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A Pre-lasing Reliable Dynamic Filter Single-longitudinal-mode Q -switched Laser

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ABSTRACT A dynamic filter (DF) single-longitudinal-mode (SLM) selection scheme is presented for the first time. Combined with pre-lasing technique, a reliable DF SLM Q -switched Nd:YAG Laser is successfully achieved. The scheme has the advantage of high stability and high probability (>95%) of SLM selection rate. The scheme has also the speciality of low technical requirement, high anti-interference ability and a wide working range of pumping energy for stable SLM operation.

KEY WORDS dynamic filter, pre-lasing technique, single-longitudinal-mode Q -switched, Nd:YAG laser

1. Introduction

SLM Q -switched Nd:YAG laser is an important light source for laser guidance, lider, high resolution spectroscopy, etc. However, as the Q -switched Nd:YAG laser has a broad linewidth of the gain profile, a very high innercavity gain and a very short pulse shaping time, common frequency-selection devices can' t work well.

The adoption of pre-lasing mode-selection Q -switching technque has made it possible to realize SLM operation[1]. The idea of this technique is that a single frequency pre-lased light with an adequate amplitude is formed in the cavity before Q -switching. The amplitude is "adequate", that means it is just large enough to suppress other longitudinal modes after Q -switching and to form a SLM giant pulse output. This requirement can be fulfilled, in principle, by controlling the pumping energy or by adjusting the threshold to preset the population inversion of the working material to a level slightly higher than the threshold of the cavity before Q -switching and to keep it for an adequate time interval to ensure the light-beam able to pass through the etalon in the cavity many times to enhance the equivalent fineness of the etalon for giving full play to mode-selection. The Q -switch is presently operated. If the pre-lasing is strong enough, other longitudinal modes can be suppressed and a SLM giant pulse is formed. However, multi-mode output still happens since it is possible for other longitudinal modes to surpass their threshold owing either to too weak pre-lasing or to too high innercavity gain. Thus, the adoption of pre-lasing mode-selection Q -switching sets a very severe technical requirements, it needs complicated control systems with high sensitivity and fast-time response[1,2]. This is hard to realize for moderately-equipped labs. We have made experiments with this scheme using a self-made laser system and two etalons with thickness $d_1 = 2\text{mm}$ and $d_2 = 10\text{mm}$ and fineness $F_1 = 4$ and $F_2 = 5$. In our experiments show that the single-mode selection-rate is less than 70% and it is hard to suppress the output energy fluctuation below 10%.

A novel technique of mode-selecting and Q -switching is reported in 1992[2]. However, the devices are still hard to obtain for common labs.

Here we propose a dynamic filter mode-selection scheme, which combined the pre-lasing Q -switching technique with the dye mode-selection Q -switcheing technique. With the scheme a DF SLM Q -switched Nd:YAG laser has been successfully achieved. The new system shows an enormously improved mode-selection property.

2. The principle

2.1 The idea of dynamic filter mode-selection

The action of mode-selection of common dye- Q -switched laser lies in that, when a light pulse is built-up from noise, the mode of superiority with a high gain and a lower loss will have its amplitude increase much more quickly than other modes[3]. That shows, aside from the difference of gains and losses among the modes, the round-trip times of pulses in their building-up process from noise must also be taken into account. If the round-trip times increase, the difference of the amplitudes of two modes will increase to a more drastic value. Sooy gives a very good approximation for this process[4]

$$\frac{P_n}{P_m} = [(1 - L_n)/(1 - L_m)]^q (1 - L_n)^{q(g_m/g_n - 1)} \tag{1}$$

where P_n and P_m are the powers of n -th-mode and m -th-mode, L_n, L_m and g_n, g_m are the loss and gain coefficients respectively of these two modes for each round-trip, and q the round-trip times. The first factor in Eq. (1) corresponds to loss discrimination while the second gain discrimination.

It can be draw from the above argument that in the case of Nd:YAG laser that features by its high gain and by a broad linewidth of gain profile, it often results in a multi-longitudinal-mode Q -switched pulse output when the dye Q -switching scheme is used. The reason is that though the pulse-shaping time is comparptively long (μs order) dye Q-switching process and hence the round-trip times q is large, which in favour of enhaceing the discrimination rate, the gain difference of adjacent modes is very small, therefore, when the superiority mode reaches its saturation in the dye and bleaches it, the other modes have also the possibility to oscillate and arrive at certain level and it is hard to suppress all these modes thoroughly. Thus, in order to obtain SLM output with common dye Q-switching scheme, it is necessary to operate the laser in the vicinity of the threshold so that only one mode, the superiority mode, is let to surpass the threshold and to increase and reaches its saturation while other modes are unable to oscillate. The energy output of such a laser is too small to have a practical value and is unstable in addition.

The DF mode-selection scheme we suggested here is to combine the pre-lasing technique with the dye mode-selection Q-switching technique with the dye as DF. The laser is first let to operate at a level slightly higher than the threshold of the cavity before the operation of Q-switch, when only one logitudinal mode located near the center of the gain profile begins to oscillate and thus a SLM pre-lasing light is generated. The strength of the pre-lasing light grows gradually and reaches the saturation strength of the dye placed in the cavity, the loss of this mode in the dye goes to zero while the absorption loss of the dye to other modes still exists. Presently the Q-switch operates, the existing pre-lasing light will be amplified in a avalanche fashion while the possibility of oscillation for other lognitudinal modes are suppressed owing to the larger absorption losses and the drastic decrease of population inversion, and a SLM giant pulse is achieved. This is the guiding idea of the equivalence of the dye to DF. It is worthwhile to give a more detailed analysis on the process and mechanism of the transformation from a dye-plate into a equivalent dynamic filter. If the dye BDN is a nonhomogeneously broadened medium, the answer would be ready. During Q-switching, only dye molecules with their resonance frequency corresponding to the pre-lasing light' s frequency are saturated while the rest molecules with their resonance frequencies corresponding to other longitudinal modes are still at the ground states and show absorbing characteristics. However previous work shows[5] that dyes are generally belong to homogeneously braodened media. For such kind of a material, how can the dynamic filter formation mechanism be explained?

As is well known, a homogeneously broadened gain medium, when operated, will show space hole-burning effect owing to the standing waves effect and this in turn will result in multi-longitudinal-mode operation. By the same token, a homogeneously braodened saturable absorbing medium will also show space hole-buring owing to standing wave effect. Dye particles located at the amplitudes of the pre-lasing light are saturated while those located near the nodes are left in their ground states and still show absorption characteristics. Multi-mode operation can thus be suppressed and this is the mechanism for a homogeneously braodened saturable absorbing medium to form an equivalent dynamic filter. Evidently, a longitudinal wave with its amplitudes coincide with the nodes of the pre-lasing light will subjected to largest absorption loss and will exhibit the most striking filtering effect. The optimum location for the dye plate in the cavity can be found through this maximum filtering condition. For example, presume that only three modes in the cavity need to be considered, one mode with longitudinal mode index n is just the pre-lasing mode while the other two modes with index $n \pm 1$ are the modes to be filtered. According to the standing wave condition, we have:

$$n \cdot \frac{\lambda_n}{2} = L \tag{2}$$

$$(n \pm 1)\frac{\lambda_{n\pm1}}{2} = L \tag{3}$$

and

$$\frac{n}{2}\left[\frac{\lambda_n}{2} - \frac{\lambda_{n\pm1}}{2}\right] = \pm \frac{\lambda_{n\pm1}}{4} \tag{4}$$

It can be seen that at the middle point of the cavity, the accmulated location difference between the node of the pre-operated mode and the node of two adjacent modes is just a quarter wavelength, i. e. the amplitudes of ($n \pm 1$) modes coincide with the node of n mode. That means that an optimum filtering effect would be obtained if the dye-plate is placed at the middle point of the cavity.

2. 2 Operation principle

A schematic experimental setup of dynamic filter single-longitudinal mode Q -switched Nd : YAG laser is shown in Fig. 1, in which P is polarizer, PC is Q -switching crystal, D is BDN filter dye plate, M_1 is total reflection mirror, M_2 is output mirror with a reflectivity $R =$ 20%, QW is a switch matching quarter-wave plate inserted between M_2 and PC, D_1 is a fast-response photo-electric detector, QS is the driving source for the pressurizing-type Q -switch.

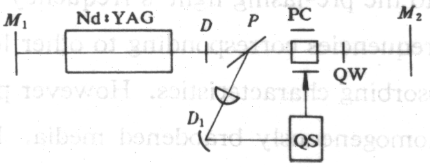

Fig. 1 Shematic diagram of the single-longitudinal mode Q -switched Nd : YAG laser using a dynamic filter

At the beginning of operation, we rotate the quarter-wave plate QW to set the laser into a high loss state, then insert the dye-plate D and increase the pumping energy level to make the laser operating just above the threshold. The homogeneously broadened dye-plate will select one mode to operate. The mode nearest to the center of the gain profile is the very pre-lasing light. The dye absorbs the light and is gradually bleached to form a dynamic filter.

When the strength of the pre-lasing light increases to a level near the saturation light strength of the dye, the fast-response photo-electric detector receives a signal and triggers the avalanche-type fast Q -switch suddenly. The dye-plate is bleached momentarily and a SLM giant pulse output with the frequency of pre-lasing light is formed, while other modes can not operate because of the dye-plate absorption loss and the rapid decrease of the inverted population. When the gain of the laser decreases to a level under the operation threshold, the dye molecules also returns to their ground state and prevent the newly accumulated inverted particles from emiting. Thus the stability and anti-interference ability of the system is also enhanced.

Besides, the present Q -switching dye-plate could not bear a high-repetition rate operation. To aviod laser light illuminating on the same spot of the dye plate under a high-repetition rate operation condition, the dye-plate is fixed on a ring-type frame. The frame is perpendicular but drifted off the light path. It can be rotated around its own symmetric axis by a driving dc motor and thus a repetition rate operation as high as 1-20 pulse/sec can be achieved.

3. Experiment results

3. 1 Pulse width measurement and mode distiguishment test of SLM laser light

(A) Oscilloscope observation. The measurement and test are ran by using a VP 5530B 300MHz oscilloscope (Japan) and a monofrequency output of pulse width~16ns is observed. Long term observation shows that an overwhelming major of the output are smooth beat-modulationless Gaussian waves. The SLM selection rate is larger than 95%. Fig. 2 is the measured result by using a HP 54111D digitizing oscilloscope (USA).

(B) F-P etalon test. The characteristics of the etalon are: fineness $F=40$, thickness $d=36$mm and resolution $\delta\nu = C/2Fd \sim 104$MHz.

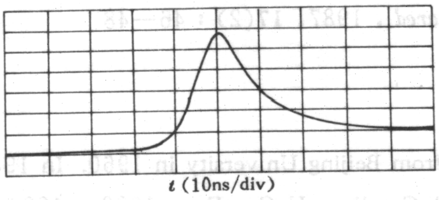

Fig. 2 The measured result using a HP54111D digitizing oscilloscope

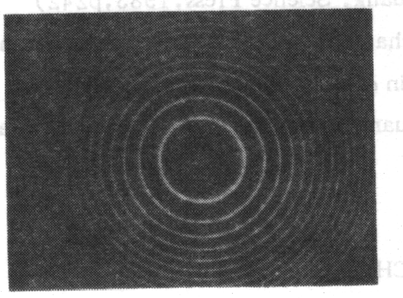

Fig. 3 The interference ring fringe obtained by a F-P etalon

The laser to be measured has a cavity length $L=550$mm and the frequency interval between two adjacent longitudinal modes is accordingly $\Delta\nu_n = c/2L = 273$MHz. This frequency interval changes to $\Delta\nu'_n = 546$MHz after frequency doubling. For the frequency-doubled 0. 53 μm laser light, our etalon with a resolution 104MHz has enough power to discriminate the laser modes with a mode interval 546MHz. The result of test is shown in Fig. 3 and the SLM laser light is readily confirmed.

3. 2 Output energy test

Many-time measurements of output energy are made by using a self-made laser pulse sampler[6] under the condition of 10 pulse/sec. The average output energy and energy fluctuation are found to be

$$\overline{W} = (\sum_{i}^{n} W_i)/n = 46\ mJ$$

$$(\sum_{i}^{n} |W_i - \overline{W}|)/(\sum_{i}^{n} W_i) < 2\%$$

From these results it can be seen that the dynamic filter single-longitudinal-mode Q-switched Nd : YAG laser has the merit of stability and high SLM selection (>95%). This scheme also has the speciality of low technical requirement, high anti-interference ability and a wide range of pumping energy variation for stable SLM operation. These features make this scheme to be readily used and widened.

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Biography

CHEN Changmin was born in Nov. 1938 and graduated from Beijing University in 1960. In 1988, he was a viviting scholar in Applied Physics, University of South Carolina, U. S. . From 1990 to 1994, he was the chairman of Department of Electronics & Information Technology, Shanxi University, China. His current research interests includes ultrashort optical pulse, optical soliton transmission and their applications.