1.3414 μm Nd:YAP pulse laser in Q-switched mode

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Abstract

In this paper, a flash-lamp pumped 1.3414 μm Nd:YAP Q-switched pulse laser are presented. The experimental results for about 45 ns of pulse duration and more than 300 mJ of output energy have been obtained and discussed.

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1. Introduction

Laser emission at 1.3414 μm generated from the transition of 4F3/2→4I3/2 by Nd3+ ions doped in YAlO3 crystal has attracted great interests for medical and dental applications due to its good absorption of water molecules and very good capability of blood hemostasis. The absorption coefficient at this wavelength is 20 times more than that of 1.064 μm Nd:YAG laser [1]. The 1.3414 μm Nd:YAP CW medical machine (US Patent: us005910140) of output power 100 W we developed, which has a good capability of blood hemostasis and tissue incision, has successfully been used in a commercial laser for clinical applications [2]. [1,2] indicate the laser emission at this wavelength is a better compromise between tissue cutting and coagulation. Additionally, Lafond and Hirth have obtained 50 ns of pulse duration and 30 mJ of energy in TEMoo mode using a flash-lamp pumped 1.3414 μm Nd:YAP Q-switched laser, which is to generate the harmonies of the 1.3 μm Q-switch laser for a pulsed holography application [3]. However, to the best of our knowledge, the reports about the clinical applications using a Q-switched 1.3414 μm Nd:YAP laser emission have scarcely been published. Whereas 1.064 μm Nd:YAG laser in Q-switched mode has been widely used in dermatology and cosmetology. Our aim of developing a flash-lamp pumped 1.3414 μm Nd:YAP laser in the Q-switched mode is to make more applications, at which wavelength very good results have been obtained in continuous-wave operation state. According to the selective photothermolysis put forward by Professor Anderson and Parrish [5], the good results in the therapy of dermatology, dental and cosmetology applications using 1.3414 μm Q-switched laser will be shown because of its good absorption of water molecules and of very good capability of blood hemostasis [4].

2. Q-switch device

The key to achieve efficient Q-switching of 1.3414 μm laser is also the selection of Q-switched materials. In spite of Cr4+:YAG crystal being an excellent crystal for passively Q-switching [5], its wavelength range of saturable absorption is only from 0.9 to 1.2 μm, it cannot cover 1.34 μm of wavelength region and it is usually used in a lower energy Q-switched pulse laser. It is well known that the selection of the crystal as Q-switched device is mainly high transparency, large electro-optic coefficients, high...
damage threshold and low half-wave voltage. After making a comparison of KD*P and LiNbO₃ crystals, we found that each has its strong point. The former has a high damage threshold but a lower transmittance at 1.3414 μm. On the contrary, the transparency of the latter is higher but its damage threshold is lower. We use them as the materials for making Q-switched device in our experiments, respectively. The dimension of LiNbO₃ crystal is 10 × 10 × 23 mm and of KD*P crystal is φ10 × 25 mm. In order to decrease the surface lose caused by the refractive index, the anti-reflective film of 1.3414 and 1.0795 to decrease the surface lose caused by the refractive index, the anti-reflective film of 1.3414 and 1.0795 was coated on both of incident and exit surfaces of LiNbO₃ crystal and the glass plates which were used as the transmitted windows of KD*P Q-switched device. The reason why the 1080 nm anti-reflective film must be coated on the corresponding surfaces is to avoid the generation of sub-cavity effect at 1080 nm, that is, the laser oscillation at 1.0795 μm should be restrained. We measured the transmittances of both Q-switched devices between 1000 to 1500 nm wavelength range using a Perkin–Elmer UV/Vis/NIR-spectrometer (model Lambda 9000), their transparencies at 1342 nm are not ideal because of larger absorption coefficients at the same wavelength, for which the quality of LiNbO₃ crystal is not very good and there is a larger absorption coefficient for KD*P crystal at 1.3414 μm wavelength. We select the operating mode of LiNbO₃ Q-switched device that the direction of beam propagation parallels to Z-axis of the crystal and the direction of the electric field is along with X-axis, in which there is no natural birefringence. The KD*P Q-switched device obtained from the supplier is directly used in our experiment. Through a Q-switched module, the ±/2 voltages is applied to the Q-switched device to transmit the laser beam during a very short time and then the huge pulse of laser was obtained.

3. Experimental results and discussion

In our previous work, we have obtained the conclusion that Nd:YAP is one of the best laser crystals for continu-ous-wave operating at 1.3 μm wavelength band [6]. In the state of pulse operation, because the product of fluorescence lifetime $\tau_s$ and fluorescence width $\Delta \nu$ of Nd:YAP crystal is larger than that of Nd:YAG, the former is on the order of magnitude of $6 \times 10^7$ and the latter is about $3 \times 10^7$. This is advantage to store the energy and suitable for the mode of free running operation. In addition, Nd:YAP crystal possesses better properties of thermal diffusion and a larger optomechanical coefficient $(4.29 \times 10^{-4} \text{ m}^{-1} \text{k}^{-1} \text{w}^{-1})$ whereas the value of Nd:YAG is $3.8 \times 10^{-4} \text{ m}^{-1} \text{k}^{-1} \text{w}^{-1}$ [7]. Moreover, the output laser of Nd:YAP is nearly linear polarized. On the basis of above analysis, the arrangement of our experiment is shown in Fig. 1. A b-axis Nd:YAP crystal with a dimension of 100 mm in length and 6 mm in diameter was used as the laser rod. In order to restrain the 1.0795 μm laser oscillating, the anti-reflective film of 1.0795 μm wavelength should be coated at both end surfaces of it besides that of 1.3414 μm. The flash-pumped lamp uses a xenon lamp that is 8 mm of diameter and 90 mm of the distance between two electrodes. According to our previous experimental results, the distance between two electrodes of the pumping lamp is shorter than the length of the laser rod, which is favorable to raise the electro-opto conversion efficiency. A plano-parallel resonant cavity was adopted to increase the mode volume inside the laser rod. The length of the resonant cavity is 45 cm, because the shorter cavity length not only reduce the influence of thermal effect, which will lead to decay the output power while the pumping power increases, but also is in favor of narrowing the pulse duration. We made several experiments with the different reflectivity of output coupler, the better result finally obtained by 60% of output coupler $M_2$. However, the transmittance at 1.0795 μm for the mirrors $M_1$ and $M_2$ should be as high as possible. In our experiment, the transmittance of both mirrors are bigger than 94%. We inserted a polarizer between the Q-switched device and the laser rod to optimize the degree of polarization. Through frequency doubling outside the cavity, we did not find the green radiation frequency doubled of 1.0795 μm laser and the orange radiation sum frequency mixed of 1.3414 and 1.0795 μm dual wavelength laser but the red radiation frequency doubled of 1.34 14 μm laser. The experimental results are listed in Table 1. Fig. 2 shows the relationship of the pump energy and Q-switched output energy under the conditions of not adding and adding a $\lambda/4$ wave plate. The pulse duration is given in Fig. 3.

![Fig. 1. The setup of 1.34 μm Nd:YAP Q-switching pulse laser. $M_1$: high reflectivity mirror, $M_2$: output mirror, $M$: Q-switching device, $P$: polarizer.](image)

Table 1

| Experimental results of 1.34 μm Nd:YAP Q-switching pulse laser |
|---------------------|-----------------|-----------------|-----------------|---------------------|---------------------|
| Q-Switched crystal | Laser rod | Wavelength (nm) | Pump energy (J) | Q-Switched output (mJ) | Q-Switched output (mJ) | Pulse duration (ns) |
| LiNbO₃       | Nd:YAP     | 1341.4         | 280            | 312                  | 255                | ~45                |
| KD*P          | Nd:YAP     | 1341.4         | 280            | 328                  | 275                | ~45                |

* The output energy obtained after inserting a $\lambda/4$ wave plate in the cavity.
It can be seen from Table 1 that after inserting $\frac{\lambda}{4}$ wave plate in the cavity, the output energy is smaller whenever LiNbO$_3$ or KD*P crystal was used as a Q-switched device but the pulse duration hardly changed, and the electro-opto conversion efficiency is, however, low using LiNbO$_3$ or KD*P crystal as Q-switched device. The reason is mainly that the transmittance of them is too low to decrease the loss inside the cavity. As long as raising the transmittance of them, we confirm the Q-switched output energy can be effectively increased. The work we are going to do is to select a good quality crystal with lower absorption coefficient and excellent processing quality as Q-switched device.

4. Conclusion

We made the experimental investigations of 1.3414 $\mu$m Nd:YAP Q-switched pulse laser using a LiNbO$_3$ and KD*P Q-switched device, respectively. The Q-switched output energy of 312 mJ for LiNbO$_3$ Q-switched device and of 328 mJ for KD*P Q-switched device with about 45 ns of pulse duration were obtained. It is necessary to point out that the anti-reflective film at 1341.4 and 1079.5 nm wavelengths should be coated on the surfaces of mirrors, Q-switched device and laser rod to restrain 1.0795 $\mu$m laser oscillating. Through selecting the lower absorption coefficient of KD*P crystal at 1341.4 nm and raising the transmittance of the Q-switched device, the 1.3414 $\mu$m Q-switched output energy will be increased. This work posses wide application prospect on the therapy of dermatology, dental and cosmetology.

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