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Integrated Wavelength Tunable Filters Based on Resonant Mach-Zehnder Interferometer

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Abstract---We present a novel wavelength tunable filter based on resonant Mach-Zehnder Interferometer using electric thermooptic phase shifter.

Optoelectronic components specially designed for broadband communication systems are critical to establish this strategy for increasing optical network capability and functionality. One of the most important optoelectronic components is wavelength selective filter for employing wavelength-division-multiplexing (WDM) technique[1,2].

A number of optical filters have been investigated using different approaches, grating-resonator-coupled waveguide filter[3], grating assisted co-directional coupler filter[4] or the meander coupler[5,6], Mach-Zehnder (MZ) interferometer filter[7-9] and cascaded coupler Mach-Zehnder filter[10-11]. Integrated Mach-Zehnder filter is one of the most promising devices based on the capability and functionality points of view.

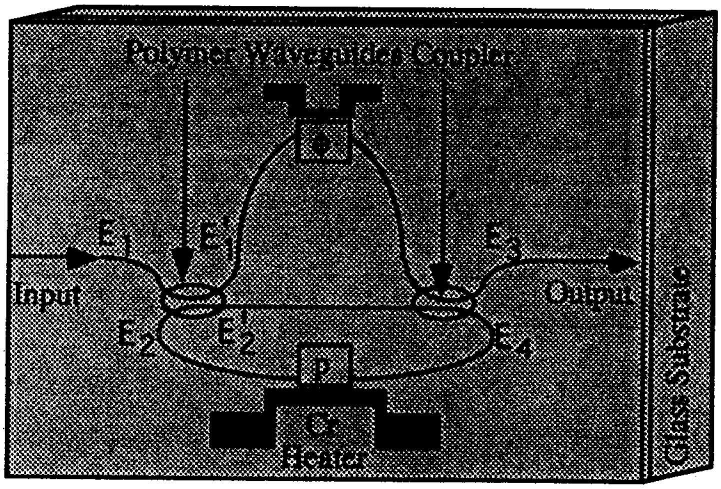

Figure 1. Schematic diagram of the proposed devices.

In this paper, we present a novel wavelength tunable filter as shown in Fig. 1. This device is based on resonant Mach-Zehnder interferometer with optical phase shifter in the recirculating arm of the interferometer. The filtering capability is improved due to the optical resonant effect. The electrical thermooptic phase shifter (ETOPS)[11,12] in the recirculating arm of a Mach-Zehnder interferometer provides an effective means for tuning the selective wavelength of filter. The second ETOPS, located on the side of on traveling arm of the MZ interferometer, is employed to reduce the common mode noise. Note that

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the common mode noise are the effects of all perturbations that uniformly affect the entire device. The device is further demonstrated using integrated polymer waveguides on glass substrate with a thin film electrical heater as a electrical thermooptic phase shifter.

As shown in Fig. 1, the presented device can be treated as a MZ interferometer with the output from the unused port fed back coherently through the previously unused input. port. It consists of two standard waveguide couplers, named C_1 and C_2. Assuming only one polarization of the single-mode traveling in the waveguide couplers, the optical field amplitude (with the reference of Fig. 1) at the output of the coupler can be written as

$$\begin{matrix} E_3 \\ E_4 \end{matrix} = \begin{bmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{bmatrix} \begin{matrix} E_1 \\ E_2 \end{matrix} = \begin{bmatrix} A_2 & B_2 \\ B_2 & A_2 \end{bmatrix} \begin{bmatrix} t_r & 0 \\ 0 & t_s e^{i\phi} \end{bmatrix} \begin{bmatrix} A_1 & B_1 \\ B_1 & A_1 \end{bmatrix} \begin{matrix} E_1 \\ E_2 \end{matrix} \qquad (1)$$

Where t_r and t_s are the field transmission coefficients for the two arms of the MZ interferometer, respectively, and ϕ is the relative phase difference between the two arms. A and B can be written as[13,14]

$$A = [ae^{jg}]\cos\beta \ , \qquad (2)$$

$$B = j[be^{jh}]\sin\beta \ . \qquad (3)$$

For realistic couplers, a and b will be slightly less than unity, and $h, g << 1$ radian.

With the inclusion of a feedback path in Fig. 1 consisting of a fiber link with transmission coefficient t_f and phase shift p, the feedback optical field is

$$E_2 = E_4 t_f e^{jp} \ . \qquad (4)$$

Using Eq. (1) and (4), the transmittance of the optical circuit in Fig. 1 becomes

$$T = \left| \frac{E_4}{E_1} \right|^2 = \left| \frac{C_{11} - (C_{11}C_{22} - C_{21}C_{12})t_f e^{jp}}{1 - C_{12}t_f e^{jp}} \right|^2 \qquad (5)$$

For the case of identical couplers C_1 and C_2 with $\beta_1 = \beta_2 = \pi/2.25$, $t_r = t_s = 1.0$, and $t_f = 0.97$, the transmittance of optical circuit can be simulated based on Eq. (5). Fig. 2 shows the results of transmittance versus feedback loop phase p for different values of $\phi = 0.10*2\pi$, $\phi = 0.15*2\pi$ and $\phi = 0.25*2\pi$, respectively. A desired value of ϕ can be selected for common mode noise compensation purpose. In Fig. 2, $p = 0.48*2\pi$ is assumed. Fig. 3 shows the results of a numerical calculation of transmittance T versus the two arm phase difference ϕ. As indicated in Fig 3, $(\delta T)/(\delta\phi)$ has positive value for $\phi = 0.10*2\pi$, and has negative value for as . In other words, a phase shift can be used to control the sign of $(\delta T)/(\delta\phi)$, and of course its value too.

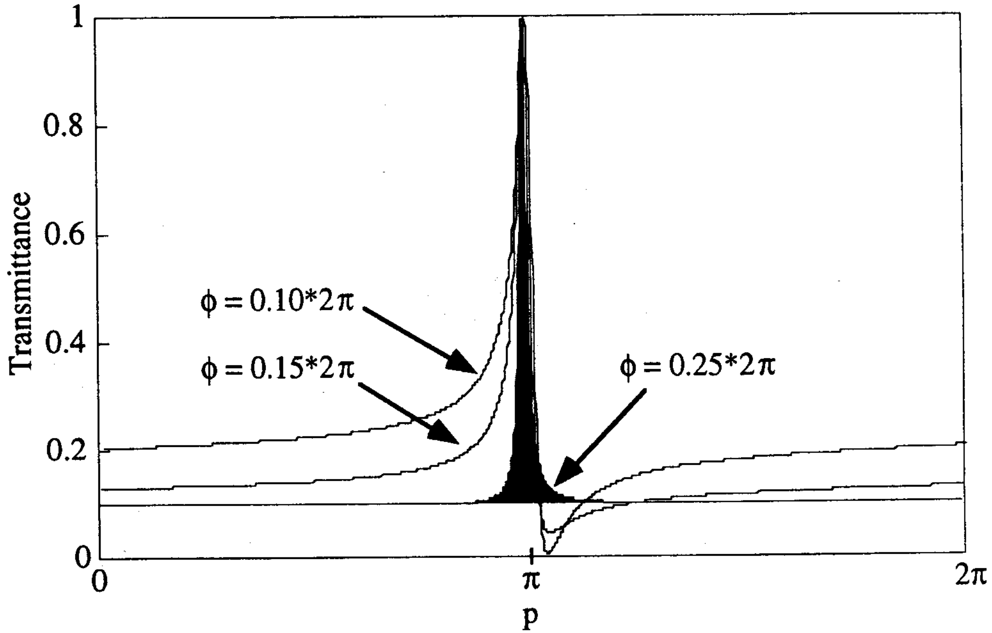

Figure 2. Transmittance versus feedback loop phase.

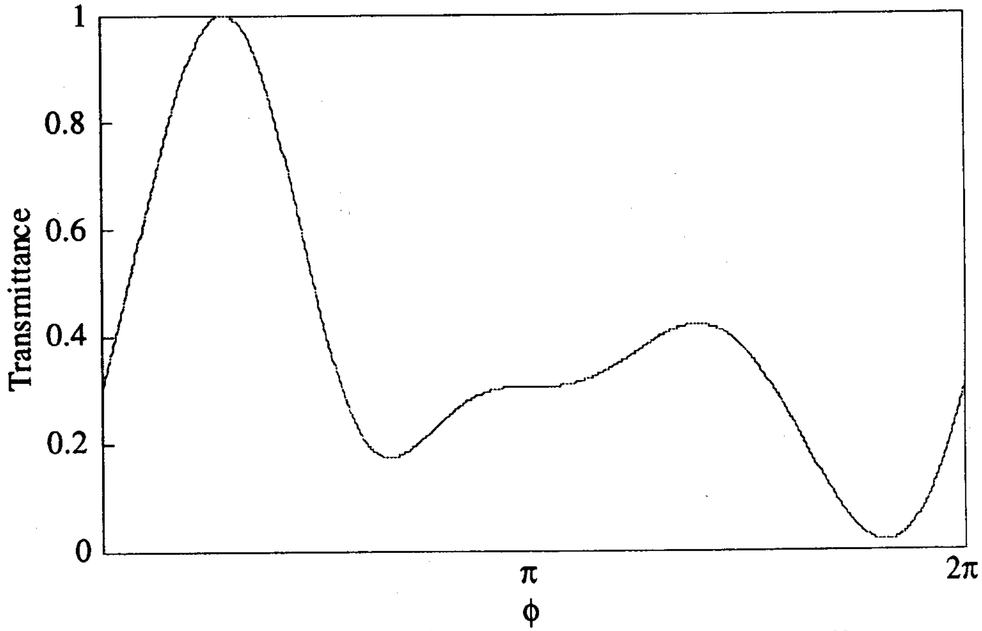

Figure 3. Transmittance versus Mach-Zehnder phase difference.

Common mode compensation is important in optical resonant devices, which is defined as minimum sensitivity of device to environmental variables. To achieve common mode compensation for the device shown in Fig. 1, it is necessary to have

$$\frac{\delta T}{\delta \phi}\left[\frac{Ls - Lr}{\lambda}\right] + \frac{\delta T}{\delta p}\,\frac{L_f}{\lambda} \rightarrow 0 \quad . \qquad (6)$$

Through careful selecting the length of the feedback loop and the arm difference, the common mode compensation can be achieved for the device shown in Fig. 1 with a suitable phase bias of ϕ.

To verify the proposed concept, a polymer-based resonant MZ interferometer has been fabricated on glass substrate. The graded index single-mode waveguides employed have 2 μm width and depth with optical propagation loss about 0.5 dB/cm[15-16]. The polymer waveguide has optical refractive index of ~1.5. Two identical waveguide couplers are employed with splitting ratio of 97% at wavelength of 800 nm. The device dimension is 7 mm x 7 mm. The ETOPS is made out of thin film Cr heater, 0.2 μm thick, 35 μm wide and 5 mm long. The resistance of the heater was about 700 Ω. Note that the thermooptic coefficient of the polymer is estimated around 10^{-5} (1/C^{o}).

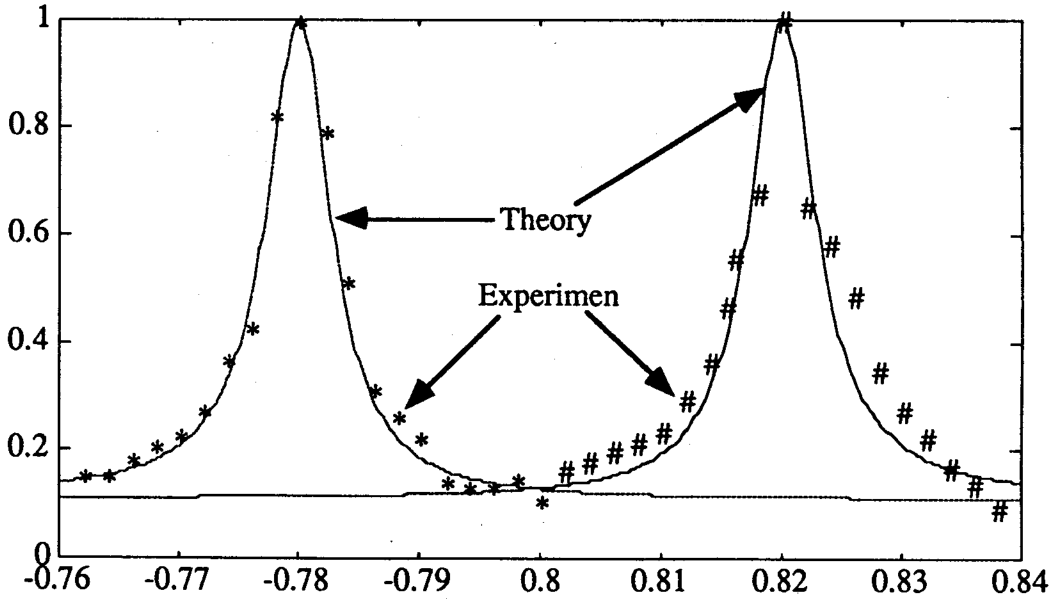

Figure 4. Measured and calculated filter transmission linewidth.

Titanium: Sapphire tunable laser (Coherent 870) is employed to measure the transmission linewidth of filter. The linewidth of the Titanium: Sapphire tunable laser is determined about 1 nm, at the wavelength range from 0.75 nm to 0.85 nm. The measured filter linewidth together with the calculated curve based on Eq. (5) are shown in Fig. 4 together with theoretical simulation. 10 nm linewidth is determined. A good agreement is been found between the theory and the experiment as indicated in Fig. 4. The electrical power needed to shift the transmission window from 780 nm to 820 nm is 0.2 W. The wavelength tunable range is larger than 100 nm.

In summary, a wavelength tunable filter based on a resonant MZ interferometer is investigated, together with experimental demonstration, employing polymer waveguide and Cr thermooptic phase shifter. Further research are under going to include the device polarization characteristic, dynamic range of tunable wavelength, and the minimum filter linewidth.

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