

Design and Characterization of V^{3+} :YAG Passive Q-switched end-pumped Nd: YAG Microlaser

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Abstract

Q-switched Microchip laser emitting radiation at wavelength 1342 nm was designed and characteristic study of a passively Q-switched (V^{3+} :YAG) diode pumped solid state laser system is presented , An active laser part (Nd $^{3+}$:YAG), and a saturable absorber (V^{3+} :YAG, $T_0 = 97\%$). The microchip resonator consists of dielectric mirrors directly deposited on the monolith Surfaces, the output coupler has reflecting 95% @ 1342 nm was placed on the V^{3+} -doped part. Q-switched microchip laser was tested under pulsed laser diode, has been investigated the laser output parameters such as energy, peak power, and pulse width a comparison between theoretically calculated results and simulation results using a software which calculates the Q-switched solid state laser parameters was performed. There was a good agreement with the theoretical calculations and the simulation values.

الخلاصة

تم في هذا البحث تصميم ليزر الحالة الصلبة ذات المفتاح السليبي نوع (V^{3+} :YAG) والمضخوخ بشكل طولي بواسطة ليزر أشباه الموصلات والذي يدعي (Microchip laser) لإنتاج نبضة ليزر ذات طول موجي (1342nm) باستخدام بلورة (Nd $^{3+}$:YAG) كوسط فعال . المرنان البصري يتألف من مرآتين أحدهما ذات انعكاسيه تامة والمرآة الأخرى ذات انعكاسيه جزئيه 95% للطول الموجي 1342 nm ، كما تمت دراسة تأثير خصائص المفتاح السليبي نوع (V^{3+} :YAG) ذات النفاذية . ($T_0 = 97\%$) على خصائص نبضة ليزر الحالة الصلبة نوع (Nd:YAG) من حيث ألقدره , الطاقة وعرض النبضة . نتائج الحسابات التصميمية المستخلصة تمت مقارنتها مع نتائج ألتشيبييه المستخلصة من برنامج معد لغرض حساب معلمات ليزرات الحالة الصلبة ذات مفتاح عامل نوعيه و أظهرت توافقا جيدا فيما بينها .

1- Introduction:

Most of the solid state passive Q-switches which have been developed have operated using the 1064nm transition of Nd $^{3+}$ and therefore have been based on the saturable absorption of Cr $^{4+}$ ions [Swidersti 2005]. The operation of Cr $^{4+}$ devices ranges from approximately 900-1100nm, depending on the host properties [Zhang 1997]. a new saturable absorber, which could operate at longer wavelengths, in particular with the 1342nm transition of Nd $^{3+}$ two absorption peaks were observed at 1140nm and 1320nm, and attributed to the 3A $_2 \rightarrow$ 1E(1D) and 3A $_2 \rightarrow$ 3T $_2$ (3F) transitions respectively of the tetrahedrally coordinated V $^{3+}$ ion [Malyarevich 1998]. The fast decay of the 1E(1D) level to 3T $_2$ (3F) has previously been measured to be 0.13ns[Jabczy 2001]. To complete our knowledge of the system we measured the lifetime of the longer-lived decay 3T $_2$ (3F) \rightarrow 3A $_2$ using a pump-probe technique. Laser pulses at 1080nm with 15ps pulse duration were used for pumping and probing. The lifetime of the 3T $_2$ (3F) level was found to be (22 - 6)ns[Sun and Hou 2008]. Trivalent neodymium was the first rare-earth ion to be used in a gain material, and has remained the most commonly used active ion found in solid state lasers. The intense luminescence and absorption of the narrow energy levels of Nd $^{3+}$ along with a workable fluorescence lifetime have helped Nd $^{3+}$ achieve its

dominance. It is traditionally pumped on either the 760nm or 810nm absorption bands though it can also be pumped in the green spectral region. The two main photon decay routes from the 4F3/2 metastable level are the 4F3/2 → □4I11/2 transition (producing radiation at ~1.06μm) and the 4F3/2 → □4I13/2 transition (producing radiation at ~1.3μm). Both of these are four level systems, giving efficient CW operation on these transitions at 300K and above, without significant population in the lower lasing level causing reabsorption. The third transition 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 thermal population. The fourth transition is two orders of magnitude weaker, though has been shown 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) [Svelo 1998]. 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 the inversion is roughly equal to the upper –state lifetime (τ) of active medium, 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 pumped source . 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] .

$$E = \frac{\pi * h \nu * W_o^2}{4 * \gamma * \sigma} \ln\left(\frac{1}{R}\right) * \Phi_{integ} \text{-----} (1)$$

$$P_m = \frac{\pi * h \nu * W_o^2}{4 *} \left[\ln\left(\frac{1}{R}\right) + \ln\left(\frac{1}{T_o^2}\right) + L \right] * \ln\left(\frac{1}{R}\right) * \Phi_m \text{---} (2)$$

$$W = \frac{t_r * \Delta \tau}{\ln\left(\frac{1}{R}\right) + \ln\left(\frac{1}{T_o^2}\right) + L} \text{-----} (3)$$

Where:

- 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
- W_o is the beam waist
- R is the reflectivity of the output mirror

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T_o small –signal transmission of the saturable absorber is equal

$\Delta\tau$ 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

$h\nu$ 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), [Degnan 1989].

$$\alpha = \frac{\sigma_{gsa}}{\gamma * \sigma} \text{-----} (4)$$

The inversion reduction factor is equal to ($\gamma = f_a + f_b$) where f_a , f_b 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, $f_a = 0.19$ and $f_b = 0.41$ [Sulc 2005]. The ratio of the initial population inversion density to the threshold population inversion density can be expressed in equation (5)

$$N = \frac{\ln\left(\frac{1}{R}\right) + \ln\left(\frac{1}{T_o^2}\right) + L}{\ln\left(\frac{1}{R}\right) + \left(\frac{\sigma_{esa}}{\sigma_{gsa}}\right) * \ln\left(\frac{1}{T_o^2}\right) + L} \text{-----} (5)$$

Where:

σ_{esa} is the excited –state absorption cross-section area of the saturable absorber.

σ_{gsa} is the ground-state absorption cross-section area of the saturable absorber.

3-The Proposed set-up of the design

A schematic set-up of the passive Q-switched device is shown in Fig.(1) It consists of the driver unit, the laser head, which contains the pump diode laser emitting optical power about 2 W pulses of 808 nm wavelength and collimating the beam by a focusing lens of 238 μ m 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 ($6.5 \times 10^{-19} \text{ cm}^2$) and Spontaneous fluorescence lifetime (240 μ s) [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 ($7.2 \times 10^{-18} \text{ cm}^2$). 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 121 μm .

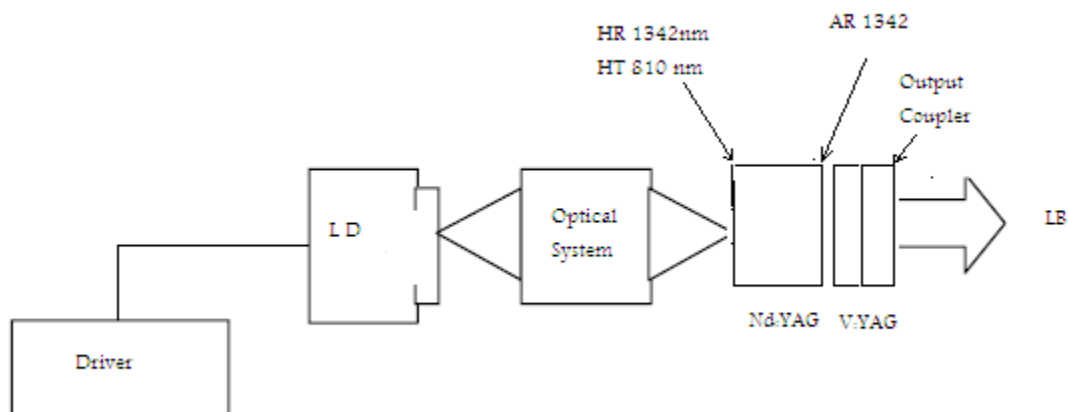


Figure (1) Schematic set-up of the passive Q- switched device

4-Calculations of system parameters

In the present work ,pulse energy (E), Peak power (P_m) , and Real pulse width (W) have been calculating using equations[1,2&3] are 70 μJ , 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	$6.5 \times 10^{-19} \text{ cm}^2$
Spontaneous ;putrescence lifetime	240 μs
Length of the laser rod	3 mm
Cavity round trip time t_r	0.026ns
Photon energy	$1.48 \times 10^{-19} \text{ J}$
Spot size at the laser rod	121 μm
Spot size at the GaAs wafer	100 μm
Absorption Coefficient	$31.4 \text{ cm}^{-1} @ 808 \text{ nm}$
Absorption Length	0.32 mm @ 808 nm

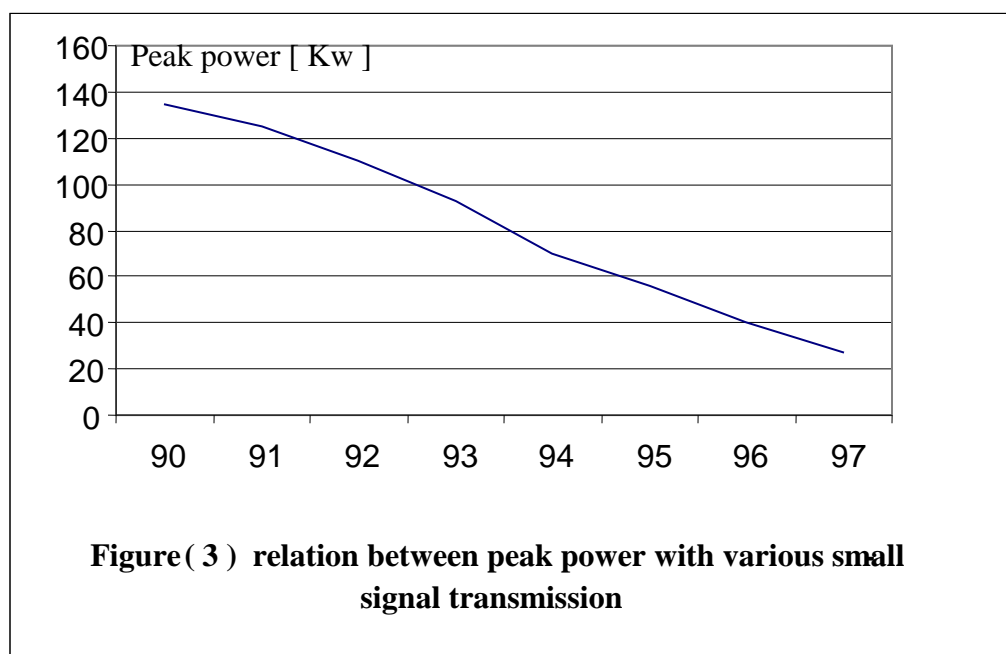
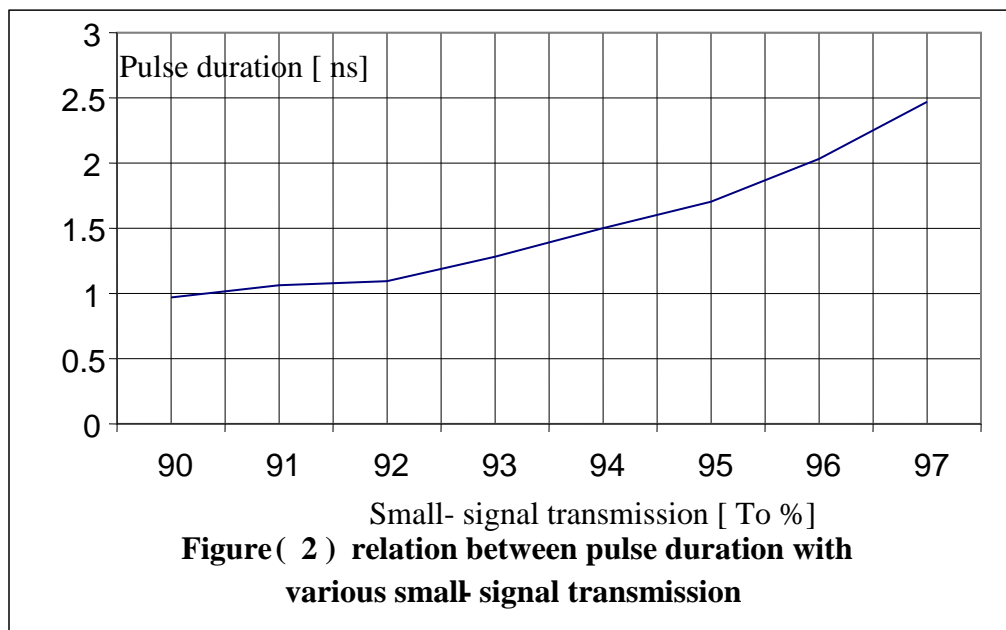
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Intrinsic Los	Less 0.3% cm ⁻¹ , @1064 nm
Refractive Index to saturable	1.82
Saturated Transmission Tmax @1342 nm	97 (%)
Small Signal Transmission T0 @ 1342nm	40 (%)
Ground State absorption Cross-Section	(7.2x10 ⁻¹⁸ cm ²)
Excited State absorption Cross-Section	(7.4 x10 ⁻¹⁹ cm ²)
Contrast Ratio	10
Saturation Intensity	30 (MW/cm ²)
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 V³⁺: 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

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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 .



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 (P_m), and pulse width (W). The output of such package is shown in figure (4). The pulse energy $E = 69\mu J$, peak power $P_m = 28 KW$, 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, $cm^{-3} = 1.380E+020$

τ_{32} , us = 240.000

τ_{43} , us = 3.000

τ_{31} , us = 10000.000

τ_{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

$q_1 = 0.014$

$q = 0.000064$

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, $cm^2 = 0.0090$

L_a , cm = 0.300

L_b , cm = 0.100

L_d , cm = 0.100

Pump

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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, cm² =0.010
Average pump flow Fav, a.u. =1.019
Effective pump flow, W/cm² =968.301
Input intensity, W/cm² =950.000
Saturation pump intensity, W/cm² =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, cm² =10.000
SIGRESS =10.000
Shutter transmission caused by nonresonator losses =1.000
Special Simulation period add, us =2.000

Result

Interactivity peak intensity, MW/cm² =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

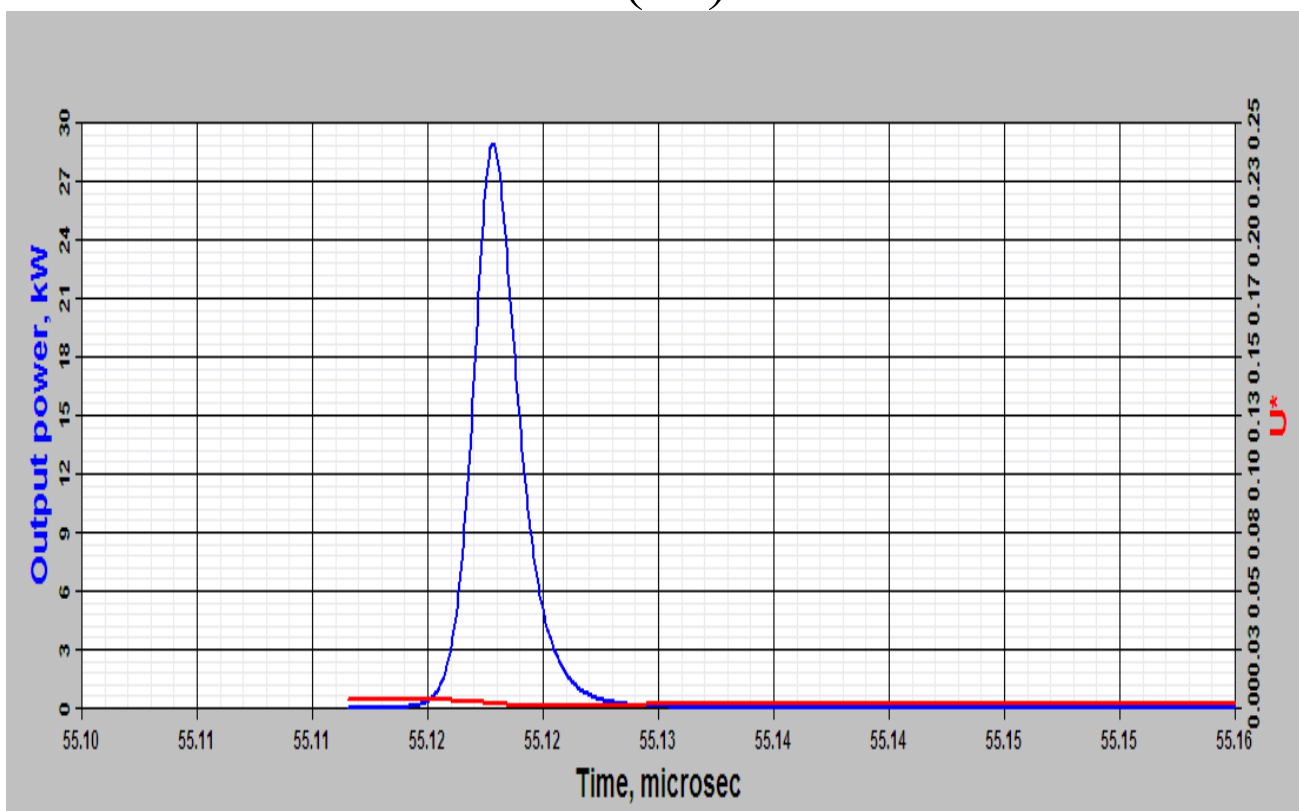


Figure (4) Laser pulse

6-Conclusions

Simplest Q-switched laser system construction and adjustment, shorter laser resonator more compact laser system, smaller sensitiveness to all mechanical disturbance, rugged and low-maintenance system, generation of shorter pulses. The important parameter of V:YAG passive Q-switched affecting the pulse energy ,peak power and pulse duration ,which have been studied in this work is thickness. The thickness increase lead to decreased pulse duration and increased peak power. Thus it can be concluded that a careful choice of Q-switched crystal thickness should be satisfied.

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