New all-solid-state tunable UV Ce^{3+},Yb^{3+}:$LiY_{0.4}Lu_{0.6}F_4$ laser

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Here we report laser test results of the new UV solid-state active medium based on a Ce^{3+},Yb^{3+}:$LiY_{0.4}Lu_{0.6}F_4$ mixed crystal pumped by radiation from Ce:LiCAF laser. The 10-Hz pulse repetition rate Ce^{3+},Yb^{3+}:$LiY_{0.4}Lu_{0.6}F_4$ laser yielded a maximum output power of 0.25 mJ at 311 nm in non-optimized non-selective resonator with a maximal slope efficiency of 13 %. Tunability from 304 to 332 nm was achieved in the selective single-prizm resonator.

Introduction. Currently, there are only two UV solid-state active media used for commercially available lasers – Ce:$LiCaAlF_6$ (LiCAF) and Ce:$LiLuF_4$ (LLF) single crystals. Growing demand for the efficient and cheap UV radiation sources urges the search for the new UV active media and improvement of their performance. Here we report the results of the first lasing experiments on the new solid-state active medium – Ce^{3+},Yb^{3+}:$LiY_{0.4}Lu_{0.6}F_4$ mixed crystal.

The promise of the replacing $LiYF_4$ (LYF) and LLF monocrystals by their mixed crystals was demonstrated in [1]. It was established there that the increase of Lu^{3+} content (x) in Ce^{3+}:$LiY_{1-x}Lu_xF_4$ mixed crystals leads to the decrease of the power loss ratio in the lasing frequency range. It happens due to reciprocal shifting of $5d$-$4f$ luminescence of Ce^{3+} ions and color centers absorption bands, as well as increase of $5d$-$4f$ luminescence quantum yield of active dopants. Besides, Ce^{3+} ions segregation coefficient in $LiY_{0.4}Lu_{0.6}F_4$ mixed crystals is 3–4 times as much as the one in YLF or LLF crystals [2]. This means that for the same level of the impurity content crystal lattice of mixed crystal endures lesser strain as compared with the LYF and LLF crystals. Therefore, fewer amounts of color center seeds and lower color center absorption intensity will occur. And, last but not the least, active element made of $LiY_{1-x}Lu_xF_4$ mixed crystal turns out to be much cheaper as compared with LLF, since it requires less amount of lutetium, while keeping or even improving its laser performance. It was also demonstrated earlier [3, 4] that coactivation of Ce^{3+}:$LiY_{1-x}Lu_xF_4$ crystals ($x = 0{-}1$) by Yb^{3+} ions is an effective method of color centers suppression, which results in higher gain in wider spectral domain [1].

Similar to Ce:YLF and Ce:LLF single crystals five $4f$-$5d$ absorption bands are observed in Ce^{3+},Yb^{3+}:$LiY_{0.4}Lu_{0.6}F_4$ mixed crystals at about 295, 245, 205, 195, and 185 nm (see Fig. 1). It

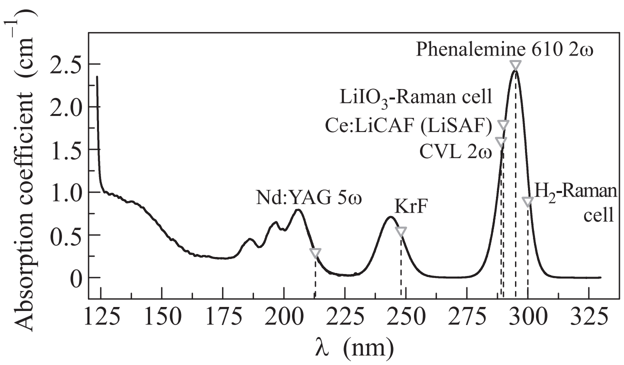

Fig. 1. Ce^{3+} ions $4f$-$5d$ absorption spectrum in Ce^{3+},Yb^{3+}:$LiY_{0.4}Lu_{0.6}F_4$ crystal. Possible suitable pumping sources are indicated

allows the use of quite a few lasers as a pumping source: frequency-quintupled Nd:YAG laser (213 nm), KrF laser (248 nm), frequency-doubled yellow output of a copper-vapor laser (289 nm), frequency-quadrupled output of the 1st Stokes line of $LiIO_3$ Raman-shifted Nd:YAG laser (289 nm), 1st Stokes line of H_2 Raman-shifted frequency-quadrupled Nd:YAG laser (300 nm), frequency-doubled or -tripled outputs of organic dye lasers (e.g. 300 nm by Phenalemine 610), and frequency-quadrupled Nd:YAG-pumped Ce:LiSAF or Ce:LiCAF lasers (290 nm).

The latter pumping source will provide the most compact and simplest all-solid-state laser system with the best long-term output stability. Besides, pumping into the band peaking at 295 nm rather than into 245 nm band appears more favorable since parasitic processes related to impurity ion photoionization arise in Ce:LYF and Ce:LLF at ~300 nm and intensify with the shortening of pumping wavelength [5].

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Experimental results and discussion. Ce^{3+},Yb^{3+}:$LiY_{0.4}Lu_{0.6}F_4$ mixed crystal has been grown and treated at the Laboratory of Crystal Growth of Kazan Federal University. Ce^{3+} and Yb^{3+} ions content in the mixture was 1 at.%. A 1.5 mm thick active element was disk-shaped and polished, with a C-axis parallel to the disk plane.

All lasing tests were carried out at the room temperature. The Ce^{3+},Yb^{3+}:$LiY_{0.4}Lu_{0.6}F_4$ laser was pumped with 290 nm output of a tunable Ce:LiCAF laser produced by "Ultraviolet Solutions" LLC that provided up to 6 mJ at a pulse repetition rate of 10 Hz. The polarization of the pump beam was aligned parallel to the C-axis of the laser crystal since it is in this polarization the gain is highest and the color centers absorption is less intense [6]. A quasi-longitudinal geometry has been used due to the difficulty of manufacturing a suitable dichroic resonator mirror with a high transmission at the pumping wavelength that would withstand the high energy density of the pumping radiation. The pump beam was focused on the laser crystal (4) to a spot 0.06 cm in diameter by an $f = 150$ mm fused silica lens (3).

Fabry-Perot resonator (see Fig. 2) consisted of high reflector ($R \sim 100\%$) (5) and an output coupler ($R \sim$ $\sim 25\%$) (6) separated by 30 mm. To obtain spectral tun-

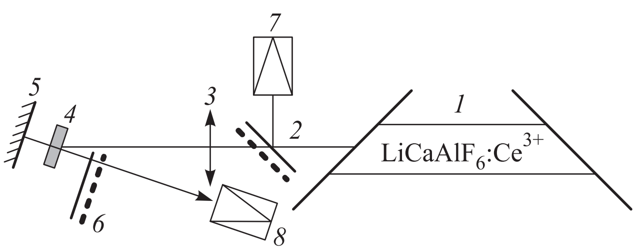

Fig. 2. Laser scheme with non-selective resonator: *1* – pumping Ce:LiCAF laser, *2* – SiO_2 wedge, *3* – 150 mm convex lens, *4* – Ce^{3+},Yb^{3+}:$LiY_{0.4}Lu_{0.6}F_4$ crystal, *5*, *6* – high reflector and output coupler, respectively, *7*, *8* – power meter heads

ability the resonator length was increased to 50 mm to allow insertion of a single 60° fused silica prism into the resonator. Lasing energy as well as a portion of pumping radiation energy, taped by a calibrated wedge (2), have been controlled by an Ophir dual-channel power meter (7).

First laser experiments on Ce^{3+},Yb^{3+}:$LiY_{0.4}Lu_{0.6}F_4$ active medium in flat non-selective resonator have yielded stable π-polarized lasing at 311 nm. Slope efficiency of 13% and a threshold of 100 mJ·cm^{-2} have been achieved without any optimization of the resonator whatsoever. For comparison lasing on Ce(1 at.%):LLF crystal of the similar shape and size at the same resonator and under the same pumping conditions was obtained. The slope efficiency was about 10% at 310 nm, which is probably because of the worse photochemical stability of Ce:LLF crystals as compared with Ce^{3+},Yb^{3+}:$LiY_{0.4}Lu_{0.6}F_4$ mixed crystal and/or lower absorbed pumping energy in Ce:LLF active element. This, apparently, is due to the anti-solarant Yb^{3+} codoping effect [3].

In selective resonator with an 80% output coupler and a single 60° fused silica prism (8) mounted near the high reflector (see Fig. 3) tunable operation of

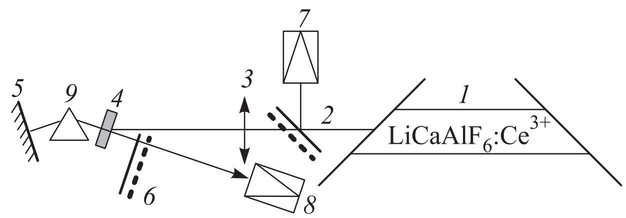

Fig. 3. Laser scheme with a selective resonator: *1* – pumping Ce:LiCAF laser, *2* – SiO_2 wedge, *3* – 150 mm convex lens, *4* – Ce^{3+},Yb^{3+}:$LiY_{0.4}Lu_{0.6}F_4$, *5*, *6* – high reflector and output coupler, respectively, *7*, *8* – power meter heads, *9* – 60° fused silica prism

Ce^{3+},Yb^{3+}:$LiY_{0.4}Lu_{0.6}F_4$ laser from 304 to 316 and from 323 to 332 nm has been achieved. The tuning curve is shown on Fig. 4. In the longer-wavelength part of the

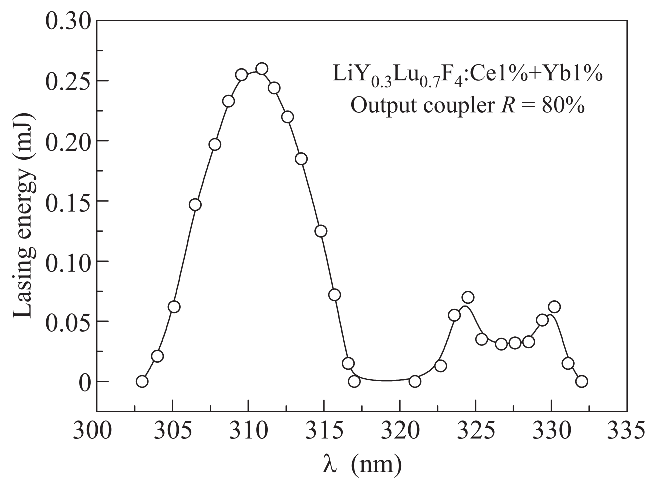

Fig. 4. Tuning curve of Ce^{3+},Yb^{3+}:$LiY_{0.4}Lu_{0.6}F_4$ laser at the room temperature

tuning curve from 325 to 329 nm there is an apparent dip in the output power. It is also peculiar that the laser was oscillating in the σ polarisation in this spectral region even though the prism was aligned so as to favour π-polarised oscillation. At all other wavelengths in the tuning curve the laser output was π-polarised. Similar behavior of the tuning curve has been reported earlier in [7] in Ce:LLF crystal. It appears to us that this shape of the tuning curve as well as the spontaneous repolarisation of the laser radiation is due to the *F*-type color centers absorption, which is more pronounced in this spectral region for the π-polarized radiation [8].

The output power performance of Ce^{3+},Yb^{3+}:$LiY_{0.4}Lu_{0.6}F_4$ laser at 311 and 327 nm presented in Fig. 5 testifies in favor of this considera-

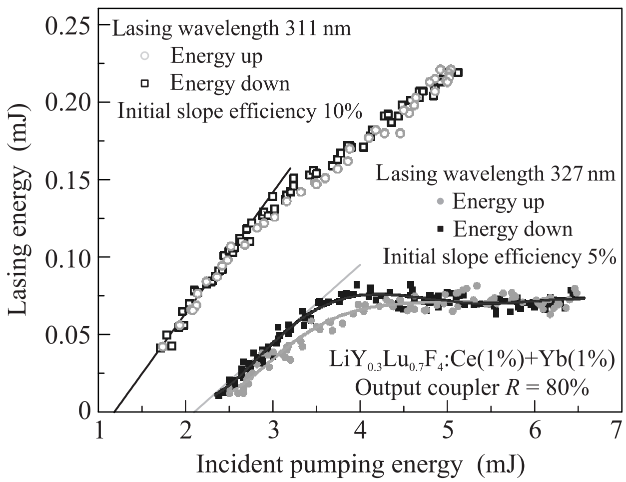

Fig. 5. Lasing energy versus pumping energy for the Ce^{3+},Yb^{3+}:$LiY_{0.4}Lu_{0.6}F_4$ laser at the room temperature at 311 and 327 nm. The black symbols represent data registered with pulse-to-pulse increase of pumping energy, the grey ones – with the decrease of pumping energy

tion. First of all, the slope efficiency at 311 nm turned out to be almost twice as high as that at 327 nm (10 and 5%, respectively). Secondly, at 327 nm the output energy changes linearly with the incident pumping energy up to 4 mJ and completely saturates when the pumping energy exceeds 4 mJ, while at 311 nm deviation from linearity is not as well pronounced. And finally, at 327 nm the same dependence, registered at first with pulse-to-pulse increase of pumping energy, and then with the decrease of pumping energy, demonstrates a hysteresis effect (see Fig. 5). Such dependence of the laser output on the history of the sample's irradiation, previously observed in [9], also exposes color center's deteriorating influence.

Conclusion. Here we reported lasing on the new UV solid-state active medium Ce^{3+},Yb^{3+}:$LiY_{0.4}Lu_{0.6}F_4$ obtained for the first time. Ce^{3+},Yb^{3+}:$LiY_{0.4}Lu_{0.6}F_4$ mixed crystal demonstrates stable output power and tunability that are similar to those of its homologous analogue – Ce:LLF single crystal. However, higher impurity distribution coefficient and lower cost of the new active medium gains an additional advantage. We consider it necessary to emphasize that presented results have been achieved without any optimization of the experimental conditions whatsoever. Therefore, adjustment of chemical composition, optical quality, pumping conditions as well as application of additional illumination and selection of temperature regime of the laser element [10] should result, in our opinion, in much more impressive output characteristics. Corresponding investigations on our part are in progress.

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