C-band Performance of a Novel Tunable Integrated Filter for Dispersion Compensation

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***Abstract*—A novel dispersion compensating filter comprising higher order MMI couplers is fabricated in SOI platform. Characterization of the filter has shown that it can compensate residual dispersion for WDM channels over the entire C-band.**

***Index Terms*—Dispersion Compensation, Multimode Interference Coupler, Silicon-on-Insulator**

I. Introduction

In integrated optics, various basic and advance filtering operations have been realized. Mostly they involve 2-port couplers. Realization of future filter applications using 2-port couplers will lead to complex filter architectures. [1] and [2] have proposed filters for signal processing applications using higher order couplers but they have not been experimentally demonstrated. Filters involving higher order couplers will require smaller number of couplers and smaller waveguide lengths. This will result in compact filters with smaller loss.

Silicon photonics provides higher order Multimode Interference (MMI) couplers with low imbalance and small phase errors over the entire C-band [3]. Such higher order couplers are imperative for the realization of advance filtering applications. We have experimentally demonstrated a filter for fiber chromatic dispersion compensation using 4-port MMI couplers in silicon photonics. Chromatic dispersion is the major cause of Inter Symbol Interference (ISI) at high data rates in Standard Single Mode Fiber (SSMF). ISI can be eradicated by pre or post compensation of dispersion using dispersion compensating filter.

II. Filter Description and Design

A generalized waveguide layout of an N stage filter for dispersion compensation using symmetric M-port MMI couplers is shown in Fig. 1. Each stage is composed of an M-port Mach-Zehnder Interferometer (MZI) as shown by the dotted section in Fig. 1. The first MMI coupler splits the input signal distorted by chromatic dispersion into M equal components. They are time delayed, recombined and split by each stage of the filter. The dispersion compensated signal is received at one of the output ports of the last MMI coupler. Remaining output ports of the last MMI couplers are used for monitoring purpose. By adjusting the phase of the time-delayed signals on the delay lines, the filter produces different linear group delay slopes for a certain fraction of the filter Free Spectral Range (*FSR*) making the filter tunable [4].

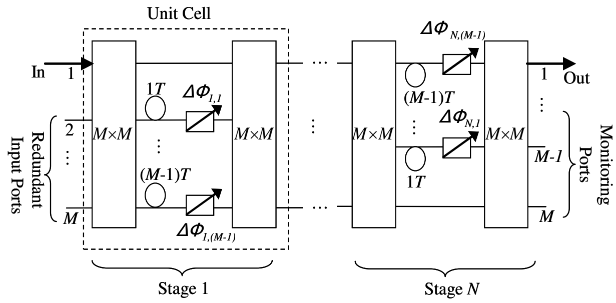

Fig. 1. Waveguide layout of a generalized filter comprising M-port MMI couplers. A single stage is shown in the dotted section. Ports with arrows are for input and output. Other ports are either redundant or used for monitoring purpose.

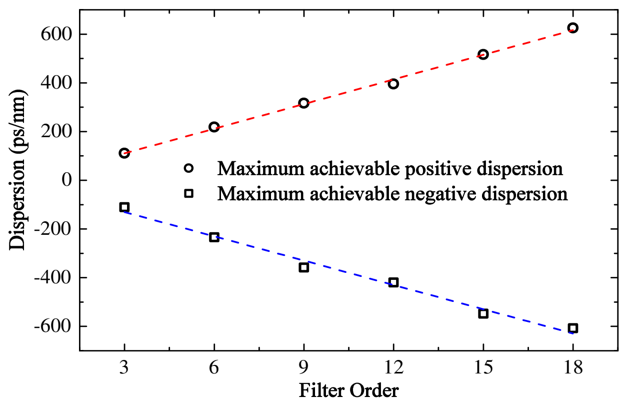

Fig. 2. Relation of attainable dispersion from a filter comprising M-port MMI couplers vs the filter order.

The maximum achievable dispersion from the filter depends on the order R of the filter. For a given group delay ripple and fraction of filter *FSR* with linear group delay slope, the attainable dispersion increases with an increase in the order R of the filter. In order to have a linear group delay for at least 40 % of the filter *FSR* and a group delay ripple of less than ±3 ps, fig. 2 shows the relationship of the maximum achievable filter dispersion and the order R of the filter. The filter order

R, defined as $N(M-1)$ for the filter shown in fig. 1, can be increased by either increasing the order *M* of the MMI coupler or the number of stages *N*. The two approaches lead to a compromise between the performance and loss of the device. Former approach degrades the filter performance due to more susceptibility to fabrication tolerance and bandwidth limitation of the higher order MMI coupler, which is related inversely with the order of the MMI coupler. Latter approach leads to filter with large loss resulting from the large overall waveguide length for the filter.

We have realized a filter which is composed of three 4-port MMI couplers, which are connected by delay lines. It is a 6th order filter. The filter is designed to have an *FSR* of 100 GHz. 4-port MMI couplers provide a good compromise between the performance and loss of the filter. Phase shifting elements are embedded on the delay lines by using thermo-optic effect in metallic heaters. The filter is fabricated in 4 μm Silicon on Insulator with 1 μm buried oxide.

III. Results and Discussion

The fabricated device is characterized for transmission and group delay. A laser signal swept with a wavelength increment of 3 pm is in and out coupled by using lensed fibers. Modulation Phase Shift (MPS) method is used for the measurement of group delay. The polarization of the input signal is adjusted at the tip of the in-coupling fiber. Polished facets and lensed fibers limit the coupling loss to 0.5 dB per facet. The insertion loss originating from the waveguide loss and excess loss of the MMI couplers is 6 dB.

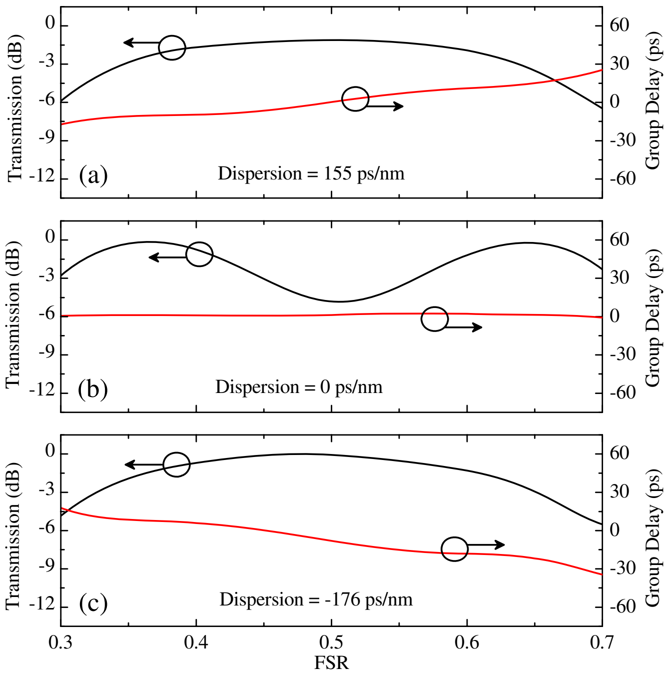

Fig. 3. Measured transmission (solid, black) and group delay slope (solid, red). Fraction of the filter *FSR* with positive (a), zero (b) and negative (c) dispersion for the fabricated filter.

Measurement results for only TE polarization are presented here because the fabricated device is not subjected to birefringence tuning. Fig. 3 is a measurement result, which shows the fraction of the filter *FSR* that has a linear group delay slope. The filter is tuned to compensate positive, no and negative residual dispersion as shown in fig. 3 (a), (b) and (c) respectively. In each FSR, the group delay is linear for atleast 0.32 nm (40 % of the filter *FSR*), which is sufficient to compensate residual dispersion for 40 Gbps WDM systems. The group delay ripple for the tuned filter stays below ±5 ps.

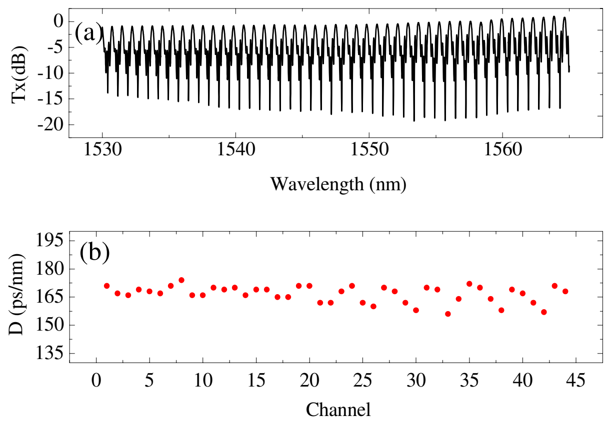

Fig. 4. (a) Measured transmission over a bandwidth of 35 nm (44 WDM channels) in the C-band, (b) Variation in filter dispersion for group delay ripple of less than ±5 ps with more than 40 % of filter *FSR* with linear group delay.

To characterize the filter in C-band, measurement result in fig. 3 (c) is performed from 1530 nm to 1565 nm (44 WDM channels). Fig. 4 (a) shows the measured transmission for the filter. The variation in insertion loss is around 1.5 dB. Fig. 4 (b) shows the variation in filter dispersion for 44 WDM channels in the C-band. For a group delay ripple of less than ±5 ps with more than 40 % of filter *FSR* with linear group delay, the maximum variation in filter dispersion is only 18 ps/nm.

IV. Conclusion

We have demonstrated the performance of a novel dispersion compensating filter over the entire C-band. 40 % of the filter *FSR* has a linear group delay with less than ±5 ps of group delay ripple. The variation in dispersion for multiple WDM channels is only 18 ps/nm.

Acknowledgment

The authors would like to thank the financial support of German Research Foundation (DFG).

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