CONTROL OF LASER RADIATION PARAMETERS

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Influence of a constant magnetic field on non-stationary operation regimes of solid-state ring lasers

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***Abstract*. The effect of a constant magnetic field on the nonlinear radiation dynamics of a monolithic chip ring Nd : YAG laser pumped by modulated radiation is studied experimentally. It is found that the application of a constant magnetic field to the active element of the solid-state ring laser operating in the non-stationary regime results in the displacement of the regions of existence of quasi-periodic and chaotic lasing regimes to the low-frequency region of pump power modulation. In addition, the application of a magnetic field to the active element of the laser gives rise to the spectral nonreciprocity.**

Keywords: *spectral nonreciprocity, solid-state ring laser, magnetooptics, nonlinear dynamics, dynamic chaos.*

1. Introduction

The study of non-stationary and quasi-stationary operation regimes of ring Nd : YAG lasers produced upon modulation of pumping attracts great recent attention (see, for example, [1 – 5]). Such studies can give not only new information on the nonlinear interaction of counterpropagating waves in the active medium of ring lasers but also promote the development of new methods for controlling the radiation parameters of monolithic ring lasers.

A monolithic solid-state ring laser is a highly stable nonlinear system in which various stationary, quasi-periodic, and chaotic lasing regimes can exist. These regimes can be switched and output parameters can be controlled by modulating laser parameters (pump power, effective resonator length, coupling coefficients of counterpropagating waves, intracavity losses, etc.) [6].

The specific design of monolithic chip lasers precludes the use of controlling intracavity elements for their modulation. In our opinion, a promising method for controlling the operation regimes of such lasers is based on the use of an external magnetic field. This was demonstrated, in particular, in [7], where it was shown that a constant magnetic field can be used under certain conditions to stabilise chaotic oscillations in solid-state ring lasers.

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This paper is devoted to the study of the nonlinear radiation dynamics of diode-pumped monolithic ring Nd : YAG lasers (ring chip lasers) operating in the region of excitation of quasi-periodic and chaotic oscillations in a constant external magnetic field applied to the active element. We also studied the evolution of boundaries of the regions of existence of different lasing regimes depending on the magnetic field strength.

2. Experimental setup

The experimental setup was similar to that described in [7]. We studied a highly stable monolithic ring Nd : YAG laser which operated in the self-modulation regime of the first kind in the absence of external perturbations. The intensities of counterpropagating waves in this regime execute antiphase sinusoidal oscillations whose frequency is determined by the value of the feedback of counterpropagating waves through backscattering (see details in [8]). The geometrical perimeter the ring resonator was 2.6 cm and the nonplanarity angle of the resonator was 85°. The laser was pumped by a laser diode with a power supply allowing a continuous variation of the pump power and its modulation in the range from 10 to 100 kHz. The modulation amplitude could achieve 100 %. A constant magnetic field was produced by using a small electromagnet located near the active element. The magnetic field strength was variable from zero to 100 Oe and measured by the frequency shift of self-modulation oscillations appearing in the ring chip laser in the magnetic field [8].

The experimental setup allowed us to measure simultaneously the time dependences of the intensities of counterpropagating waves and their spectra. The dependences of the regions of existence of different lasing regimes and the correlation coefficients of the intensity (K_I) and spectra (K_S) of counterpropagating waves in different lasing regimes on the magnetic field strength were studied by using computer-aided data processing.

3. Experimental results

In the absence of external perturbations, when the pump power excess of the threshold was $\eta < 0.3$, the laser operated in the self-modulation regime of the first kind. The self-modulation oscillation frequency in our experiments was 180 kHz, while the relaxation oscillation frequency was 55 kHz for $\eta = 0.11$. Upon modulation of the pump power, the dynamic chaos regime was excited in the laser. This regime was alternated with windows (regions) in which different quasi-periodic regimes existed, which were studied earlier [6].

In this paper, we studied the influence of an external magnetic field on the position of the regions of existence of different quasi-periodic regimes within the region of dynamic chaos for pump power excesses over the threshold $\eta = 0.11$ and 0.22. The pump modulation frequency f_p and depth h were varied at fixed values of the external magnetic field H and pump power excess η over the threshold, which allowed us to obtain the dynamic chaos regime and to study the evolution of the regions of existence of different quasi-periodic lasing regimes.

Figures 1 and 2 demonstrate the mutual arrangement of the regions of existence of quasi-periodic and chaotic lasing regimes for $\eta = 0.11$ and 0.22 and different external magnetic fields strengths. One can see that, when the magnetic

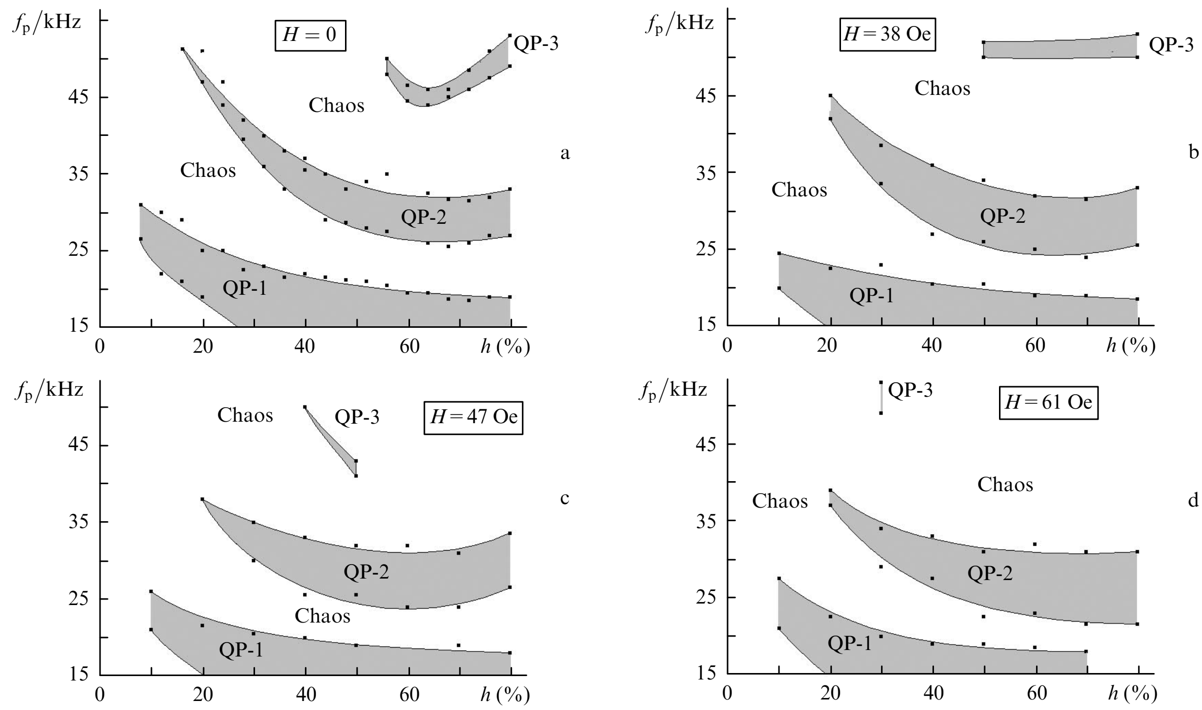

Figure 1. Evolution of the regions of existence of quasi-pulse lasing regimes for the threshold power excess $\eta = 0.11$ depending on the magnetic field strength $H = 0$ (a), 38 Oe (b), 47 Oe (c), and 61 Oe (d).

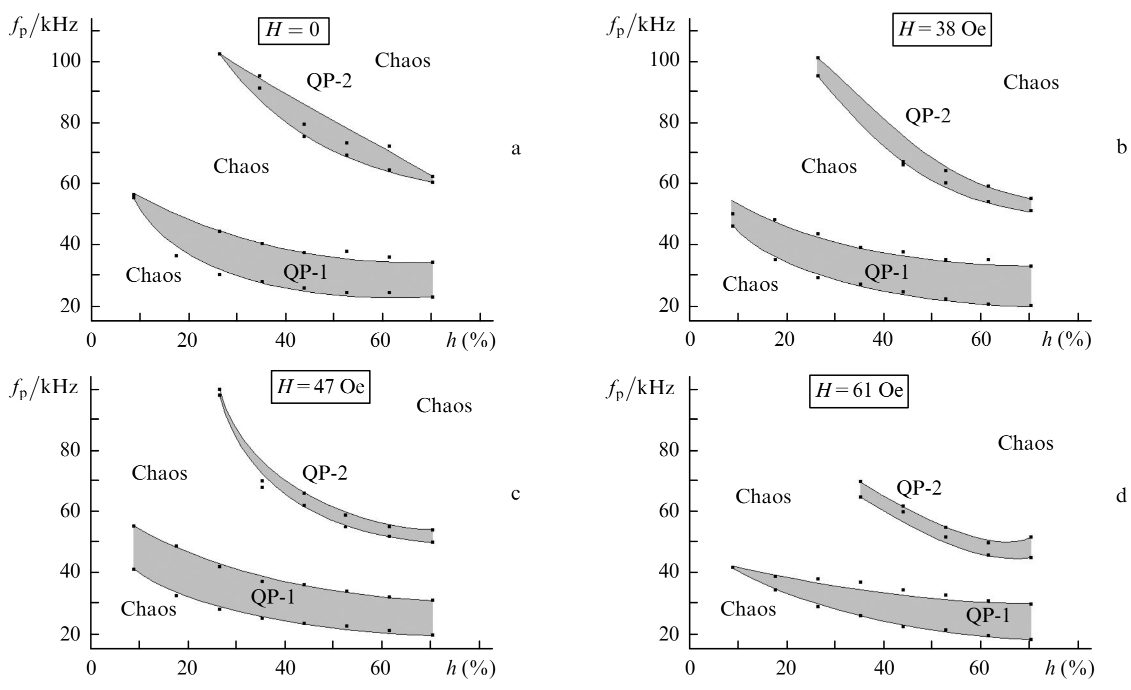

Figure 2. Evolution of the regions of existence of quasi-pulse lasing regimes for the threshold power excess $\eta = 0.22$ depending on the magnetic field strength $H = 0$ (a), 38 Oe (b), 47 Oe (c), and 61 Oe (d).

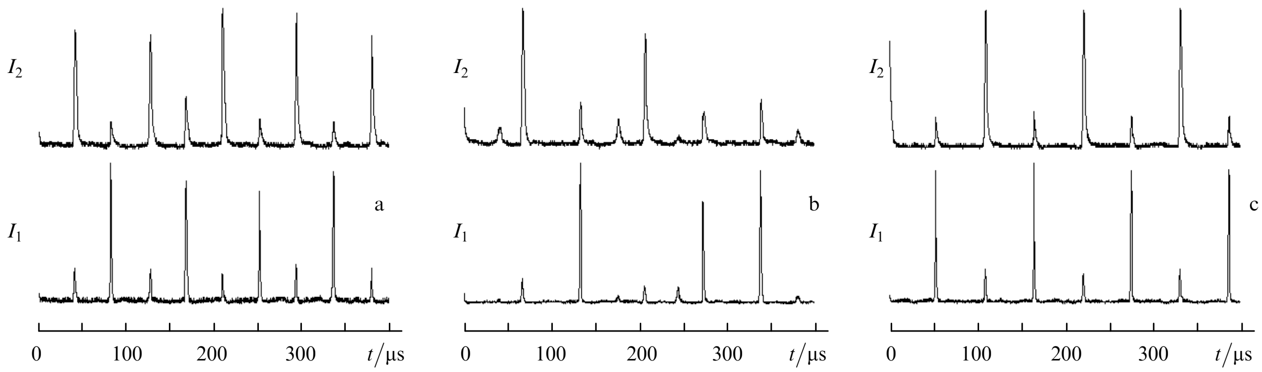

Figure 3. Typical oscillograms of the radiation intensity of counterpropagating waves in quasi-periodic QP-1 ($f_p = 22$ kHz) (a) and QP-2 ($f_p = 35$ kHz) (c) regimes and in the chaotic lasing regime ($f_p = 29$ kHz) (b) for $\eta = 0.11$ and $H = 47$ Oe.

field is switched on, the regions of existence of quasi-periodic regimes appear at lower modulation frequencies f_p of the pump current. Indeed, while in the absence of the magnetic field the region of existence of the QP-1 quasi-periodic regime (at which the oscillation frequency of the intensity of counterpropagating waves coincides with the pump modulation frequency [6]) appeared at the frequency $f_p = 27 - 32$ kHz for the pump modulation depth $h = 10\,\%$, when the magnetic field of strength $H = 61$ Oe was applied, the boundaries of this region displaced to lower values of $f_p = 22 - 26$ kHz. The boundaries of other quasi-periodic lasing regimes changed similarly.

One can see from Fig. 1 that the regions of existence of some quasi-periodic lasing regimes decrease with increasing the magnetic field strength. In particular, the QP-3 quasi-periodic regime exists in a rather broad modulation frequency band from 45 to 55 kHz in the absence of the magnetic field (Figs 1a and b), whereas for $H = 61$ Oe, this regime is observed only in a narrow frequency band near 50 kHz (Fig. 1d). We found that the application of a magnetic field to the active medium of the monolithic ring laser results in the appearance of a strong spectral nonreciprocity of counterpropagating waves in quasi-periodic and chaotic lasing regimes, which can be characterised by the Pearson coefficient [9].

The spectral nonreciprocity was measured at fixed pump power excesses over the threshold $\eta = 0.11$ and 0.22 and fixed values of the magnetic field strength $H = 47$ Oe and modulation depth $h = 27\,\%$ by recording the intensities (Fig. 3) and spectra of counterpropagating waves, from which the Pearson correlation coefficients K_I and K_S were calculated for the intensities and spectra of these waves.

Let us present the typical values of spectral correlation coefficients for quasi-periodic lasing regimes: for $\eta_1 = 0.11$, we have $K_S = 0.89$ and 0.93 in the QP-1 and QP-2 regimes, respectively. In the intermediate region of dynamic chaos ($f_p = 29$ kHz), we have $K_S = 0.68$. For $\eta_2 = 0.22$, we have $K_S = 0.92$ and 0.90 in the QP-1 and QP-2 regimes. One can see that spectral correlation coefficients in the magnetic field can differ from unity by more than 10 %.

Our studies showed that the dependences of boundaries of the regions of existence of different lasing regimes and the spectral nonreciprocity on the magnetic field strength were similar in a rather broad region of excess over the threshold pump power (see Figs 1 and 2).

4. Conclusions

We have studied experimentally the effect of a constant magnetic field on the nonlinear radiation dynamics of a monolithic chip ring Nd : YAG laser in the region of dynamic chaos alternated by windows in which quasi-periodic lasing regimes were excited. A constant magnetic field applied to the active element of the ring laser gives rise to the spectral nonreciprocity of counterpropagating waves. It has been also shown that the magnetic field causes the shift of the regions (windows) of existence of quasi-periodic regimes to the lower pump power modulation frequencies.

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