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Integrated optical demultiplexer based on the $SiO_2 - SiON$ waveguide structure

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***Abstract*.** **An integrated optical demultiplexer based on the $SiO_2 - SiON$ waveguide structure and operating in the wavelength range of 1.5 μm is fabricated. The demultiplexer chip has a size 10×10 mm. The parameters of the optical scheme of the device are presented, the technology of its fabrication is described, and the results of measurement of working parameters are given. It is shown that the crosstalk between communication channels ($K = 8$) does not exceed −25 dB. The operation of the demultiplexer as a selective reflecting mirror is demonstrated. It is shown that it can be used for constructing multifrequency lasers for fibreoptic communication systems.**

Keywords: *integrated optics, demultiplexer, multifrequency laser*.

1. Introduction

The demultiplexer under study is the first all-integrated optical device for primary processing of the optical signal. The designing, implementation and subsequent application of the device revealed its multifunctional potentialities. The analysis and refinement of the demultiplexer as well as the development of its production technology during the last 15 years have ensured high working parameters of the device.

The principle of operation of a demultiplexer has been described in a number of papers (see, for example, review [1]), including our paper [2] in which it was analysed as an integrated optical Michelson echelon. The basic parameters of a multiplexer are the number of channels being separated, the working wavelength range, the spectral separation of channels, optical losses per transit, the crosstalk, and the uniformity of losses over the spectrum. At present, demultiplexers with the required parameters have been developed on the basis of various waveguide systems such as SOI, InP, and $SiO_2 - SiON$ [3]. The $SiO_2 - SiON$ system has become the most popular in recent years due to the low cost of the materials employed, a wide range of variation of the structure parameters, and the possibility of obtaining a high-quality demultiplexer [4]. We used this system to fabricate a demultiplexer for our study. In this paper, we demonstrate the possibilities of the SiON technology and present the results of its application in practice.

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2. Technology of the waveguide structure fabrication

We used standard 480-μm thick silicon wafers of diameter 100 mm as the substrate for the waveguide structure. A 8-μm thick SiO_2 layer with the refractive index $n_s = 1.46$ was first deposited on the silicon wafer. This layer served as the optical insulator for preventing the loss of light with a wavelength of 1.5 μm from the waveguide layer deposited on the SiO_2 layer to the silicon substrate with the refractive index $n = 3.5$. The waveguide layer was formed by silicon oxynitride of thickness $h = 2.5$ μm with the refractive index $n_w = 1.495$. The SiO_2 and SiON layers were deposited by the plasma chemical method in the PECVD Plasmalab80$^+$ setup.

After fabrication of the plane waveguide structure, standard photolithographic method was used to form a photoresistive mask (1 : 10 projection printing) for producing the optical scheme of the demultiplexer formed by the channel and plane waveguides. The waveguide elements of the scheme were produced by reactive ion etching in the RIE Plasmalab80$^+$ setup. Then, the structure was annealed for two hours in the argon atmosphere at a temperature of 1150 °C. This was followed by the deposition of a 8-μm thick SiO_2 layer to protect the integrated circuit from external perturbations. The fabrication of the integrated circuit ended by cutting the silicon substrate into chips of size 10×10 mm and polishing of one end-face of the chip to which all input and output channels of the demultiplexer were brought out.

3. Optical scheme of the demultiplexer

The optical scheme of the demultiplexer (Fig. 1) is a set of single-mode channel waveguides of different lengths, the difference in the lengths of adjacent waveguides being constant ($\Delta L = \text{const}$). The ends of channel waveguides are arranged equidistantly on the circular boundaries of planar waveguide regions which serve as the focusing elements of the scheme. The ends of channel waveguides for the light coupling and coupling out from the scheme are also arranged equidistantly at the other boundaries of the focusing elements. The radius of curvature of the inner boundaries of the focusing elements is double the radius of curvature of the outer boundaries, which provides a better

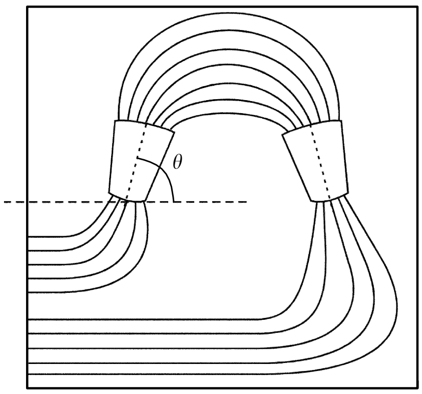

Figure 1. Scheme of a demultiplexer based on the $SiO_2 - SiON$ waveguide structure.

focusing of light on the input and output ends of the waveguides.

The set of channel waveguides of various lengths together with the focusing elements form the dispersion element of the demultiplexer and the number N of channel waveguides in it determines the operation efficiency of the device. The number N of channel waveguides in the set must be at least double the number K of the channels being separated, and is limited by the number of channels for which tunnel coupling between the channels is established. More detailed information about the relations between the parameters of the demultiplexer can be found in [2, 5].

4. Some details of the optical scheme of the multiplexer

Our aim was to fit the entire demultiplexer setup into a chip of size 10 × 10 mm. Because of this, the width W of channel waveguides in the set was 3.0 μm; the length of the shortest waveguide was only 5729 μm and the difference ΔL between the waveguide lengths achieved 75.503 μm. The number N of channel waveguides in the dispersion element was 59, i.e., more than seven times the number K of channels ($K = 8$). The separation between the ends of channels at the boundary of the focusing elements was 8.4 μm. The ends of channel waveguides were butted to the boundaries of the focusing elements of the demultiplexer through adiabatic junctions of length 110 μm and initial width 6.5 μm. The radius of curvature R of the boundary of the focusing elements of the device was 1.823 mm.

The symmetry axis of the focusing elements passed through the centres of curvature of its boundaries and divided the set of channel waveguides of dispersion elements into two halves. Since each focusing element has its own symmetry axis, the angle $\varphi = \pi - 2\theta$ between the axes of the focusing elements was chosen equal to 24.62° so that the entire demultiplexer can be accommodated on a chip of the given size. The outer boundary of each focusing element had a radius of curvature $R' = 0.912$ mm, and was a part of the Rowland circle. The period of distribution of the input and output waveguide channels over this boundary of the focusing elements was 8.4 μm, and the waveguide width W_{in} was 6.5 μm. The other end-faces of the channel waveguides were drawn to the polished end of the chip. Because the focusing elements were at different distances from the edge of the chip, the input and output waveguides also had different lengths but all of them had a 90° bend with different radii of curvature. The smallest radius of curvature was 2.0 mm, and the jump Δn in the refractive index of channel waveguides at this bend for minimising radiation losses was 0.035.

5. Study of the demultiplexer characteristics

The spectral characteristics of transmission of the channels of the integrated demultiplexer chip were measured by using a tunable radiation source (integrated into the EXFO IQ-206 measuring complex) and a Burleigh WA-7100 spectrometer. The emission linewidth $\delta\lambda$ of the EXFO IQ-206 laser complex was 0.1 nm at a level of −30 dB. We measured the spectral transmission of the demultiplexer in the wavelength range 1550 – 1560 nm in the $I_{in} \rightarrow J_{out}$ regime (where I_{in} and J_{out} are the input and output channel numbers, respectively). To provide the optical contact between single-mode waveguides and channel waveguides of the integrated chip, the latter were polished mechanically. The intensity of light transmitted through the demultiplexer was measured with the Burleigh WA-7100 spectrometer, which was also used to control the frequency and intensity of the tunable laser from whose signal was supplied to input No. 1 of the demultiplexer. All the measurements were performed at room temperature ($T = 24$ °C), the integrated chip was not thermally stabilised and the input radiation had an arbitrary polarisation.

Figure 2 shows the spectral transmission characteristic of the fabricated chip for the coupling of channels 1 – 4 ($I_{in} = 1$, $J_{out} = 4$). In this regime, the integrated chip functions as a demultiplexer, i.e., when a broadband frequency spectrum is supplied to one of the inputs, a specified spectral component of the input signal is separated at each of the output channels. One can see from Fig. 2 that the spectral transmission width of the channel is 1.3 nm at a level of −20 dB. A change in the polarisation of the input signal led to a change in the amplitude of the output signal at the level of the measurement fluctuations. The free spectral range $\Delta\lambda_{FSR}$ of the demultiplexer measured in the same regime [2] was 17.3 nm, in agreement with the theoretical value.

Figure 3 shows the spectral characteristics of the demultiplexer measured for the entire group of the output

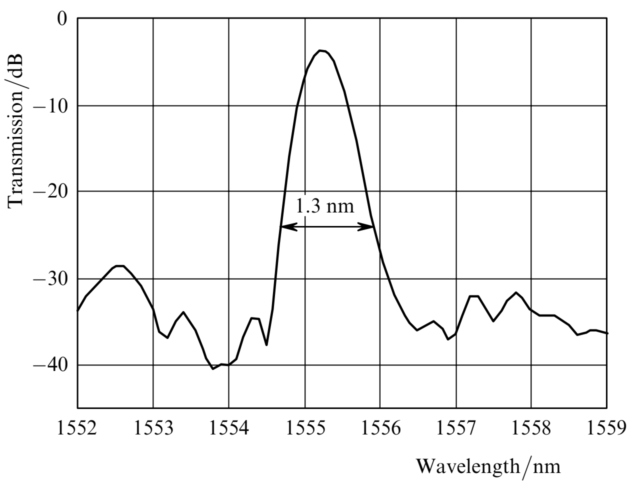

Figure 2. Spectral transmission characteristic of a demultiplexer.

channels ($I_{in} = 1$, $J_{out} = 1 - 8$), which demonstrate the equidistant separation of the spectral maxima of the transmission channels equal to 0.8 nm. The crosstalk did not exceed -25 dB when a signal containing eight spectral components corresponding to the transmission maxima of the channels was supplied to the input. The overall radiation losses per transit by neglecting splice losses between supply fibres and channel waveguides did not exceed 3 dB.

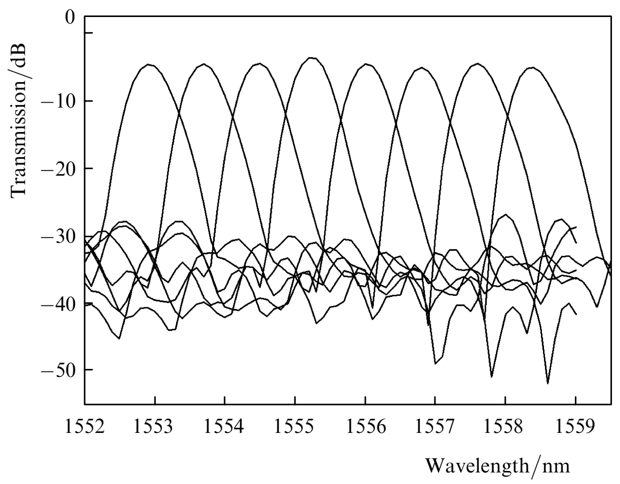

Figure 3. Spectral characteristics of a demultiplexer measured for all the output channels (1 − 8) upon switching on of the first input channel.

6. Demultiplexer as a laser mirror

In wavelength-division multiplexing (WDM) communication systems, radiation sources with the required wavelengths and appropriate spectral linewidths are of prime importance. Until recently, distributed feedback lasers were used for this purpose. Now, new possibilities have emerged following the advent of the devices described above. The matter is that a demultiplexer can operate as a selective laser mirror if reflecting mirrors are placed at the output ends of the waveguide channels. We used micromirrors mounted in front of the polished end-faces of output channel waveguides of the demultiplexer [6].

The source of radiation was a 1.550-μm semiconductor laser [7] with the gain spectrum of width $\Delta\lambda = 20$ nm. A reflecting dielectric coating with $R_{out} = 30\,\%$ was deposited on one end of the laser chip and an AR coating with $R_{out} = 0.5\,\%$ was deposited on another end. The AR coated end of the laser chip was butted to the polished input end of the channel waveguide through an immersion liquid (glycerine) (Fig. 4a). For the pump current $I_{max} = 50$ mA, lasing was observed at several wavelengths corresponding to the transmission spectrum of the demultiplexer. The emission linewidth was 0.3 nm [6]. The equidistant location of the emission lines in the spectrum is one of the advantages of such a laser over the set of DFB lasers whose frequencies are determined by individual independent gratings.

To produce lasers with given emission wavelengths determined by the transmission spectrum of the demultiplexer, it is necessary to use a semiconductor laser array with the period of the laser arrangement coinciding with the separation between the output channel waveguides of the demultiplexer (Fig. 4b). The fabrication of such an array is a simple task for the existing technology level. Note that the modulation of laser radiation in the array and switching of the laser channels for varying the wavelength is purely an electrical engineering problem.

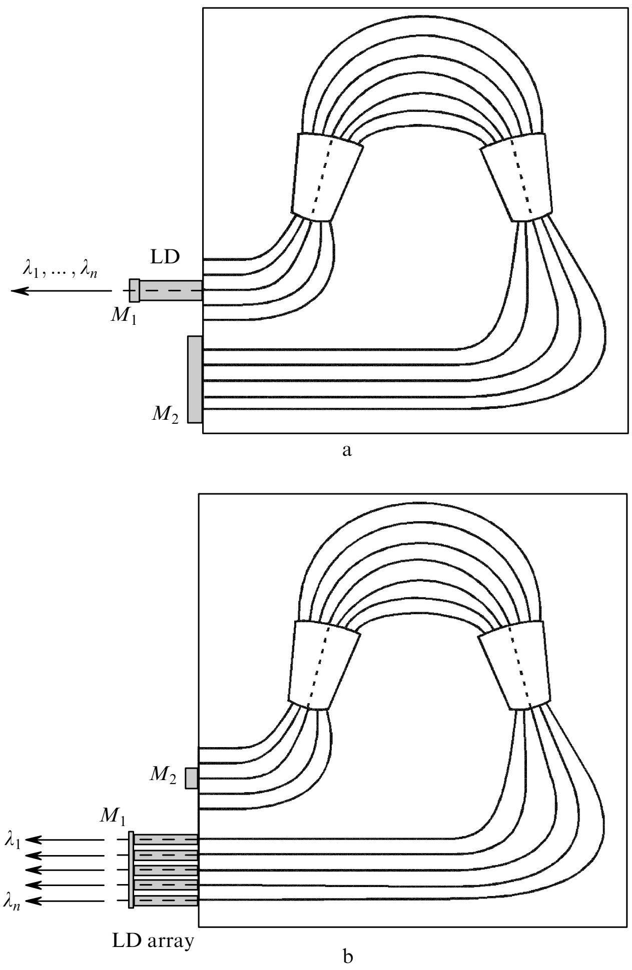

Figure 4. Scheme of the operation of a demultiplexer in the spectrally selective mirror regime (a) and multifrequency laser radiation source regime (b).

7. Conclusions

We have shown that the SiON technology can be used to fabricate an integrated optical demultiplexer operating in the wavelength range 1.5 μm and having acceptable parameters for practical applications. The use of a demultiplexer as a feedback mirror in a multifrequency radiation source that can be employed in WDM communication systems is demonstrated experimentally. Note that the demultiplexer (DemWDM) developed by us is multifunctional and can be used in various devices for optical communication systems [8].

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