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Compact superluminescent AlGaInAs/InP strain-compensated quantum-well diodes for fibre-optic gyroscopes

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Abstract. **Compact superluminescent diodes based on AlGaInAs/InP separate-confinement double heterostructures with strain-compensated quantum wells are studied. The characteristics of these diodes that allow their application for development of fibre-optic gyroscopes in a temperature range from −55 °C – +70 °C are demonstrated. The devices demonstrate an acceptable reliability and a potential for further improvement.**

Keywords: *superluminescent diode, quantum well, strain compensation, AlGaInAs/InP, fibre-optic gyroscope.*

1. Introduction

Fibre-optic gyroscopes (FOGs) have been actively developed in recent decades due to a combination of some important characteristics. These gyroscopes do not have moving parts, rapidly reach the operation regime, and have a long service time. Advances in technology lead to the development of modern FOGs with a resolution that allows one to use them in navigation systems. In addition, FOGs are relatively inexpensive, which makes them attractive for many practical applications [1–3].

As a rule, optical fibres used in FOGs have minimal optical losses in the spectral range 1500–1600 nm, which requires light sources with corresponding wavelengths. These sources should have an output power of several milliwatts, a short coherence length, and a low residual spectral modulation depth. This is necessary for minimisation of parasitic effects [1]. Therefore, superluminescent diodes (SLDs) with a centre wavelength in the region of 1550 nm are widely used as light sources for FOGs.

Last but not least, the design of light sources for FOGs should take into account such characteristics as overall dimensions, weight, and price. Because of this, a common solution is to mount SLDs in compact housings without Peltier elements. For practical implementation of such a device, it is necessary to use heterostructures with high thermal stability. This problem for SLDs emitting near 1550 nm is solved by using AlGaInAs/InP heterostructures. This material system has a larger conduction band offset than the alternative GaInAsP material system [4]. This enhances electron localisation in AlGaInAs quantum wells and improves the working ability of the device at high temperatures. Further increase in the quantum well energy depth and improvement of the thermal stability of SLDs can be achieved by using strain-compensated active regions [5, 6], which, in addition, will decrease the negative effect of nonradiative Auger recombination [7–9]. Thus, it seems promising to study the applicability of AlGaInAs/InP heterostructures with strain-compensated quantum wells [10] for development of SLDs, which is the aim of the present work.

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2. Experimental

Similar to work [10], the experimental SLDs were fabricated using the AlGaInAs/InP separate-confinement double heterostructures with multiple strain-compensated quantum wells in the active region. The conventional SLD design, which includes a straight inclined waveguide, antireflection coatings on the crystal facets, and electrically isolated absorber on the inoperative end of the crystal, is aimed at the suppression of optical feedback in order to minimise the parasitic spectral modulation and achieve the maximum width of the spectrum. To couple radiation into a single-mode fibre (SMF), we used fibre-end microlenses with optimised geometry, which made it possible to obtain a coupling coefficient of about 35%. In contrast to [10], the SLD chips in this work were mounted in housings without a Peltier element. These housings with overall dimensions 22.7 × 10.0 × 6.3 mm are considerably smaller than the previously used housings with a Peltier element (overall dimensions 30.0 × 12.7 × 10.8 mm). The housings themselves were mounted on a massive copper heat sink, which maintained a constant temperature of their lower surface.

In the first experiment, the heat sink with the studied devices was placed in a heat and cold chamber, and the fibres and contacts were led out of the chamber to control the pump current and measure characteristics. The measurements were performed using a Maiman SF8150 driver in a constant pumping regime. To provide a stable temperature regime, the devices on the heat sink were kept before measurements for an hour at each given temperature.

A series of experiments was devoted to investigation of the reliability of developed SLDs. To this end, the modules were successively subjected to such tests as exposure at a temperature of −55 °C for 100 h, exposure at +70 °C for 100 h, and fast changes in the environmental temperature (10 thermal cycles in which the temperature varied from – 55 °C to +70 °C).

The last stage of experiments was thermoelectric testing (TET). The devices were mounted on a passive heat sink and tested under constant pumping by a current of 150 mA at room temperature for a month. The spectral parameters and output powers were measured after each step.

3. Results and discussion

The main problems of FOGs with SLDs as radiation sources are related to changes in the SLD spectrum with temperature and during operation. In this work, it was possible to avoid forced temperature stabilisation of SLDs operating in a wide range (from –55 °C to +70 °C) owing to the use of the AlGaInAs/InP strain-compensated quantum-well heterostructure.

Figure 1 shows the dependences of the output power of SLDs on the environment temperature at a constant pumping level. A decrease in the output power with temperature at $T >$ –40 °C is not surprising, whereas a slight increase in the output power with increasing temperature in the low-temperature range (from – 55 °C to – 40 °C) is most probably explained by a misalignment of the optical system of the used SLD due to a change in the size of its components with changing temperature. One can see from Fig. 1 that the output power at constant pumping changes in very wide ranges, which may lead, in particular, to an increase in the noise level in FOGs. Subsequent measurements were performed at a constant output power kept at a level of 100 μW by adjusting the pump current (Fig. 2). It is obvious that an increase in temperature requires an increase in the pump current to retain a given output power.

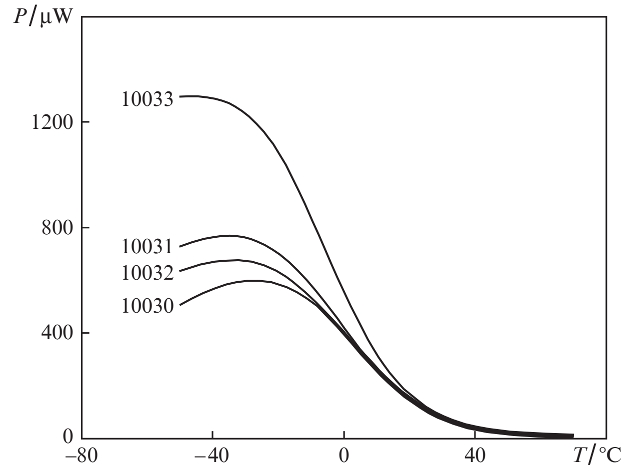

Figure 1. Dependence of the output SLD power on the environmental temperature under constant pumping. The figures near the curves correspond to the tested SLD numbers.

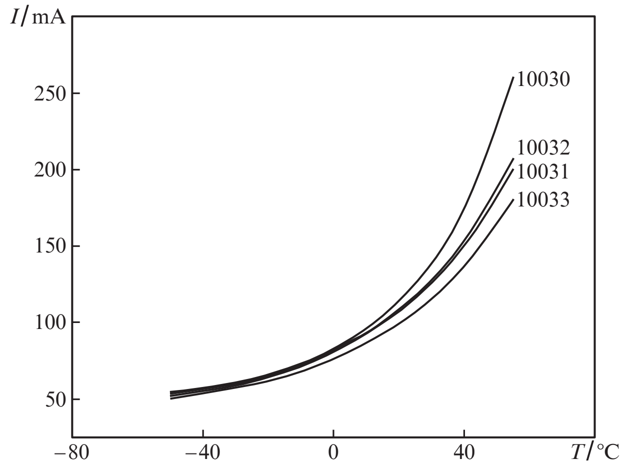

Figure 2. Dependences of the pump current of SLDs on the environmental temperature at a constant output power of 100 μW.

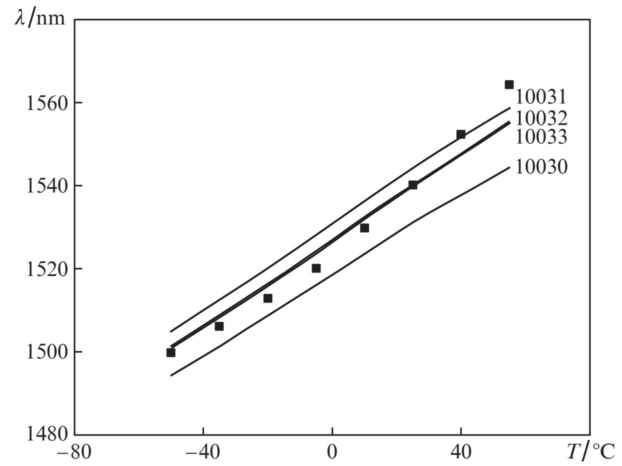

Figure 3. Dependences of the centre wavelength of SLDs on the environmental temperature at a constant output power of 100 μW and corresponding dependence for sample 1032 at constant pumping (squares).

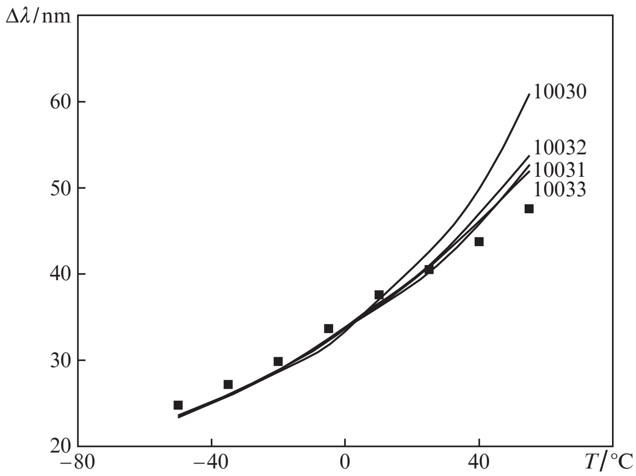

Figure 4. Dependences of the half-width of the SLD spectrum on the environmental temperature at a constant output power of 100 μW and corresponding dependence for sample 1032 at constant pumping (squares).

Figure 3 presents the dependences of the centre wavelength of SLDs on the temperature in the test chamber. For comparison, measurements for one of the devices were also performed in the regime of constant pumping. On can see that the dependences in the regime of a constant output power are almost linear and characterised by identical slope angles, because of which they can be easily taken into account when calibrating the output FOG signal as a function of temperature.

The half-width of the radiation spectrum predictably decreases with decreasing temperature (Fig. 4), but even at –50 °C it exceeds 20 nm, which ensures a coherence length of about 100 μm and is sufficient for minimisation of FOG errors caused by parasitic interference.

The changes in the output SLD power resulted from the reliability tests are shown in Fig. 5. In these tests, the spectral characteristics of the studied samples remained almost unchanged.

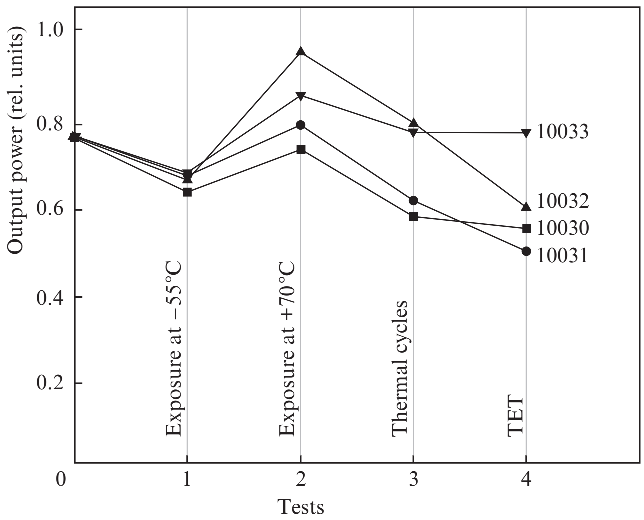

Figure 5. Changes in the output power of experimental SLD samples under different tests.

One can see that the tests do not cause catastrophic degradation of the output SLD power. However, to prove the output power stability within an accuracy of ±10 %, it is necessary to perform additional analysis and optimise the device design.

4. Conclusions

We have studied the temperature dependences of the output parameters and the reliability of experimental uncooled SLDs based on AlGaInAs/InP strain-compensated quantum-well heterostructures. The devices demonstrated operation in the temperature range from –55 °C to +70 °C with output characteristics satisfying the requirements for light sources for FOGs.

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