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Phase shift of self-modulation oscillations in a ring chip Nd:YAG laser in a magnetic field

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***Abstract*.** **A ring chip Nd:YAG laser operating in the self-modulation regime of type I in the presence of a permanent magnetic field is shown to display a magnetic-field-dependent phase shift of self-modulation oscillations in counterpropagating waves.**

Keywords: *magnetooptics, laser dynamics, self-modulation regime.*

The self-modulation regime of type I is one of the most interesting regimes of ring lasers. It was believed until recently that antiphase self-oscillations of intensities of counterpropagating waves (with a phase shift equal to π) are inherent in this regime of lasing. It was shown that, when a magnetic field is applied to the active medium of a ring laser, the frequency of self-oscillations changes [1 – 3] and the spectrum of relaxation oscillations is split [4, 5]. These effects, as shown in [6], are caused by the frequency nonreciprocity arising in a cavity of a ring laser due to the Faraday effect. However, the frequency nonreciprocity, as demonstrated in [4 – 6], should not change the phase difference of self-modulation intensity oscillations in counterpropagating waves.

In this paper, we provide the first experimental demonstration of the appearance of the phase shift between self-modulation oscillations for counterpropagating waves in a ring solid-state laser in the presence of a permanent magnetic field.

Our experiments were performed with a stabilised single-frequency monolithic ring chip Nd:YAG laser operating in the self-modulation regime of type I. The design of this laser and its characteristics are described in detail in [7]. The geometric perimeter of the cavity was equal to 2.6 cm and the angle characterising the deviation of the cavity from the planar geometry was $\beta = 80^\circ$. The system was pumped by 0.81-μm radiation of a diode laser. A permanent magnetic field with a strength H up to 500 Oe was induced by an electromagnet. Radiation of both counterpropagating waves was detected in our experiments. (An additional selective mirror transparent for pump radiation and reflective for laser radiation was employed to detect the second wave.) The signals produced by the photodetectors were fed to a dual-beam oscilloscope. The mode structure of radiation was monitored using a Fabry – Perot interferometer.

When no magnetic field was applied (with a pump power exceeding the lasing threshold by 10 %), the laser operated in the self-modulation regime of type I. The self-modulation frequency was equal to 200 kHz, and lasing occurred in a single longitudinal mode. Investigations of the parameters of self-modulation oscillations as functions of the magnetic field strength have shown that the dependence of the frequency of these oscillations on H agrees well with theoretical predictions of [1 – 3].

These studies have also demonstrated that, when a permanent magnetic field $\boldsymbol{H}$ is applied to the active medium of a ring chip laser, an H-dependent phase shift $\Delta\phi$ between

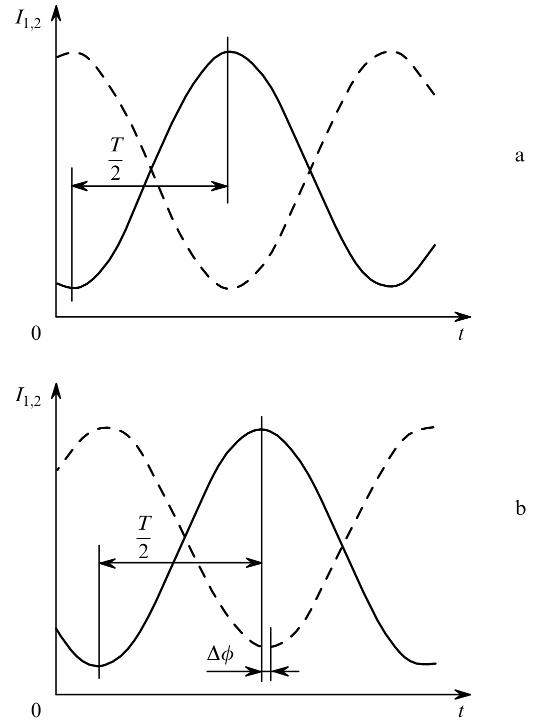

Figure 1. Oscilloscope traces of intensities $I_{1,2}$ of counterpropagating waves (a) in the absence and (b) in the presence of a permanent magnetic field (T is the period of self-modulation oscillations).

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self-modulation oscillations in counterpropagating waves is induced (Fig. 1). The phase shift depends on the strength of the magnetic field and its orientation relative to the contour of the chip-laser cavity. The sign of this phase shift is reversed when the polarity of the electromagnet is changed. The maximum phase shift detected in our experiments reached $\sim 10^{\circ}$.

Thus, a magnetic field applied to the active medium of a ring chip laser not only changes the frequency of self-modulation oscillations in each of the directions, but also gives rise to a magnetic-field-dependent phase shift between these oscillations. The observed effect may be, in principle, related to the amplitude nonreciprocity of a ring cavity (the difference in cavity Q factors for counterpropagating waves) [8], which may arise due to the Faraday effect [9], and changes in polarisation characteristics of a ring cavity in the presence of an external magnetic field. We cannot also exclude that this phase change may be caused by frequency nonreciprocity, since the conclusion that the phase shift is insensitive to the frequency nonreciprocity of the cavity was made within the framework of a rather crude model of a laser. We plan to perform more detailed studies of the effect described in this paper. Such experiments are of interest for understanding nonlinear dynamics and magnetooptics of solid-state ring lasers and for various practical applications.

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