Passband flattened interleaver using a Mach-Zehnder interferometer with ring resonator fabricated in SiON waveguide technology

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A wavelength interleaver having almost rectangular wavelength response, with 50 GHz free spectral range has been demonstrated using SiON waveguide technology. The device consists of an asymmetric Mach-Zehnder Interferometer (MZI), with a ring resonator coupled to one of its branches. A passband flattened and stopband broadened transfer function with 15 dB isolation for TM polarized light (12 dB for TE) has been measured. The isolation was less than the designed 30 dB due to fabrication errors causing a deviation in coupling coefficient between MZI-branch and ring. The chromatic dispersion was measured to be zero in the center and 1660 ps/nm at the edge of the passband.

Introduction

In order to efficiently use the available bandwidth in multiwavelength optical networks, filters with a rectangular-shaped wavelength transfer function are needed. Filters which are periodic in frequency or wavelength (known as slicers, or interleavers) can be used as building blocks in a binary tree arrangement in order to realize more complicated filter functions like add-drop multiplexers [1]. Such composite filters can be fully tuned if each of the component slicers is tuneable over one free spectral range (FSR). In this paper, we demonstrate a thermo-optically tuneable slicer having a nearly rectangular-shaped wavelength transfer function, with 50 GHz FSR, consisting of a Mach-Zehnder Interferometer (MZI) filter with a ring resonator coupled to one of its branches [2,3,4].

Device structure and design

Figure 1 shows the layout of the MZI + ring filter. The length difference of the two MZI branches is 3.996 mm resulting in a 50 GHz FSR. A ring is connected to the short MZI channel using a directional coupler (DC) having a power-coupling coefficient $k_r = 0.82$. The ring roundtrip length is twice the MZI length difference. The MZI input and output couplers each consist of two 3dB DC's interconnected by equal length channels. Heaters are located on the long MZI branch (for tuning the filter central frequency), the ring (for synchronising it with the MZI), and on one of the channels in each of the input and output couplers (for adjusting their coupling ratios k_1, k_2). Using 1.5 mm long heaters, a 2π phase change could be easily obtained.
Figure 2 shows two simulated filter responses.

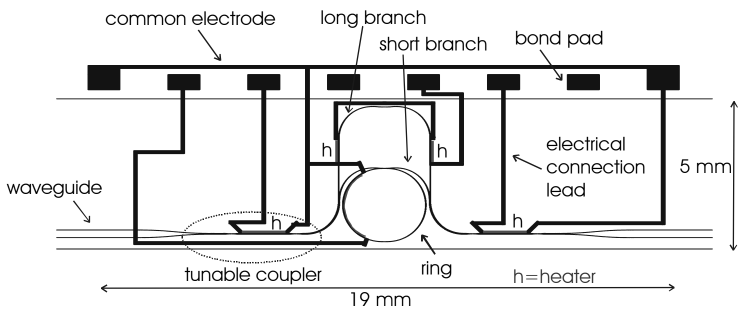


Figure 1: Layout of the MZI + ring filter.

The solid curve is the desired response (power coupling to the ring is k_r = 0.82). The isolation is 29 dB and the width of the stop band 31 % of the FSR @ -25 dB. The dashed curve is for an MZI without a ring, which has rounded passbands. The device has been fabricated at MESA[+] using a combination of plasma enhanced chemical vapor deposition (PECVD) SiON technology [5,6,7] and reactive ion etching (RIE) where the layers were annealed to lower the SI-H and N-H absorption peak around 1510 nm [8].

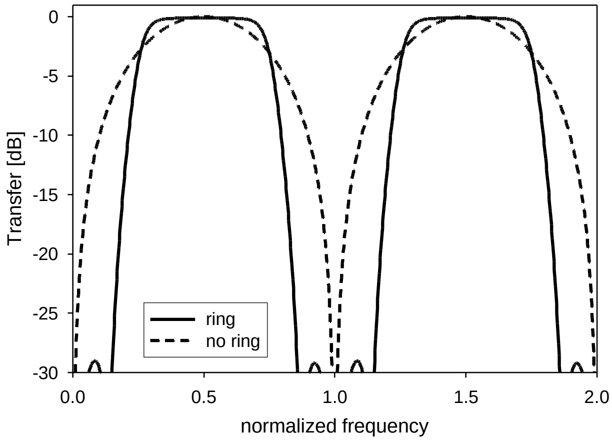
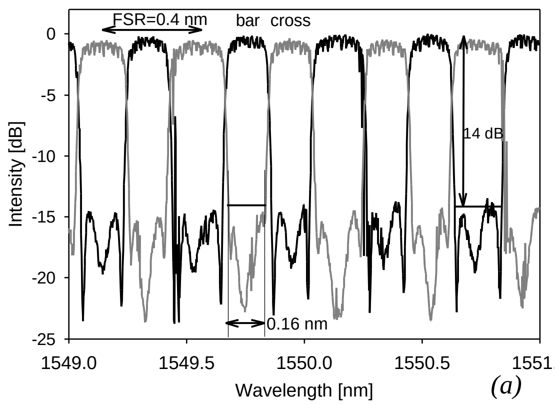
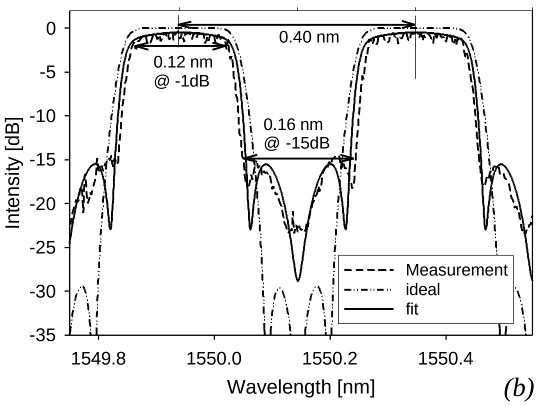


Figure 2: Calculated filter curves for power coupling coefficients of k_r = 0.82 (solid line) and no ring (dashed line) respectively.

Device characterization

The measured intensity transfer spectra of the filter are shown in figure 3. The measurement was performed with TM polarized light (fig. 3.a). Both tuneable couplers were tuned to the 3 dB splitting point and the ring was tuned to the desired relative phase (compared to the MZI). Passband flattened and stopband broadened response is clearly observed. The measured FSR is 50 GHz and the measured crosstalk is –15 dB, which is higher than the designed value of –29 dB. This difference can easily be explained. The measured power coupling of separate ring-waveguide DCs turned out to be only 0.59 for TM polarized light instead of the designed value of 0.82. Simulating the filter





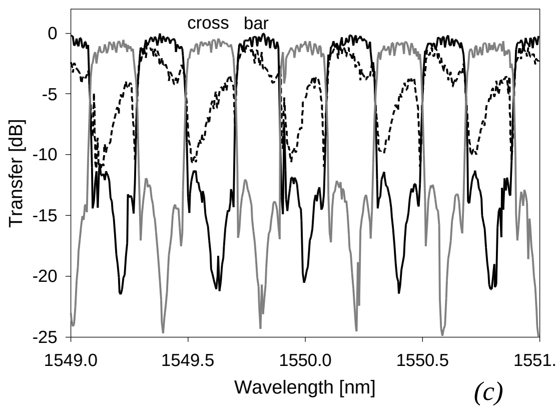


Figure 3: Intensity transfer functions.
(a) Measured bar (black) and cross (gray) filter response for TM-polarized light.
(b) Comparing measured and calculated cross transfer for TM polarized light: measured, ideal (k_r = 0.82, $k_{1,2}$ = 0.5, no loss) and fit (k_r = 0.59, k_1 = 0.5 and k_2 = 0.51, 1.7 dB/cm loss) respectively.
(c) Measured bar (gray) and cross (black) filter response for TE-polarized light. The dashed curve was found without retuning.

response for this erroneous 0.59 coupling factor (and 1.7 dB/cm waveguide loss) resulted in a characteristic almost equal to the measured one, as shown in figure 3.b. The passband of the filter is somewhat rounded, which can be explained by loss in the ring, which is higher near resonance. The measured filter response for TE polarized light is shown in figure 3.c, without retuning the heater settings (dashed line) and after retuning the ring (solid line). Two problems can be identified: the ring is detuned with respect to the MZI and a 0.03 nm TE-TM shift occcurs. Both problems are due to waveguide birefringence, which may be different in the straight and the curved ring. Further research is needed for tackling this birefringence problem. It is difficult to make 50 GHz FSR filters without an appreciable TE-TM shift using our standard waveguide design having a waveguide birefringence $\Delta N_{eff,TE\text{-}TM} = 2{\cdot}10^{-4}$, which always results in a 25 GHz frequency shift, independent of the FSR of the filter. The crosstalk for TE polarized light (after retuning) is 12 dB, which is higher than for the TM polarized light. This can be explained by the even smaller power coupling ratio of 0.52 for TE polarized light.

Chromatic dispersion measurement

The group delay response was measured for the MZI + ring filter with an FSR = 50 GHz using the phase shift method [9,10]. A tuneable laser was swept in 5 pm steps and the modulation frequency was 1 GHz. The measured transmission, group delay and dispersion are shown in figure 4. The maximum group delay difference in the passband is 44 ps. The dispersion (maximum slope) in the passband is 1660 ps/nm, which is roughly equal to 100 km of standard single mode fiber (=17 ps/nm/km). A good fit to the data was achieved using the theoretical model of the filter. The fitted parameters were 0.7 dB differential loss of the MZI (corresponding to 1.7 dB/cm waveguide loss), power coupling ratios of 0.52 for the tunable couplers and 0.59 power coupling ratio to the ring.

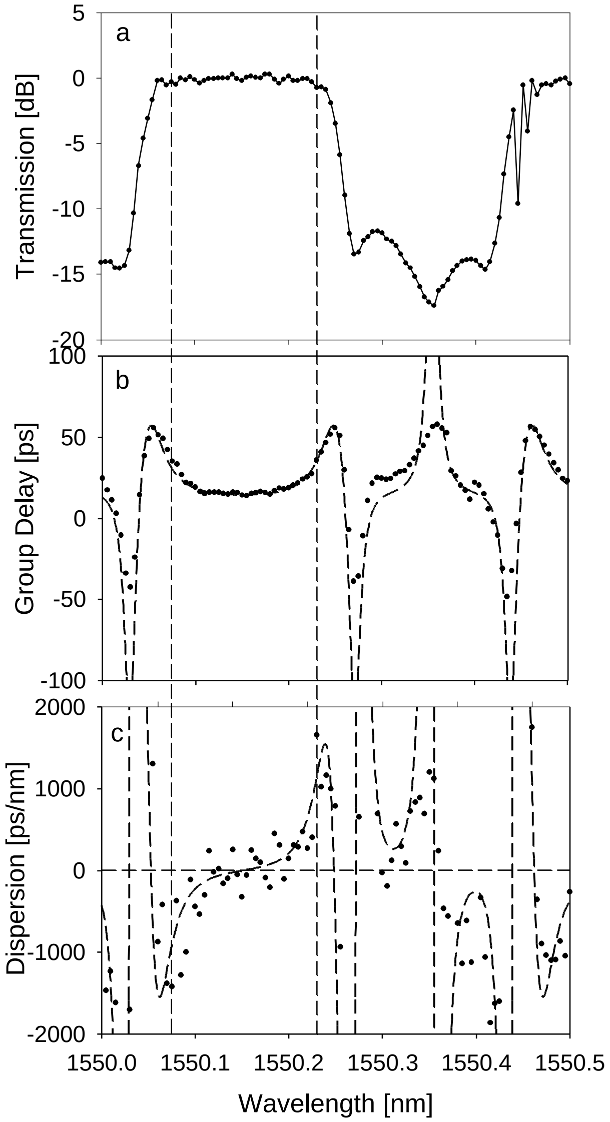


Figure 4: Dispersion measurements (TM) and fits of the MZI + ring filter. (a) Measured intensity transfer spectrum; (b) measured group delay and theoretical fit with parameters $k_r = 0.59$, $k_{1,2} = 0.52$ and differential loss 0.7 dB; and (c) dispersion, calculated (dots) from measured group delay and fit (dashed line).

These values are very close to the ones used in fitting the intensity transfer spectra and those found in separate characterizations of test structures.

Conclusions

An MZI + ring resonator can be used as an alternative for the lattice type filters. This filter has been designed, fabricated and measured. The measured isolation values are 15 dB for TM and 12 dB for TE polarized light respectively, which deviates from the designed value of 30 dB. The deviations are mainly due to errors in the fabrication, which caused a large offset of the couplers. The measured power-coupling ratio to the ring was 0.59 for TM and 0.52 for TE polarization, which deviates from the designed value of 0.82. The measured waveguide loss was 1.7 dB/cm, which is rather high. The measured maximum chromatic dispersion is 1660 ps/nm (equal to about 100 km single mode fiber). Again the model could be fit to the measurement using the same parameters as found in the model fit of the power transfer measurement, giving confidence in the accuracy of the used model. The filter does not work for both TE and TM without retuning the ring. The shift between the TE and TM curve after tuning the ring was 0.03 nm (= 0.08 FSR), corresponding to a birefringence of $3 \cdot 10^{-5}$.

Acknowledgements

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