Analysis of Q-switched effect of LiF: F₂⁻ crystal in long pulse width solid state laser

Yan Sun
Air Force Aviation University, Changchun 130022, China

Corresponding author’s e-mail: 3507549885@qq.com

Abstract. LiF: F₂⁻ crystal is used as Q-switched crystal in a pulsed adjustable laser system to realize passively Q-switched dynamic laser output. The output laser waveform is a series of sub-pulses, the width of the sub-pulses is nanoscale, the repetition frequency is 3.3kHz, and the average power is relatively high. In this paper, the characteristics of experimental law are analyzed. Combined with the metastable energy level characteristic of LiF: F₂⁻ crystal, the reason why the long pulse width laser can output pulse train is explained.

1. Introduction
In general, due to the influence of growth conditions, atomic thermal motion, and the introduction of artificial impurities, crystal atoms will shift their arrangement, resulting in crystal defects [1]. Crystal coloration is related to crystal defects. In the study, a crystal defect that causes colorless crystals to appear colored is called "color center." Color center crystals have been widely used in many fields such as luminescence and photoconductivity. In this paper, the Q-switched effect of chromaticity LiF: F₂⁻ in laser has been observed and analyzed experimentally.

For pulsed lasers, Q-switch is an important technology to compress the pulse width of the laser. The main methods include active Q-switch and passively saturable Q-switch [2]. Passively Q-switch is a method to automatically change the Q value using the characteristics of certain saturable absorbers, and has the advantage of simple design.

Some materials will become transparent as the input energy density increases. When the energy density reaches a certain value, the material will be "saturated" or "bleached" and the transmittance becomes very high. The materials with this characteristic are called saturable absorbers, and the bleaching process is based on the saturation of spectral transitions. If a certain material has a high absorption rate for the laser wavelength, it can be installed in the laser cavity [3]. In the initial stage, the low transmittance of the material will sometimes prevent laser oscillation. As the gain increases and exceeds the round-trip loss, the luminous flux in the cavity will increase sharply, causing the passively Q-switch to reach saturation. At this time, the loss in the cavity is very low and a Q-switched pulse is established. A kind of saturable absorption material LiF: F₂⁻ color center crystal can be used to greatly improve the durability and reliability of passively Q-switch. The color center in the crystal is caused by gamma, electron or neutron radiation [4-5].

The crystal is extremely stable at room temperature and can be irradiated by high density visible and near-infrared light without damaging the color center. It has a wide strong absorption band with a peak wavelength of 980nm and considerable absorption at the Nd³⁺ laser wavelength (1.06 µm). It also has good chemical thermal stability and can work under high repetition rate. LiF: F₂⁻ crystal has a higher light damage threshold than Nd:YAG laser crystal, that allows it to operate at peak power.
above the damage threshold of the laser-activated medium. Therefore, color center crystal is an ideal passively Q-switch.

2. Design of experimental device
In the Q-switched experiment study of LiF: F₂⁻ color center crystal, the solid-state laser is pumped by double xenon lamps. The laser schematic diagram and device diagram are shown in Figure 1 and 2. The laser working material is Nd³⁺:YAG, and the size of the laser rod is \( \Phi 9 \times 75 \text{mm} \). The size of the pulsed xenon lamp is \( \Phi 7 \times 80 \text{mm} \), and a double elliptical cylindrical condenser cavity is adopted, and the length of the condenser cavity is 70mm. Double lamps are symmetrical to the working material on both sides, so the design makes the working substance pumped more evenly.

The resonant cavity of the laser is a flat-concave cavity. The lenses are housed in the two-dimensional adjusting frames. Among them, the total mirror is a concave mirror with a curvature radius of 2m and is coated with a 1064nm total reflection film. The output mirror is a flat mirror with a transmittance of \( T = 30\% \) and a higher gain can be obtained. The front cavity length is \( L_1 = 140 \text{mm} \), the working material (refractive index of \( n = 1.82 \)) length is \( L_2 = 75 \text{mm} \), back cavity length is \( L_3 = 200 \text{mm} \), the total effective cavity length is \( L = L_1 + L_2 \times n + L_3 = 476.5 \text{mm} \). The curvature radius of the concave mirror is larger, up to 2m, which is more than 4 times the length of the resonant cavity. The resonant cavity composed of large-radius lenses has a high utilization rate of the working material, and the resonant cavity is reliable.

The xenon light pumping time of the laser can be adjusted within the range of 1 to 12ms. When the pump light time is longer, the pulse width of laser waveform is also wider under static operation, and the output pulse width can be adjusted. Since the formation of laser pulse is based on the accumulation
of reverse particle number, it takes a certain amount of time to accumulate a certain number of particles. Thus, the resulting laser pulse width is narrower than that of the pumped xenon lamp.

In the experiment, LiF: F2− color center crystal is used as passively Q-switch, and its specification is 11.65×12.00×34.10mm. Color center crystals have many advantages as passively Q-switched components. First, the switching efficiency is high, up to 60%. The second is that the laser pulse width is narrow and the output energy is stable. The third is that it is not affected by electrical interference, easy to operate and has a long service life.

3. Passively Q-switched experiment

Before the experiment, the experimental instrument and the place of LiF: F2− crystal in the optical path is assembled. According to the height of the laser rod center, a LD collimating light source is used to make the optical axis of the laser rod parallel to the guide rail and adjust each optical element to be coaxial. Connect the electrical system and the water cooling system. After checking, turn on the power and turn on the power switch. The dynamic optical output is adjusted to the optimal output, and the system debugging is completed. Next, the output characteristics of dynamic pulse-width adjustable laser are studied.

Experiment 1 is the measurement of a single pulse. The pump working voltage is 580V, and the pump pulse width is set to 1ms. A pulsed PIN detector is used to receive the laser light reflected from the light barrier, and the resulting pulse is shown in Figure 3. The width of a single dynamic tunable pulse reaches the order of nanoseconds.

![Figure 3. Dynamic single pulse laser diagram.](image)

![Figure 4. Laser pulse at 600V.](image)

![Figure 5. Laser pulse at 640V.](image)
In the experiment 2, we keep the input pulse width unchanged at 8ms, change the working voltage, and keep the other experimental conditions the same. The resulting pulses are shown in Figures 4 and 5. In experiment 3, we keep the working voltage unchanged at 600V, change the input pulse width, and keep the other experimental conditions the same. The pulse diagram obtained from the experiment is shown in Figures 6-9.

![Figure 6. Laser pulse at input pulse width 3ms.](image1)

![Figure 7. Laser pulse at input pulse width 5ms.](image2)

![Figure 8. Laser pulse at input pulse width 8ms.](image3)

![Figure 9. Laser pulse at input pulse width 12ms.](image4)

From the above second and third set of experiments, some laws can be seen from the experimental phenomena obtained.

The output waveform of the dynamic laser is a sequence of sub-pulses. When the operating voltage or input pulse width is increased, the number of sub-pulses will increase, and the output sub-pulse spacing will gradually become smaller.

In the same pulse diagram, the height and width of each sub-pulse are basically the same, and the distance between adjacent sub-pulses is slightly increasing.

Except for the input pulse width and working voltage, when the experimental conditions are the same, the amplitude of the obtained laser pulse is the same, that is, the energy of a single sub-pulse output by a pulse-width tunable pulse laser in the passively Q-switch mode is a certain value.

The interval of the sub-pulse reaches 300μs, and the frequency is 3.3kHz from the frequency calculation formula $f=1/t$.

When the pulse width is 5ms, the measured pulse energy after Q-switch is 0.24J, and its peak power can be estimated.
We suppose the number of sub-pulses at this time is \( n \), then
\[
5 \times 10^{-3} = \frac{3 \times 10^{-5}}{n}.
\]
The energy of a single pulse is
\[
E = \frac{0.24}{n}.
\]
The peak power is
\[
P = \frac{E}{\tau} = \frac{E}{3 \times 10^{-9}} = 0.49 \times 10^6 \text{ W}.
\]

4. Analysis of experimental results

(1) As the operating voltage increases, the number of sub-pulses increases. The reason is that the energy storage of the capacitor is proportional to the square of the operating voltage. The higher the pump voltage, the more energy the capacitor stores and the more energy it releases. This makes the energy in the cavity very large, so the chromatically centered crystals have less time to "bleach" [6]. Therefore, under the same pulse width condition, the greater the operating voltage, the greater the number of sub-pulses formed.

(2) Under the same voltage condition, changing the input pulse width, the number of sub-pulses will also change. This is when the input pulse width increases, the discharge time of the capacitor increases, the released energy increases, and the number of sub-pulses formed increases.

(3) In the same light pulse, multiple sub-pulses appear in the dynamic laser output, and the height and width of each sub-pulse are basically the same. This is because the input energy is large. After the laser outputs the first optical pulse, the remaining optical pump energy continues to excite, again increasing the number of inverted particles to the threshold, and once again causing the Q-switched crystal to be "bleached" to form the second optical pulse. Because of the strong light pumping, the xenon lamp emits light for a long time, while the fluorescence lifetime of the laser rod is short, and the crystal is "bleached" many times. Therefore, many sub-pulses can be formed before the xenon lamp is extinguished. Since the formation conditions of each sub-pulse are basically the same, the height and width of each sub-pulse are basically the same, and the output energy is approximately the same. Therefore, the greater the number of sub-pulses, the greater the laser output energy.

(4) In the same pulse diagram, the distance between adjacent sub-pulses gradually increases. The reason is that the discharge of the capacitor shows a downward trend with time, which makes the waveform of the pump lamp not a standard square wave, but shows a downward trend as time increases. As a result, the pump energy gradually decreases and the luminous power gradually decreases, so that the time for the Q-switched crystal to be "bleached" gradually becomes longer, the distance between adjacent sub-pulses gradually becomes larger.

According to the analysis of the above two points (1) and (2), the more the number of sub-pulses is more. F\(_2\) color center has a four-level transition structure and metastable state. The metastable life is 70ns at room temperature. LiF: F\(_2\) crystal has the maximum transmittance during Q-switching, and the color center is mostly excited to the metastable energy level. The decay time of chromaticity crystals as saturable absorbers is very short. In the experiment, it is shown that the time required for Q-switched crystals to be "bleached" is shorter and the pumping energy increased. Because of the short bleaching time, the number of inverted particles in the working substance can only accumulate to a low value, so the peak power of the output laser pulse is low. But because of its serial output, its average output power is very high. It can be seen from the experiment that, as a Q switched element, LiF: F\(_2\) crystal can generate enough switching speed to play the role of passively mode locking. In the case of high input pulse intensity, the laser with narrow pulse width can be generated, and the nanosecond laser output can be further realized.

5. Conclusion

The peak power of each pulse output by the pulse width adjustable laser dynamic laser through LiF: F\(_2\) crystal passively Q-switch is small and this pulse can be transmitted by optical fiber. The pulse width of the sub-pulse is in the order of nanoseconds, with a high repetition frequency of several kHz, so its peak power is very high and the overall energy output is very large, ranging from a few to a dozen joules. It can be seen that LiF: F\(_2\) crystal is an excellent Q switch. In addition, the LiF: F\(_2\) crystal
also has an absorption band of 0.8-1.1 microns. Depending on the high failure threshold, it can also be used as a gain medium to improve the laser power output. In this way, the application potential of LiF: F₂ crystal in the detection field can be further exerted [7-8].

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