Frequency Stabilization of an Adaptive Self-phase-conjugated Passively Q-switched Laser using Volume Bragg Grating on the Photo-thermo-refractive Glass

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Abstract: In conclusion, we successfully demonstrated laser frequency stabilization of an adaptive self-phase-conjugated passively Q-switched laser by mean of the transmitting volume Bragg grating on the photo-thermo-refractive glass. Application of such grating inside the cavity provides desired pulse to pulse frequency stability and reduce bandwidth of the radiation from 18 to 4 pm with outstanding output parameters such as pulse energy of 100mJ, peak power of 10MWt and beam quality of M^2=1.15. We assume that the key factor of wavelength stabilization in our case is angular selectivity of the grating. But this kind of selection operates only with feedback mirror. These results have shown that transmitting volume Bragg gratings on photo-thermo-refractive glass are great candidate for stabilization of pulsed laser systems.

1 INTRODUCTION

A recent interest in powerful pulsed solid-state lasers with high spatial brightness and narrow bandwidth is caused by many possibilities of its applications, for example, in the remote monitoring (Boreysho et al. 2005), the laser-induced breakdown spectroscopy (Lebedev et al. 2011), and the ultra-hard material processing (Basiev et al. 2007).

A high-brightness, high-beam-quality laser radiation can be achieved by mean of self-adaptive laser cavity based on self-pumped four-wave mixing directly inside laser medium. It provides phase conjugate self-compensation of laser beam oscillation distortions (Bel'dugin et al. 1989; Damzen et al. 1992). Increasing of phase conjugation efficiency via the number of feedback loops leads to a simultaneous increase in energy of the free-running trains and beam quality. Improvement of spatial characteristics is provided by the increasing contrast of gain gratings in the active medium. Increasing feedback efficiency leads to self-Q-switching. Furthermore, mode competition leads to the spectral selection and a single-frequency pulse with a bandwidth of about 300 MHz. However, the frequency of the radiation varies from pulse to pulse within the gain bandwidth. This instability substantially limits the applications of such laser.

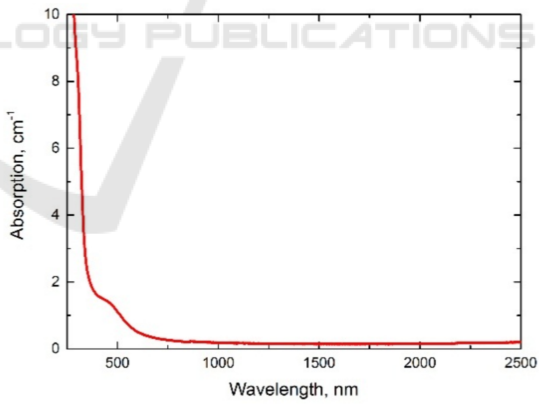

Figure 1: Absorption spectra of photo-thermo-refractive glass.

A promising way to solve this problem is an implementation of additional selective element such as volume Bragg grating on photo-thermo-refractive(PTR) glass. PTR glass is very promising optical material for recording of highly efficient volume phase holograms operating in red visible and near IR spectral range (700-2500nm) (Dubrovin, et al., 2016; Dotsenko, et al., 1998; Efimov, et al., 1999;

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Ivanov, et al., 2014). This glass is a multicomponent photosensitive sodium-zinc-aluminosilicate glass doped with fluorine, antimony, cerium, and silver. UV exposure followed by thermal treatment leads to precipitation of nano-crystalline phase of NaF (NikonorovN V, et al., 2010) in glass host which is responsible for refractive index change. Such mechanism opens a way of manufacturing different kinds of holographic optical elements with high uniformity and diffraction efficiency, spectral and angular selectivity. Moreover, since the sizes of nanocrystals are relatively small (10-20 nm), that is why PTR glasses exhibit rather a low level of scattering. Also this glass has no absorption band in visible and NIR spectral regions (Fig.1) which makes it great candidate for high energy laser optical elements fabrication. Laser-induced damage threshold of PTR glass is of 10 J/cm2 (1 ns pulse at 1.06 µm) (Efimov et al. 1999).

In this paper, we discuss laser frequency stabilization of an adaptive self-phase-conjugated passively Q-switched laser by mean of the volume Bragg grating on the photo-thermo-refractive glass.

2 EXPERIMENTAL

In this study we have used volume Bragg grating recorded in PTR glass. Grating was recorded with He-Cd laser (325nm) with period of 1167nm. Grating had 15mm aperture, 1.2mm thickness and diffraction efficiency of 90%. Angle of diffraction at operating wavelength of 1064 was calculated to be $\theta_{Br} = 27.1^o$. Angular selectivity of this grating was measured to be $\delta = 0.07^o$ (Fig.2).

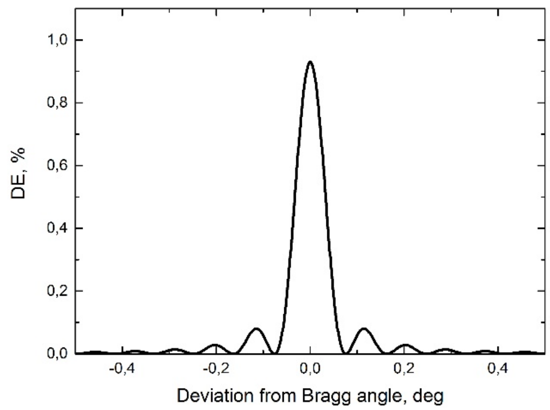

Figure 2: Angular dependence of the first order of diffraction.

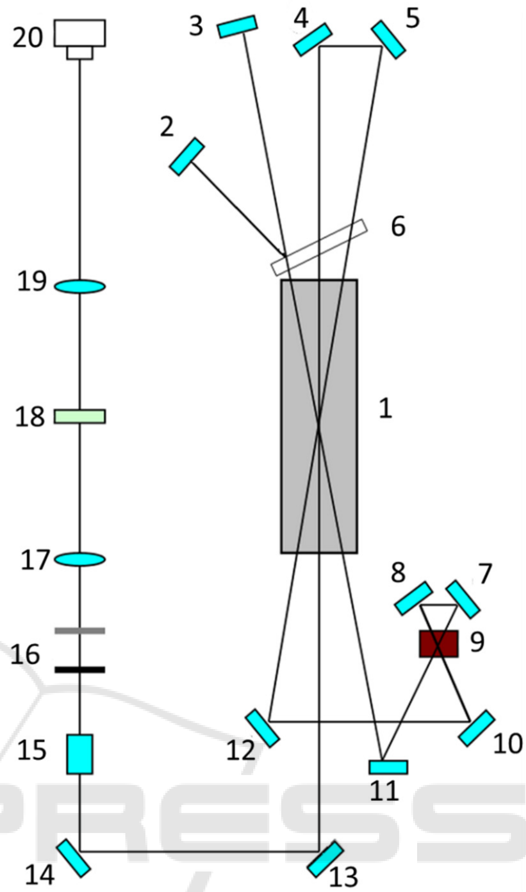

Figure 3: Experimental setup. 1 – active element, 2 – grating feedback mirror 3-5,7,810-12 – cavity mirrors, 6 – volume Bragg grating, 9 - LiF:F$_2$ crystal, 13,14 – rotational mirrors, 15 – KTP crystal, 16 – filters, 17-18 – projection lenses, 18 – Fabry-Perot etalon, 20 – CCD camera.

To study the lasing properties laser head with a cylindrical active element of Nd: YAG (1.1 at.% Nd^{3+}) with rod size of Ø 6.3 × 100 mm was used. Transverse four-side pumping was carried out with twelve arrays of laser diodes such as SLM 3-2 with the size of the emitting area of 5 × 25 mm and a peak power of up to 2 kW per stack. The maximum pump energy was Ep = 10.3 J. For the passive Q-switch LiF: F$_2$ crystal with initial transmission T_0 = 14% was used. Results are obtained at the optimal length of the cavity L = 55cm. Spectral composition of the radiation was measured in the second harmonic generation mode obtained with nonlinear KTP crystal. The second harmonic radiation passing through the infrared and the neutral filters was directed at the Fabry-Perot interferometer with a free spectral range of 28 pm. The resulting interference pattern was projected by a lens on the CCD camera Ophir-Spiricon. Next the interference pattern was analyzed with Fiji software. Experimental setup is shown on fig. 3.

Due to the high angular selectivity grating placed in 3 beams was operating only for one fulfilling Bragg condition. Unfortunately for rest beams it was acting as losses which naturally decreased output power of the system. Grating was placed on a holder which allowed to switch it on and off replacing it with equal thickness PTR glass slab. We had to replace grating with equal PTR glass sample to maintain generation conditions. Mirror 2 was providing feedback for the radiation diffracted on the grating.

3 RESULTS AND DISCUSSIONS

Fig. 4 present interference pattern of the laser radiation while no grating is present in the setup.

Figure 4: Interference patter of the laser radiation without volume Bragg grating.

As one can see interferogram consists of up to six rings in the one order of diffraction which mean that corresponding number of longitudal modes is present.

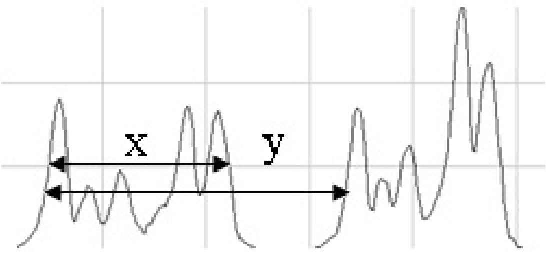

Figure 5: Cross section of interference fringe.

Analysis of the fringe cross section (Fig. 5) obtained with CCD camera was made using folowing relation between free spectral range (FSR) interaval of Fabry-Perrot etalon and line bandwidth:

$$\Delta\lambda = x/y * FSR \quad (1)$$

Where x – bandwidth in pixels, y – free spectral range in pixels, FSR – free spectral range of etalon (28pm). Calculations shows that total bandwidth of laser radiation in this case is about 18pm. Fig. 6 presents interference patter of the laser radiation with volume Bragg grating inside the cavity. One can see that in this case there is only one ring is present in each difraction order which means that with our grating laser operates on single logitudal mode.

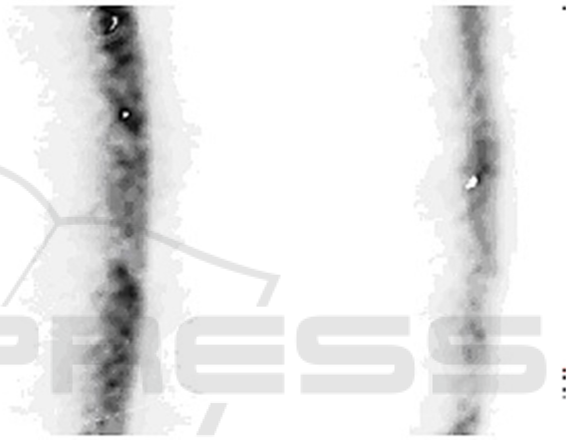

Figure 6: Interference pattern of the laser radiation with volume Bragg grating.

Cross section (Fig.7) analysis shows that in this case laser radiation has a bandwidth of a 4pm which is almost 5 times lower that without grating. Moreover, in our experiment we observed that slight rotation of the grating can adjust output wavelength. Due to the high angular selectivity of the grating adjustment can be done very precise.

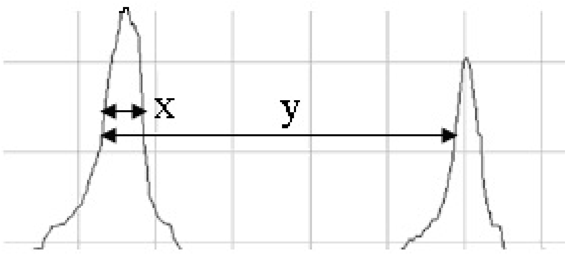

Figure 7: Cross section of interference fringes.

Worth noting that in case of transmitting volume Bragg grating its spectral selectivity is not so high as expected. For instance, in this work grating spectral selectivity was just 0.7nm which is exceeding neodymium gain bandwidth. Therefore, we assume that parameter which plays key role in frequency stabilization is angular selectivity of the grating. Placing the grating inside the cavity provide strict conditions on the radiation direction of propagation. This conditions so strong that only one wavelength in the cavity can fulfill it during spontaneous luminescence. And thus this wavelength has a better feedback and lower threshold in comparison with other frequencies. Thus this results in narrowing the emission spectra of the laser. But in terms of stability it still unclear why application of transmitting volume Bragg grating locks pulse to pulse frequency. We presume that combination of high angular selectivity and mirror 2 position in our setup defines the wavelength. Their relative orientation determines the optical path inside the cavity and the only frequency which can travel through this path considering Bragg condition is start to rise. In confirmation of this speculation we build up a single loop cavity in which loop was made by 3 cavity mirrors and transmitting Bragg grating (Fig. 8).

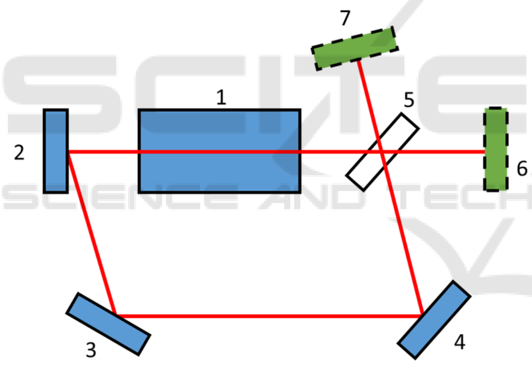

Figure 8: Single loop cavity with transmitting VBG. 1 – active element, 2-4 – cavity mirrors, 5 – volume Bragg grating, 6,7 – output coupler.

This setup differs from what we used before but in this case we also achieved frequency stabilization and narrowing with transmitting volume Bragg grating in presence of any of output couplers (OC). But if we remove both mirrors 6 and 7 we obtain a narrow line pulses with no stability in pulse to pulse frequency. Interesting fact that there is no difference if mirror 6 or 7 is in cavity, any of them in combination with volume Bragg grating provides frequency stabilization. Thus we assume that in this kind of setup optical path of a beam inside the cavity depends from wavelength and in the absence of OC operating frequency is undetermined. But as soon as we apply any of OC we induce additional selection to the cavity. As before there is plenty of optical paths with different wavelength exist in the cavity but now only one of them fulfill Bragg condition and receive feedback from OC which decrease its threshold. In addition, we could adjust operating frequency by slight rotation of either grating or OC itself. This can serve as a proof of our ideas about wavelength stabilization.

4 CONCLUSIONS

In present work we successfully demonstrated laser frequency stabilization of an adaptive self-phase-conjugated passively Q-switched laser by mean of the transmitting volume Bragg grating on the photo-thermo-refractive glass. As expected this grating provides desired pulse to pulse frequency stability. Moreover, our investigation shows that implementation of the volume Bragg grating in the multiloop cavity reduce the bandwidth of the radiation from 18 to 4 pm with outstanding output parameters such as pulse energy of 100mJ, peak power of 10MWt and beam quality of M^2=1.15. We assume that the key factor of wavelength stabilization in our case is angular selectivity of the grating. But it operates only with feedback mirror.

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REFERENCES

Boreysho A. S., Konyaev M. A., Morozov A. V., Pikulik A. V., Savin A. V., Trilis A. V., Chakchir S. Ya., Boiko N. I., Vlasov Yu. N., Nikitaev S. P., and Rozhnov A. V., 2005 Mobile multiwave lidar complexes *Quantum Electron.*, 35, pp.1167-1178.

Lebedev V. F., and Shestakov A. A., 2011 Fast LIBS identification of solids during the laser ablation process. *Proc. SPIE Int. Soc. Opt. Eng.*, 7822, p. 78220V.

Basiev T.T., Garnov S.V., Klimentov S.M., Pivovarov P.A., Gavrilov A.V., Smetanin S.N., Solokhin S.A., and Fedin A.V., 2007. High-speed ablation of ultradeep channels by a phase-conjugate dynamically controlled passively Q-switched Nd:YAG laser *Quantum Electron.*, 37, pp. 956-960.

Bel'dugin I.M., Berenberg V.A., Vasil'ev A.E., Mochalov I.V., Petnikova V.M., Petrovskii G.T., Harchenko M.A., and Shuvalov V.V., 1989. Solid-state lasers with self-pumped phase-conjugate mirrors in an active medium. *Sov. J. Quantum electron.*, 19, pp. 740-742.

Damzen M. J., Green R. P. M., Crofts G. J., 1992. High-reflectivity four-wave mixing by gain saturation of nanosecond and microsecond radiation in Nd:YAG. Optics letters, v. 17, No. 19, pp.1331-1333.

Dotsenko, A., Glebov, L. & Tsekhomsky, V., 1998. *Physics and chemistry of photochromic glasses*, CRC Press.

Dubrovin, V.D., Ignatiev, A.I. & Nikonorov, N.V., 2016. Chloride photo-thermo-refractive glasses. *Optical Materials Express*, 6(5), pp.1701–1713.

Efimov, O.M., Glebov, L.B., Grantham, S. & Richardson, M., 1999. Photoionization of silicate glasses exposed to IR femtosecond pulses. *Journal of Non-Crystalline Solids*, 253(1–3), pp.58–67.

Ivanov, S.A., Angervaks, A.E. & Shcheulin, A.S., 2014. Application of photo-thermo-refractive glass as a holographic medium for holographic collimator gun sights. *Proceedings of SPIE*, 9131, p.91311B.

Nikonorov, N., Aseev, V. & Ignatiev, A., 2010. New polyfunctional photo-thermo-refractive glasses for photonics applications. In *ODF'10*. pp. 209–210.

Efimov O.M., Glebov L.B., Papernov S., Schmid A.W., 1999 Laser-induced damage of photo-thermo-refractive glasses for optical-holographic-element writing. *Laser-Induced Damage in Optical Materials. Proc. SPIE* 3578, pp.554-575.