Quantum Electronics **31** (12) 1113 – 1114 (2001)

PACS numbers: 07.60.Ly; 07.60.Vb; 42.81.Pa
DOI: 10.1070/QE2001v031n12ABEH002100

Recirculating fibre ring interferometer with compensation for losses in the cavity

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***Abstract*. A new recirculating fibre ring interferometer with an intracavity fibre amplifier and a broadband light source is developed. A substantial increase in the threshold sensitivity of the interferometer to rotation and an increase in the scale factor are experimentally demonstrated in the near-threshold regime.**

Keywords: *ring cavity, fibre amplifier, recirculating interferometer.*

A recirculating fibre ring interferometer (FRI) [1] is a new type of a low-coherence interferometer, which combines the advantages of traditional FRIs: a low-coherence single-pass Sagnac interferometer [2] and a high-coherence (resonator) FRI [3]. The sensitivity of a recirculating FRI (RFRI) is enhanced by accumulating a signal due to multiple round-trip transits (recirculations) in the ring cavity (high-Q optical cavity). At the same time, the use of a low-coherence light source reduces the influence of main destabilising factors [2]. At present, the RFRI attracts attention as a sensor of physical quantities. In particular, the importance of reducing intracavity losses was theoretically demonstrated [4], passive RFRIs were developed [5, 6], and active recirculating delay lines were studied [7].

In this paper, we demonstrate experimentally an angular velocity sensor based on an active RFRI with a broadband light source and a fibre amplifier compensating for losses in the cavity. The scheme of the RFRI is shown in Fig.1. It includes superfluorescence fibre source (*4*), directional fibre couplers (*1–3*), polariser (*5*), phase modulator (*6*), fibre coils (*7, 8*), and fibre amplifier (*9*). A ring cavity formed by series-connected elements (*3, 7, 9, 8*) is a sensitive element of the RFRI. The output signal is detected using modulation and phase detection at the first harmonic.

All the optical elements except fibre source (*4*) are made of a polarisation maintaining fibre. The fibre source and amplifier are made of an ytterbium – erbium fibre ($\lambda = 1.55$ μm). The gain of the fibre amplifier was varied up to 10 dB by changing the pump-diode current.

The output signal of the RFRI can be represented as a sum of m signals ($m = 1, 2, \ldots, \infty$) of single-pass FRIs, which have nonreciprocal shifts $m\phi_{\mathrm{S}}$, where $\phi_{\mathrm{S}} = (2\pi LD/c\lambda)\Omega$ is the phase Sagnac shift during a transit in the cavity; Ω is the angular velocity being measured; $L = 2 \times 100$ m and $D = 125$ mm are the total length and diameter of coils, respectively. As the number of transits in the cavity increases, the output characteristic $T(\phi_{\mathrm{S}}) = |E_{\mathrm{out}}(\phi_{\mathrm{S}})|^2/|E_{\mathrm{in}}|^2$ of the interferometer becomes more sharp, resulting in the increase in the sensitivity [here, E_{in} and $E_{\mathrm{out}}(\phi_{\mathrm{S}})$ are the fields at the RFRI input and output, respectively, see Fig.1].

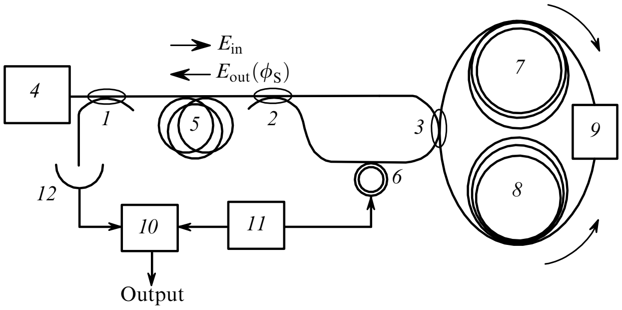

Figure 1. Scheme of a RFRI: (*1–3*) directional couplers; (*4*) fibre light source; (*5*) polariser; (*6*) phase modulator; (*7, 8*) fibre coils; (*9*) fibre amplifier; (*10*) phase detector; (*11*) reference generator; (*12*) photodetector.

We measured the slope of output curve (the scale factor) of the FRI $Q_{\mathrm{S}} = \Delta U/\Delta\Omega$ by detecting the output voltage ΔU of the phase detector at the first modulation harmonic, the average power P_0 on photodiode 12, and the threshold sensitivity $\Omega_{\min}$ of the FRI (1σ, 1 Hz). We studied the dependences of these parameters on the optical gain. Fig.2 shows the dependences of the threshold sensitivity $\Omega_{\min}$ and the normalised slope Q_{s}/P_0 on P_0. The regime with the unity gain was achieved at $P_0 \approx 20$ μW, while the near-lasing regime was observed at $P = 120$ μW. The data were analysed using the relation [4]

$$T(\phi_{\mathrm{S}}) = \frac{t_0^2}{1 - R^2}\frac{1 - R^2 + 0.5(h - 2)\sin^2\phi_{\mathrm{S}}}{1 - R^2 + h\sin^2\phi_{\mathrm{S}}}, \qquad (1)$$

where $t_0 = a^2gf(1 - k^2)$; $R = kgfa$; $h = 4R^2/(1 - R^2)$; $k = 0.707$ is the amplitude through coupling ratio of directional coupler (*3*); $a = 0.5$ dB; $f = 6.1$ dB (including losses at four splices); g is the amplitude transmittance for elements (*3*), (*7+8*), and (*9*), respectively.

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Received 13 September 2001
Kvantovaya Elektronika **31** (12) 1113 – 1114 (2001)
Translated by M N Sapozhnikov

A linear approximation of the slope of output curve (*2*) in Fig.2 was calculated by expression (1) taking into account that $Q_{\rm S}$ is proportional to $\mathrm{d}^2T(\phi_{\rm S})/\mathrm{d}\phi_{\rm S}^2$ for $\phi_{\rm S}=0$ and $P_0 \sim T(0)$. It follows from Fig.2 that $\Omega_{\min}$ decreases by a factor of eight in the case of the maximal possible amplification. Note, however, that the sensitivity enhancement obtained in the experiment is not maximal, as indicated by the deviation of the slope (*2*) from the theoretical (linear) dependence and also by a relatively small parameter R in the near-threshold regime. There are reasons to assume that the discrepancy between the theory and experiment is explained, in particular, by the 'deformation' of the spectral dependence of the gain in the near-threshold regime.

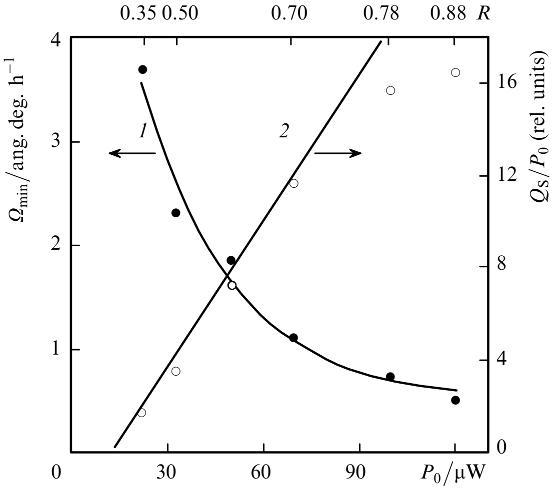

Figure 2. Dependences of the threshold sensitivity $\Omega_{\min}$ (*1*) and the normalised slope $Q_{\rm s}/P_0$ (*2*) of the RFRI on the average power P_0.

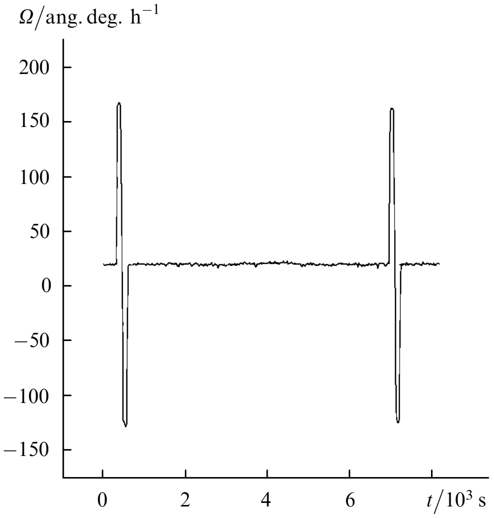

Figure 3. Zero drift of the RFRI.

The prototype of a RFRI developed by us has quite stable parameters. Fig.3 shows the zero drift of the RFRI recorded in the near-threshold regime for 2.5 h with calibration signals at the beginning and end of the recording. The zero instability was 0.5 ang. deg. h^{-1} (1σ, $\tau = 20$ s) for a linear drift of less than 0.1 ang. deg. h^{-1}, while the instability of the scale factor was about 2.5 %.

Thus, we have demonstrated experimentally a considerable improvement in the threshold sensitivity of the RFRI to rotations (by a factor of ~ 8) when an optical amplifier operating in the near-threshold regime was introduced inside the cavity.

Acknowledgements. The authors thank V P Gapontsev, I E Samartsev, and Yu A Barannikov for their help in this study and also I A Andronova and G B Malykin for discussions. This work was supported by the Russian Foundation for Basic Research (Grant No. 00-02-17344).

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