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Dual-wavelength *Q*-switched laser based on a lens-shaped Nd : YAG active element and a Cr^{4+} : YAG passive *Q*-switch

A.L. Koromyslov, I.M. Tupitsyn, E.A. Cheshev

Abstract. **Dual-wavelength *Q*-switched lasing at wavelengths of 1047 and 1053 nm is achieved in a longitudinally diode-pumped laser with a lens-shaped Nd:YLF active element and a Cr^{4+} : YAG passive *Q*-switch. Dual-wavelength lasing is achieved as a result of transverse mode locking due to the choice of a cavity length corresponding to the close-to-semiconfocal configuration, which provides identical gains for the two laser wavelengths.**

Keywords: *solid-state lasers, longitudinal diode pumping, transverse mode locking, dual-wavelength lasing.*

Dual-wavelength lasers are used in various engineering fields, such as optical communications, lidar systems, and sum and difference frequency generation [1–3]. Therefore, development of new schemes and methods of two-wavelength generation in one laser is rather topical. At present, there exist many various schemes and methods for dual-wavelength lasing in diode-pumped lasers, for example, introduction of dispersive elements into cavities, use of two independent cavities with a common output mirror, tuning to two wavelengths using the temperature dependence of the cavity length, employment of thermooptical effects, and frequency generation in nonlinear media [4–11]. Dual-wavelength lasing was obtained in a number of materials, in particular, in Nd : YAG, Nd : YVO_4, Nd : YAP, Nd : $GdVO_4$, and Nd : YLF crystals and others [7, 8, 12–17].

One of the frequently used crystals is Nd : YLF. Its attractive properties are the comparatively long laser level lifetime (twofold longer than that in Nd : YAG) and weak thermal effects. For example, the thermal lens in Nd : YAG crystals is several times stronger than in Nd : YLF [18]. In addition, since Nd : YLF is a uniaxial crystal, an *a*-cut Nd : YLF element can generate radiation with different polarisations, i.e., π- and σ-polarised radiation with wavelengths of 1047 and 1053 nm, respectively [19, 20].

In some works, dual-wavelength lasing was achieved in passively *Q*-switched lasers [14, 21]. However, in this case it is difficult to obtain pulses coinciding in time or it is necessary to introduce additional losses into the cavity. At the same time, advantages of passively *Q*-switched lasers are their relative simplicity and compactness. The aim of the present work is to study the possibility of dual-wavelength lasing in lasers passively *Q*-switched by a Cr^{4+} : YAG crystal and having identical gains at two different wavelengths due to transverse mode locking (like, e.g., in [22]), as well as to determine the specific features of this regime in the case of splitting of mode frequency degeneracy regions for a lens-shaped active element.

In the case of transverse mode locking in longitudinally diode-pumped solid-state laser, the lasing threshold in the degeneracy regions decreases, and the spatial structure of radiation exhibits a large number of transverse modes with high spatial indices, i.e., the output beam profile has a structure of multiple concentric rings. The laser radiation in this case is concentrated in several near-axial cavity regions [23]. It is known that a passive *Q*-switch selects the zero cavity mode [24], which, in turn, may lead to high losses for higher modes and to suppression of transverse mode locking.

The principal scheme of the experiment is shown in Fig. 1. As an active element (AE) of the laser, we used an *a*-cut Nd : YLF crystal 6 mm long. One face of the element was plane, and the other face was spherical with the curvature radius $R = 60$ mm. The plane AE face was coated with antireflection layers for the pump wavelength of 808 nm and with reflective layers for laser wavelengths of 1047 and 1053 nm. The spherical AE face was antireflection coated for the pump and laser wavelengths. The AE was pumped by a laser diode (LD) with wavelength $\lambda_p \approx 808$ nm and an output power up to 8 W. To decrease the heat load on the AE, the LD radiation was quasi-cw with a pulse duration of 2 ms and an off-duty factor of 20. The pump radiation was focused on the input face of the AE; the pump spot radius was 60 μm.

The laser cavity was formed by the plane AE face and a plane output mirror M2 with a reflection coefficient of 96% for the laser wavelengths. The cavity loss was modulated

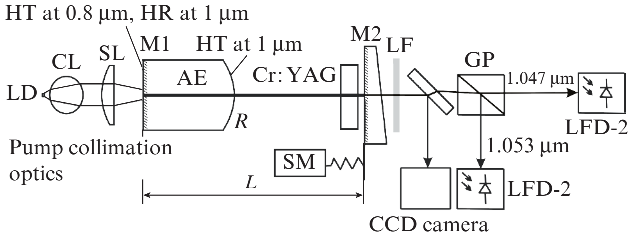

Figure 1. Scheme of a passively *Q*-switched laser: (LD) laser diode; (CL) cylindrical lens; (SL) spherical lens; (M1) input mirror; (AE) active element; (Cr : YAG) passive *Q*-switch; (M2) output cavity mirror; (LF) light filter; (SM) step motor; (GP) Glan–Taylor prism; (LFD-2) avalanche photodiode. The AE faces have high transmittance (HT) at 0.8 and 1 μm, and the plane AE face had high reflectance (HR) at 1 μm.

A.L. Koromyslov, I.M. Tupitsyn, E.A. Cheshev P.N. Lebedev Physical Institute, Russian Academy of Sciences, Leninskii prosp. 53, 119991 Moscow, Russia; e-mai: akorom@mail.ru

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using Cr^{4+}:YAG Q-switches with initial transmittances T_0 = 87%, 89%, 94%, and 97%. The Q-switches were antireflection coated for the laser wavelengths. The cavity configuration was varied by changing the cavity length L by moving mirror M2 with a step motor. The laser radiation was recorded by a CCD camera and LFD-2 avalanche diodes.

The experimentally measured dependences of the threshold pump power on the cavity length for Nd:YLF lasers with passive Q-switches with different T_0 are shown in Fig. 2. The cavity length L was changed from 55 to 80 mm, which corresponds to the mode frequency degeneracy region with r/s = 1/4 (depends on the cavity stability parameters [25]).

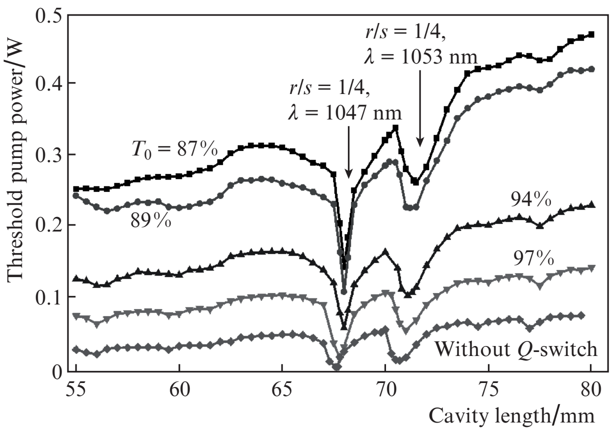

Figure 2. Dependence of the threshold pump power on the cavity length.

The regions of dual-wavelength lasing are schematically shown in Fig. 3. One can see a decrease in the pump threshold near the degeneracy region where r/s = 1/4, which is obviously related to transverse mode locking. In addition, since the AE is bifocal for radiation with laser wavelengths of 1047 and 1053 nm and mutually orthogonal polarisations, one observes splitting of the degeneracy regions and, hence, of the lasing threshold minima [22], i.e., an overlap of the lasing thresholds for the different wavelengths. Thus, it is possible to obtain stable pulsed dual-wavelength lasing at a particular cavity length.

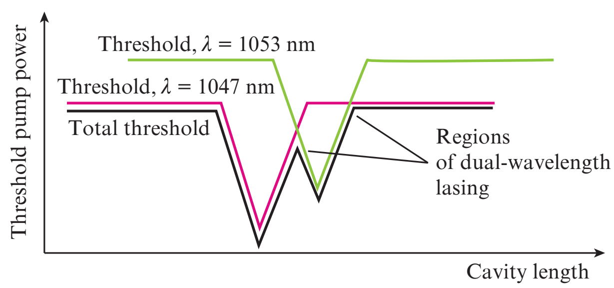

Figure 3. Regions of dual-wavelength lasing.

The oscillograms of dual-wavelength pulses obtained using Q-switches with different T_0 are presented in Fig. 4. The beams with wavelengths of 1047 and 1053 nm were separated using a Glan–Taylor prism. The signals were recorded on a TDS 2012C oscilloscope with a transmission band of 100 MHz.

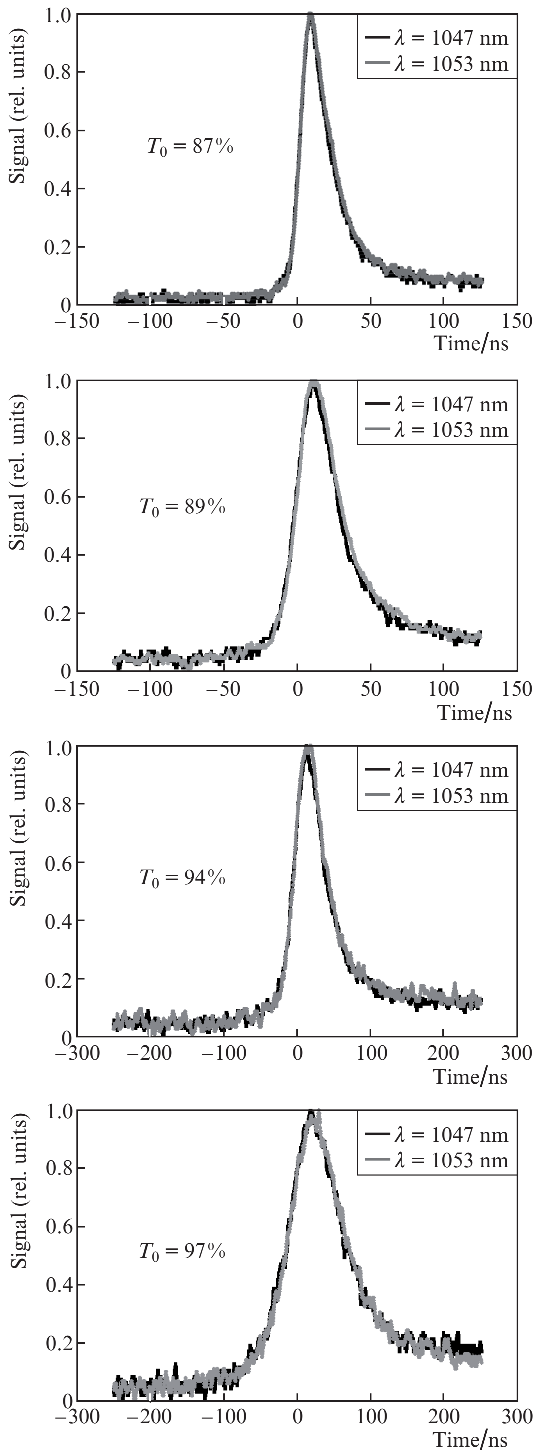

Figure 4. Pulses of dual-wavelength lasing near a mode frequency degeneracy region at different T_0.

At the initial passive Q-switch transmittances T_0 = 87%, 89%, 94%, and 97% and the average dual-wavelength laser powers of 30, 50, 90, and 110 mW, we obtained pulses with durations of 24, 34, 51, and 88 ns and total pulse powers of 1.9, 1.1, 0.35, and 0.09 kW, respectively. The laser pulses with different wavelengths almost completely coincided in time.

Thus, we obtained dual-wavelength Q-switched lasing in a longitudinally diode-pumped laser with a lens-shaped Nd^{3+}:YLF active element and a Cr^{4+}:YAG Q-switch near the mode frequency degeneracy regions. This opens prospects for application of compact all-solid-state dual-wavelength lasers in systems of laser location and THz imaging.

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