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Si wire waveguide polarization independent optical wavelength filters

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1. Introduction

The Si wire waveguide technology [1,2] can reduce the size of optical waveguide circuits to a range compatible with the most electronic IC circuits, opening the door toward the integration of optic and electronics on a same chip. In this report we describe the design of wavelength demultiplexer for bi-directional optical communication such as the optical network unit (ONU) used in the fiber to the home (FTTH). Since the signal light sent to the ONU has random polarization after transmitted through long optical fiber transmission line, the ONU has to be polarization independent. There is little report on polarization independent Si-wire waveguide device so far. We investigated three types of filter devices to attain polarization independence. They are Mach-Zehnder interferometer (MZI), arrayed waveguide grating (AWG) and multi-mode interference (MMI) coupler devices. All the devices were fabricated on SOI wafer by photolithography using 365 nm UV light and RIE process. The upper clad was deposited using CVD.

2. Filter using single mode waveguide

Four-stage MZI

This type of device is the best choice for the ONU, since the device has simple structure and reflection is small. The crosstalk is defined mainly by the reflection in ONU. To obtain a polarization independent MZI, both the effective index of the interferometer waveguide and the couplers should be made polarization independent. We have reported [3] a method to achieve polarization independence by using a square cross section for the interferometer waveguide and narrow width waveguide for the directional coupler. The interferometer wire waveguide and directional coupler have 300x300 nm and 290x300 nm cross sections respectively. We used a four stage MZI structure [3] to attain flat top filter response. The waveguide length difference of 1.4 μm is used for the interferometer and the total directional coupler length is 7 μm. The gap between waveguides composing the directional coupler is 360 nm. A 5 μm radius curved waveguide is used to connect elements. The total length of the fabricated device is 80 μm. A filter response obtained from fabricated device is shown in Fig. 1. The measurement noise is smoothed out. The device is in the bar state at 1310 nm wavelengths. The cross state is attained at a wavelength slightly longer than the design (1490 nm). The ONU wavelengths can be separated for both the TE and TM modes. The loss was almost identical to a straight waveguide. In this device the characteristics of the directional coupler and interferometer arm should be adjusted to attain desired filter response. The deviation from the designed filter response for the TE mode is due to the directional coupler which is not fully optimized yet for the fabrication process. The TE mode is more sensitive to the fabrication size deviations than the TM mode.

We have been investigating several Si waveguide structures and found that the SSC (spot size converter) compatible high-index-upper-clad Si-wire or sub-micron ridge waveguide can attain polarization independent device with common cross sections for the interferometer and the directional coupler. Using appropriate wavelength dispersion obtained by latter waveguide design, a more compact two-stage point-symmetric MZI can be employed for demultiplexing the ONU wavelengths with a flat-top response.

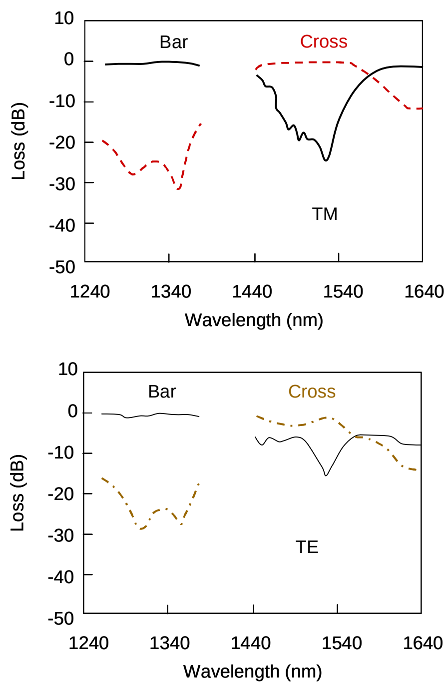

Fig. 1 Measured Si wire waveguide 4-stage MZI filter response

AWG

The device is relatively fabrication tolerant since only the waveguide array is affected by the available precision of the fabrication process. The device can separate more than three wavelengths with single device stage, expanding possible applications than MZI. A device design for ONU wavelength is shown in Fig. 2. Since the wavelength difference between the two wavelengths used in ONU is large, the required waveguide length difference in the arrayed waveguide is small. To generate small length difference, we employed a point symmetric structure that has been used in silica waveguide devices.

The device consists of an array of 16 waveguides with 300 nm widths and adjacent length difference of 6.6 μm. The thickness of the waveguide layer is 300 nm. The polarization independence is obtained by square cross section for the wire waveguide. The slab waveguide length is 17 μm. To minimize the polarization dependence of the slab waveguide, the output port of the 1490 nm wavelength is placed at the center of the output slab waveguide. The total length of the fabricated AWG is 180 μm. A 90 μm long device is possible by improved design. We have found that attaining a flat-top response in Si-wire waveguide AWG is difficult due to a large polarization dependence of the slab waveguide. We are investigating new schemes to overcome this problem.

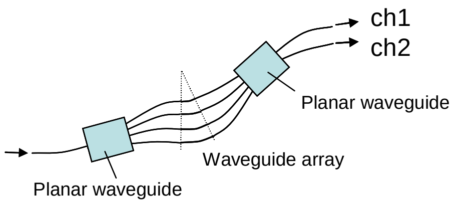

Fig. 2 Arrayed waveguide grating with point symmetric structure

A polarization independent operation was attained by fabricated devices. An example of noise-smoothed-out measured filter response is shown in Fig. 3.

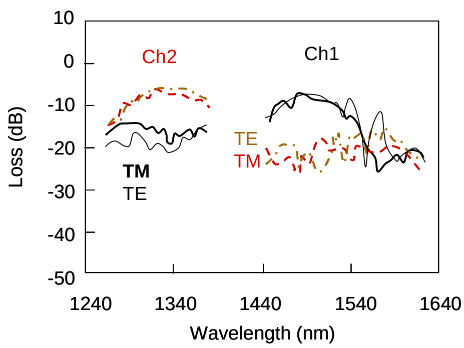

Fig. 3 Measured Si wire AWG filter response

3. MMI device

By using MMI, a filter function can be achieved by only one component in contrast to MZI and AWG. There are two methods to attain polarization independence for a device using MMI coupler. One method uses equal interference order for TE and TM normal modes. For certain thickness there is a multimode waveguide width that can attain polarization independent output. The other method uses different interference order for TE and TM normal modes.

The device design for the latter method is shown in Fig. 4. The input port is connected to a narrow multimode waveguide to excite low order normal modes to avoid interference noise. A wide multimode waveguide is placed at the output. We use tapered output waveguide structure and wider waveguide at the output to make the fraction of the gap small at the MMI coupler end to minimize the excess loss. Each section with different waveguide width exhibits different polarization dependence. Polarization independence and desired filter wavelength can be attained by choosing appropriate length for each section. The lengths of narrow, tapered and wide multimode waveguide sections are 17, 13 and 3 μm respectively. The waveguide thickness is 300 nm. A polarization independent filter operation was attained. The 1490 and 1550 nm wavelengths could be separated by the device with 13 dB crosstalk.

4. Conclusions

We have reported wavelength filter designs using Si wire waveguide. The devices we have chosen are MZI, AWG and MMI coupler. The device size of less than 0.2 mm was attained. Preliminary experiments on fabricated devices are reported verifying the principles of operation.

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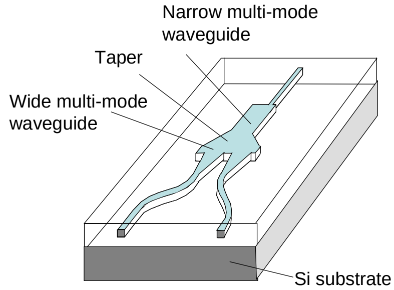

Fig. 4 MMI wavelength filter