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Two-frequency mode-locked lasing in a monoblock diode-pumped Nd^{3+}:GGG laser

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***Abstract*. The locking of two mutually orthogonal polarisation modes of a diode-pumped cw Nd^{3+}: GGG laser is experimentally demonstrated. The mode locking is accomplished with a radio signal at the intermode beat frequency.**

Keywords: *mode-locked lasing, monoblock laser, diode pumping.*

1. Introduction

In Ref. [1], two-frequency lasing was demonstrated at two orthogonally polarised axial modes in a solid-state Nd^{3+}: YAG laser with the difference frequency locked by an external radio-frequency 23-MHz signal. The locking of the difference frequency was shown to be possible in some relatively narrow interval of detuning between the intermode beat and external signal frequencies. In this case, the phase of the intermode beats was observed to depart from the phase of the modulating signal with increasing detuning.

However, attempts to obtain a stable laser operation in the regime of intermode beat locking did not meet with success in Ref. [1]. It was assumed that the reason was the frequency drift of the lasing polarisation modes caused by the thermal and acoustic instability of the resonator of the flashlamp-pumped laser, resulting in an inadmissible large mismatch between the intermode beat and locking signal frequencies.

The aim of our work was to accomplish a stable intermode beat locking by an external radio-frequency signal. This problem was solved by using a diode pump, the thermal stabilisation of the monoblock resonator, and protection of the latter against the external acoustic action.

The experimental setup is shown schematically in Fig. 1. The laser resonator was formed by two plane mirrors *1* and *2*. The output dichroic mirror *1* had a reflectivity of ~ 90 % at the laser wavelength and a transmittance of no less than 80 % at the pump wavelength. The reflectivity of the totally reflecting mirror was no less than 98 %.

The active medium was a plane-spherical Nd^{3+} : GGG crystal *3* of thickness of about 3 mm and a neodymium concentration of ~ 2 %. The output mirror was deposited on the plane surface of the crystal, its spherical side, which had a radius of curvature of 50 cm, being mechanically pressed against the plane surface of an acousto-optic modulator *4*. The pressing was effected by applying a polymerisation glue *6* on the peripheral part of the active element and the modulator. The glue contraction during its polymerisation ensured a firm mechanical connection of the active element and the modulator. The radius of curvature of the contact surface was so selected that the interference effects in the gap resulted in additional transverse mode selection in the resonator.

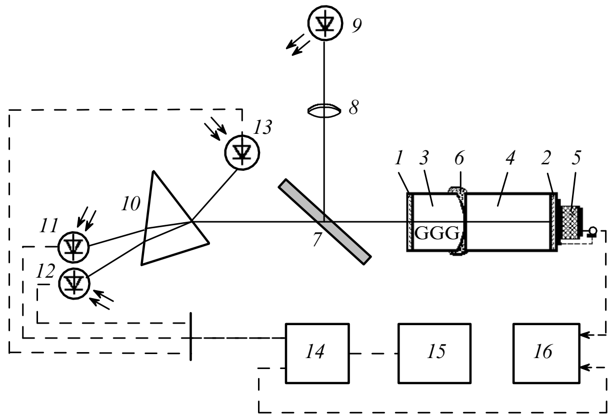

Figure 1. Experimental setup for studying mode locking: (*1*) output mirror; (*2*) totally reflecting mirror; (*3*) active element; (*4*) acousto-optic modulator; (*5*) ultrasonic radiator; (*6*) place of gluing of two optical elements; (*7*) beamsplitter; (*8*) focusing objective; (*9*) diode pump laser; (*10*) Iceland spar prism; (*11*)–(*13*) avalanche photodiodes; (*14*) mixer; (*15*) digital oscilloscope; (*16*) modulating-voltage generator with a frequency of 19.3 MHz.

The acousto-optic modulator was made of a $CaMoO_4$ crystal cut out along the optical axis. The totally reflecting laser mirror was deposited on one of end faces of this crystal; a metal film was deposited on the exterior side of the crystal, which served as one of the electrodes of the piezoelectric ultrasonic radiator *5*.

An alternating voltage with a frequency of 19.3 MHz was applied from a generator *16* to the modulator to accomplish the regime of collinear light diffraction for the 1.062-μm radiation. In this case, the diffracted component was shifted in frequency by 19.3 MHz and changed the state of polarisation by 90°. To improve the diffraction efficiency, the length of the modulator crystal was selected according to

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the acoustic resonance condition and was close to 7 mm. Note that the thickness of the active element was selected to minimise the lowering of the diffraction efficiency due to the influence of the mechanical contact of the modulator with the active element on the acoustic resonance of the modulator.

To change the fundamental frequencies of the polarisation laser modes, an adjustable transverse anisotropy was introduced into the resonator owing to the electrooptical effect in the crystal of the acousto-optic modulator *4*. For this purpose, current conducting electrodes were attached to two opposite side crystal surfaces to which a constant (or varying slowly compared to the modulation frequency) voltage was applied to provide the adjustable birefringence.

The laser under study was mounted on a massive copper thermally insulated damped platform. It was pumped by a diode laser *9* with an output power up to 0.8 W using a dichroic deflecting mirror *7*, at which the radiation loss did not exceed 10 %. The pump beam was shaped with a two-lens objective *8* with the focal length $F = 15$ mm, which produced in the active medium a beam with a waist of 200–300 μm. The diode laser was tuned to the absorption maximum in the active medium by changing its temperature with a Peltier heater-refrigerator.

The output radiation of the monoblock laser passed through the deflecting mirror and was split by a prism *10* of Iceland spar into two beams with mutually orthogonal polarisations. To record the output laser radiation, we used three avalanche photodiodes, two of which (*11, 12*) were placed in the beams after the polarisation splitting and one (*13*) in the summary beam. The photodiode signals were alternately fed to the mixer *14* to be mixed with the high-frequency electric signal that was fed the acousto-optic modulator. After this, the signal was extracted near the zero frequency within the ~ 100 kHz band. The output signal from the mixer was amplified and stored with a digital oscilloscope.

The laser adjustment was accomplished in the following way. The high-frequency voltage was fed to the acousto-optic switch and a constant voltage was simultaneously applied to the electrodes of the electro-optical modulator. The latter voltage was carefully selected to maximise the beat signal at the mixer output and was stabilised. The unit consisting of the double-beam prism and the photodiodes was rotated around the optical axis of the laser to minimise the beat signals from photodiodes *11, 12*.

Upon rotation through 360°, we observed four such minima and maxima, in agreement with the data of Ref. [1]. This means that lasing occurs at two polarisation modes shifted in frequency relative to one another by the modulating signal frequency. However, unlike Ref. [1], this operating regime was relatively stable to persist for a long time (from few to several tens of seconds). Like in Ref. [1], the beat signal disappeared upon turning off the acousto-optic modulator and was observe in the limited interval of induced birefringence in the electro-optical modulator.

Fig. 2 shows the change of the beat signal amplitude upon application of the additional (to the constant voltage) 1-kHz sinusoidal voltage with two different amplitudes to the electro-optical modulator. The constant voltage was adjusted to eliminate the dip in the region of maxima in curves (in other words, to maximise the beat amplitude in passing through the maximum of the amplitude of the modulated voltage at the electro-optical modulator). Curve U_2 demonstrates the quenching of mode-locked lasing with increasing modulation amplitude (the region of a nearly zero signal), which suggests that this regime exists only in some region of induced anisotropy in the resonator.

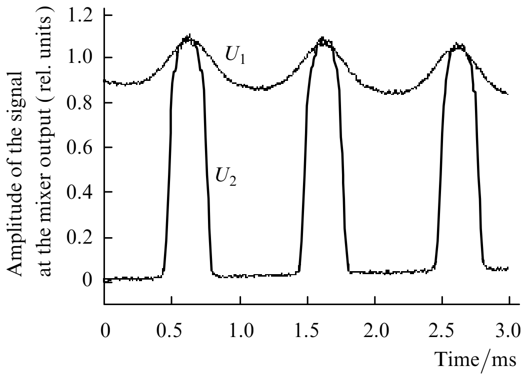

Figure 2. Oscilloscope traces of the amplitude of the signal at the mixer output for two amplitudes ($U_1 < U_2$) of the 1-kHz sinusoidal voltage across the electrodes of the acousto-optic modulator.

Therefore, a stable two-frequency lasing at two orthogonally polarised modes locked by an external signal is possible in a solid-state laser. The above mode locking is realised when the frequency of external modulation approximately coincides with the intermode beat frequency of the two polarisation laser modes.

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References

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