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Semiconductor laser with a birefringent external cavity for information systems with wavelength division multiplexing

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Abstract. **The spectrum of a semiconductor laser with a birefringent external Gires – Tournois cavity is studied. The generation of two main laser modes corresponding to the ordinary and extraordinary wave resonances is found. It is shown that the radiation spectrum is controlled with a high energy efficiency without losses for spectral filtration. The possibility of using two-mode lasing in optical communication systems with wavelength division multiplexing is shown.**

Keywords: *optical communication systems, semiconductor laser, external cavity, birefringent crystal, electro-optics.*

1. Introduction

The spectral (frequency) modulation of optical radiation is used to create fibre-optic systems insensitive to amplitude noise. The modulation can be either internal, for example, formed by changing the laser pump current, or external, based on controlled spectral filters. Most widely used among the external modulation elements are the Bragg gratings in the bulk [1], fibre-optic [2], or integral-optic [3] form, as well as diffraction gratings and interference filters [4, 5]. The reflection/transmission spectrum of these elements can be changed by different methods, namely, by mechanical stretching, rotating, changing the temperature, and application of an electric field. The known drawbacks of these elements are a low energy efficiency due to the spectral filtration of broadband radiation and a slow response to mechanical or thermal actions.

Most of the used external cavities (ECs) are optically homogeneous and have no pronounced polarisation properties. However, using the EC birefringence and the ordinary or extraordinary wave resonances, it is possible to change the radiation source spectrum. With a proper selection of the optical cavity thickness, spectral encoding of information can be performed by neighbouring semiconductor laser modes (intermode distance about 0.1 nm) or within the laser spectrum (0.5 – 2 nm). For this spectral-mode encoding, the laser cavity and the external cavity must be optically coupled. In this case, the radiation spectrum is automatically stabilised due to the positive feedback. Simultaneously, the high energy efficiency of the laser is retained and the losses related to the spectral filtration are almost completely eliminated.

The aim of the present work is to study the possibility of controlling the spectrum of a semiconductor laser using a birefringent external Gires – Tournois cavity.

2. Experimental

As an external cavity, we used *x*- and *z*-cut plane-parallel plates of congruent lithium niobate crystals 0.21 mm thick. A highly reflecting aluminium mirror was deposited on one face of the crystalline plates, and a 19-layer SiO_2/ZrO_2 interference mirror with a calculated reflection coefficient of 98.5% in the range 635 – 640 nm was deposited on the other face. The diameters of the mirrors were 3 mm, while the diameters of the plates were 5.5 mm. The radiation source was a KLM-A635-2-5 collimated red semiconductor laser (beam divergence 0.1 – 0.2 mrad, beam diameter 8 mm). The spectra were studied using an SHR spectrometer with a resolution of 6 – 7 pm and a recorded band of 4 – 5 nm within the range 630 – 650 nm. The setup scheme is shown in Fig. 1.

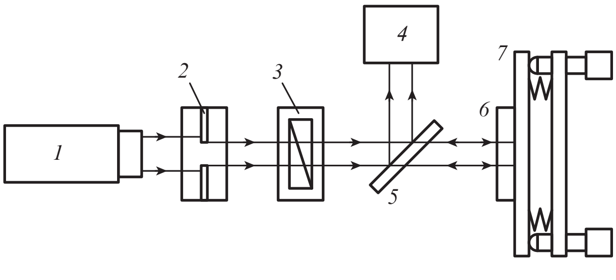

Figure 1. Scheme of the experimental setup: (*1*) semiconductor laser; (*2*) aperture; (*3*) polariser in a rotating holder; (*4*) spectrometer; (*5*) semitransparent mirror; (*6*) external cavity; (*7*) angular mount.

The scheme was adjusted by achieving the normal angle of beam incidence on the cavity and by rotating the polariser. The normal incidence was controlled roughly by the coincidence of the reflected beam with the collimating lens of the semiconductor laser and precisely by the short-wavelength shift of the laser spectrum. The polariser rotation angle was changed using a rotating holder with a scale factor of 2°, and the external cavity position was adjusted by a two-dimensional angular mount with a sensitivity of 0.001°.

In the first experiment, we studied the change of the radiation spectrum caused by changing the optical thickness of the external cavity. A *z*-cut plane-parallel plate of congruent lithium niobate 0.21 mm thick served as a cavity. A change in the

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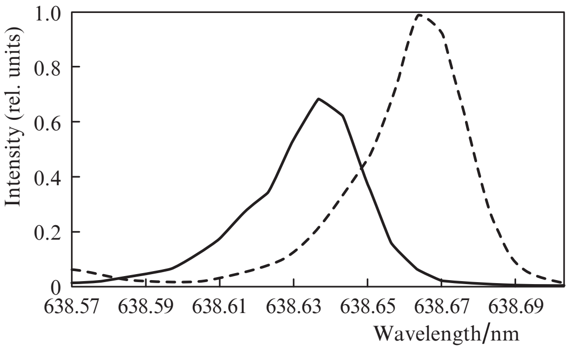

Figure 2. Shift of the laser mode caused by rotation of the external cavity: the solid line corresponds to the normal incidence and the dashed curve corresponds to the incidence at an angle of 0.02°.

angle of incidence on the external cavity led only to an increase in the optical thickness without noticeable change in the reflection coefficient of the interference mirror. The measured spectra are presented in Fig. 2.

The laser modes shown in Fig. 2 are partially overlapped, which points to a continuous character of the spectral shift. As the angle of incidence on the external cavity changes from 0 to 0.02°, the main mode continuously shifts from λ_1 = 638.636 nm to λ_2 = 638.664 nm. At the angle of incidence exceeding 0.02°, the cavities were decoupled and the radiation spectrum remained in the extreme left position with λ_2 = 638.664 nm.

In the second experiment, we studied the resonances of the ordinary and extraordinary waves excited sequentially. As a cavity, we used a birefringent x-cut plane-parallel plate of congruent lithium niobate with the refractive indices n_o = 2.286 and n_e = 2.2 [6]. The ordinary or extraordinary waves were excited when the polarizer was rotated in the position 0 or 90°, respectively. The measurement results are shown in Fig. 3.

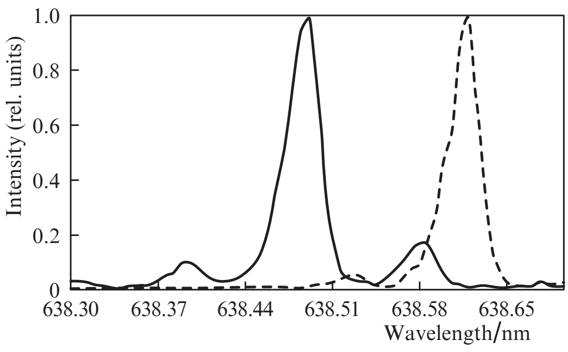

Figure 3. Spectrum of a semiconductor laser with a birefringent external cavity in the case of extraordinary (solid line) and ordinary (dashed line) wave resonances.

The partial overlap of the radiation modes in Fig. 3 confirms the continuous character of changes in the spectrum, which is determined mostly by the properties of the external cavity. The external cavity birefringence makes it possible to shift the main laser mode by rotating the polariser from 0 (parallel to the ordinary axis) to 90° (parallel to the extraordinary axis). According to these polariser positions, lasing occurs at the wavelengths λ_max = 638.489 nm or λ_max= 638.621 nm. The obtained experimental data qualitatively coincide with the results of work [3], in which a birefringent channel waveguide in lithium niobate with a Bragg grating cavity was used.

For a fast (few nanoseconds) rotation of the polarisation plane in communication systems, one can use an electro-optic half-wave plate. If the laser radiation is polarised, an external cavity made of an electro-optic material may serve as such a plate.

The resonance of the ordinary and extraordinary waves excited simultaneously was studied in the third experiment. In this case, we used an external cavity made of an x-cut plate of congruent lithium niobate, and the polarizer was positioned at an angle of 45° to the extraordinary axis. The results of this experiment are shown in Fig. 4.

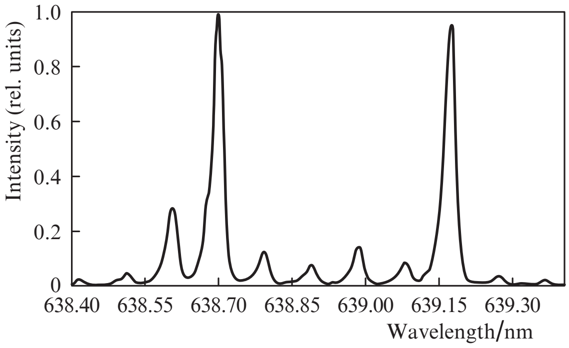

Figure 4. Lasing of two main waves of a semiconductor laser with a birefringent external cavity upon simultaneous excitation of the ordinary and extraordinary waves.

The simultaneous excitation of the ordinary and extraordinary waves leads to lasing of two main modes comparable in intensity. In this case, the number of secondary modes increases from 6–7 to 12–13, which is obviously caused by the positive feedback created by the external cavity in several regions of the spectrum. This reveals the resonance structure of the external cavity superimposed on the spectrum of the semiconductor laser. Depending on the external cavity thickness, the relative positions of the spectral maxima of the ordinary and extraordinary waves can be different. However, the distance between the two main modes formed due to the external cavity birefringence obeys the relation

$$\Delta\lambda_\text{main} \leqslant \text{FSR} + \Delta\lambda_\text{mod}/2, \tag{1}$$

where FSR is the free spectral range of the external cavity equal to 0.43 and 0.44 nm for the ordinary and extraordinary waves, respectively; and $\Delta\lambda_\text{mod}$ is the distance between the neighbouring cavity modes equal to 0.095–0.098 nm for a KLM-A635-2-5 laser. The possible shift of the main mode $\Delta\lambda_\text{mod}/2$ relates to the positions of the intrinsic modes of the semiconductor laser cavity. To satisfy relation (1), the width of the external cavity reflection spectrum must be comparable with the intermode distance of the semiconductor laser cavity. As follows from the data of Fig. 4, $\Delta\lambda_\text{main}$ = 0.47 nm, which agrees with the estimate 0.39–0.48 nm followed from (1) at the average FSR of 0.435 nm. This estimate is also true for the data of Fig. 3. The effect of the external cavity on the radiation spectrum is confirmed by the low intensity of the central modes observed in Fig. 4 between the fundamental modes. It should be noted that, for reliable detection of the spectral peaks of the external cavity, they must be sufficiently narrow, no broader than $(1-2)\Delta\lambda_{\rm mod}$. In the opposite case, several modes near the resonance peak will be simultaneously excited or random lasing of one mode from several near-resonance modes will occur. For a reflection coefficient of 98.5%, a beam divergence of 0.1–0.2 mrad, and a wedge angle of the lithium niobate plate of 10″, the peak width at half maximum does not exceed 15 nm, which satisfies the conditions of observation.

For unambiguous selection of the lasing mode upon information transfer, the FSR of the external cavity must be larger than the width of the laser spectrum, $\text{FSR} > (1.5-2)\Delta\lambda_{\rm las}$. For a red KLM-A635-2-5 laser, the measured spectral width is $\Delta\lambda_{\rm las} = 0.7-0.8$ nm at $\Delta\lambda_{\rm mod} = 0.095-0.098$ nm. For IR lasers with the central wavelength within the range 840–850 nm, the spectral width is $\Delta\lambda_{\rm las} = 1.5-2$ nm. This means that the thickness of the external cavity based on lithium niobate must be no larger than 60–80 μm for the red laser and 40–50 μm for near-IR lasers.

3. Conclusions

It is experimentally proved that the use of a birefringent external cavity optically coupled to the semiconductor laser cavity makes it possible to obtain lasing at two main modes. The spectral positions of these modes are determined by the resonances of the ordinary and extraordinary waves in the external cavity. The generated modes lie within the laser spectrum and are dominant and stable in time. This ensures a high spectral coding efficiency and allows one to use lasers with a birefringent cavity for solving the following problems:

(i) wavelength division multiplexing based on the existing technique with spectral stabilisation of radiation due to the positive external cavity feedback;

(ii) spectral coding and private communications on neighbouring modes or within the semiconductor laser spectrum;

(iii) creation of analogue highly sensitive optical analysers of chemical composition of liquid and gas mixtures with a sensitive element in the form of an external cavity.

References

1. Petrov M.P., Petrov V.M., Chamrai A.V., Denz C., Tshudi T. *Proc. 27th Europ. Conf. Opt. Commun.*, ECOC’01 (Amsterdam, 2001) Th.F.3.4, p. 628.
2. Madsen C.K., Zhao J.H. *Optical Filter Design and Analysis: a Signal Processing Approach* (New York: Willey Intersci. Publ., 1999).
3. Shamrai A.V., Kozlov A.S., Il’ichev I.V., Petrov M.P. *Kvantovaya Elektron.*, **35** (8), 734 (2005) [*Quantum Electron.*, **35** (8), 734 (2005)].
4. Sheremet’ev A.G. *Kogerentnaya volokonno-opticheskaya svyaz’* (Coherent Fibre-Optic Communications) (Moscow: Radio i svyaz’, 1991).
5. Grodnev I.I., Muradyan A.G., Sharafutdinov R.M. *Volokonno-opticheskie systemy peredachi i kabeli: spravochnik* (Fibre-Optic Communications Systems and Cables: Handbook) (Moscow: Radio i svyaz’, 1993).
6. Yariv A., Yeh P. *Optical Waves in Crystals* (New York: Wiley, 1984).