Experimental study of cavity length influence on lasing characteristics Q-Switched Nd:YLF laser

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Abstract. The influence of the resonator configuration on the temporal characteristics of Nd: YLF crystals laser generation in the region of frequency degeneracy of the transverse modes of a resonator operating in the Q-Switch mode is studied. It is shown that in the degeneracy regions, the pulse duration stretches, while the peak pulse amplitude and the pulse repetition period decrease.

1. Introduction

Laguerre-Gaussian beams for polar coordinate systems, Hermite-Gaussian beams for cartesian coordinates and Ince-Gaussian beams for elliptic coordinates are used to describe resonator modes. The description and properties of such beams are well known and described in [1-4]. Laguerre-Gaussian beams can find various applications in high-tech applications. At low laser intensities, they can be used to manipulate and capture small particles, in studies of the propagation of laser radiation in the atmosphere, and in high-resolution microscopy [5]. In this regard, it seems promising to study the schemes and methods for generating laser beams on Laguerre-Gaussian modes of higher orders.

For axisymmetric systems it is most logical to use Laguerre-Gaussian beams, whereas for an empty cavity the modes are characterized by longitudinal indices q, radial p and azimuthal l [1,6]. The mode frequency v_{qpl} is defined by the following expression:

$$v_{qpl} = \frac{c}{2L}\left(q + \frac{1}{\pi}(2p + l + 1)\, arccos\sqrt{g_1 g_2}\right) \tag{1}$$

where L is the cavity length, R1, R2 are the radii of curvature of the resonator mirrors, c is the speed of light, $g_{1,2} = 1\text{-}L / R_{1,2}$ are the resonator parameters. In the future, we assume that the azimuthal index is $l = 0$. Then, the longitudinal modes are separated from each other by a "distance":

$$\Delta v_q = \frac{c}{2L} \tag{2}$$

And transverse modes - at a "distance":

$$\Delta v_p = \frac{c}{2L}\frac{2}{\pi}arccos\sqrt{g_1 g_2} \tag{3}$$

In the case when $p = 0$, it is possible to obtain ultrashort pulses formed due to longitudinal mode-locking [7]. On the other hand, it is possible to obtain the synchronization of transverse modes when q = const [8]. For this, it is necessary to modulate losses with a frequency equal to the difference of adjacent transverse frequencies. This will lead to periodic motion of the maximum of the laser beam profile on the cavity mirrors [8, 9]. The same principle of synchronization of transverse modes in injection lasers leads to a motion in the direction of propagation of laser radiation [10, 11]. In [12, 13],

it was shown that it is possible to realize simultaneous synchronization of the longitudinal and transverse cavity modes, at which pulse generation with different divergence or propagation directions is observed.

Under condition

$$arccos\sqrt{g_1 g_2} = \pi \frac{r}{s} \qquad (4)$$

where r and s are natural numbers, and r / s is an irreducible fraction, frequency degeneracy in the cavity occurs for which sq + 2pr = const [6]. It is worth noting that, when (4) is fulfilled, the superposition of any modes is periodically reproduced, and, as was noted in [6], such a laser mode is "full". Such an approach to changing the cavity configuration was implemented in the works for the continuous mode [14, 16] and for the Q-switching mode [17]. However, the influence of the cavity configuration on the temporal characteristics of the generated radiation has not been investigated.

2. Experimental setup

To study the lasing characteristics of the laser in various cavity configurations, an experimental bench was assembled. The experimental setup is shown in Figure 1. The laser cavity was formed by two mirrors 4 and 5. A spherical mirror 4 with a radius of curvature of 150 mm was highly reflecting at the lasing wavelengths (R_{1047}=99.96%) and transparent at a pump wavelength (T_{808}>99%). The reflectivity of output plane mirror 5 at the lasing wavelength was 96%. To change the parameter $g_1 g_2$, the output mirror 5 and the saturable absorber (SA) Cr: YAG were fixed to the translational stage with a stepper motor, which made it possible to adjust the cavity length L from 50 mm to 140 mm with an accuracy of 1 μm, i.e. the resonator parameter $g_1 g_2$ varied practically from 0 to 0.7.
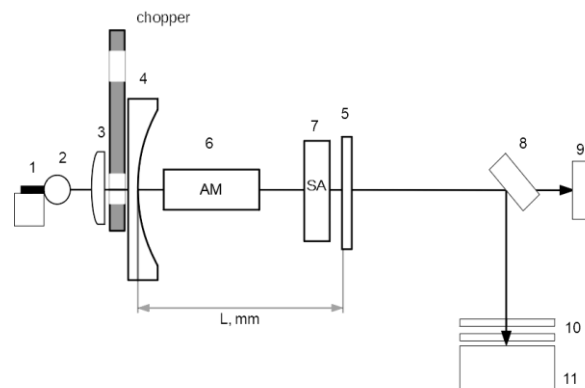

Figure 1. Scheme of laser with passive q-switching 1-laser diode, 2-cylindrical lens, 3-spherical lens, 4-input mirror, 5 - output mirror, 6- AM (Nd:YLF), 7- SA (Cr:YAG),8 - plane - parallel plate , 9 - photodiode, 10 - light filter, 11-CCD Camera.

An a-cut 4mm diameter and 10 mm length cylindrical crystal Nd: YLF was used as the active medium (AM) of the laser. The faces of the active medium were antireflection coated for the lasing and pump wavelengths.

To modulate the cavity quality factor, a saturable absorber Cr4 +: YAG 1.45 mm long was placed inside the resonator with an initial transmittance (IT) = 80% on plane-parallel faces, which were coated with antireflection coatings at the generation wavelengths.

An LD with lasing wavelength of 808 nm and a radiating aperture width of 2x150 μm was used as a pump radiation source. The width of the LD spectral line was about 1 nm. To match the LD emission line with the absorption band of the activator ion, we used the temperature adjustment of the LD radiation wavelength using a Peltier element. The pump radiation was focused into a spot with a diameter of ~ 120 μm at a depth of 1 mm from the end of the active element. In all experiments, the polarization of the LD radiation coincided with the crystallographic axis [100] of the Nd: YLF crystal. The divergence of the LD radiation was 30 ° along the axis of the perpendicular plane of the heterojunction ("fast" axis) and 8 ° along the axis parallel to the plane of the heterojunction ("slow"

axis). The LD radiation was collimated along the "fast" axis by a cylindrical lens, then a spherical lens formed a pump beam in the AM. To reduce the thermo-optical effects, LD radiation was modulated by an optomechanical interrupter with a duty cycle of 1:20. The generation threshold was recorded using THORLABS IC106-VIS CCD camera. An avalanche photodiode LFD-2 with a speed of up to 1 ns, connected to the Tektronix TDS 4032 oscilloscope with a bandwidth of 350 MHz, was used to record the lasing characteristics of the laser.

3. Experimental results

The experiment investigated the dependence of the lasing threshold of a laser with a passive shutter on the cavity length. Varying the cavity length from 50 to 140 mm corresponds to $g_1 g_2$ values from 0 to 0.7. The generation thresholds were measured by adjusting the LD pump current, and the generation was detected using a CCD camera. It is seen that in the regions of frequency degeneracy of the resonator modes, where r/s is 1/5, 1/4, 1/6, 3/10, 1/3, 3/8, and 2/5, a decrease in the threshold pump power was observed. The threshold dependences characteristic of a CW laser was observed [17]. In this case, the synchronization region is noticeably wider, which is associated with additional losses introduced into the cavity by the saturable absorbers [18]. It turned out that the installation of a passive shutter in the cavity with an initial transmission of 80% does not violate the effects of synchronization of the transverse modes of the resonator near the frequency degeneracy of the modes. The dependence of the lasing pulse duration on the cavity length was measured using the LFD-2 avalanche photodiode shown in the figure 2b.
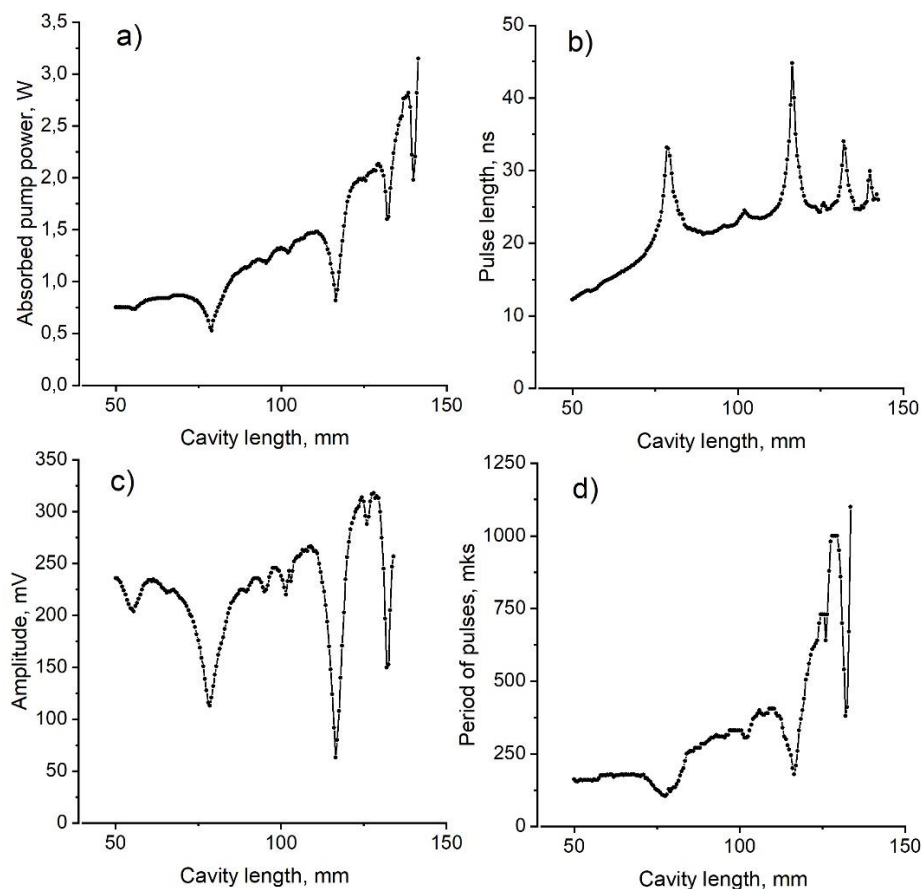

Figure 2. The dependence of the threshold pump power (a), the duration of the generation pulse(b), the pulse amplitude (c) and the repetition period(d) on the length (configuration) of a resonator with Nd:YLF with an output mirror R = 96% and a Cr:YAG SA with IT = 80%.

It is seen that a decrease in the threshold pump power is observed in the regions of frequency degeneracy (figure 2a). It can be noted that the synchronization of the transverse modes of the cavity significantly affects the pulse duration near the frequency degeneracy of the modes. This can be attributed to an increase in gain in the regions of transverse mode-locking, and to a decrease in the saturation threshold of the saturable absorber, which, in turn, led to a decrease in the amplitude of the pulses shown in figure 2c and a decrease in the pulse repetition period (increase in frequency) in figure 2d.

4. Conclusion

We can conclude that the synchronization of the transverse cavity modes in Q-Switched lasers leads to a significant change in the lasing characteristics, such as the lasing threshold, amplitude, pulse duration, and pulse repetition period. When designing devices with longitudinal diode pumping with a passive shutter, it is necessary to calculate the configuration of the resonator and choose the value of the parameter g1g2. In solid-state lasers with longitudinal diode pumping with a cavity Q-switched by a passive gate, in the regions of transverse mode synchronization, a drop in the lasing threshold is observed, while a sharp increase in the radiation pulse duration, a decrease in the peak pulse repetition rate and an increase in the pulse repetition period are caused by a decrease in the passive gate bleaching threshold with increasing gain.

References

[1]   Siegman A E 1986 *Lasers* (Califorina: University science books)
[2]   Ananev Yu A 1990 *Opticheskie rezonatory i lazernye puchki (Optical Resonators and Laser Beams)* (Moscow: Nauka) [In Russian]
[3]   Bandres M A and Gutierrez-Vega J C 2004 *Optics Letters* **29** 144
[4]   Bykov V P and Silichev O O 2004 *Lazernye rezonatory (Laser cavities)* (Moscow: Nauka) [In Russian]
[5]   Senatsky Yu, Bisson J-F, Li J, Shirakawa A, Thirugnanasambandam M and Ueda K 2012 *Optical Review* **19** 201
[6]   Anan'ev Yu A 1992 *Laser resonators and the beam divergence problem* (Bristol: Adam Hilger)
[7]   Krykov P G. 2001 *Quantum Electronics* **31** 95
[8]   Auston D H 1968 *IEEE J. of Quantum Electronics* **4** 420
[9]   Mak A A and Fromzel V A 1969 JETP Lett. **10** 199
[10]   Vyshlov S S, Ivanov L P, Logginov A S, Senatorov K Ya 1971 JETP Letters **13** 131
[11]   Logginov A S and Plisov K I 2002 *Quantum Electronics* **32** 553
[12]   Bykov V P, Prokhorov A M and Savranskii VV 1997 *Quantum Electronics* **24** 837
[13]   Smith P W 1968 *Applied Physics Letters* **13** 235
[14]   Bezotosnyi V V, Balashov V V, Bulaev V D, et al. 2018 *Quantum Electronics* **48** 802
[15]   Cheshev E A, Gorbunkov M V, Kostryukov P V, et.al., 2019 *Laser Physics Letters* **16** 035001
[16]   Bezotosnyi V V, Gorbunkov M V, Dashkevich V I, Koromyslov A L, Orlovich V A, Popov Yu M, Tunkin V G, Cheshev E A and Chulkov R V 2016 *Bulletin of the Lebedev Physics Institute* **43** 203
[17]   Bezotosnyi V V, Gorbunkov M V, Kostryukov P V, Krivonos M S, Popov Yu M, Tunkin V G and Cheshev E A 2011 *Bulletin of the Lebedev Physics Institute* **10** 43
[18]   Gorbunkov M V, Kostryukov P V and Tunkin V G 2008 *Quantum Electronics* **38** 689