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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_2^- 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_2^- 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:F₂⁻ CRYSTALS

Up to now, the F_2^- 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_2^- 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_2^- 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 ($1.5 \div 2 \times 10^{-17} \text{ cm}^2$), a lifetime of 70-100ns at 300K, good stability against both thermal destruction at room temperature and bleaching by $1.064 \mu\text{m}$ irradiation.

The LiF:F_2^- passive Q-switch can be characterized by a set of parameters [2,3] as: (i) the small signal absorption coefficient α at $1.06 \mu\text{m}$; (ii) the coefficient of residual losses B at $1.06 \mu\text{m}$ under saturated F_2^- absorption; (iii) the absorption coefficient γ at $1.3 \mu\text{m}$ which can be taken as a measure of losses which are not generated by F_2^- color centre absorption. A variety of LiF:F_2^- saturable absorbers ($0.17 \text{ cm}^{-1} < \alpha < 0.39 \text{ cm}^{-1}$, $0.05 \text{ cm}^{-1} < B < 0.10 \text{ cm}^{-1}$, $1.13 \text{ cm}^{-1} < \gamma < 0.07 \text{ cm}^{-1}$) was used in our experiment.

Several factors can affect the exploitation of a LiF:F_2^- 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 $1.064 \mu\text{m}$ 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 ($0.5 \div 10 \text{ ms}$) Nd:YAG laser, Q-switched by LiF:F_2^- 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 ($0.5 \div 50 \text{ Hz}$).

A $6.6 \times 84 \text{ mm}$ Nd:YAG active medium was placed into a plan-plan optical resonator of 450mm length and pumped in a single elliptical cavity. LiF:F_2^- crystal was placed between the rear mirror and active medium. The laser pulse energy was measured by SCIENITECH362 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_2^- 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.

Nr. Q-sw	Q-switch parameter				Free laser pulse energy (J)	Q-switch laser pulse energy (J)	Length of train pulses (ms)	Repetition rate of Q-switch pulses (kHz)	Intensity of Q-switch pulses (a.u.)
	l (mm)	α^{-1} (cm^{-1})	β^{-1} (cm^{-1})	γ^{-1} (cm^{-1})					
1	50	0.19	.08	.05	6.9	2.77	5.5	500	4.5
2	40	0.17	.05	.04	6.9	3.6	5.9	1000	0.6
3	37	0.39	.06	.03	6.9	2.5	5.2	100	4.5
4	32	0.23	.1	.07	6.9	3.3	5.7	500	3.5
5	35	0.33	.06	.04	6.9	3.3	5.5	100	7
6	45	0.17	.09	.05	6.9	2.8	5.5	600	2.5
7	35	0.34	.1	.06	6.9	3.9	5	200	11
8	68	0.37	.06	.06	6.9	1.7	4	5	24

Depending by β/α 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 β/α ratio and the pumping level.

Fig. 1. Laser pulse intensity for free-generation and Q-switching regime for 6 ms pumping pulse length.

The correlation between the pumping levels and β/α ratio is very important in order to obtain the ratio $E_{\text{Q-switch}}/E_{\text{free running}}$ 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_2^- crystal, can be obtained by using a proper variable reflectivity mirror unstable resonator. The major impediment in using the LiF:F_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 $1.06\mu\text{m}$ radiation.

CONCLUSION

The trains of tens to thousands Q-switched laser pulses obtained from a Nd:YAG laser operating at $1.06\mu\text{m}$ and Q-switched by a LiF:F_2^- passive absorber could be useful for some technological applications. If the laser is operated below 100W average power and the LiF:F_2^- are careful selected the fading effect can be surpassed.

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