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ORIGINAL RESEARCH ARTICLE

Laser Study on Q-switch of Cr4 +: YAG Self-saturated Crystals

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ABSTRACT

In recent years, with the rapid development of computer technology applications, computer simulation experiments have been widely used in various fields of science and application, plays an important and indispensable role. Similarly, computer simulation experiments in laser research are also important; it can be a limited amount of time in a large number of repeated experiments, resulting in the characteristics of the laser curve to study. If the same actual experiment, the time required is very long, the investment of funds is huge. So through the computer simulation experiment to guide the actual experiment, can study the smooth progress. It is the guarantee of actual experiment.

KEYWORDS: -

1. Introduction

Solid tunable laser has the advantages of compact structure, wide tuning range, convenient tuning, large output power and high repetition rate. It quickly replaced the dye tunable laser as the active field of laser research. The tunable range of Cr4 + ions can cover the spectral region of 1.1μm-1.8μm, which includes many very important bands, such as the zero loss of the fiber, the zero dispersion area and the safety band of the human eye. In the optoelectronic information technology, Spectroscopy, atmospheric measurement, environmental monitoring, life sciences and semiconductor materials research has important applications. In the Cr4 + ion as the activation of the central ion of the laser crystal, the transition metal ion solid tunable laser was successfully operated. Cr4 + -doped solid-state lasers become an important member of solid tunable lasers. The study of Cr4 + -doped laser materials is also one of the main hotspots in the study of solid tunable lasers, which is the main direction of future long-term development.

Q-switched lasers, also known as giant pulsed lasers, were proposed in 1961. It was envisioned to use a method to compress all the optical radiation into a very narrow pulse; in 1962, Q-switched lasers output peak power of 600 kilowatts, pulse width of 10-7s order of magnitude; the next few years the development of very fast, there have been a variety of Q-Q method (such as electro-optical Q, acousto-optic Q, saturable absorption Q, etc.), the output power is almost straight up, pulse width compression has also made great progress;

As the laser Q switch material Cr: YAG, in the 0.9 ~ 1.2μm band has a wide absorption band and saturable absorption characteristics, compared with the traditional Q-based material with a large state of alkali absorption, high doping concentration, good thermal conductivity, saturation Low strength, high damage threshold, stable physical and chemical properties, no degradation phenomenon, etc., can be a good alternative to the commonly used saturated absorber, which is high power, high repetition rate Nd or Yb ion doped solid-state laser ideal Q switch material The 1.06μm absorption band is the result of four-coordinated Cr ion transitions. This wide absorption band coincides well with the 1.06μm emission band of Nd ion, making it ideal for Q-switched luminescence with ion-doped lasers. Cr4 +: YAG passive Q-switched lasers provide pulses with high peak power and high repetition rate in the nanosecond range and can be used in a wide range of applications such as micro machines, ranging, telemetry and miniature surgery, and have saturated light intensity Small, good thermal conductivity, stable chemical properties, high damage threshold characteristics, it is easy to make small size, cheap pulse laser. Cr4 +: YAG passive Q-switched lasers have the characteristics of high beam quality, high stability, long life, short pulse and wavelength tunable. Therefore, the research of Cr4 +: YAG passive Q-switched lasers are of great significance and value.

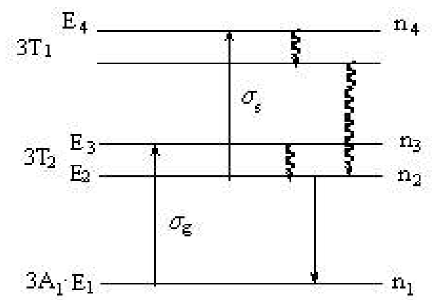
2. The principle of introduction

(A), Cr: YAG crystal Q-switched principle

YAG crystal in the xenon lamp under the light pump to launch natural light, through the polarized prism, into the x-direction linear polarization, if the modulation of the crystal without voltage, light along the optical axis through the crystal, the polarization state does not change, After the mirror is reflected, again (no change) through the modulation of the crystal and the polarized prism, the electro-optical Q switch is in the 'on' state. If the voltage is applied to the modulating crystal, the linearly polarized light passes through the crystal in the x direction and is reflected by the omnidirectional mirror. After passing through the modulated crystal again, the polarization plane is deflected by 900 with respect to the incident light. With the polarized prism, the Q switch is in the 'off' state. If the xenon lamp dares to start igniting, the voltage is applied to the crystal in advance, so that the resonator is in the low state of 'off', and the laser oscillation is blocked. When the number of particles on the laser can be reversed to the maximum, the voltage on the crystal is suddenly removed, and the laser is instantaneously in a high Q state, resulting in a blood-shaking laser oscillation. Complete a series of Q-transfer process.

(B), Cr $^{4+}$: YAG crystal properties and spectral characteristics

$Cr^{4+}:YAG$ Crystal is a new type of optical crystal, the crystal of Cr $^{4+}$ ions on the 1.06 μm light intensity with self-saturation performance. The Cr $^{4+}$ ions in the crystal have self-saturation properties for the strong light of 1.06 μm. This is related to its energy level properties, as shown in Figure 1 for its energy level diagram. The four energy levels associated with self-saturation are E_1 , E_2 , E_3 , E_4 , the corresponding number of particles is n_1 , n_2 , n_3 and n_4 , apparently $n_1 + n_2 + n_3 + n_4 = n_0$, where the n_0 concentration of Cr $^{4+}$ ions in the self-saturated crystal.



As the E_3 life of the E_4 very short, so $n_3 \rightarrow 0$, $n_4 \rightarrow 0$, inherent $n_1 + n_2 = n_0$.

When the incident light is weak, that is $Cr^{4+}:YAG$, when the crystal is not bleached, the transmittance is

$$T_0 = \exp(-\sigma_g n_1 l')$$

Where $\sigma_g = 1.2\times 10^{-9}\ cm^2$ for $E_1 \rightarrow E_3$ is the transition section, l' the length of the $Cr^{4+}:YAG$ crystal.

In the incident light intensity, $Cr^{4+}:YAG$ the crystal is bleached after the transmittance

$$T_s = \exp(-\sigma_s n_2 l')$$

Where $\sigma_s = 1\times 10^{-9}\ cm^2$ for $E_2 \rightarrow E_4$ is the transition section.

The equation of the number of particles in the $Cr^{4+}:YAG$ crystal, since the previous analysis has been, $n_3 \to 0$, $n_4 \to 0$, and $n_1 + n_2 = n_0$, it is only necessary to n_2 establish the rate equation can be.

Ignoring the tiny spontaneous radiation and so on by the above figure shows the n_2 particle rate equation:

$$\frac{dn_2}{dt} = S_{32} n_3 - S_{23} n_2 - A_{21} n_2$$

Because the E_3 energy level of the energy level is extremely short, and the E_3 energy levels of the particles almost all of the transition to the E_2 energy level, there are. So the above $S_{13} n_1 = S_{32} n_3$ rewrite is:

$$\frac{dn_2}{dt} = S_{13} n_1 - S_{23} n_2 - A_{21} n_2$$

So $N' = n_2$, and $n_1 + n_2 = n_0$, $S_{13} = c_3\sigma_g(\nu)\frac{L}{l'}\Phi$, $S_{23} = c_3\sigma_s(\nu)\frac{L}{l'}\Phi$, $A_{21} = \frac{1}{\tau'}$ so you can get:

$$\frac{dN'}{dt} = c_3\sigma_g(\nu)\frac{L}{l'}(n'_0 - N')\Phi - c_3\sigma_s(\nu)\frac{L}{l'}N'\Phi - \frac{N'}{\tau'} \quad (1)$$

τ' for the E_2 energy level of the particle.

(3) Rate equation theory

The theory of velocity equation is used to describe the process of Q-pulse formation and the influence of each parameter on the process. The main contents are the equations describing the law of the number of intra-cavity oscillating photons and the number of reversed particles with time. According to the equations, the relationship between the peak power, the pulse width and the number of particles inversion can be deduced.

$$\frac{d\Delta n}{dt} = 2n_1 W_{13} - 2\Delta n\frac{A}{g}\phi - 2n_2 A$$

$$\frac{d\phi}{dt} = \Delta n\frac{A}{g}\phi - \delta\phi$$

Three - Level rate equation

$$\frac{d\Delta n}{dt} = n_1 W_{14} - \Delta n\frac{A}{g}\phi - \Delta n_2 A$$

$$\frac{d\phi}{dt} = \Delta n\frac{A}{g}\phi - \delta\phi$$

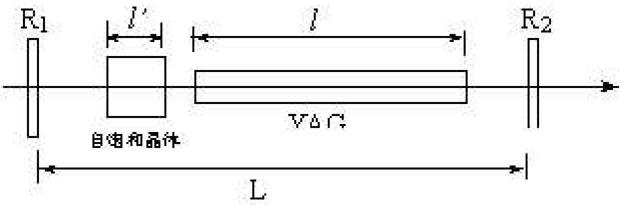
Four - level rate equation

The rate equation is first described by A.A.Vuylsteke and W.G.Wanger, and the rate equations of the fast Q-Q mechanism are given. Two equations are used to describe the intra-cavity photon number density and the number of particles in the active medium to change with time. A.Szabo et al. presented a passive Q-switched rate equation group with the third equation used to describe the density of the saturated absorber particle with time. These equations are continually modified and referenced in subsequent studies, but the above equations are based on the assumption that the pump light distribution, the intra-cavity photon density distribution, the saturation the recovery rate of the absorber is uniform. For the currently used LD pumped Q-switched lasers, these assumptions are too simple to describe the number of ions in the cavity, using the above equation of velocity to calculate the pulse output characteristics, especially the pulse width calculation, and the actual Deviation is greater. After Zhang and others consider the use of the rate equation to study the laser output characteristics, the proposed cavity photon density was spatial Gaussian distribution theory, the results show that this assumption is closer to the actual results. The problem is that they do not consider the effect of pumping rate and the stimulated radiation lifetime of the laser medium on the Q-switched effect. In addition, they considered the influence of the cross-sectional area of the laser-activated medium and the saturated absorber on the Q-Q characteristics, but only gave an average photon number density value, without describing the longitudinal distribution of the photon density along the resonator. In recent years, there are scientific research workers in this regard as far as possible all aspects of consideration, can be consistent with the results of the experiment.

3. The overall design of Q-switched lasers

(A) Q-switched laser experimental device

In Fig. 2, L is the cavity length, l Nd: YAG rod length, l self-saturated crystal (Q-switch) length, output mirror reflectivity R, total reflector reflectivity l, set the cavity photon concentration Φ, YAG rod The inversion concentration of the number of inner particles is N, the concentration of the low energy level particles is the concentration of the particles in the N_1, $C^{4+}:YAG$ crystal, that is N', the foregoing n_2 .



This experiment assumes that

Diameter

Length L = 300 mm.

Cr: YAG $^{4+}$ crystal and Nd: YAG crystals have a refractive index of 1.82.

(B) Working material

Working material is the core of the laser; it is doped with ionic dielectric crystal or glass material processing. Working material according to the activation of ion energy level structure can be divided into three levels and four levels of system. The shape of the working material is rod-like, flat and tubular, of which the use of rods most. The solid laser working material consists of activated ions and matrix two parts, in which the activation of the ion energy level structure determines the laser spectral characteristics and fluorescence life and other laser properties. The matrix determines the physical and chemical properties of the working substance.

To obtain a good pulse laser, for the working material, we must first have the high energy storage performance, that is, the laser energy level can accumulate a large number of particles, it requires the stimulated radiation cross-section is small, that is, the energy level of long life, spectrum Line wide, which can prevent or reduce the occurrence of super-radiation. In addition, it also requires a higher anti-glare damage threshold, can withstand higher laser power density. The Nd: YAG crystal basically satisfies the above requirements and also has excellent physical, chemical, laser and thermal properties, can be made with continuous high repetition efficiency devices, Q-switched device peak output power has been up to several hundred megawatts , So be selected as the working material of this laser.

(C) Focus chamber

The role of the condenser cavity is to effectively and uniformly converge the light energy radiated from the pump source to the working material in order to obtain high pumping efficiency. The efficiency of the radiant energy emitted from the pump source to the laser working material determines the overall efficiency of the laser system to a large extent. In addition to providing good coupling between the pump source and the working material, the condenser chamber also determines the distribution of the pump optical density on the laser material, thereby affecting the uniformity, divergence and optical distortion of the output beam. As the laser working material and pump lamps are installed in the condenser cavity, the rational design of the condenser cavity is to determine the performance of solid-state laser one of the important conditions.

A wide range of condenser cavity, commonly used in the following types: elliptical column condenser cavity, tight coupling non-focusing condenser cavity, diffuse cavity and so on. Taking into account the Nd: YAG laser efficiency is low, in order to improve the output power, improve the pump uniformity, we use Teflon diffuse tight package cavity.

Q-pulse operation requires that the laser working material has high energy storage. If the energy storage distribution is not uniform, the dynamic laser output energy will be limited. Therefore, the solid-state lasers with Q-switched operation must be pumped evenly both sex and efficiency. In contrast, pump uniformity is more important. Diffuse reflector cavity is a non-imaging lighting cavity, due to the results of diffuse reflection, light uniformity is better, in the laser rods in the distribution of energy storage more uniform, eliminating the crystal 'strong', an increase of 'closed door' ability.

The structure and focusing characteristics of the diffuse reflector cavity are similar to those of the tight coupling cavity, which has a reflection coefficient of up to 90% to 98%, so that it's optical efficiency is high. And it has good stability, can be used for a long time, the production process is not complicated, low cost, in particular, it can achieve uniform optical pumping, which is to improve the output of Q-switched lasers is very important

Concentration efficiency is an important index to evaluate the quality of the condenser chamber. The total energy converted from the light source to the laser rod can be approximated by the following equation [133]:

$$\eta = \eta_g \times \eta_p \qquad (5.1)$$

Where Ge is the geometric transfer function of the condenser cavity, indicating that the direct light and the cavity wall reflect the percentage of the laser rod in a lossless state. Op is the optical efficiency of the focusing chamber, which essentially reflects the total loss in the system. Op is represented by:

$$\eta_\varphi = r_w(1-r_r)(1-\alpha)(1-f) \qquad (5.2)$$

Rw is the reflectance of the cavity wall to the pump light, rr is the reflection loss of the surface of the laser rod and the surface of the glass coolant sleeve, and the Fresnel loss of any filter inserted in the cavity, The absorption loss of the medium, and f is the ratio of the nonreflective area of the cavity to the total inner surface area. When the cavity type is selected, op is basically determined; Ge is determined by the specific structural parameters of the condenser chamber.

The transmission efficiency of the focusing chamber refers to the ratio of the amount of light energy that is intercepted by the laser rod to the total light energy converged to the rod, depending on the size of the pump light converging at the rod and the size of the laser rod radius. In general, the condenser cavity is designed by using its inner wall reflection to pump the pump light onto the laser rod, and the diffuse reflection cavity is a non-imaging system. Instead of using geometric reflection imaging, the diffuse reflection material with high reflectivity is used as a condenser The inner and the reflector pump light are uniformly mixed in the condenser, so that the transmission efficiency of the diffuse reflection condenser chamber is lower than that of the imaging mirror reflection condenser chamber. In order to reduce the loss of light energy, the diffuse reflection condenser cavity should be designed as tight coupling form, compressed space volume.

In addition, the output efficiency of solid-state lasers is only a few percent, and the energy of the input pump lamps becomes heat in most of the conversion links. Roughly estimate that the heat dissipated on the pump lamp is about 50% of the total input energy, about 15% of the heat dissipated on the laser rod, and about 30% of the heat dissipated in the condenser chamber. Thereby increasing the temperature of the rod, lamp and condenser chamber. This is especially true in devices that operate continuously and with high repetition rates. Therefore, it is very important to design the cooling channel of the condenser cavity reasonably. In order to ensure the normal operation of the entire pump system, we use the condenser, pump and laser rods are water-cooled way: the condenser cavity itself is dry, a special cooling pipe; krypton lamp and laser rods were installed in the cooling Liquid pipe, and through the liquid hole and the condenser in the water channel connected to the entire laser into the water circulation cooling system.

4. The initial conditions for solving the equation:

To solve the ordinary differential equations, also need a set of initial conditions:

(1), when the Q switch is turned on, the initial concentration of Nd + 3: YAG is equal to the threshold when the self-saturated crystal is 'off' N_{th}' . Which is $N_0 = N_{th}'$

Because: $$\gamma(\upsilon) = \frac{a_0(\upsilon) - \ln(T_0 R)}{l}$$

$$N_{th}' = \frac{\gamma(\upsilon)}{\sigma_2(\upsilon)}$$

And so: $$N_0 = \frac{a_0(\upsilon) - \ln(T_0 R)}{\sigma_2(\upsilon) \times l}$$

(B), the initial laser low-energy particles concentration, due to low-level spontaneous emission probability, it can be considered at the initial moment is zero,

$$n_1(0) = 0$$

(C), the initial cavity photon concentration, that is, the resonant cavity reaches the threshold when the cavity of the ultra-radiation intensity, the experiment

$$\phi(0) = 0.0002 N_{th}$$

And then the corresponding pump rate can be calculated according to the following formula

$$W_p = \frac{N}{n\tau_2}\left[1 - \exp(-\frac{t}{\tau_2})\right]$$

Pump time should not exceed $\tau_2 / 2$.

(D), $\mathcal{E}^{4+}$ YAG crystal of the initial particle concentration, that is, the initial is: $\mathcal{E}^{4+}$ YAG crystal high-energy particles,

Because the initial pump has not yet begun, very little $(N'(0) \to 0)$ energy level particles, so we can think

$$N'(0) = 0$$

Since the equations of this experiment are nonlinear differential equations, and the optical pulses are completed in tens of nanoseconds, the selection of the step size is very important. If the results are too large, they are not accurate and lost Pulse curve, if too small a small number of computers will be calculated, spend a lot of time the process of generating a large pulse is completed within a few tens of ns, can set the maximum running time of 200ns. The time step of the drawing is (1) the step size of the self-saturated crystal bleach is 200ns / 2000; (2) the run pulse is 200ns / 600;

5. The fourth - order Runge - Kutta method is used to solve the differential

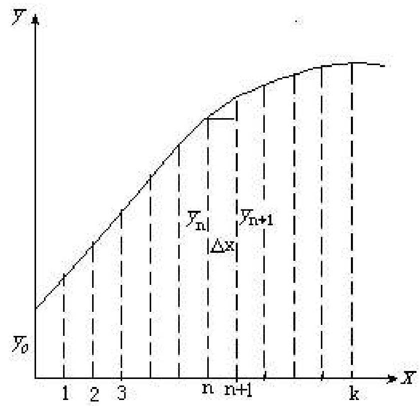
equation

The ordinary differential equation can be expressed as follows:

$$\frac{dy}{dx} = f(x, y) \qquad (1\text{-}1)$$

Which is

$$dy = f(x, y)dx$$



(3) Numerical calculation of differential equation

Its solution can be expressed with indefinite integral

$$y = \int f(x, y)dx \qquad (4)$$

In the case of known initial conditions, the above equation can be calculated point by point using the following approximate formula

$$y_{n+1} = y_n + f(x, y)\Delta x \qquad (5)$$

This can be clearly seen by (Figure 1). The calculation starts at n = 0. Where the step is called step size, if the step length is shorter, the calculation is more accurate. But the more time spent. In order to take the step size is not too large, but to ensure certain accuracy, we use (1-4) to replace (1-3) type of calculation, which is the Longge - Kutta method.

$$y_{n+1} = y_n + \frac{h}{6}(k_0 + 2k_1 + 2k_2 + k_3) \qquad (6)$$

Where

$$k_0 = f(x, y)$$

$$k_1 = f(x + h/2, y + k_0 h/2)$$

$$k_2 = f(x + h/2, y + k_1 h/2)$$

$$k_2 = f(x + h/2, y + k_2 h)$$

In the solution of differential equations, with x_i and y_i instead of y and x, where i is the number of equations.

6. Parameter calculation and rate equation standardization

From the above we can see that we asked for the equations

The following are the same as the

$$\frac{d\Phi}{dt} = c_1\sigma(\nu)\frac{l}{L}N\Phi - c_1\sigma_g(\nu)(n'_0 - N')\frac{l'}{L}\Phi - c_1\sigma_s(\nu)\frac{l'}{L}N'\Phi - \frac{\Phi}{t_c}$$

$$\frac{dN}{dt} = W_p(n_0 - N - 2N_1) - 2\times 0.6c_2\sigma(\nu)\frac{L}{l}N\Phi - \frac{2(N+N_1)}{\tau_2} + \frac{N}{\tau_0}$$

$$\frac{dN_1}{dt} = 0.6c_2\sigma(\nu)\frac{L}{l}N\Phi + \frac{(N+N_1)}{\tau_2} - \frac{N}{\tau_0}$$

$$\frac{dN'}{dt} = c_3\sigma_g(\nu)\frac{L}{l'}(n'_0 - N')\Phi - c_3\sigma_s(\nu)\frac{L}{l'}N'\Phi - \frac{N'}{\tau'}$$

In order to facilitate the solution of the equation, the following transformation is used for the above equation

$$\phi = \frac{\Phi}{n_0} \quad n = \frac{N}{n_0} \quad n' = \frac{N'}{n_0} \quad F = \frac{n'_0}{n_0} \quad n_1 = \frac{N_1}{n_0}$$

N represents the concentration of neodymium ions doped in the YAG rod, and the constants in the equation are calculated using the following formulas:

$$B_1 = c_1\sigma(\nu)n_0\frac{l}{L}$$

$$B_2 = c_1\sigma_g(\nu)n_0\frac{l'}{L}$$

$$B_3 = c_1\sigma_s(\nu)n_0\frac{l'}{L}$$

$$B_4 = c_2\sigma(\nu)n_0\frac{L}{l}$$

$$B_5 = c_3\sigma_g(\nu)n_0\frac{L}{l'}$$

$$B_6 = c_3\sigma_s(\nu)n_0\frac{L}{l'}$$

$$c_1 = c/\eta$$

$$c_2 = c/\eta$$

$$c_3 = c/\eta'$$

The equation can be reduced to:

$$\frac{d\phi}{dt} = B_1 n\phi - B_2(F-n')\phi - B_3 n'\phi - \frac{\phi}{t_c}$$

$$\frac{dn}{dt} = W_P(1-n) - 2*0.6B_4 n\phi - \frac{2(n+n_1)}{\tau_2} + \frac{n_1}{\tau_0}$$

$$n_1 = 0.6B_4 n\phi + \frac{n_1+n}{\tau_2} + \frac{n}{\tau_0}$$

$$\frac{dn'}{dt} = B_5(F-n')\phi - B_6 n'\phi - \frac{n'}{\tau'}$$

7. The results and analysis of the simulation experiment

Through the above data modeling, we can write a simulation for the Cr4 +: YAG crystal Q-switched process of the computer

Simulate the program. I changed the chrome particle concentration and output mirror reflectivity R, Cr4 +: YAG crystal Q-switched process to carry out multiple tests.

(A), the chrome particle concentration is respectively $n_0 = 3\times10^{18}cm^3$, $4\times10^{18}cm^3$, $5\times10^{18}cm^3$ and the output mirror reflectivity is fixed at R = 0.4,

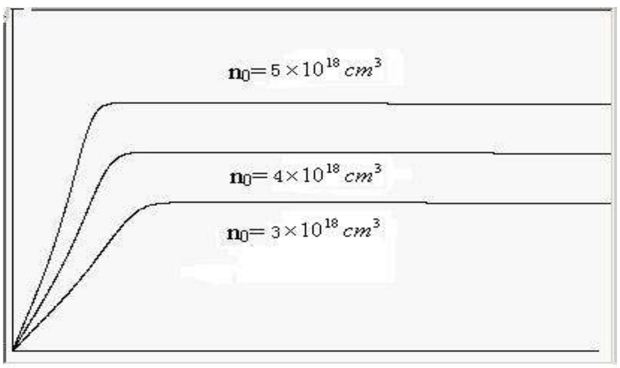


Figure 1. Q switch bleach map

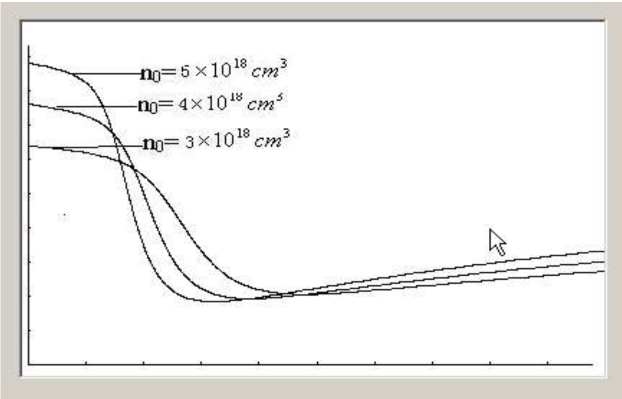


Figure 2. gain saturation diagram

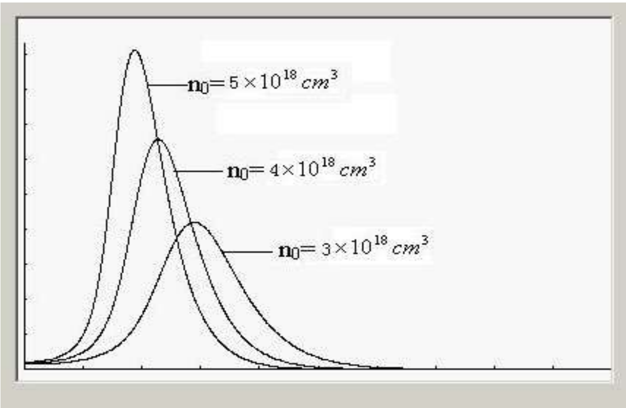


Figure 3. laser giant pulse map

N0 (*10^{19}) (Chromium particle concentration)	T0 (Initial transmittance)	Ts (Saturation transmittance)	Nth (Threshold)	$R = \frac{T_s}{T_0}$ (Transmittance)
0.5	*0.11*	*0.9999*	*4.41*	*9.02*
0.4	*0.17*	*0.9999*	*3.80*	*5.81*
0.3	*0.27*	*0.9999*	*3.21*	*3.74*

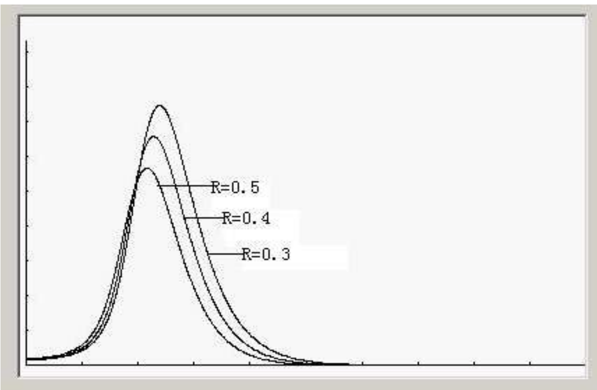
From (Figure 1), we can get the following results: With the increase of $Cr^{4+}:YAG$ crystal doping concentration, the particle inversion concentration of the crystal after bleaching also increases. And the particle inversion concentration of the crystal increases with time, and when the time increases to a certain value, the curve of the particle inversion concentration tends to be stable, indicating that the particle inversion concentration of the crystal has reached Saturated, with a certain value, the transmittance tends to T_s (i.e., the transmittance after bleaching).

(Figure 2) (Figure 3) and Table 1 can be the following results:

With the increase of the $Cr^{4+}:YAG$ crystal doping concentration, the initial transmittance is reduced, which is equivalent to the threshold when the laser Q-switched crystal 'off' is increased, so that the concentration of the $Nd^{+3}:YAG$ particle inversion is increased, The increase of the concentration of the laser, the laser output pulse peak power increases, the formation of a good giant pulse.

It can be seen from the above two graphs that increasing the concentration of chrome particles (doping concentration) can make the $Cr^{4+}:YAG$ crystal reach saturation more quickly and increase the peak value of the laser giant pulse, so increase the doping concentration for high energy pulse Q-switched lasers Play a major role.

(C), the chrome particle concentration is fixed at $n_0 = 4\times 10^{18}\ cm^{-3}$ and the output mirror reflectivity is R = 0.3, 0.4, 0.5, respectively.



Giant pulse peak power $p_m = \eta\phi_{max} n_0 h\nu c_1$; giant pulse width $t_w = (t_{p2} - t_p)t_m n_0$; pulsed laser output energy $E_{out} = P_{max} t_w$ so we can get the following table:

R (Output mirror reflectivity)	t_w (Giant pulse width)	N_{th} (Threshold)	P_{MAX} (Giant pulse peak power)	E_{out} (Output energy)	η_5 (Resonant cavity efficiency)
0.5	*16*	*3.50*	*1.23*	*0.20*	*0.63*
0.4	*15*	*4*	*3.81*	*0.16*	*0.59*
0.3	*15*	*4.21*	*7.99*	*0.12*	*0.536*

(Table II)

In the above table, when the initial particle inversion concentration is constant, the reflectivity of the output mirror is increased, and the initial power density in the cavity is increased, and the bleaching time is shortened. At this time the number of reversal particles can only be accumulated to a lower value, so the photon concentration is also reduced, the natural output giant pulse peak power will also be lower values.

There are many factors that affect the output characteristics of Q-switched laser. From the data of this experiment,

The higher the doping concentration of the crystal, the lower the transmittance, so that the laser threshold is increased, so that the initial number of inverted particles of the working substance increases, so the peak of the Q-switched pulse increases. The increase in the reflectivity of the resonator output mirror increases the initial optical power and shortens the bleaching time. At this time the number of reversal particles can only be accumulated to a lower value, the natural output power will drop.

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