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Discretely tunable single-frequency fibre Bragg grating diode laser

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***Abstract*. The results of the development of discretely tunable single-frequency semiconductor lasers with the external cavity based on fibre Bragg gratings (FBGs) written in a single-mode fibre are presented. It is shown, in particular, that, by using an external cavity semiconductor laser with the output mirror representing a superposition of several FBGs with different resonance wavelengths, it is possible to obtain lasing at one or several wavelengths simultaneously by varying the injection current and (or) the temperature of the active area of the laser diode.**

Keywords: *fibre grating, single-frequency laser.*

The use of an external cavity in semiconductor lasers considerably extends the scope of their applications in systems for measuring physical quantities, data communication lines, spectroscopy, etc. With the development of the manufacturing technology of refractive-index fibre Bragg gratings (FBGs) these gratings are widely used as mirrors forming the external cavity. Some variants of stabilisation of the wavelength of semiconductor lasers, obtaining single-frequency lasing and mode locking are considered in review [1] and references cited therein.

We described earlier [2 – 4] the designs and parameters of single-frequency hybrid FBG cavity semiconductor lasers emitting at wavelengths 1060, 1300, and 1530 – 1560 nm. The continuous tuning of a laser within a FBG reflection peak by varying the injection current was demonstrated in [3].

It was shown in a number of papers that, by using appropriate FBG structures with a set of reflection peaks, semiconductor lasers can be discretely tuned within a comparatively broad spectral range ($\sim$ 20 nm), which allows the use of such lasers in wavelength-division multiplexing (WDM) fibreoptic communication lines [5, 6]. The authors of these papers formed the external cavity with the help of identical FBGs with a certain spatial period (sampled FBGs).

In this paper, we present the results of the experimental study of the discrete tuning of an external cavity semiconductor laser with a FBG mirror produced by the successive recording of several FBGs with different periods at the same site of a fibre (superimposed FBG [7, 8]). This method of producing an external cavity minimises the total length of the laser, making it very compact.

The principle of discrete tuning of a laser is based on the Vernier effect. The free spectral region of a Fabry – Perot interferometer formed by the facets of a semiconductor crystal (chip) differs somewhat from the frequency interval between the reflection maxima of a FBG. Lasing occurs at the wavelength for which a reflection peak of the FBG coincides with one of the modes of the crystal cavity. As the temperature of the active region of the crystal is changed under the action of the pump current or with the help of a Peltier element, such a coincidence occurs at a different wavelength [5].

Fibre Bragg gratings used in our study were written by the 244-nm second harmonic of an argon laser in the Lloyd interferometer scheme [9]. The length of fibre regions in which each grating was written was 5 – 6 mm.

Figure 1a shows the design of our discretely tunable laser diode LD1 with two spatially separated FBGs with reflection maxima at $\lambda_{\rm Br}^{(1)} = 1063.3$ nm and $\lambda_{\rm Br}^{(2)} = 1064.2$ nm. A laser chip of length 1000 μm with the gain maximum at 1064 nm was used in the laser. The rear facet of the crystal had a reflection coating with the reflectance $\sim 80\,\%$. The front facet had an AR coating providing the

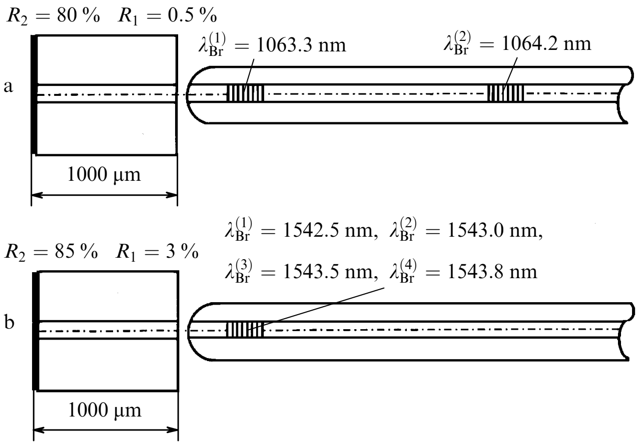

Figure 1. Design of tunable laser diodes LD1 (a) and LD2 (b) with two and four FBGs, respectively; $R_{1,2}$ are reflectances of crystal facets.

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reflectance ~ 0.5 %. Two FBGs were written in the core of a single-mode fibre with the core diameter 5.6 μm and cladding diameter 125 μm. The FBGs were separated by ~ 0.5 m. To increase the radiation coupling efficiency, a microlens with the radius of curvature ~ 10 μm was formed at the fibre end facet. One of the FBGs was located close (3 – 5 mm) to the front AR-coated facet of the laser diode. Both gratings had the maximum reflectance ~ 30 % and the half-width of reflection peaks was ~ 0.35 nm. Lasing occurred at the wavelength of the reflection peak of the grating for which the cavity *Q* factor at the given temperature and current was greater (the resonance wavelength of the grating coincides better with the wavelength of the intrinsic laser chip cavity).

Figure 1b presents the scheme of a laser diode LD2 with the external cavity formed by four FBGs with different resonance wavelengths, which were written by successively exposing the same site of a fibre to UV light. As in [7], the writing of a new FBG was accompanied by a decrease in the reflectance of FBGs written before and by the red shift of the resonance wavelength. Figure 2 presents the transmission spectrum of a superposition of four FBGs written in this way. One can see that the reflectance at each of the four peaks is 25 % – 30 %. The spectral width of the reflection peaks is ~ 0.3 nm, and they are separated by ~ 0.4 nm.

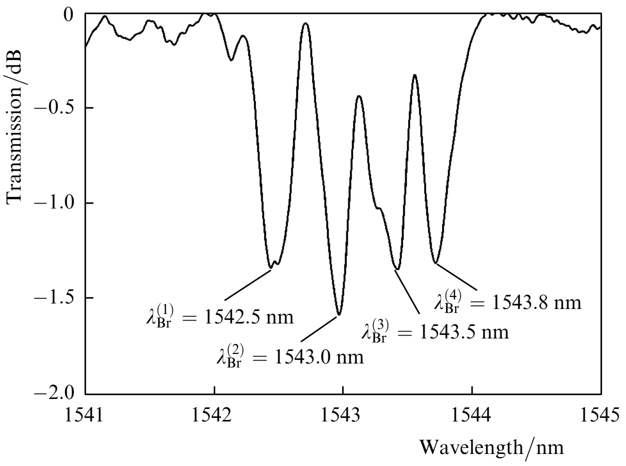

Figure 2. Transmission spectrum of the superposition of four FBGs.

In this case, a laser chip of length 1000 μm with reflectances from its facets equal to 3 % and 85 % was used. As in the first case, a fibre with FBGs written in it was coupled with the laser chip with the help of a microlens formed at the fibre end, the FBGs being located at distances of 3 – 5 mm from the diode facet.

Figure 3 shows the current tuning of the laser LD1. The threshold pump current $I_{\rm th}$ was 64 mA. For the temperature of a metal base to which the chip and detector were soldered equal to 25 °C and the pump current $I_{\rm p} = 80$ mA, the laser wavelength was 1063.35 nm (Fig. 3a), in good agreement with the wavelength $\lambda_{\rm Br}^{(1)}$ of the reflection peak of the short-wavelength grating. The output power emitted by the fibre with FBGs was 2 mW.

For the pump current $I_{\rm p} = 100$ mA (Fig. 3b), lasing occurs simultaneously at two wavelengths corresponding to the reflection peaks of both FBGs, and the total output power achieves 3 mW. For the pump current $I_{\rm p} = 125$ mA (Fig. 3c), the laser emitted 5 mW at 1064.22 nm.

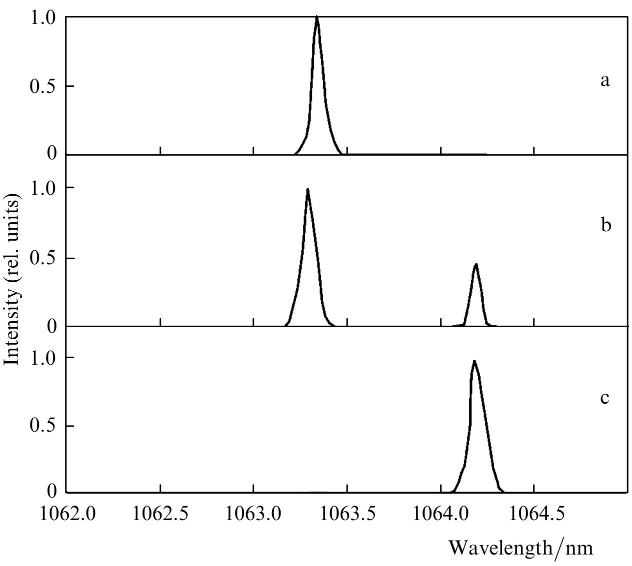

Figure 3. Current tuning of the laser LD1 with two FBGs for injection currents $I_{\rm p} = 80$ (a), 100 (b), and 125 mA (c).

Thus, by varying the pump current $I_{\rm p}$, we perform the current tuning of the 1064-nm laser LD1 with the external cavity with two FBGs written in one fibre. The laser linewidth at both wavelengths was smaller than the width

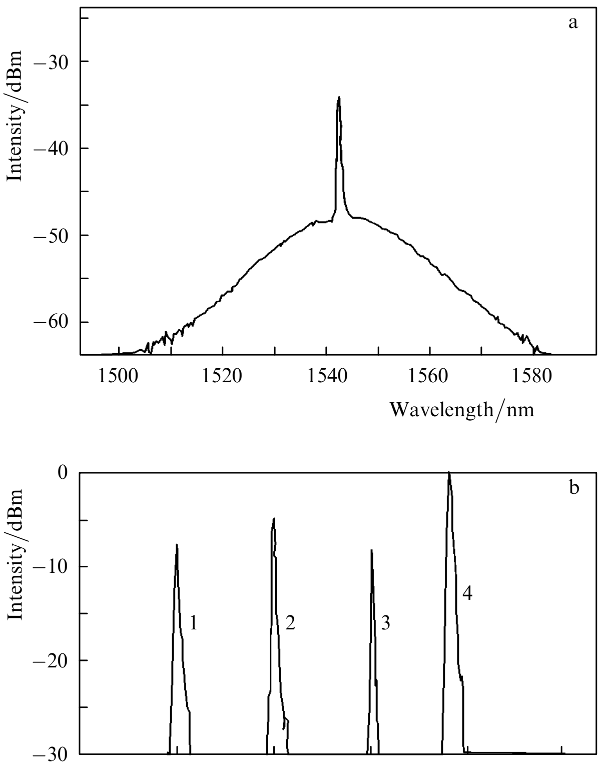

Figure 4. Luminescence spectrum of the laser LD2 for the threshold current $I_{\rm th} = 54$ mA (a) and its emission spectra (b) for injection currents $I_{\rm p} = 73$ (1), 1009 (2), 56 (3), and 153 mA (4).

if the instrumental function of our spectrum analyser (0.08 nm), which confirms single-frequency lasing at one longitudinal mode of the crystal cavity [4]. The suppression of side modes in the laser spectrum was approximately −40 dB.

Figure 4 shows the current tuning of the 1542-nm laser LD2 for which the threshold current is $I_{\text{th}} = 54$ mA. As follows from Figs 2 and 4a, all the resonances of the composite grating are located close to the maximum of the amplification band of the laser. For the chip base temperature equal to 25 °C and certain pump currents, we obtained lasing at one of the longitudinal modes of the crystal coinciding with the corresponding reflection maximum of the FBG (Fig. 4b). The lasing parameters were:

(1) $\lambda = 1542.5$ nm for $I_{\text{p}} = 73$ mA and $P_{\text{out}} = 1.2$ mW;
(2) $\lambda = 1543.0$ nm for $I_{\text{p}} = 100$ mA and $P_{\text{out}} = 3.2$ mW;
(3) $\lambda = 1543.5$ nm for $I_{\text{p}} = 56$ mA and $P_{\text{out}} = 0.5$ mW;
(4) $\lambda = 1543.8$ nm for $I_{\text{p}} = 153$ mA and $P_{\text{out}} = 6.4$ mW.

Thus, we have demonstrated the current discrete tuning of the 1542-nm hybrid laser LD2 with four FBGs written in one site in a single-mode fibre.

Note in conclusion that similar tuning can be performed by changing the laser crystal temperature with the help of a Peltier element at a fixed pump current.

Thus, we have considered laser designs and studied the properties of the discrete tuning of single-frequency semiconductor lasers with external cavities formed by several FBGs, in particular, gratings written (for the first time) in the same site of a fibre.

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