PONDEROMOTOR FORCES IMPACT ON PROPERTIES OF UV SOLID-STATE LASER

V. V. Semashko [1], O. R. Akhtyamov [1], A. S. Nizamutdinov [1], M. A. Marisov [1], E. Sarantopoulou [1,2], A. C. Cefalas [1,2]

[1] *Kazan Federal University, Kazan, Russia; e-mail: vadim.semashko@kpfu.ru*
[2] *National Hellenic Research Foundation, TPCI, Russia*

Incident pumping laser radiation initiates diffusion of molecules and impurities particles adsorbed on surface of solid-state active media (SSAM) into the bulk and leads to laser properties degradation. In contrast, transmitted through the SSAM laser beam cleans the exit aperture.

Ponderomotor forces of radiation (PFR), which were perceived like as exotic effects at the beginning of XX century, at the recent time exhibit practical importance in case of laser radiation. For instance, the PFR are widely and successfully applied in biomedicine (laser tweezers) [1], atom optics, laser cooling of gases and separation of isotopes [2–3]. In addition, there are data about modification of surfaces of solid-state materials in vacuum due to light induced enhanced diffusion of environment atoms and molecular or adsorbed ones on the surface [4] and even about their micro engraving by laser beam accelerated suspended particles in liquid [5]. In this way, to our knowledge, the lack of literature data about ponderomotor forces impact on properties of solid-state active media or nonlinear optics elements pumped by intensive and coherent laser radiation are seemed surprising. Here the experimental data of ponderomotor effects impact on the properties of UV solid-state laser based on Ce:$LiCaAlF_6$ (Ce:LiCAF) single crystals pumped by UV radiation at 266 nm are presented and discussed for the first time.

The idea of the research is to study laser properties distinctions of the thin near-surface front and rear areas of solid-state active medium transversally pumped by laser radiation. To maximize a detectability of the PFR effects, the well-known UV solid-state laser medium Ce:LiCAF was investigated [6]. This medium provides high optical net gain, because of dipole allowed 5*d*–4*f* transition of Ce^{3+} active ions and does not demonstrate noticeable laser properties degradation associated with the photodynamic processes, which can be camouflaged PFR induced extra losses [7].

The experimental results and the setups peculiarities are shown on Fig. 1. The 1.1 mm thick all sides polished plate of Ce:LiCAF (c = 1 at.% in the melt) single crystal was used as active element (1). It was 5.5 mm in length and about 4 mm in height. The fourth harmonic radiation of Nd:YAG laser (λ = 266 nm, 12 ns pulse length. 10 Hz pulse repetition rate) was applied as a pumping (5). Fabri-Perrot laser cavity formed by plate dielectric mirrors with 100% (3) and 80% (4) reflectivity at 280–330 nm spectral range was used. To study the laser properties of thin layers (about 0.1–0.2 mm) of active media situated just on the front surface of sample irradiated by pumping (volume A) or on the rear one (volume B), the two metal blade shields (2) were attached to the ends of laser crystal rod. Pumping and laser output energies were measured by 4-channel OPHIR power meter. The 3 ns pulse of laser oscillation at 290 nm were observed in the experiments. It was established that the volume “B” demonstrates higher laser slope efficiency, than volume “A” – 12.7 % and 8.4 %, respectively. At the same time intracavity losses demonstrates a reduced level for volume “B” compared to the volume “A”.

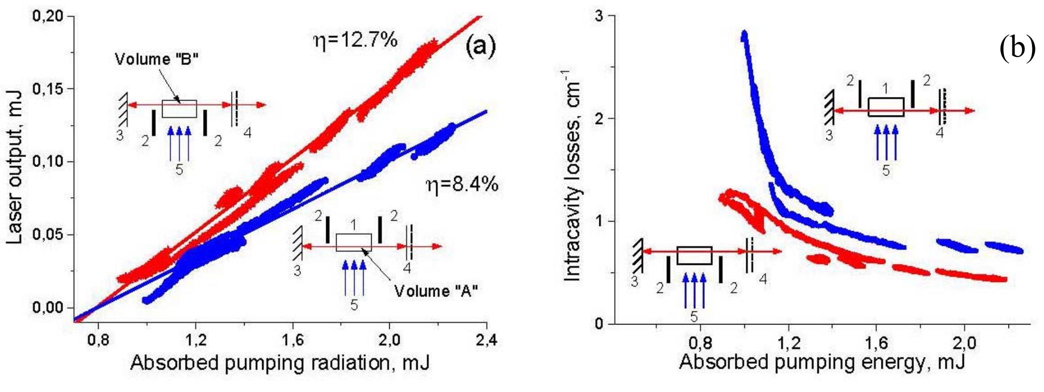

Fig. 1. Laser output (a) and intracavity losses (b) versus absorbed pumping energy for the directly irradiated volume A (red stars) and the irradiated through the sample volume B (blue dots), respectively. Experimental setup peculiarities are shown in the insets: 1 – Ce:LiCAF active medium, 2 – the metal blade shields, 3 and 4 – laser cavity mirrors, 5 – the pumping radiation.

The Fig. 2a demonstrates the ratio of laser output energy at 290 nm to pumping energy versus exposure time for both “A” and “B” areas. The graphs were also normalized to maximum of laser output. As it can be seen, the normalized laser output is dropping with exposure time with the speed about -5×10^{-3} c^{-1} for the area “A”. In contrast, it is about 8 times higher than for area “B” (-6×10^{-4} c^{-1}). It means that the intracavity losses arise with time for area “A” and they are almost constant for area “B”.

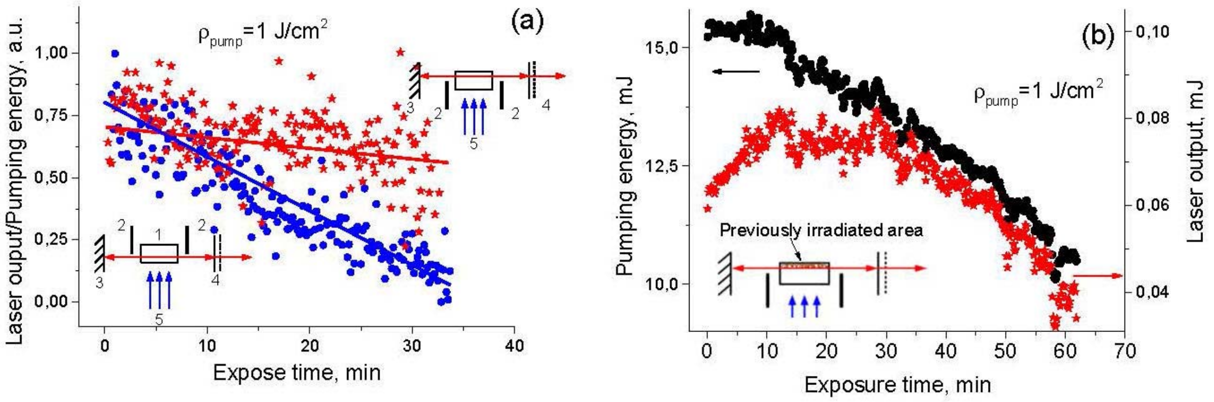

Fig. 2. Normalized laser output to pumping energy vs exposure time by pumping radiation for the directly irradiated volume A (red stars) and for the irradiated through the sample volume B (blue dots), respectively (a). The “cleaning effect” of previously exposed near- surface area “A” of Ce:LiCAF active medium by the outgoing pumping radiation beam transmitted through the sample (b). The black dots demonstrate pumping energy trend vs time and the red starts is the laser output one.

The Fig. 2b elucidates a “cleaning effect” of previously 1 hour exposed near-surface area “A” of Ce:LiCAF active medium by the outgoing pumping radiation beam transmitted through the sample. As it can be seen, the laser output (red stars) rises during about 30 min started from the moment experiment’s beginning and then follows for the slowly falling pumping radiation energy (black dots). Further irradiation of this area or virgin one does not produce greater cleaning effect even by more powerful beam. Besides the similar experiments with alignment positioning 250 μm-slits and results of the pump-probe experiments with the probe beam reflected from the front and from the rear surfaces of the sample prove the modification and cleaning of thin near-surface areas of samples by pumping radiation.

The theoretical evaluation of pump-induced photodynamic processes impact on these experimental results testify that it are negligible. Thus the observed effects can be attributed to the PFR enhanced diffusion of environmental molecular, atmospheric dust and/or impurities particles adsorbed on the surface into solid-state laser media and, vice versa, the impurities can be removed from the near-surface thin layer by outgoing laser radiation transmitted through the sample.

The AFM investigation of the sample’s surfaces results prove that the few nm-sized surface modifications are observed only. At the same time, the surface parameters (roughness) of the irradiated areas have higher values than the non-irradiated ones. It means that small molecular species are forced by the laser irradiation to be deposited on the front surface (area “A”) of the crystal. In contrast, the surface parameters of the “cleaned” area have lower values than the non-cleaned ones. It indicates that small contaminants are removed from the surface following outgoing laser beam. The XPS studies are still in progress and their results will be presented on the conference.

This work were performed due to financial support by Russian Scientific Foundation grant (project № 15-12-10026).

1. A. Ashkin, *Phys. Rev. Lett.*, **24**, 156–159 (1970).
2. V. I. Balikin, *Herald of RAS*, **81**, 91–100 (2011).
3. N. V. Karlov and A.M. Prokhorov, *Sov. Phys. Usp*., **19**, 285–300 (1976).
4. E. Sarantopoulou, et al., *Appl. Surface Sci.*, **254**, 804–810 (2007).
5. S. D. Zakharov, M. A. Kazaryan and N. P. Korotkov, *JETP Lett.*, **60**, 322–324 (1994).
6. M. A. Dubinskii, et al., *J. Mod. Opt*., **40**, 1–5 (1993).
7. V. V.Semashko, *Phys. Solid State*, **47**, 1507–1511 (2005).