High extinction ratio multiplexer/demultiplexer with a Mach-Zehnder interferometer and a fiber loop mirror

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A novel structure of high extinction ratio multiplexer/demultiplexer with a Mach-Zehnder interferometer (MZI) and a fiber loop mirror (FLM) is proposed. The experimental results show that the extinction ratio can be enhanced about two times in comparison with the conventional MZI.

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Wavelength-division-multiplexing (WDM) is an attractive fiber-optic communication technique due to its great increase in the network capacity. Multiplexers/demultiplexers or switches are the key components in such system[1−4]. In WDM networks, each optical node needs to have various functions, such as dropping a wanted signal, adding a new signal or passing all of the incoming signals to the next node. Multiplexers/demultiplexers or switches can be used to realize these functions. Among the devices, Mach-Zehnder interferometers seem to be ideal candidates, since they are inherently low loss, spectrally selective, and potentially low-cost. When Mach-Zehnder interferometers are used for Multiplexers/demultiplexers or switches, the extinction ratio plays an important role in the reduction of adjacent channel crosstalk. Therefore, how to improve the extinction ratio is a crucial problem. As a rule, a polarization controller (PC) is used for polarization state adjustment of one of two interfering beams in order to get better extinction ratio. But this method can not obtain satisfactory results. In this letter, a novel structure of high extinction ratio multiplexer/demultiplexer with a MZI and a fiber loop mirror is proposed. The extinction ratio can be enhanced about two times in comparison with the conventional MZI.

Figure 1 represents the configuration of high extinction ratio multiplexer/demultiplexer. It consists of an optical circulator, a FLM and a MZI. The optical circulator and the FLM are spliced to one input port of the MZI and one output port of the MZI, respectively. The FLM is composed of a wide-band 3-dB coupler (C_3). The MZI consists of two 3-dB couplers (C_1, C_2) with path length difference between two arms. One arm is adhered on a piezoelectric translator (PZT) to have the phase difference modulated. E_1 and E_2 are the input optical fields of the MZI at port 1 and port 2, respectively. While E_2', E_3 and E_4 are the output optical fields of the MZI at port 2, port 3, and port 4, respectively. E' is the output optical field at the output port of the optical circulator. It can be seen from Fig. 1 that the input light from the input port 1 is coupled into MZI. The output light at port 3 will be reflected completely back to the interferometer from the fiber loop mirror. Then it is reversedly coupled into the MZI from the output port 3, and the interfering light can be obtained from the output port of the optical circulator and port 2 of the interferometer, which is decided by the phase difference between the two arms.

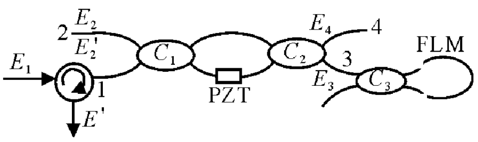

Fig. 1. Schematic diagram of high extinction ratio multiplexer/demultiplexer.

Supposing that the initial boundary conditions are $E_1 = E$ and $E_2 = 0$, then the output field of port 3 and port 4 is as

$$\begin{bmatrix} E_3 \\ E_4 \end{bmatrix} = \frac{1}{2}\begin{bmatrix} 1-\exp(j\Delta\phi) & -j[1+\exp(j\Delta\phi)] \\ -j[1+\exp(j\Delta\phi)] & -[1-\exp(j\Delta\phi)] \end{bmatrix}\begin{bmatrix} E \\ 0 \end{bmatrix} = \frac{E}{2}\begin{bmatrix} 1-\exp(j\Delta\phi) \\ -j[1+\exp(j\Delta\phi)] \end{bmatrix}, \tag{1}$$

where j is the imaginary unit, $\Delta\phi = 2\pi n_{\text{eff}}\Delta L/\lambda$, ΔL and n_{eff} are the difference between the two arms and the effective refractive index of the fiber, respectively. If the field E_3 is reflected completely, the output fields E' and E_2', at the output port of the optical circulator and port 2 of the interferometer are

$$\begin{bmatrix} E' \\ E_2' \end{bmatrix} = \frac{1}{2}\begin{bmatrix} 1-\exp(j\Delta\phi) & -j[1+\exp(j\Delta\phi)] \\ -j[1+\exp(j\Delta\phi)] & -[1-\exp(j\Delta\phi)] \end{bmatrix}\begin{bmatrix} E_3 \\ 0 \end{bmatrix} = \frac{E}{4}\begin{bmatrix} [1-\exp(j\Delta\phi)]^2 \\ -j[1-\exp(j2\Delta\phi)] \end{bmatrix}. \tag{2}$$

From Eq. (2), the transmission spectrum of the MZI is characterized by a series of equally spaced transmission peaks in the wavelength domain. Maxima in the spectrum occur for $\Delta\phi = (2m+1)\pi$, with m being an integer. The transmission period in wavelength domain,

$\Delta\lambda$, is derived from

$$\Delta\lambda = \lambda_2 - \lambda_1 = \frac{\lambda_1\lambda_2}{n_{\mathrm{eff}}\Delta L} \cong \frac{\lambda^2}{n_{\mathrm{eff}}\Delta L}. \tag{3}$$

A wavelength spacing of 5 nm is achieved with ΔL=0.3298 mm at a 1.55 μm wavelength, and n_{eff} = 1.457. Tuning the peak wavelength is possible by changing the path length difference of two arms ΔL. When a direct current (DC) electric voltage is applied on the PZT, ΔL will change. Then the output spectrum will shift correspondingly. The device can act as a tunable wavelength-selection multiplexer/demultiplexer.

Figure 2 shows the numerical results of output spectra E' and E_3, at the output port of the optical circulator and the port 3 of the interferometer, respectively. The curve 1 corresponds to the output spectrum of the port 3 without fiber loop mirror, while the curve 2 corresponds to the output spectrum of the output port of the optical circulator with fiber loop mirror. It is seen that the transmission period is 5 nm. The extinction ratio of output spectra E' and E_3 are 60.12 and 30.06 dB, respectively. The extinction ratio of output spectrum with fiber loop mirror is two times higher than that of output spectrum without fiber loop mirror.

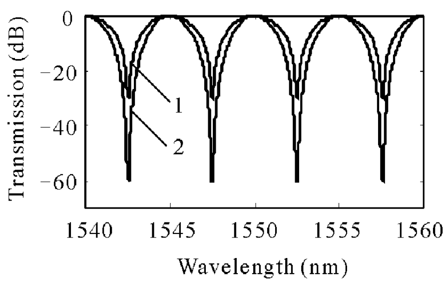

Fig. 2. Numerical transmission curve of MZI. curve 1: field E_3; curve 2: field E'.

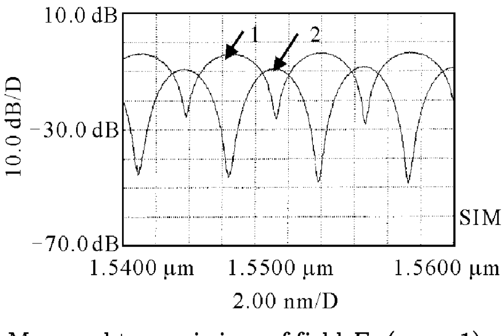

Fig. 3. Measured transmissions of field E_3 (curve 1) and field E' (curve 2) of MZI.

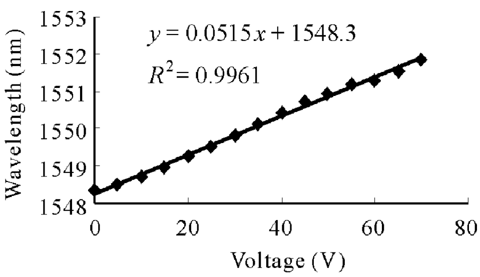

Fig. 4. Relationship between the wavelength shift and the electric voltage applied on PZT. y: wavelength; x: voltage; R^2: linearity.

In experiment as shown in Fig. 1, the light of broadband is launched to the input port of the optical circulator. The output spectrum of the interferometer is monitored with an optical spectrum analyzer (OSA, Advantest Q8383) with the resolution of 0.1 nm. Adjusting the state of polarization of the signal in one arm, we are able to achieve the maximum extinction ratio of the interferometer fringe pattern. Figure 3 shows the output spectra of the interferometer. The curve 1 is the output spectrum of field E_3 at the port 3 without fiber loop mirror whose extinction ratio is about 22.8 dB, while the curve 2 is the output spectrum of field E' at the output port of the optical circulator and the extinction ratio is about 40.8 dB. The extinction ratio can be enhanced 18 dB.The transmission period of the interferometer is 5.46 nm. These experimental results agree with the theoretical analysis. Apparently, the extinction ratio of the interferometer is improved greatly by using a fiber loop mirror.

In our experiment, a changeable DC electric voltage is applied on the PZT to change the path length difference of two arms. The tuning range of the electric voltage is from 0 to 70 V. Figure 4 shows the shift of the wavelength of the interferometer with different DC electric voltage. The square symbols are experimental results, and the line is the fitting line. It is easy to see that the relationship between the electric voltage and peak wavelength shift is basically linear (R^2 = 0.9961). We only measure the wavelength shift of one transmission peak. With the DC electric voltage increasing, the wavelength moves to the longer wavelength. The shift of the wavelength is 3.42 nm over the DC electric voltage range from 0 to 70 V. When the DC electric voltage changes to 57 V, the phase change of the interferometer happens to change π rad, and the transmission peak changes for half of a period.

In a conclusion, a novel structure of multiplexer/demultiplexer with a Mach-Zehnder interferometer and a fiber loop mirror is proposed. It has the characteristic of high extinction ratio. The extinction ratio is enhanced about two times in comparison with the conventional MZI, Because of simple structure and high isolation, this device is a potential candidate for WDM networks.

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