investigated. The results of the simulations and theoretical calculations were compared using software that calculates the Q-switched solid state laser parameters. The simulation and the theoretical computations were in good agreement.

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1-Introduction:

Most of the solid state passive Q-switches which have been developed have operatedusing the 1064nm transition of Nd^{3+} and therefore have been based on the saturableabsorption of Cr^{4+} ions[Swidersti 2005]. The operation of Cr^{4+} devices ranges from approximately900-1100nm, depending on the host properties[Zhang 1997]. a new saturable absorber, which could operate at longerwavelengths, in particular with the 1342nm transition of Nd^{3+}two absorption peaks were observed at 1140nm and 1320nm, and attributed to the3A2→1E(1D) and 3A2→3T2(3F) transitions respectively of the tetrahedrally coordinatedV3+ ion [Malyarevich1998]. The fast decay of the 1E(1D) level to 3T2(3F) haspreviously been measured to be 0.13ns[Jabczy 2001]. To complete our knowledge of thesystem we measured the lifetime of the longer-lived decay 3T2(3F) →3A2 using apump-probe technique. Laser pulses at 1080nm with 15ps pulse duration were usedfor pumping and probing. The lifetime of the 3T2(3F) level was found to be (22-6)ns[Sun andHou2008].Trivalent neodymium was the first rare-earth ion to be used in a gain material, andhas remained the most commonly used active ion found in solid state lasers. Theintense luminescence and absorption of the narrow energy levels of Nd^{3+} along with aworkable fluorescence lifetime have helped Nd^{3+} achieve its dominance. It is traditionallypumped on either the 760nm or 810nm absorption bands though it can also be pumpedin the green spectral region. The two main photon decay routes from the 4F3/2metastable level are the 4F3/2 → 4I11/2 transition (producing radiation at ~1.06µm) andthe 4F3/2 →4I13/2 transition (producing radiation at ~1.3µm). Both of these are fourlevel systems, giving efficient CW operation on these transitions at 300K and above,without significant population in the lower lasing level causing reabsorption. The thirdtransition 4F3/2 →4I9/2 (producing radiation at ~0.9µm) is a quasi-four level system,with the lower lasing level close to the ground level, having a significant thermalpopulation. The fourth transition is two orders of magnitude weaker, though has beenshown to lase at 1.83µm [Koechner , 2006].

2-Theory

When a cw power is pumped the active medium, the population inversion would reach a maximum value and decreases thereafter and the cavity losses are periodically switched from high to low value ,then the laser output consists of a continuous train of Q-switched pulses .During each pulse inversion falls from its initial value N_i (before Q- switching) to the final value N_f (after the Q-switched pulse)[Svelo1998]. The population inversion is restored to its initial value N_i by the pumping process before the next Q-switched event. Since the time taken to restore theinversion is roughly equal to the upper –state lifetime (τ) ofactive meduim, the time between two consecutive pulses must equal or be shorter than (τ) .The repetition rates of cw –pumped Q-switched lasers typical range from a few kilohertz to a few tens of kilohertz and for pulsed pumped the repetition rate equal repetition pumpedsource . For this can many expressions may be found for pulse energy (E) ,pulse peak power (P_m) and real pulse duration (W) and by using the following equations,[Zhang 2000 ,Degnan 1995] .

σ is the stimulated emission cross-section of active medium
L is the remaining round-trip dissipative optical loss.
W_p is the radius of the pump beam in the gain medium
Wo is the beam waist
R is the reflectivity of the output mirror
T_o small –signal transmission of the saturable absorber is equal
Δτ is the normalized pulse duration
Φ_m is the maximum value of photon density
Φ_{integ} is the integral of photon density over τ from zero to infinity
h is the Planck's constant
γ is inversion reduction factor
hv is the laser photon energy

A saturable absorber is designed to have large ground state absorption (σ_{gsa}) at the lasing wavelength this prevent laser oscillation untill the population inversion gives gain exceeding the losses provided by the output mirror and saturable absorber. The ratio of the laser saturation energy to the absorber saturation energy defined by (α), [Degnan1989].
The inversion reduction factor is equal to ($\gamma = f_a + f_b$)where *fa* ,*fb* are,respectively, the Boltzman occupation factors of the upper and lower laser levels of the gain medium. For a Nd:YAG gain medium at room temperature, *fa* =0.19 and *fb* = 0.41 [Sulc 2005]. The ratio of the initial population inversion density to the threshold population inversion density can be expressed in equation (5)

3-The Proposed set-up of the design

A schematic set-up of the passive Q-switched device is shown in Fig.(1) It

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consists of the driver unit, the laser head, which contains the pump diode laser emitting optical power about 2W pulses of 808 nm wavelength and collimating the beam by a focusing lens of 238 µm focal length in active medium type (Nd:YAG) .One end has a high-reflection coating for the 1342nm wavelength to function as a mirror for the resonator and an antireflection (AR) coating for the 808nm wavelength to allow the pump beam to enter the rod. The other end has an AR coating for the 1342nm .The Stimulated emission cross section (6.5 × 10^{-19} cm^2) and Spontaneous fluorescence lifetime (240µs)[3]. The passive Q-switching V^{3+}:YAG. Crystal has 0.01 mm thickness, Small Signal transmission of 97 (%)@1342nm and ground state absorption cross(7.2x10^{-18} cm^2). This crystals was coated AR/AR at 1342nm to reduce losses, with 98.8 % transmission at 1342nm, and the output-coupling mirror radius of curvature of coupler mirror is 300mm with 5% transmission at 1342nm,this mirror with another plane mirror construct the optical resonator of hemispherical type having a length of 4 mm with beam waist of 121µm.

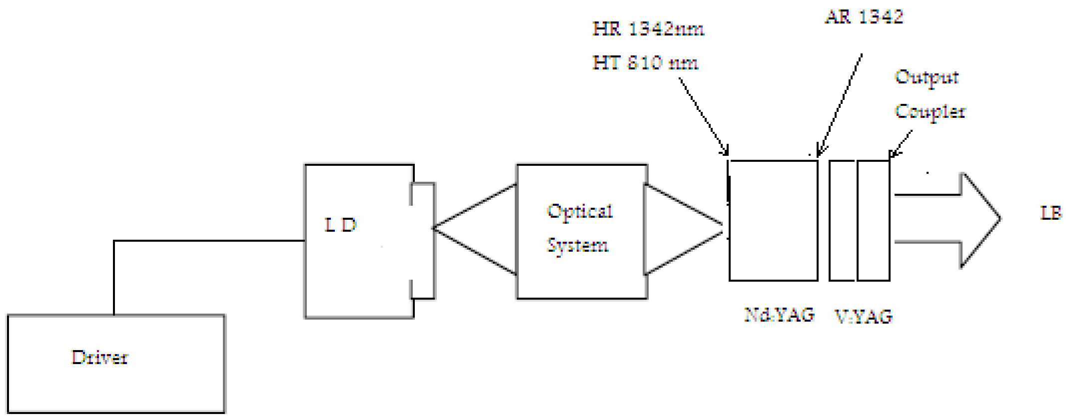


Figure (1) Schematic set-up of the passive Q- switched device

4-Calculations of system parameters

In the present work , pulse energy (*E*), Peak power (*Pm*) , and Real pulse width (*W*) have been calculating using equations[1,2&3]are70µj, 26KW and 2.6 ns respectively. We can shown in table (1) all parameters used for calculating the design model of passively Q- switched end pump laser system.

Table (1) design parameters

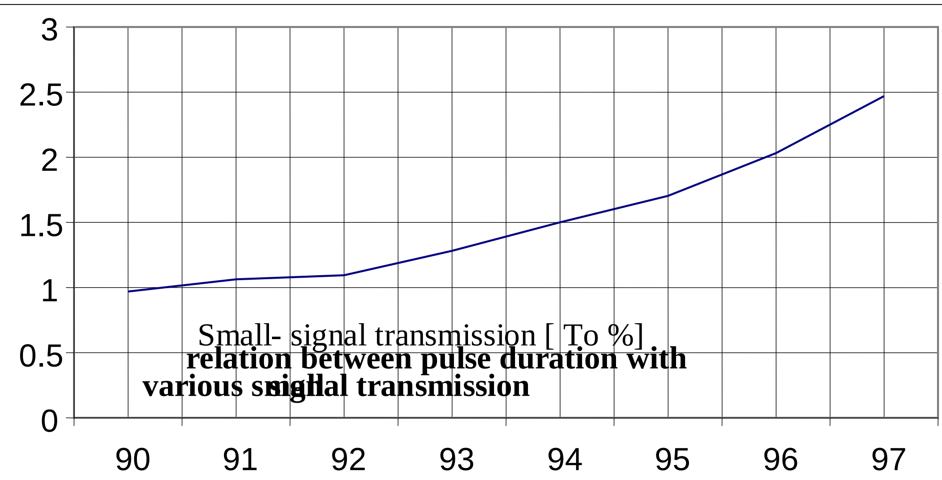
Parameters	Value
Simulated emission cross section	6.5 ×10^{-19} cm2
Spontaneous ;putrescence lifetime	240µs

Length of the laser rod	3 mm
Cavity round trip time tr	0.026ns
Photon energy	1.48×10^{-19} J
Spot size at the laser rod	121µm
Spot size at the GaAs wafer	100 µ m
Absorption Coefficient	31.4 cm^{-1} @ 808 nm
Absorption Length	0.32 mm @ 808 nm
Intrinsic Los	Less 0.3% cm^{-1} , @1064 nm
Refractive Index to saturable	1.82
Saturated TransmissionTmax @1342 nm	97 (%)
Small Signal TransmissionT0 @ 1342nm	40 (%)
Ground State absorption Cross-Section	($7.2x10^{-18}$ cm^2)
Excited Stateabsorption Cross-Section	(7.4 $x10^{-19}$ cm^2)
Contrast Ratio	10
Saturation Intensity	30 (MW/cm2)
Pump power	2W pulsed
Optical length of resonator	4 mm
Radius curvature of coupler mirror	300 mm
Beam waist	121µm
Focal length of afocal lens	200 µm
Reflectivity of the output mirror	0.95
Inversion reduction factor	0.6
length of saturable absorber	0.01 mm

the [α]	20
the [Δτ]	14
the [Φ_m]	0.1
the [Φ_{integ}]	1

Small- signal transmission of passive Q-switched ($V3^+$: YAG) has been investigated, figure (2) shows the relation between pulse duration with different Small- signal transmission of V: YAG passive Q-switch, the pulse duration decreasing slightly less than 1ns duration when the small- signal transmission of decreased to [90%]. When the small- signal transmission of V^{3+}: YAG decreased this will yields decreasing in quality factors which yield increased losses . Exceeding these losses with more pumping power means large energy store which is done by preventing laser oscillation until the population inversion gives a high gain exceeding the losses yielding fast oscillation and fast decreasing to the population inversion. Hence getting shorter pulse duration. In figure (3) shows the relation between peak power with different Small- signal transmission of V: YAG passive Q-switch, the peak power increased with decreased small- signal transmission. Normally when the pulse duration decreased ,the peak power increased .

Pulse duration [ns]



Figure(2)

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Peak power [Kw]

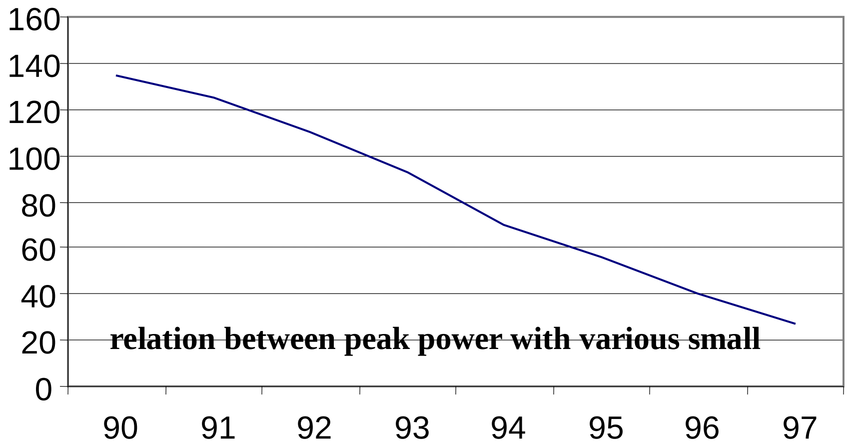

Figure (3) -
signal transmission

5-Simulation results

To check the designed calculated results we tried to compare such results with some simulation results. Which were evaluated using a software package for Q-switched solid state laser dynamics to evaluate the pulse energy (*E)*, peak power (*Pm)* , and pulse width (*W)* .The output of such package is shown in figure (4) .Thepulse energy *E = 69µJ*, peak power *Pm =28 KW* , and real pulse width *W = 2.47 ns* .We can shwon all parameters used for calculating the simulation model of passively Q- switched end pump laser system .

Laser Medium

Stimulated emission cross-section, cm^2 =7.140E-019
Peak absorption cross-section, cm^2 =7.200E-020
Absorption coefficient, cm^-1 =2.500
Degeneracy factor =1.000
Spectra overlap coefficient =0.252
Lasing wavelength, nm =1342.000
Active element refractive index =1.810
Concentration Nd, cm^-3 =1.380E+020
Tau 32, us =240.000
Tau 43, us =3.000
Tau 31, us =10000.000
Tau 21, us =0.010
Initial 1-level concentration =0.999937
Initial 2-level concentration =0.000063
Initial 3-level concentration =1.060E-024
Initial 4-level concentration =1.140E-026
Excitation quantum yield =1.000
Branching of luminescence =0.100
q1 =0.014
q =0.000064

Configuration
Cavity length, cm =0.400
Reflectivity of output coupler =0.950
Active element dissipative losses, cm^-1 =0.015
Intrinsic resonator losses =0.0040
Overlap efficiency =0.900
Lasing area, cm^2 =0.0090
La, cm =0.300
Lb, cm =0.100
Ld, cm =0.100

Pump
Pump duration, us =240.000
Pump power, W =2.000
Pump coupling optics efficiency =0.950
Pump reflectivity =0.950
Pump wavelength, nm =810
Pump scheme type =Endpump
Pumped length, cm =0.300
Pumped area, cm^2 =0.010
Average pump flow Fav, a.u. =1.019
Effective pump flow, W/cm^2 =968.301
Input intensity, W/cm^2 =950.000
Saturation pump intensity, W/cm^2 =2.255E+006

Shutter
Thickness, cm =0.010
Refractive index =1.835
Initial transmission =0.970
Shutter Type =Passive
Decay time, us =0.220
Absorption cross-section, cm^2 =10.000
SIGRESS =10.000
Shutter transmission causeed by nonresonator losses =1.000
SpecialSimulation period add, us =2.000

Result
Interctivity peak intensity, MW/cm^2 =99.244
Full output energy, J =0.00063
Full efficiency =0.263
Time of peak pulse, us =55.121
Output pulse duration, ns =2.472
Giant pulse output energy, J =0.000069
Giant pulse generation efficiency =0.028
Stored energy before the shutter switched on, J =0.00014

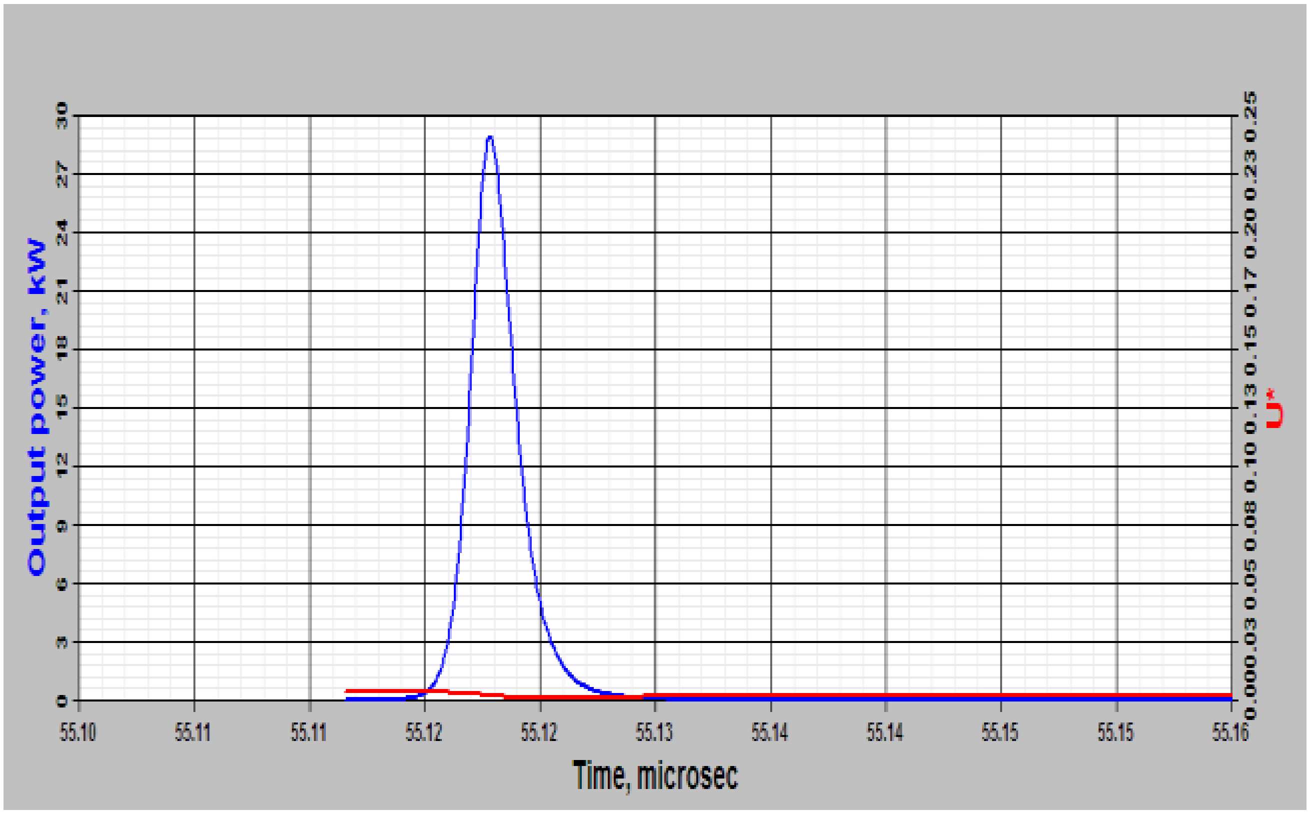

Figure (4) Laser pulse

6-Conclusions

Construction and adjustment of the simplest Q-switched laser systems, shorter laser resonators that are more compact, a smaller sensitivity to all mechanical disturbances, a robust and low-maintenance system, and the generation of shorter pulses. The crucial V:YAG passive Q-switched parameter that has been researched in this work that has an impact on the pulse energy, peak power, and pulse duration is thickness. Peak power and pulse duration were both enhanced as thickness increased. In light of this, it can be said that a careful selection of Q-switched crystal thickness should be fulfilled.

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