Thermo-optic Tuning of Silicon Photonic Multimode Waveguide for Post-Fabrication Optimization

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Abstract: We examine the effect of thermo-optically varying the effective mode index of an asymmetric y-junction that multiplexes three modes. This work aims to optimize multimode operation, thereby improving performance.
OCIS codes: (130.0130) Integrated Optics; (120.6810) Thermal Effects; (060.1810) Buffers, couplers, routers, switches, and multiplexers

1. Introduction

Mode-division multiplexing offers the benefit of increasing bandwidth on-chip when used in conjunction with wavelength-division multiplexing [1-3] and polarization-division multiplexing [4, 5]. The eigenmodes are induced by phase-matching the multiplexing region to the multimode waveguide (MMWG). The asymmetric y-junction structure examined in this paper has engendered new ways to route signals on-chip [6]. Previous electro-optic routing of the mode through a device was demonstrated in [7]. Here we look to add a form of active control in order to account for fabrication variations.

As we continue to scale modal channels, potential sources of crosstalk need to be taken into consideration. With two modal channels, there is one source of crosstalk; with three modal channels, there are two. For these devices, we want to ensure the two sources of crosstalk are minimal across an overlapping regime for improved performance. A small spectral shift is introduced to optimize an arm's crosstalk contribution towards the throughport signal.

A controllable third arm could be useful when scaling the number of multiplexing arms (ie. the number of supported modes through the device), as has been shown in prior works with this device [8]. In this paper, an asymmetric y-junction structure is simulated to show a shift in wavelength due to thermo-optic control, allowing for overall improvement in crosstalk.

2. Device Parameters

The device simulated, as shown in Fig. 1, has a multimode length of L=1.003 mm with w_1=550 nm, w_2=600 nm, and w_3=650 nm. The angles θ_1 and θ_2 are 0.75^O and 0.585^O respectively. The geometry of the multiplexing arms induces a range of effective indices (n_{eff}) that then propagates as three different-ordered quasi-transverse magnetic (QTM) modes in the MMWG.

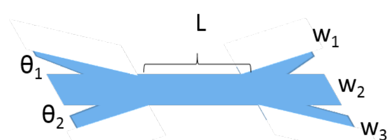

Fig. 1. MMWG supporting three modes with dimensions θ_1=0.75, θ_2=0.585, w_1=0.55 μm, w_2=0.6 μm, and w_3=0.65 μm, and L=1.003 mm. w3 arm is the Left Arm, w2 arm is the Center Arm, and w1 arm is the Right Arm.

3. Results

The graph in Fig. 2 plots every possible combination of crosstalk on the throughport arms due to the neighboring arms. The crosstalk level is the difference in power seen at the throughport arm with respect to the crossport arm. The labels in the legend indicate the crosstalk contribution of one arm on the other labeled arm. The crosstalk value contributed by arm i can be expressed as equation (1).

$$CT(\lambda_o)_{arm,i} = 10\log_{10}(P(\lambda_o)_{throughport} - P(\lambda_o)_{crossport,i}) \quad (1)$$

where $P(\lambda_o)$ is the power in dBm at λ_o. This crosstalk value then translates to power penalty when we are performing system measurements [9].

From this particular graph, we can select λ_o=1549.4 nm as an operational wavelength. However, the largest contribution of crosstalk at this operational wavelength seems to originate from the source at the right arm. The closest dip due to interference of the right arm is offset from the selected λ_o by ~0.4 nm. A thermo-optic control is placed at this arm to shift the spectral regime shown in the zoomed in region of Fig. 2.

The thermal coefficient of silicon is 1.87 x 10^{-4} /K. We see that $\Delta\lambda$ is directly related to n_{eff} by starting with equation (2), derived in a similar way as in [10]

$$p\lambda_o = \Delta n_{eff} * L \qquad (2)$$

where p represents a positive integer and L is the length of the multimode waveguide. Then, waveguide dispersion is taken into account, resulting in equation (3) and P replacing p.

$$P = p - L*\partial\Delta n_{eff}/\partial\lambda \qquad (3)$$

Dips in the crosstalk regime as a result of temperature variation can be written in the form of equation (4).

$$\partial\lambda/\partial T = (L*\partial(\Delta n_{eff})/\partial T)/P \qquad (4)$$

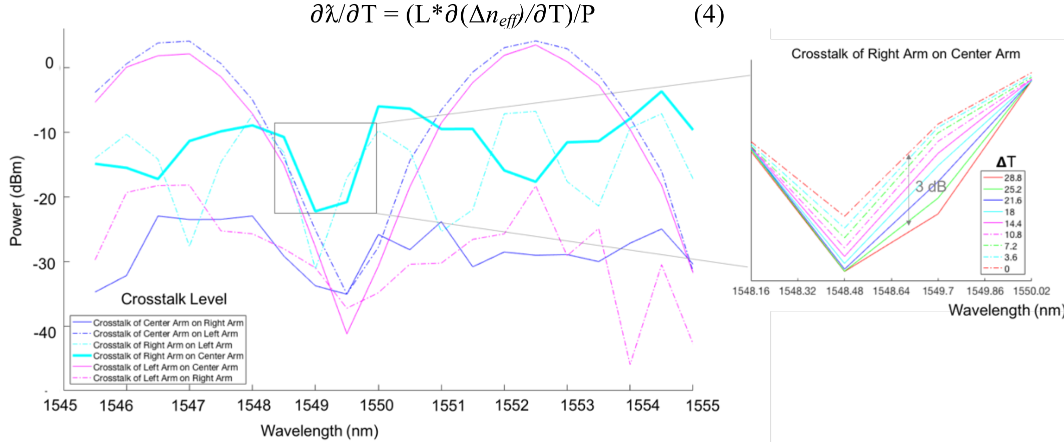

Fig. 2. Crosstalk level at all arms of the device described in Sec. II. The legend indicates the crosstalk contribution of the crossport arm on the throughport arm. The arm that is the main contributor to crosstalk has its crosstalk level drawn in bold. The spectral region investigated is boxed. By zooming in on that region, we see the resultant reduction in contribution to crosstalk by the right arm as it is thermo-optically induced.

At the selected right arm, we perform a temperature sweep over about 30 degrees. The derived shift at the examined wavelength regime is about 0.043 nm/K. At 28.8 degrees, we see a crosstalk value 3 dB lower than without thermo-optic tuning. It should be noted that the amount of thermal adjustment will vary across different modes. Additionally, finer resolution on the thermal study can provide more granularity in the spectral content.

4. Discussion

The effect from the thermo-optic control is localized on one of the arms, as opposed to possible integration on the multimode region. Thermal isolation of the tuning region could also ensure other channels are not also affected by this active thermo-optic inducement [11].

The parameter of interest for multimode operation is the difference in phase between all possible combinations of signals traversing across the different arms. Phase mismatch in our case can be represented by $\Delta\beta_{eff} = \beta_{arm} - \beta_{TO}$ that takes into account $\Delta\beta_{eff} << \beta_{arm} - \beta_{neighboring\ arms}$, where β_{arm} indicates the original mode propagation constant, and β_{TO} indicates the mode propagation constant with the additional tuning applied.

As multimode operation is realized through different designs, bandwidth continues to scale via spatial-multiplexing. New tools can be developed for optimizing performance. This paper describes a possible way to improve performance when scaling the number of modal channels to support high aggregate bandwidth.

We acknowledge support from Intel/SRC Ph.D Fellowship and the Columbia Photonics IGERT under NSF grant DGE-1069420. Thanks to Xiang Meng for useful discussion of simulations.

5. References

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