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LASER GYROSCOPES

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Semiconductor laser gyro with optical frequency dithering

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Abstract. **The semiconductor laser gyro is described, in which the optical frequency dithering implemented by intracavity phase modulation suppresses the frequency lock-in and provides the interference of multimode radiation. The sensitivity of the device amounted to 10 – 20 deg h^{-1}.**

Keywords: *semiconductor laser gyro, frequency lock-in, dithering.*

The possibility to measure the velocity of rotation by means of a semiconductor laser gyro (SLG) was first demonstrated in Refs [1, 2]. The semiconductor optical amplifier (SOA) on the basis of an InGaAsP/InP structure was used as a gain medium, and the ring resonator was implemented using a 3-m-long optical waveguide. The laser emission was multimode, as a result of which the small signal in the form of beats could be measured only at rather high rotation velocities. The studies were continued, but the sensitivity could be increased only up to 1 deg s^{-1} [3].

As it could be concluded, the main causes of low SLG sensitivity were the frequency lock-in and the multimode lasing. The frequency lock-in is related to the backscattering of optical radiation, the level of which in SLGs is a few orders of magnitude higher than in the He – Ne gyros. The multimode lasing is caused by the small value of the mode frequency spacing, even in a laser with relatively small cavity length.

The solution of one of these problems was demonstrated by us in Ref. [4], where a device consisting of two lasers, the master and the slave, was used. The master laser was a single-frequency laser diode, whose radiation was periodically injected into the slave laser, the SLG itself, having a multiturn fibre coil as a cavity. The phase difference accumulated during a large number of circulations of the single-frequency radiation in the SLG cavity was significant. In the same paper the model of frequency lock-in in a ring laser was proposed, directly related to the level of backscattering and the parameters of the ring laser.

Next it was planned to use optical frequency dithering in the SLG with injection of single-frequency radiation, i.e., to introduce a constant or alternate bias between the circulating waves that moves the beat frequency out of the lock-in zone.

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As it is known, in the techniques of He – Ne gyros the dithering is an approved means of overcoming the frequency lock-in, but in SLGs it was not used so far because of the large width of the frequency lock-in zone and the multimode oscillation.

However, from the calculation of the ring laser frequency response using the model [4] for frequency lock-in, it follows that for a significant level of backscattering a great (of the order of hundreds of metres) length of the ring resonator allows a reduction of the lock-in zone width to the level of 1 – 2 kHz. In this case it is possible to use optical frequency dithering, rather simply implemented by means of a fibre phase modulator placed inside the ring cavity.

The very first experiments have demonstrated that the optical frequency dithering gives rise to large-amplitude beats at the output of a multimode SLG or, in other words, to high-contrast interference of the output radiation even without injecting the single-frequency radiation. This was an unexpected, observed for the first time, but stably reproducible effect.

Figure 1 shows the schematic diagram of an SLG with reversible optical frequency dithering. We used the SOA based on the InGaAsP/InP structure; the ring cavity was implemented in the form of a coil of single-mode SM-28 optical fibre, the fibre length being L = 570 m and the coil radius R = 5 cm. Two fibre couplers served to provide a partial power pickup from the waves, circulating in the opposite

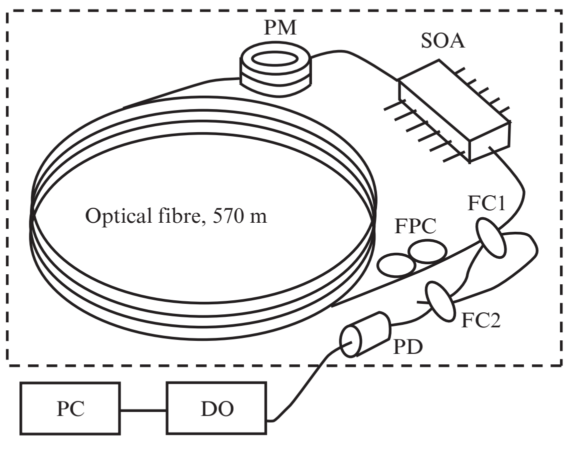

Figure 1. Schematic diagram of the device:
(SOA) semiconductor optical amplifier; (FC1, FC2) fibre couplers; (PD) photodetector; (FPC) fibre polarisation controller; (PM) phase modulator; (DO) digital oscilloscope; (PC) personal computer.

directions, and also to combine the output radiation and deliver it to the photodetector. The pump current, supplied to the SOA, amounted to 150–250 mA. The recording and processing of the signal was performed using a digital oscilloscope and a computer.

The role of the phase modulator, placed near the SLG, was played by the 10-m-long optical fibre, wound on the side surface of a piezoelectric cylinder. The frequency of the harmonic modulating voltage was set within the range from 0.8 to 3.0 kHz. The sign-changing frequency bias arose in the part of the ring cavity located near the SLG, thus localising the backscattering effect. Due to the delay of one wave with respect to the other one by the time $\tau = Ln/c$ and to the modulation character, the frequency bias possesses a sinusoidal behaviour (n being the refractive index of the fibre core).

The optical spectrum of the radiation consisted of one or two spectral lines (with the width about 1 nm each) near 1.55 μm. The radio frequency spectrum of the photocurrent had the form of a frequency comb with the spacing of 345 kHz, which corresponds to the frequency spacing $\Delta\nu = c/nL$ between the longitudinal modes of the ring cavity. Thus, the number of longitudinal modes in the radiation was not smaller than 10^5.

Figure 2 presents oscillograms of the photocurrent and modulating voltages under the SLG rotation. It can be seen that the number of photocurrent oscillations is different in two half-periods of the modulating voltage, namely, the number of oscillations during the voltage fall is greater than during the voltage growth. Under the rotation in the opposite direction the situation was different, i.e., the number of oscillations became greater during the modulating voltage growth than during its decrease. At rest the number of oscillations was equal in both half-periods.

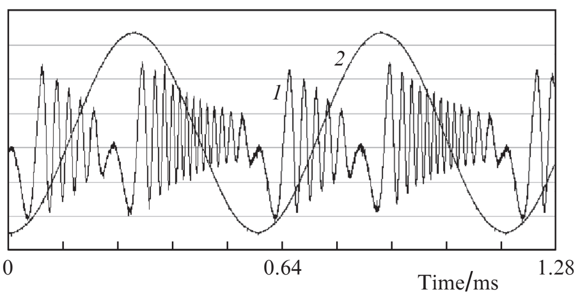

Figure 2. Oscillograms from the monitor screen, corresponding to the photodetector output (*1*) and the sinusoidal modulating voltage with the frequency $f \approx 1.6$ kHz (*2*).

This observation was an evidence of the Sagnac effect involved in the signal formation and, hence, allowed the measurement of the angular velocity Ω. The digital processing of the output signal was based on presenting the photocurrent in the form

$$i(t) = i_0[1 + V(t)\cos(2\pi\nu_s t \pm 2\pi\Phi(t))], \quad (1)$$

where i_0 is the photocurrent amplitude; $V(t)$ is the interference contrast; $\nu_s = M\Omega$ is the beat frequency in the absence of backscattering; $M = 2R/\lambda n$ is the scaling coefficient; λ is the wavelength; $\Phi(t) = \Phi_0\sin(2\pi ft)$ is the reversible frequency shift; Φ_0 is the amplitude of the frequency shift.

The algorithm of signal processing included the determination of the time moments, corresponding to the maxima of the photocurrent oscillations at the adjacent dithering segments. Each pair of the determined time moments corresponded to the change of the argument of the cosine in Eqn (1) by the value of $2\pi k$ with the sign plus or minus (k is an integer). Finally, this allowed the calculation of the frequency ν_s and the angular velocity Ω, and earlier, while processing the signal from the device at rest, the frequency shift amplitude Φ_0.

The sensitivity estimation was carried out by measuring the beat frequency ν_s in the SLG positions with a different orientation with respect to the direction of the Earth's rotation axis. As a result of multiply repeated measurements, the minimally detectable rotation velocity amounted to 10–20 deg h^{-1}.

In conclusion note that the proposed approach requires further studies. The use of a polarisation-maintaining fibre seems to provide an essential increase in the SLG sensitivity. As to the mechanism of the multimode radiation interference, we can only suppose that the frequency lock-in plays a significant role in it. During short intervals between the dithering periods with a different sign of the frequency bias, the frequency lock-in provides the equality of instantaneous frequencies of the opposite waves, which then is conserved for a limited time. During this time the dithering supresses the frequency lock-in, allowing the formation of a signal that carries information about the direction and magnitude of the angular velocity.

References

1. Taguchi K., Fukushima K., Ishitani A., Ikeda M. *Opt. Quantum Electron.*, **31**, 1219 (1999).
2. Inagaki K., Tamura S., Noto H., Harayama T. *Phys. Rev. A*, **78**, 53822 (2008).
3. Akparov V.V., Dmitriev V.G., Duraev V.P., Kazakov A.A. *Kvantovaya Elektron.*, **40** (10), 851 (2010) [*Quantum Electron.*, **40** (10), 851 (2010)].
4. Sakharov V.K. *Zh. Tekh. Fiz.*, **81**, 76 (2011) [*Tech. Phys.*, **56**, 1135 (2011)].