Novel acousto-optical KYW and KGW Q-switches for powerful 3-μm lasers

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Abstract: The first application of a KYW and KGW acousto-optical shutters in 3-μm lasers is reported. The Cr:Er:YSGG laser provides 29.6-mJ 75-ns pulses. The energy is scaled to 85.7 mJ in the MOPA system. © 2019 The Authors

OCIS codes: (140.3070) Infrared and far-infrared lasers; (140.5680) Rare earth and transition metal solid-state lasers (140.3540) Lasers, Q-switched

1. Introduction

Powerful 3-μm laser systems are of interest for many scientific and practical applications, for example, pumping of a Fe:ZnSe crystal in a gain-switched laser or a laser amplifier in the CPA system [1]. In addition, such mid-IR sources can become a convenient tool for microstructuring during the laser-induced backside wet etching of transparent materials such as sapphire and diamond in pure water. Due to the extremely high absorption of water intense cavitation and shock waves are the accompanying processes during the etching [2]. Nanosecond 3-μm lasers have been demonstrated using various methods of Q-switching, including electro-, acousto-optical and FTIR [3]. However, the low shutter material damage threshold usually limits the high output energy. Recently, there is a tendency to exploit an optical-mechanical method of Q-switching [4], [5], which has a number of advantages. Nevertheless, optical-mechanical and FTIR shutters optical jitter limits the possibility to synchronize it with another laser sources on the nanosecond timescale, for instance, pumping and injection pulses in CPA system based on laser media with a short lifetime. In this regard, the search for new electro- and acousto-optical materials with higher damage threshold and transparency at a wavelength of about 3 μm is desirable. Such materials are KGW and KYW [6]. Its acousto-optical operation was demonstrated at wavelengths of 1.06 μm [7] and 2.1 μm [8], as well as its use as Q-switch was presented in Ho:YAG laser [9]. The mechanical and optical properties of KYW and KGW make them an attractive material for high-power 3-μm Q-switched lasers. In this paper, we present the first-to-our-knowledge use of a KYW and KGW acousto-optical Q-switches in 3-μm lasers (Er:YAG, Cr:Er:YSGG, Cr:Yb:Ho:YSGG) with output energy up to 27 mJ and further energy scaling in the MOPA.

2. Experimental results and discussion

Two Q-switches of different designs were investigated. The first shutter was based on KYW crystal. It was 50 mm long and had plane-parallel facets with AR coatings at 3 μm. Acoustic power up to 30 W at a frequency of 50 MHz was applied to two 2x20 mm lithium niobate transducers mounted on it. The second shutter was based on KGW crystal. It was composed of two elements with Brewster cut facets, and thus did not cause a beam drift when the modulator was installed into the resonator. Previously, we investigated the diffraction efficiency of each shutter at a wavelength of 2.8 μm. The efficiency of the KYW shutter reached 70% at an RF power of 30 W. The efficiency of the KGW one was 16%. Such a low efficiency is probably due to the imperfection of the installation of the elements relative to each other. KYW and KGW materials possess very similar acousto-optical properties.

Three laser elements were studied: Er:YAG, Cr:Er:YSGG, Cr:Yb:Ho:YSGG. For all of them, the same experimental setup was used. The resonator was formed by plane HR and OC with a transmittance of 40%. The pumping was performed with a krypton lamp with pulse energy up to 115 J and a duration of 150 μs or 200 μs FWHM. To produce a beam with high quality, low divergence and without hot spots, the suppression of higher transverse modes was implemented using a 2.0-mm iris mounted on a crystal. Optimization of the modulator operation parameters was carried out by selecting the shutter opening moment and the supplied acoustic power.

The operation of the KYW modulator was studied in Er:YAG laser. The 4x100 mm Er:YAG crystal had AR coatings on the facets. As a result, pulses with energy up to 10 mJ and a duration of 100 ns FWHM were obtained. It was found that at higher output energy, the AR coatings of the shutter degraded at the specified intracavity fluence. Further work was carried out with the use of the Brewster-cut shutter. The Er:YAG laser provided energy up to 12 mJ. The choice of the optimal parameters of the modulator operation depends on the active element.
properties. So, the Er:YAG crystal is characterized by a comparatively low gain and a short lifetime of the upper level. With non-optimal parameters of the shutter operation, the emission of a laser pulse is accompanied by pre- and postpulses. The appearance of prepulses is associated with an insufficient diffraction efficiency of the shutter and is eliminated by increasing the acoustic power supplied to the transducer. The postpulses form due to the fact that the energy of the pump pulse contained in a part of the pulse after the opening of the shutter is sufficient for a free generation. One can get rid of them by increasing of the shutter opening delay, but this is accompanied by a drop in energy in the pulse due to the short lifetime of Er:YAG.

For higher output energy, crystals with a longer lifetime were taken: Cr:Er:YSGG (1.4 ms [10]) Cr:Yb:Ho:YSGG (0.47 ms [11]). In a Cr:Yb:Ho:YSGG laser with 5x100-mm active element, the output energy of 17.5 mJ was obtained. Due to the high gain, the prepulses were not observed at all, and the Q-switched-to-free-running pulse energy ratio was close to 100%. However, for the same reason, at higher pump energy, prelasing occurred, and this limited the output energy of the laser in a single-pulse mode.

The highest output energy was obtained from a Cr:Er:YSGG crystal with dimensions of 5x100 mm and AR facets. Laser pulses with the energy of up to 29.6 mJ and duration of 75 ns were obtained. Its input-output characteristic and beam profile close to TEM00 are presented in Fig. 1. A further increase in the pump energy caused the appearance of prepulses, which is associated with the limited diffraction efficiency of the studied shutter in conjunction with high active element gain. The output energy was scaled in a two-stage amplifier up to 85.7 mJ.

In summary, we report the first use of an acousto-optic modulator based on a KYW crystal in a set of nanosecond 3-μm lasers. The best performances were achieved in Cr:Er:YSGG laser where 29.6 mJ 75-ns laser pulses with good beam quality were obtained without any damage of the shutter. This laser design is attractive for the development of high-power Q-switched sources for pumping of CPA, OPO systems in mid-IR and CO2 regenerative amplifiers [12].

The work is supported by the Russian Foundation for Basic Research (RFBR) (18-29-20074). A. Pushkin is grateful to the Foundation for the Advancement of Theoretical Physics “BASIS.”

3. References
