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A new laser regime for high energy Nd:YAG lasers

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Abstract. Nd:YAG laser pumped at high energy level with milliseconds pulses and passive Q-switched with F\textsubscript{2}\textsuperscript{-} colour centers in LiF crystals was investigated. Q-switched pulse energy, pulse length, repetition rate and peak power are investigated in various working conditions.

INTRODUCTION

Despite of the relatively long history of using Nd:YAG solid-state lasers in material processing there is still a lot effort directed in order to assure new regimes of laser generation, that could increase the area of this kind of laser applications. As a consequence special attention has been paid to the development of high-average power Nd:YAG lasers pumped by variable long-pulse in the Q-switched regime.

The aim of this paper is to describe a new regime for a Nd:YAG laser pumped at high energy level with millisecond pulses and passive Q-switching with F\textsubscript{2}\textsuperscript{-} colour centres in LiF crystals. Laser emission of this kind of laser consists in trains of giant pulses (up to 2 MW) produced during a single pumping pulse.

An automatically controlled Nd:YAG long pulse laser [1], was used to investigate the passive Q-switched regime. Pumping pulses with variable width up to 10 ms and variable 0.5+10 Hz frequency generate up to 20 J laser pulse energy. The laser head was designed to compensate thermal transient and remanent effects specific to milliseconds pumping pulses.

LiF:F\textsubscript{2}\textsuperscript{-} CRYSTALS

Up to now, the F\textsubscript{2}\textsuperscript{-} colour centers in LiF crystals seems to be the most important system from practical point of view for passive Q-switching the Nd:YAG-laser. F\textsubscript{2}\textsuperscript{-} colour centres obtained by gamma, electron or neutron irradiation are characterized by broad absorption and emission bands centred at 300K around 960nm and 1170nm, respectively. The F\textsubscript{2}\textsuperscript{-} center consist of two <110> neighbouring anion vacancies binding three electrons. It is an example of a defect with weak electron-phonon coupling showing
pronounced zero-and one-phonon line transition in the absorption and emission bands up to relatively high temperatures. Characteristic for this system is the absorption cross section at the Nd:YAG laser wavelength ($1.5\pm2\times10^{-7}\text{cm}^2$), a lifetime of 70-100ns at 300K, good stability against both thermal destruction at room temperature and bleaching by 1.064µm irradiation.

The LiF:F$^-$ passive Q-switch can be characterized by a set of parameters $[2,3]$ as: (i) the small signal absorption coefficient $\alpha$ at 1.06µm; (ii) the coefficient of residual losses $\beta$ at 1.06µm under saturated F$_2^-$ absorption; (iii) the absorption coefficient $\gamma$ at 1.3µm which can be taken as a measure of losses which are not generated by F$_2^-$ color centre absorption. A variety of LiF:F$^-$ saturable absorbers ($0.17\text{cm}^{-1} < \alpha < 0.39\text{cm}^{-1}$, $0.05\text{cm}^{-1} < \beta < 0.10\text{ cm}^{-1}$, $1.13\text{ cm}^{-1} < \gamma < 0.07\text{cm}^{-1}$) was used in our experiment.

Several factors can affect the exploitation of a LiF:F$^-$ system as a passive Q-switch. The most important parameter determining the laser output is the contrast, the ratio between the absorption coefficient for low signal at 1.064µm and that of passive losses, characterizing the residual absorption when F$_2^-$ absorption is saturated. Published data show that the contrast and the losses are function of preparation technology: nature and impurities content, irradiation technology, etc.

**EXPERIMENTS AND DISCUSSIONS**

We investigate the laser emission of Nd:YAG long pulse (0.5±10ms) Nd:YAG laser, Q-switched by LiF:F$^-$ crystals with different characteristics. The free-laser running average power of this laser is 100W, with energy pulses up to 20J and variable repetition rate (0.5±50Hz).

A 6.6x94mm Nd:YAG active medium was placed into a plan-plan optical resonator of 450mm length and pumped in a single elliptical cavity. LiF:F$^-$ crystal was placed between the rear mirror and active medium. The laser pulse energy was measured by SCIENTECH362 energymeter and Q-switched pulses were monitored by a ROL26 photodetector with 2ns risetime and a Tektronix466 scope. The results obtained by using different LiF:F$^-$ crystals as passive Q-switches are presented in Table I.
Table I. Data about LiF:F_2 crystal and parameters of Q-switched laser pulses.

<table>
<thead>
<tr>
<th>Nr. Q-sw</th>
<th>Q-switch parameter</th>
<th>Free laser pulse energy (J)</th>
<th>Q-switch laser pulse energy (J)</th>
<th>Length of train pulses (ms)</th>
<th>Repetition rate of Q-switch pulses (kHz)</th>
<th>Intensity of Q-switch pulses (a.u.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>0.19</td>
<td>0.98</td>
<td>0.03</td>
<td>6.9</td>
<td>1.77</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td>0.17</td>
<td>0.05</td>
<td>0.04</td>
<td>6.9</td>
<td>3.6</td>
</tr>
<tr>
<td>3</td>
<td>37</td>
<td>0.29</td>
<td>0.06</td>
<td>0.02</td>
<td>6.9</td>
<td>2.3</td>
</tr>
<tr>
<td>4</td>
<td>32</td>
<td>0.23</td>
<td>0.1</td>
<td>0.07</td>
<td>6.9</td>
<td>3.3</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>0.33</td>
<td>0.06</td>
<td>0.04</td>
<td>6.9</td>
<td>3.3</td>
</tr>
<tr>
<td>6</td>
<td>45</td>
<td>0.17</td>
<td>0.09</td>
<td>0.05</td>
<td>6.9</td>
<td>2.8</td>
</tr>
<tr>
<td>7</td>
<td>35</td>
<td>0.34</td>
<td>0.1</td>
<td>0.06</td>
<td>6.9</td>
<td>3.9</td>
</tr>
<tr>
<td>8</td>
<td>68</td>
<td>0.37</td>
<td>0.06</td>
<td>0.06</td>
<td>6.9</td>
<td>1.7</td>
</tr>
</tbody>
</table>

Depending by $\beta/\alpha$ ratio and pumping pulse width, tens to thousands pulses train during a single pumping pulse were obtained. Figure 1. shows a typical example of such a behaviour. Peak intensity and Q-switched pulses frequency depends also on $\beta/\alpha$ ratio and the pumping level.

![Fig. 1. Laser pulse intensity for free-generation and Q-switching regime for 6 ms pumping pulse length.](image_url)

The correlation between the pumping levels and $\beta/\alpha$ ratio is very important in order to obtain the ratio $E_{Q\text{-switch}}/E_{\text{free running}}$ closely to one.
These observations are in good agreement with those predicted by passive Q-switching theory [4,5].

Improving of laser beam quality, affected by thermal focusing of the laser rod and LiF:F\textsuperscript{2-} crystal, can be obtained by using a proper variable reflectivity mirror unstable resonator. The major impediment in using the LiF:F\textsuperscript{2-} Q-switching system in lasers with average power over 100W is the fading effect. This effect produces a change in the Q-switch characteristics and therefore of the Q-switched pulses. Fading effects can be a results of ultraviolet irradiation from flash lamp, of thermal effects due to the residual losses or even instability at high power 1.06\mu m radiation.

CONCLUSION

The trains of tens to thousands Q-switched laser pulses obtained from a Nd:YAG laser operating at 1.06\mu m and Q-switched by a LiF:F\textsuperscript{2-} passive absorber could be useful for some technological applications. If the laser is operated below 100W average power and the LiF:F\textsuperscript{2-} are careful selected the fading effect can be surpassed.

References