Quantum Electronics **35** (6) 504 – 506 (2005)

PACS numbers: 42.55.Px; 42.60.Jf
DOI: 10.1070/QE2005v035n06ABEH004096

Broadband highly bright radiation sources based on a superluminescent diode and a semiconductor optical amplifier

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***Abstract*.** **It is shown experimentally that the use of a travelling-wave semiconductor optical amplifier (SOA) significantly improves the output characteristics of a superluminescent diode (SLD), increasing, in particular, its output power or broadening its emission band. By using SOAs based on separate-confinement double (InGa)PAs heterostructures emitting at 1300 nm and different SLDs as input radiation sources, there were obtained up to 50 mW of cw power at the output of a single-mode fibre and the emission band with the half-width up to 70 nm.**

Keywords: *superluminescent diode, semiconductor laser amplifier.*

1. Introduction

Superluminescent diodes (SLDs), combining a high brightness of semiconductor lasers and a broad emission spectrum of LEDs, are optimal radiation sources for optical coherent tomography (OCT), optical metrology, and a variety of optical sensors. Some practical applications require the use of SLD systems with a fibre output providing high output cw powers. Among standard SLD modules emitting at 1300 nm, the maximum output power of ~ 20 mW is produced by diodes manufactured by EXALOS, COVEGA, InPhenix and some other companies. A significantly higher output power (up to a few hundreds of milliwatts) can be obtained by using tapered active-channel SLDs or a system consisting of a standard SLD and a tapered active-channel semiconductor optical amplifier (SOA) [1 – 3]. However, coupling radiation from such sources into a single-mode fibre involves difficulties related to high expenses.

In this paper, we studied a travelling-wave (InGa)PAs SOA with a narrow active channel providing efficient coupling radiation into a single-mode fibre. The aim of the paper was to obtain the maximum output power for the SLD + SOA system and a broad emission spectrum of the SOA by using the amplifier for mixing its own superluminescence and the output SLD emission shifted to the red.

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Received 14 March 2005
Kvantovaya Elektronika **35** (6) 504 – 506 (2005)
Translated by M.N. Sapozhnikov

2. Experimental results

The experimental SOA module with input and output SMF-28 single-mode fibres was assembled in a Butterfly housing. The active element was based on a (InGa)PAs/InP separate-confinement double heterostructure grown by the metal-organic chemical vapour deposition (MOCVD) emitting the superluminescence line at 1280 nm. The active channel of the SOA was a ridge waveguide of width 4 μm fabricated by the method of chemical etching through a photolithographic mask. The angle between its axis and the normal to the AR-coated crystal end faces was 7°. The active channel length was 1000 μm. Such a design provided a reliable suppression of the positive optical feedback (the residual spectral modulation by the Fabry – Perot modes did not exceed 5 % even for maximal pump levels). The crystal was soldered p side up on a copper heatsink and on a thermoelectric microcooler. The crystal temperature was measured with a thermistor which was in thermal contact with the heatsink. The module design provided thermal stabilisation of the active element in a broad temperature range for the scattered power up to 1 W.

In experiments aimed to obtain the maximum output power of the SLD + SOA system, a source of the input signal was a standard SLD-561-HP2 module with a single-mode fibre pigtail and an active element based on the same semiconductor heterostructure. The radiation from the source was coupled into the SOA directly behind the splice of its single-mode fibre pigtail with the input single-mode fibre of the amplifier or through a broadband fibreoptic isolator preventing the entry of superluminescence from the SOA to the SLD active channel. Figure 1 shows light – current characteristics of the SOA in the absence and presence of the input signal coupled directly into the SOA or through an optical isolator. These curves show that the SLD + SOA system provides a substantial advantage in the quantum efficiency, especially when an optical isolator (OI) is used, which prevents the suppression of the input signal by the counterpropagating radiation from the SOA.

The dependences of the transfer characteristics of the SOA on the input signal power $P_{\rm in}$ obtained for different pump currents $I_{\rm SOA}$ (Fig. 2) show that this SOA can be used in fibreoptic communication links because it provides the pure (fibre-to-fibre) small-signal gain exceeding 20 dB. The record output power $P \approx 50$ mW was obtained upon strong saturation of the optical gain at $T = 12\,^{\circ}$C, $I_{\rm SOA} = 600$ mA, $I_{\rm SLD} = 300$ mA, $P_{\rm in} = 7.5$ mW. The corresponding emission spectra of the SLD, SOA, and the SLD + OI + SOA system are presented in Fig. 3. The half-width of the latter spectrum

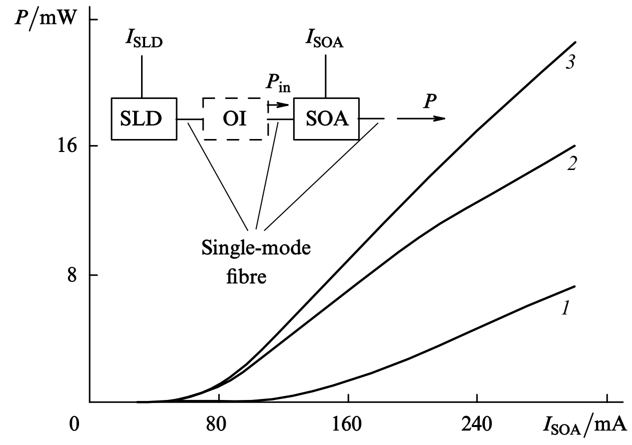

Figure 1. Light–current characteristics of the SOA without the input signal ($I_{SLD} = 0$, $P_{in} = 0$) (*1*), the SLD + SOA system without OI ($I_{SLD} = 300$ mA, $P_{in} = 8$ mW, and $I_{SOA} = 0$) (*2*), and the SLD+ OI + SOA system ($P_{in} = 7.6$ mW = const) (*3*) at $T = 20\,^{\circ}$C; I_{SLD} and I_{SOA} are the pump currents of the SLD and SOA, respectively.

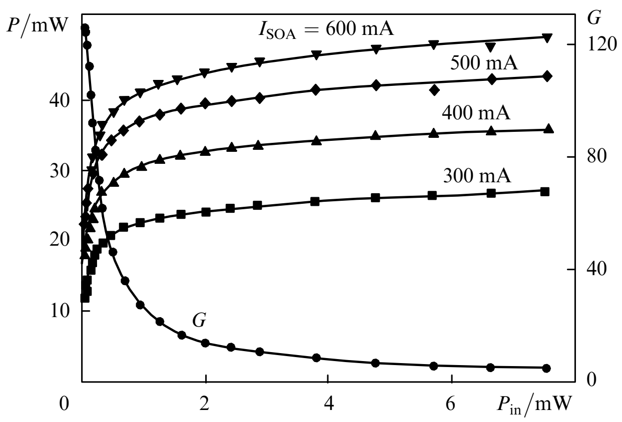

Figure 2. Transfer characteristics of the SOA for different injection currents I_{SOA} and its gain G for $I_{SOA} = 600$ mA ($T = 12\,^{\circ}$C).

is 26 nm (somewhat narrower than the half-widths of the emission spectra of the SLD and SOA), while the central wavelength 1296 nm is shifted to the red according to the maximum of the SOA gain.

In the second experiment, we used a standard SLD-561-HP1 module emitting at 1320 nm as a source of the input signal. Because its emission band lies in the transparency region of the SOA, the emission propagated through the active channel of the SOA without amplification, with weak dissipative losses. Upon pumping the SOA, its own shorter-wavelength emission was added to emission of the input SLD to produce a broad output spectrum. The shape of this spectrum (the ratio of the band maxima, the minimum between them, and the total width) can vary within some limits due to variation of the pump and temperatures of the input SLD and SOA. Such a design is somewhat simpler than that commonly used in broadband SLD sources, where emission from two or more SLD modules is summed with the help of broadband single-mode fibre couplers [4, 5]. Figure 4 shows one of the realisations of the combined spectrum with equalised band maxima corresponding to $P \approx 10$ mW and the coherent function of the intensity of

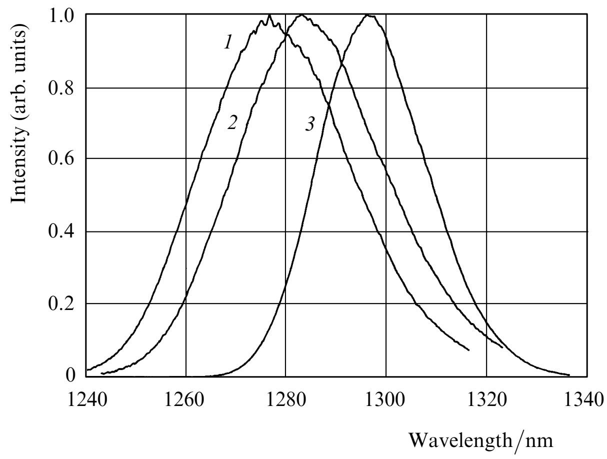

Figure 3. Emission spectra of the SOA in the absence of the input signal (*1*), of the input SLD (*2*), and the output emission spectrum of the SLD + OI + SOA system (*3*) for $T = 12\,^{\circ}$C, $I_{SLD} = 300$ mA, $P_{in} = 7.6$ mW, $I_{SOA} = 600$ mA, and $P = 49$ mW.

this radiation source. The coherent function width, determining the coherence length of emission, is 26 μm.

Therefore, we have shown that the SOA provides a noticeable increase both in the output power and the emission bandwidth of SLD sources. In particular, the output power of 50 mW is, to our knowledge, the record power for such sources emitting in the 1300-nm spectral region.

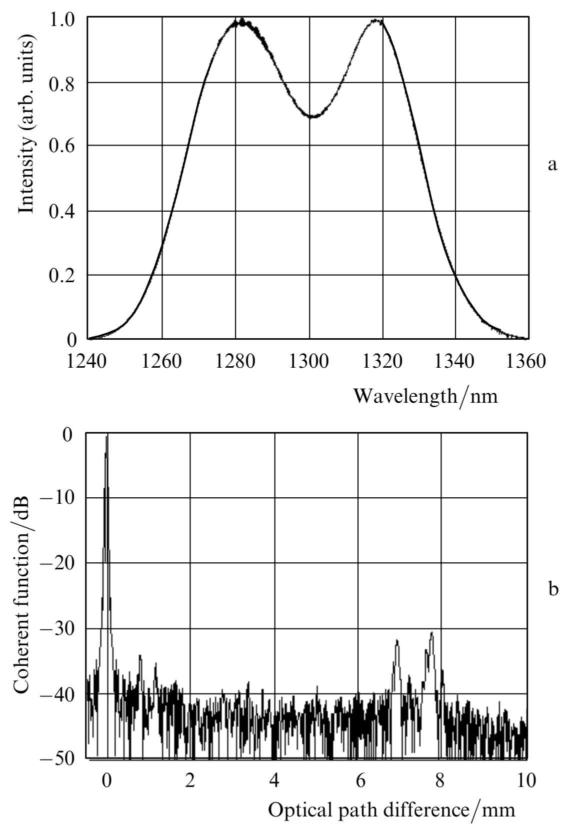

Figure 4. Output emission spectrum of the SOA obtained by mixing its superluminescence with the input emission band of the SLD shifted to the red for $T_{SLD} = 30\,^{\circ}$C, $I_{SLD} = 193$ mA, $T_{SOA} = 15\,^{\circ}$C, $I_{SOA} = 300$ mA, $P \approx 10$ mW (a) and the coherent function of combined emission (b).

Acknowledgements. The authors thank A.T. Semenov for his interest in this work. This work was partially supported by the ISTC grant No. 2651R.

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