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Q-SWITCHING OF MULTIQUANTUM WELL-LASER DIODE ARRAY (MQW-LDA) PUMPED Nd:YLF LASER

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Abstract: Acousto-optic Q-switching of a homemade MQW-LDA pumped Nd:YLF laser has been realized. A pulse width of 70 ns, energy of 1 μJ at 100 Hz repetition rate have been obtained. The fluctuation of profile is less than 1%.

Key words: acousto-optic Q-switching pumping

I. Foreword

Solid laser Q-switching devices pumped with a semiconductor lasers (DPL) have seen rapidly development internationally in recent years. Such devices have potential advantages in multiple applications of laser radar, laser ranging, and optoelectronic countermeasures [1]. The speed of acousto-optical Q-switching is not as high as that of electro-optical switching. However, the acousto-optical modulator has lower cavity-insertion wear, so that such modulators are suitable for solid laser devices pumped with a semiconductor laser. Internationally, the average power of a DPL acousto-optical Q-switching output is 1.6W (20nm, 160microjoules, 10kHz) [2], the pulse upper power is 50kW (4MJ, 8ns) [3]; when its double frequency is used to pump a Ti-gem laser, a continuously tunable and stable laser output is obtained in the range between 696 and 1000nm.

On several occasions, the authors obtained a solid laser output pumped with a Chinese-made semiconductor laser [4], together with the gain-switching effect of the DPL [5], as well as the double frequency and auto-double frequency of the DPL [6]. For the first time, this paper reported the experimental results and analytical calculations of an Nd-YLF solid laser acousto-optical Q-switching pumped with a Chinese-made MQW-LDA.

II. Acousto-optical Switch

For a pumping power between 100 and 500mW, the size of the fundamental mode of the solid laser cavity is between 100 and 200micrometers; the total wear of static optics is 3 to 6% and the cavity length is 30 to 80mm, in a DPL device. The author designed and studied the specialized acousto-optical Q-switching of a small model, low insertion wear, and high diffraction efficiency. Fig. 1 shows the principle of structural and acousto-optical function.

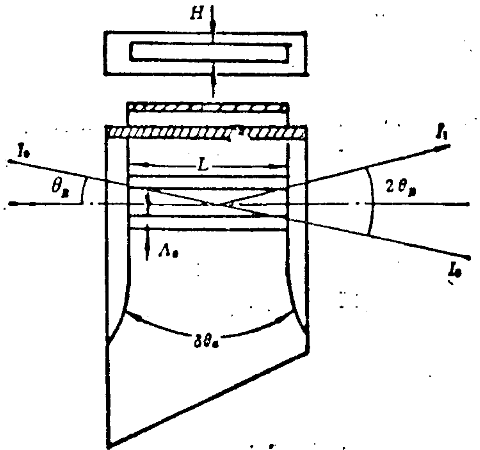

Fig. 1 Construction and action of A-O modulation

When the incident light beam and the wave plane of the acoustic beam form a Bragg angle, this satisfies the Bragg diffraction condition:

$$\sin\theta_B = \lambda_0/2n\Lambda_s$$

In the equation, θ_B is the Bragg angle, λ_0 is the light wavelength in free space; Λ_s is the sound wavelength; and n is the acousto-optical refractive index in the medium. If

$$Q = \frac{K_s^2 L}{K} > 4\pi, \quad R = \frac{\delta\theta_a}{\delta\theta_0} = 1$$

Then the acousto-optical interaction enters the Bragg zone, and satisfies the momentum matching between the optical wave vector and the sound wave vector. In the equation, K_s is the sound wave vector; K is the light wave vector; L is the length of acousto-optical action; $\delta\theta_a$ is the divergence of the acoustic beam; and $\delta\theta_i$ is the divergence of the light beam. The first-level diffraction efficiency is:

$$\eta_1 = \frac{I_1}{I_0} = \sin^2\left[\frac{\pi}{\lambda_0}\left(\frac{M_2 L P_s}{2H}\right)^{1/2}\right]$$

In the equation, I_0 is the incident light intensity; I_1 is the first-level diffraction light intensity; H is the transducer height; P_a is the supersonic power; and M_2 is the optimal coefficient of the acousto-optical medium. By changing the RF excitation power, the supersonic power is controlled, thus varying the diffraction efficiency and forming an acousto-optical switching action.

According to the above-mentioned formulas and the requirements on a DPL, acousto-optical Q-switching is developed. The acousto-optical medium is fused quartz glass; the acousto-optical action length L is 16mm; the effective action aperture is OD0.5mm; the diffraction angle θ_B=4.87mrad. At both sides, 1.05micrometer-high transparent films are coated; the insertion wear is less than 1%. The piezoelectric transducer is an $LiNBO_3$ with a tangential direction of $Y36^0$; the supersonic frequency f_0=80MHz. Good electroacoustic matching is achieved by using a vacuum indium compression welding technique and a type T matching network. Thus, the RF excitation power can be effectively converted into an acoustic transverse wave of an optoacoustic medium. When the impedance is 50ohms, the VSWR is approximately equal to 1. The driving power is variable between 1 and 5W; the first-level diffraction efficiency is adjustable, between 15 and 30%. If inspection is conducted with an He-Ne laser, when the polarization of the laser rays is perpendicular to the wave plane of the acoustic transverse waves, as excited by 1W of RF power, the diffraction efficiency is 30%.

III. DPL Q-switching Experiment

Fig. 2 shows a DPL acousto-optical Q-switching experimental setup. In the molecular beam extension (MBE) equipment developed and built in China, a 20-strip AlGaAs/GaAs multiquantum well linear array device has a well width of 10nm; the strip width is 5micrometers, the spacing is 3micrometers, and the overall dimensions of the illuminating plane is 160x1micrometers. When the thermoelectric pile of the semiconductor has its temperature controlled at 18^{0}C, the MQW-LDA radiation center wavelength is 790.7nm, and the spectral width is 3nm, thus falling within the secondary absorption peak of the Nd:YLF crystal. Driven by an electrical square wave with pulse duration 400microseconds and with pulse repetition frequency 100Hz, the threshold current value is 650mA. When the driving current is increased to 1.4A, the output power of an MQW-LDA pulse is 200mW. The conjugate image is found by optical coupling. By using the graphic processing system of a two-dimensional CCD (500x582 optical sensitive elements), the dimensions of the focal spot are 315x77micrometers. Fig. 3 shows the light intensity distribution of the near and far fields of the MQW-LDA. The near-field intensity is distributed in multiple strips; however, the light intensity of the focus is a very large single value, suitable to solid laser pumping in the longitudinal direction of the terminal surface.

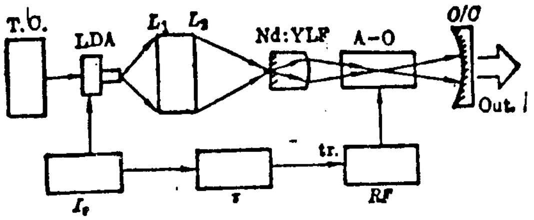

Fig. 2 Schematic diagram of *A-O* Q-switched laser

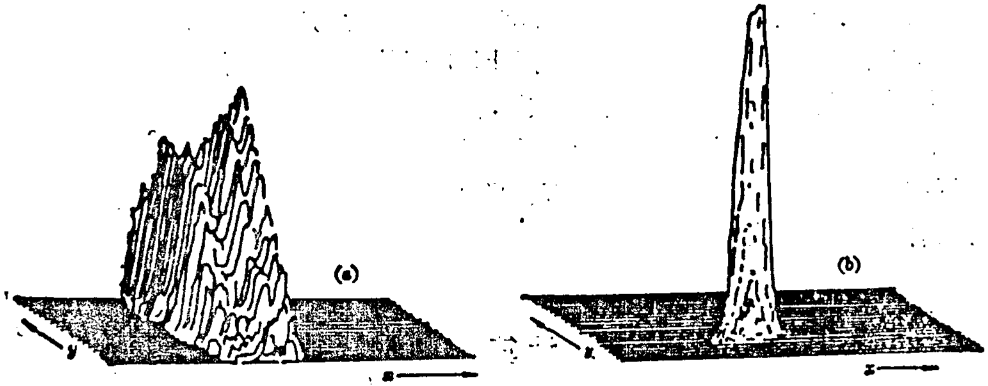

Fig. 3 Intensity distribution of MQW-LDA

(*a*) direct output; (*b*) at focus

A quasi-confocal cavity structure is designed into the solid laser device, in order to form slender light beams in the cavity for facilitating the acousto-optical function. By selecting the axis a orientation to cut the Nd:YLF crystal, when there is a larger gain cross section for π polarization (1.047micrometers), the threshold power value of pumping is decreased. The crystal is 5mm long, and the Nd concentration is 1%. The input terminal is a plane; there is 99.6% reflection at the 1.05micrometer wavelength; there is 85% transmissibility at the 0.8micrometer wavelength. The other terminal is a spherical plane with curvature R=50mm; there is high transparency at the 1.05micrometer wavelength. There is a flat concave reflective mirror at the output terminal with curvature R=50mm. There is 2% transmissibility at the 1.05micrometer wavelength. For the solid laser device, the cavity is 60mm long; for the TEM_{00} mode, the scale ω_0=90micrometers.

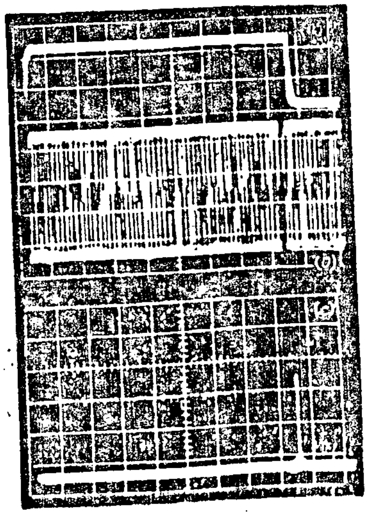

Fig. 4 Q-switching of MQW-LDA pumped Nd:YLF laser
(a) driving current pulse; (b) A-O modulation waveform; (c) Q-switched laser pulse

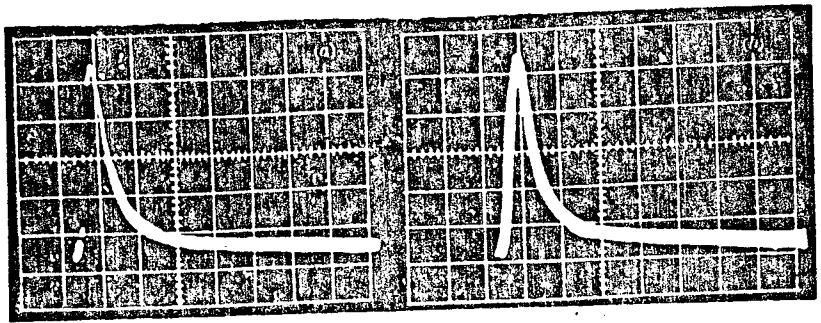

Fig. 5 Temporal waveform profile of Q-switched Nd:YLF laser
(a) single laser pulse (0.1 μs/div); (b) 100-times of record accumulated (0.1 μs/div)

Acousto-optical Q-switching takes place at the light waist within the cavity of the solid laser device. For the resonance cavity of separated elements, the threshold value pumping power of relaxation oscillation is approximately 60mW. In order to attain desirable acousto-optical diffraction, rotate the Nd:YLF crystal so that the direction of polarization of the DPL laser output is perpendicular to the action direction of the acousto-optical field. By placing the acousto-optical modulator in the RF excitation state, a high-wear Q cavity is formed. By using the front fringe of the electrodriven square waves of the MQW-LDA, a delayed tunable TTL pulse is synchronously generated with 10microsecond duration. Before finishing pumping, instantaneously the acousto-optical driven power source is triggered to de-excite the RF excitation, forming a low-wear Q cavity, thus obtaining a DPL Q-switching laser output. By using a microjoule energy meter and a nanosecond-response PIN detector, the energy and waveform of the Q-switching laser output are measured: 1microjoule in energy and 70microseconds in pulse duration. Fig. 4 shows the waveforms of the electrodriven pulses, the electro-acoustic modulation waves, and the corresponding Q-switching laser pulses. The operational repetition frequency of the device is 100Hz. Fig. 5 shows the time-extended waveforms of a single laser pulse, and 100 cumulative laser pulses. From the figure, we can see that there is a good overlapping between the single output and the 100 cumulative outputs of laser wave profiles; the fluctuation is less than 1%.

IV. Calculations and Discussion

Under approximation of the speed equation, when the Q-switch is not opened, the cavity is at the high-wear state. The velocity equations are [7]:

$$\begin{cases} \dfrac{d\Delta N}{dt} = W - \dfrac{c\sigma}{LA}\Delta N S - \dfrac{\Delta N}{\tau_f}, \quad t<t_1 & \text{(1-a)} \\ \dfrac{dS}{dt} = \dfrac{c\sigma}{LA}\Delta N(S+1) - \dfrac{\delta c}{2L}S, \quad t<t_1 & \text{(1-b)} \end{cases}$$

In the equations, ΔN and S are, respectively, the number of counter-revolving particles and photons; W is the pumping light velocity purely absorbed by Nd:YLF; c is the speed of light; σ is the cross-section of excited emission; τ_f is the lifetime of the upper energy level; L is the cavity length; A is the cross-sectional area in the rod terminal plane of the TEM_{00} mode; $\delta=\delta_1+\delta_2+\delta_3$, ; δ is the total wear when the Q-switch is not opened; δ_1 is the transmission wear of the output coupling length; δ_2 is the modulation wear of the acousto-optical crystal; δ_3 is other wear; and t_1 is the beginning time of triggering the Q-switch.

At the instant of trigger opening of the Q-switch, since the dissipation of the acoustic field has a transition period, there is a temporary state of abrupt change of wear in the cavity. Assume that the sound dissipation is attenuated exponentially, then in the process of the temporary state, the velocity equations are:

$$\begin{cases} \dfrac{d\Delta N}{dt} = W - \dfrac{c\sigma}{LA}\Delta N S - \dfrac{\Delta N}{\tau_f} \quad t_1 < t < t_s & (2\text{-a}) \\ \dfrac{dS}{dt} = \dfrac{c\sigma}{LA}\Delta N S - \dfrac{c}{2L} S \cdot \delta \cdot \left(\dfrac{\delta}{\delta_4}\right)^{(t_1 - t)/t_s}, \quad t_1 < t < t_s & (2\text{-b}) \end{cases}$$

In the equations, $\delta \cdot (\delta/\delta_4)^{(t_1 - t)/t_s}$ is the wear attenuation function; t_s is the dissipation time of the acoustic field, and $\delta_4 = \delta_1 + \delta_3$。 .

When the Q-switch is completed opened, the wear term is only δ_4. By changing δ in Eq. (1-b) into δ_4, we obtain the equations expressing velocity when the Q-switch is completely open:

$$\begin{cases} \dfrac{d\Delta N}{dt} = W - \dfrac{c\sigma}{LA}\Delta N S - \dfrac{\Delta N}{\tau_f}, \quad t_s < t & (3\text{-a}) \\ \dfrac{dS}{dt} = \dfrac{c\sigma}{LA}\Delta N S - \dfrac{\delta_4 c}{2L} S, \quad t_s < t & (3\text{-b}) \end{cases}$$

By using the fourth-order Runge-Kunta method, simultaneous numerical solutions are obtained for the three above-mentioned sets of equations. The calculation parameters are selected as the following: $W = 4.02 \times 10^{17}$ s^{-1}, $c = 3 \times 10^8$ m/s, $L = 60$ mm, $\tau_f = 480\ \mu s$, $\sigma = 3.0 \times 10^{-19}\ cm^2$, $A = \pi \times (100\ \mu m)^2$, $\delta_1 = 2\%$, $\delta_2 = 17\%$, $\delta_3 = 1\%$, $t_s = 100$ ns, $t_1 = 390\ \mu s$

Fig. 6 shows the wave profile of the acousto-optical Q-switching laser pulse in the calculation. The pulse width τ=52ns, and energy E=6.2microjoules.

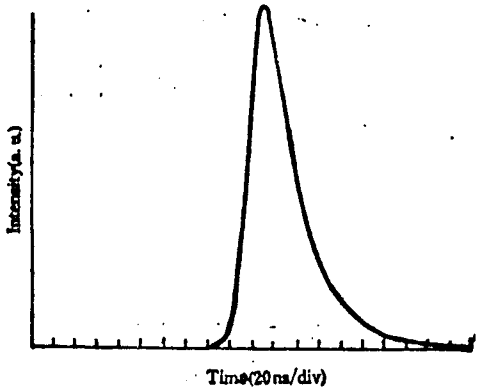

Fig. 6 Calculated waveform profile of Q-switched Nd:YLF laser

The calculated values are better than the experimental results. This is because in the calculations consideration was given to the fact that good mode matching exists between pumping light and the solid laser device; however, in the experiments, the focal spots of the pumping light are greater than the dimension of the fundamental mode of the solid laser device so that the effective pumping light efficiency is lower. Moreover, data at the main absorption peak 797nm of Nd:YLF are used, but in actuality the center wavelength of the MQW-LDA that was used is 790.7nm with larger width of spectral lines and lower absorption of the effective optical spectrum. With further study, select such solid laser media and diode laser devices so that better optical spectral absorption is attained. The coupling efficiency can be increased by designing a cylindrical surface-nonspherical surface optical coupler; increase the absorption materials on the reflective plane of the acousto-optical medium to establish a stable acoustic field, and laser output will be increased by changing the coupling of the output cavity.

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REFERENCES

1 W. C. Sohwartz *et al.*, *Laser Focus World*, **75**, *July* (1991)
2 D. C. Shannon *et al.*, *Opt. Lett.*, **16**, 318 (1991)
3 T. R. Steele *et al.*, *Opt. Lett.*, **16**., 399 (1991)
4 Zhou Fuzheng *et al.*, *SJSL*, **8A4**, Nov. 8~9 (1990)
5. Zhou Fuzheng et al, Zhongguo Jiguang [Lasers in China], 18/11, 806(19961).
6. Zhou Fuzheng et al, Jiguang Yu Hongwai [Lasers and Infrared Rays] 22/2, 1(1992).
7 P. E. Perkins *et al.*, *J. Opt. Soc. Am. B*, **4**, 1066 (1987)

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