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Measurement of the emission linewidth of a single-frequency semiconductor laser with a ring fibre interferometer

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Abstract. **A simple scanning interferometer is implemented for measuring the emission linewidth of single-frequency semiconductor lasers. The free dispersion region of the interferometer is 28 MHz, the spectral resolution being 470 kHz.**

Keywords: *ring fibre interferometer, single-frequency semiconductor laser, emission linewidth.*

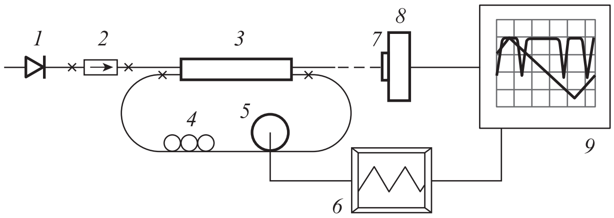

Figure 1. Schematic diagram of the ring interferometer: (*1*) laser diode; (*2*) isolator; (*3*) fibre coupler; (*4*) polarisation controller; (*5*) piezoelectric element; (*6*) generator; (*7*) optical filter; (*8*) photodetector; (*9*) oscilloscope.

1. Introduction

The unique combination of properties of single-frequency injection lasers, i.e., high monochromaticity of radiation, high efficiency and exclusively small size, determine their exceptional potentiality in coherent reflectometers, systems of coherent summation, frequency standards, etc. [1–4]. One of the key parameters of these lasers is the emission linewidth, the measurement of which is a nontrivial problem, since the expected width does not exceed a few MHz, while the spectral resolution of standard spectrum analysers is 0.01 nm. In the present paper, for measuring the emission linewidth it is proposed to use a sufficiently simple scanning ring fibre interferometer. Similar devices have already been used for mode selection in a semiconductor laser and narrowing its emission spectrum [5–9].

2. Measurement technique

The emission spectrum of an InGaAs semiconductor laser with a distributed fibre Bragg mirror was measured. The front face of the laser had an AR coating, and radiation was coupled into the single-mode optical fibre with the Bragg grating inscribed in it [10, 11]. At a wavelength of 1064 nm the grating had the maximal reflection coefficient of about 30%. The maximal output power of the laser was 25 mW. The laser radiation was linearly polarised, the degree of polarisation exceeding 0.99.

The setup of the fibre interferometer is presented in Fig. 1. Radiation from laser (*1*) was coupled into the interferometer through optical isolator (*2*) (the degree of isolation, –40 dB) which eliminated the influence of radiation propagating in the backward direction on the operation of the semiconductor laser. From the isolator output radiation entered fused fibre coupler (*3*) with the splitting coefficient 20:1. The arm, receiving the smaller part of the radiation power, was closed into a ring. The length of the fibre part of the interferometer was 7 m. The optical fibre had the cutoff wavelength of the first higher mode 1 μm, which provided the single-mode regime of radiation propagation from the semiconductor laser. The region of free dispersion of the fibre ring interferometer, corresponding to [12], is defined as

$$\Delta\lambda = \frac{\lambda^2}{nL}, \ \Delta f = \frac{c}{nL}, \tag{1}$$

where λ is the wavelength; f is the radiation frequency; c is the speed of light in vacuum; n is the refractive index of the fibre core; L is the length of the interferometer arm.

The spectral widths of the instrument functions $\Delta\lambda$ and Δf are expressed as

$$\delta\lambda = \frac{\Delta\lambda(1-r)}{\pi\sqrt{r}}, \ \delta f = \frac{\Delta f(1-r)}{\pi\sqrt{r}}, \tag{2}$$

where $r = 0.95$ is determined by the splitting coefficient of the coupler.

Based on Eqns (1), (2), the region of free dispersion is estimated as 28 MHz and the spectral width of the instrument function as 470 kHz. To compensate for the change in the polarisation state in the interferometer, polarisation controller (*4*) was included into the scheme (Fig. 1).

To scan the optical path length of the interferometer, a part of a 6-m-long optical fibre about was wound around piezoelectric element (*5*) having cylindrical shape with the diameter 5 cm. The voltage applied to the piezoelectric element caused the increase in its diameter and, therefore, the increase in the optical path length. To eliminate nonlinear distortions,

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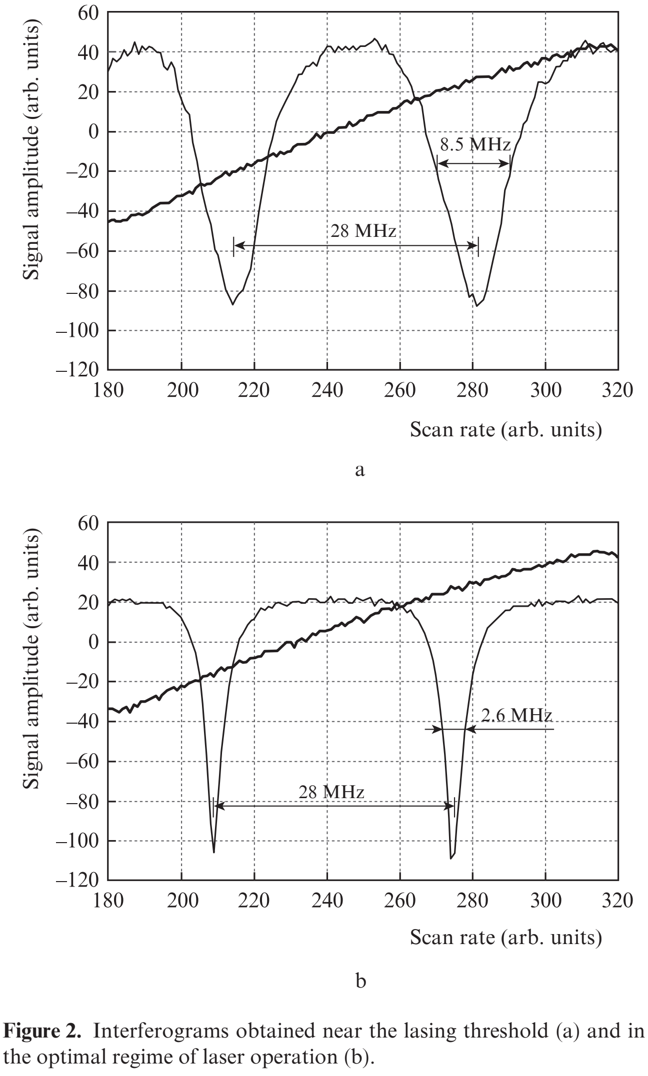
the voltage pulses applied to the piezoelectric element from generator (*6*) had triangle shape. The amplitude of the voltage applied to the piezoelectric element was 28 V, which provided the change in the optical path length of about a wavelength. The modulation frequency was 100 Hz. The radiation from the interferometer output was delivered onto photodetector (*8*) through filter (*7*) and was analysed with digital oscilloscope (*9*).

3. Results and discussion

Figure 2 presents the results of measuring the linewidth at two values of the output power of the semiconductor laser. The data shown in Fig. 2a were obtained near the lasing threshold at a pump current of 35 mA. In this regime the emission linewidth was 8.5 MHz. At a greater pump current, when the lasing power attained 16 mW, the linewidth decreased to 2.6 MHz (Fig. 2b). A further increase in the current (up to 160 mA) lead to instability of the oscillogram and temporal variations in the emission linewidth. Note that the linewidth and the stability of the interference pattern depend on the temperature of the laser diode, which was optimised using the observed interferogram.

Figure 3 illustrates the influence of the change in the polarisation state on the interference pattern. The oscillogram presented in this figure was obtained without polarisation controller. One can see the third peak, the origin of which is determined by the appearance of radiation having the perpendicular polarisation direction. The introduction of the polarisation controller allows the restoration of the linear polarisation state and the elimination of the additional peak from the interferogram.



a

b

Figure 2. Interferograms obtained near the lasing threshold (a) and in the optimal regime of laser operation (b).

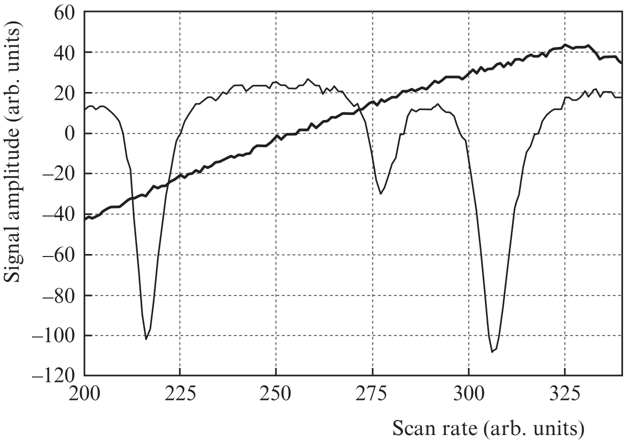


Figure 3. Interferogram obtained without polarisation controller.

Using the presented data we can conclude that the considered scanning fibreoptical interferometer allows one not only to measure the emission linewidth of the single-frequency laser, but also to control the optimal (with respect to the linewidth) pump current and temperature of the laser diode. As follows from Eqn (2), the spectral resolution of the method may be improved by increasing the length of the optical fibre, used in the interferometer. However, in this case special measures will be required to prevent the external temperature and acoustical disturbances that may cause fluctuations of the optical path length. Moreover, a polarisation-maintaining optical fibre may become necessary, since the substantial increase in the length may cause depolarisation of the propagating radiation.

Thus, a simple scanning fibreoptical interferometer is implemented for measuring the emission linewidth of the single-frequency semiconductor laser with the resolution 470 kHz. The interferometer may be also used for optimising the pump current and the temperature of the laser diode.

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