

Laser characteristics of active medium $\text{LiLu}_{0.7}\text{Y}_{0.3}\text{F}_4:\text{Ce}^{3+}$ in ultra-short pulse mode

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Abstract. We have obtained the single pulse laser oscillation with 400 ± 10 ps pulse duration at 311 nm from $\text{LiLu}_{0.7}\text{Y}_{0.3}\text{F}_4:\text{Ce}^{3+}$ crystal with 6 ns laser pump at 289 nm. We expect this due to passive Q-switch by means of pump induced color centers which absorb laser radiation and determine the intensity discrimination of laser pulses with contrast of about 1,8.

1. Introduction

Today new technologies express demand on lasers oscillating in ultraviolet (UV) spectral range and having short pulse duration [1,2]. Main methods of obtaining UV laser radiation are nonlinear and parametric conversion of non UV laser radiation [1 – 5]. These methods can be technically difficult and it takes a lot of space. But on the other hand one can obtain UV lasing by use of fluoride crystals doped by Ce^{3+} ions as active media [6, 7]. Fluoride crystals doped by ions Ce^{3+} allow us to obtain short pulses with duration from several to tens of nanoseconds and even in subnanosecond time domain. To obtain shorter pulses we should use Q-switching or mode-locking [8, 9].

The aim of this work was obtaining laser pulses with ultra-short duration of UV spectral range and study of laser characteristics of active medium $\text{LiLu}_{0.7}\text{Y}_{0.3}\text{F}_4:\text{Ce}^{3+}$ (Ce:LLYF) in ultra-short pulse mode.

Among the trivalent lanthanide ions the ion of Ce^{3+} has minimal energy of 5d configuration with the value of about 50000 cm^{-1} [10, 11]. And ultraviolet laser radiation in Ce:LLYF is driven by stimulated emission resulting from interconfigurational 5d-4f transitions in Ce^{3+} ions excited by UV laser pump the same as in known homologous UV active medium $\text{Ce}^{3+}:\text{LiLuF}_4$ [6, 12, 13].

There are photodynamic processes in UV active medium resulting in formation of color centers [14]. Color centers in there turn absorb energy of laser radiation and cause losses in active medium [15, 16]. Level of losses due to color centers depends on amount of laser radiation inside the cavity and other factors (some of them are external additional irradiation and temperature) and doesn't remain constant during experiment [16, 17]. This gives an opportunity to utilize the color center losses for arrangement the modulation of Q-factor of the cavity or even mode-locking.

2. Experimental equipment

The object of the work is $\text{LiLu}_{0.7}\text{Y}_{0.3}\text{F}_4$ mixed crystal with 1 at. % of Ce^{3+} ions put in the melt. The sample was cut and polished according to side pumping scheme and lasing through Brewster windows. This sample was grown and prepared in Kazan (Volga region) Federal University in Quantum Electronics and Radiospectroscopy department.



The experimental setup for obtaining ultra-short pulses in UV band we have built is presented in Fig. 1. It contains 10 Hz pulsed UV solid state laser with double pass amplifier based on $\text{Ce}^{3+}:\text{LiCaAlF}_6$ active medium as pump source oscillating at 289 nm wavelength and 2 mJ energy level per pulse.

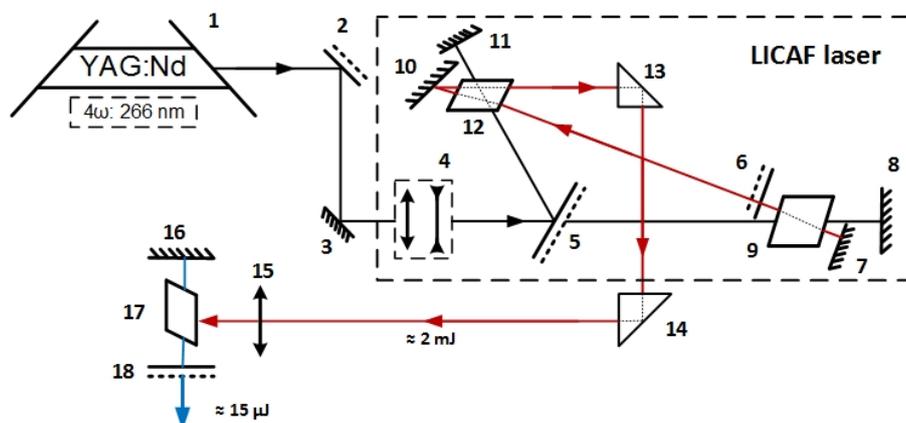


Figure 1. The experimental setup for the Ce:LLYF laser. Consists of: 1 – laser YAG: Nd; 2 - spectrum splitter; 3,7,8,10,11,16 – reflectors $R=99,9\%$; 4 – telescope; 5 – 266 nm beam splitter $R=30\%$; 6,18 – reflectors $R=65\%$; 9, 12 – crystals Ce:LICAF; 13, 14 - rectangular prisms; 15 - converging lens; 17 – crystal Ce:LLYF.

The Ce:LLYF cavity was organized by two reflectors (99,9 % and 65 % reflection in the range 270 nm – 350 nm) and corresponded to Fabri-Perrot cavity with low Q-factor determined by small length (20 mm) and low output window reflection.

Pulse duration measurement was performed by Alphaslas photodiodes with 50 ps rise time coupled to Tektronix oscilloscope with 3,5 GHz bandwidth.

3. Ultra-short pulse UV lasing

Laser oscillation from Ce:LLYF was obtained in pulse mode at the wavelength $\lambda = 311$ nm and with pulse duration $t = (400 \pm 10)$ ps (Fig. 4b). Laser radiation of pumping was pulsed with pulse duration $t = (6,375 \pm 0,025)$ ns (Fig. 4a).

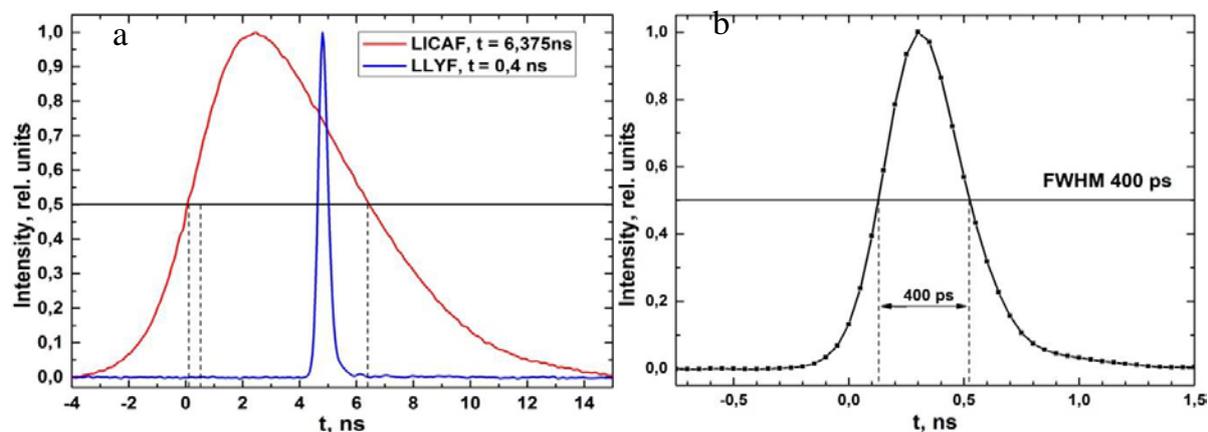


Figure 4. Temporal distribution of laser pulses obtained from Ce:LLYF (a) and Ce:LICAF (b)

The estimated photon lifetime in the cavity was $\tau_c = 281$ ps. Pulse duration of Ce: LLYF laser radiation appeared to be greater than the photon lifetime in the cavity, so it means that we have multimode nature of the laser radiation. However, we see the single pulse, which tells us about possible Q-switching.

4. Dependence of the laser radiation energy on pump radiation energy.

To determine the cause of shortening the pulse duration we have studied the dependence of the output energy on the pump energy at different pulse repetition rates and the reflection coefficients of the output mirror of the cavity. The experiment consisted also in measuring the output energy sequentially with increase and decrease of the pump energy [16]. In result we see a hysteresis loop determined by color centers accumulation inside the active medium and decrease of its square with decrease of pulse repetition rate is characteristic due to finite lifetime of color centers.

Results of study of dependence of the laser radiation energy on pump radiation energy for different reflection coefficients of output mirrors have shown that reflection coefficient increase also leads to reduction of hysteresis loop square (see dependencies for 10 Hz repetition rate at Fig. 5 a and b), which is proportional to the number of color centers. Apparently lifetime of color centers is larger than time period between pump pulses and they do not dissolve to the time of next pump pulse and amount of color centers accumulated rises with increase of pulse repetition rate.

As it was investigated earlier [15, 18] increase of laser radiation intensity inside the cavity leads to bleaching of color centers. Thus for lower reflection coefficient 65 % of an output mirror an early saturation pronounces which is absent for 80 % reflection mirror. This is also an evidence of accumulation of color centers staying inside the active medium but experiencing photobleaching by higher laser radiation intensity for the case of 80 % reflection mirror.

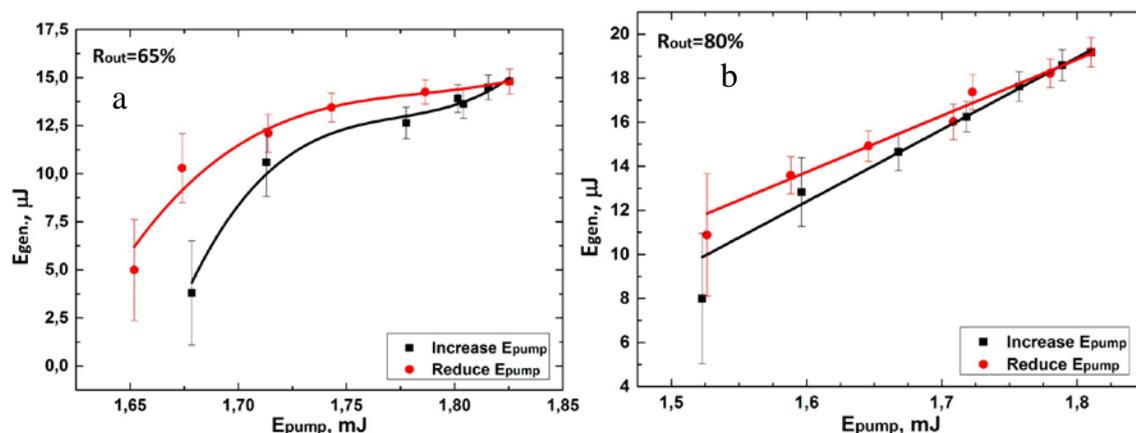


Figure 5. Dependence of Ce:LLYF laser output energy on pump radiation energy for mirrors with reflection coefficients $R=65\%$ (a) and $R=80\%$ (b) at 10 Hz pulse repetition rate

The photobleaching of color centers by laser radiation is also clearly seen from Fig. 6, where intracavity losses calculated from experimental results [18] are presented dependent on pump energy. Losses at higher energies of pump radiation where intensity of laser radiation is also high appear to be lower. And this is the principle of discrimination of laser pulses by means of saturable absorber. We have obtained the most significant contrast ratio for the highest pulse repetition rate in our experiments 10 Hz which corresponds to the case of accumulation of color centers inside the media.

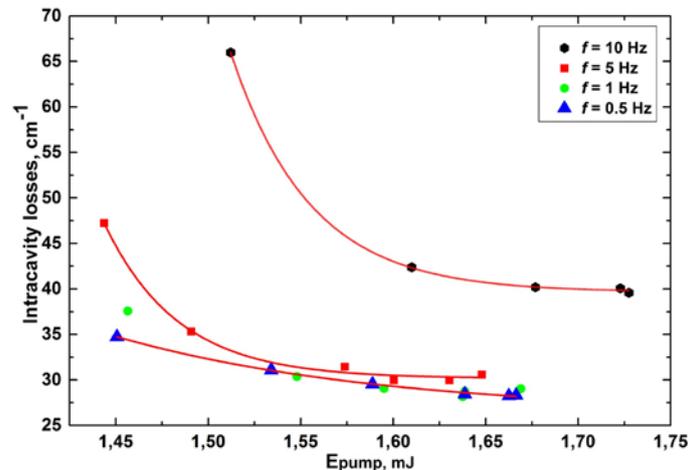


Figure 6. Intracavity losses for different frequencies.

5. Conclusion

Laser oscillation was obtained in active medium $\text{Ce:LiLu}_{0.7}\text{Y}_{0.3}\text{F}_4$ in a pulse mode at the wavelength $\lambda = 311$ nm as single pulse with duration $t = (400 \pm 10)$ ps in the low Q-factor cavity. Pumping was performed at wavelength $\lambda = 289$ nm in pulsed mode with pulse duration $t = (6,375 \pm 0,025)$ ns. Slope efficiency measured for 80 % reflection of output mirror in Fabri-Perrot nonselective cavity was 4 %. We expect that shortening of the pulse duration was achieved by passive Q-switch, which is caused by bleaching of color centers in the volume of the active medium absorbing the laser radiation. Thus measured contrast of losses level dependence on pump energy appeared to be 1,8 and methods of Q-switch control are change of pumping energy, pulse repetition rate or output mirror reflection.

Acknowledgements

This work was funded by the subsidy allocated to Kazan Federal University for the project part of the state assignment in the sphere of scientific activities.

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