Extremely compact WDM cross connect on InP

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The increasing complexity of integrated optical devices not only puts stringent requirements on the uniformity of the fabrication process but also results in larger device dimensions. An approach to reduce the effect of the process non-uniformities and increase the yield per wafer is the use of compact components. We report an extremely compact 4-channel 2×2 WDM cross-connect covering only 3.3×1.5 mm^2. The device consist of low-loss compact PHASAR (de)multiplexers and compact push-pull Mach-Zehnder interferometer switches. The crosstalk performance is better than –20 dB and the on-chip loss is less than 12 dB. These results are comparable to the best InP-based WDM cross-connects reported so far but with much smaller dimensions.

Introduction

Advanced WDM networks of the near future will require complex WDM devices for switching and routing, such as wavelength selective cross connects and add-drop multiplexers. Photonic integration of these complex optical circuits leads to a drastic reduction in volume and interconnection costs. Monolithic integration of WDM cross connects was first reported in silica technology using a combination of wavelength (de)multiplexers or routers (PHASAR's) combined with thermo optic space switches. More recently WDM cross connects have been reported using InP-technology [1],[2]. The high refractive index (contrast) of InP allows for very compact device dimensions and the electro optic effects enable high-speed and low-power switching. Both features will become increasingly important in future packet-based optical communication systems.

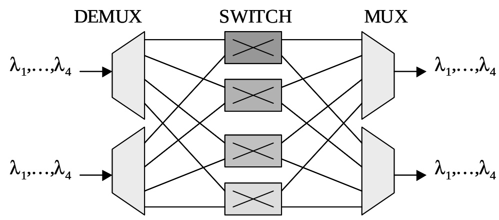

Figure 1: Functional scheme of the WDM cross connect.

Figure 1 shows the most basic WDM cross connect architecture containg two demultiplexers (one for each input) and two multiplexers (one for each output) connected by 2 × 2 switches (one for each wavelength). When realizing a monolithically integrated WDM cross connect one could choose to combine several (de)multiplexers in a single router to reduce (or avoid) wavelength mismatch between separate (de)multiplexers caused by wafer non-uniformities. Many different WDM cross connect architectures can be designed using a single up to four separate (de)multiplexers. However, the crosstalk performance of these WDM cross connects depends very much on the specific configuration used [3]. Using the wrong architecture can result in crosstalk limitations caused by signal-crosstalk beat noise [1]. Simulations demonstrate that the

best crosstalk performance is obtained when the configuration with four separate (de)multiplexers is applied.
In this paper we report on an extremely compact WDM cross-connect using this four-PHASAR configuration. Because of the small dimensions of the device the effects of wafer and process non-uniformities are expected to be sufficiently reduced to allow the use of four separate (de)multiplexers without suffering from wavelength misalignment.

Design

The basic building-blocks of an InP-based WDM cross connect are the PHASAR (de)multiplexer and the electro-optic Mach-Zehnder interferometer (MZI) switch. In order to realize a compact integrated WDM cross connect, these building blocks need to be fabricated in a single process. At the same time they should be compact, exhibit low insertion loss and a high tolerance towards process fluctuations in order for the whole WDM cross connect to function with reasonable specifications. To meet all these requirements we used the PHASAR design from [4], which combines compact dimensions with low-loss performance and was realized in a process used in our previous WDM cross connect experiments [1],[2]. This low-loss compact PHASAR uses high-contrast deep-etched array-waveguides for compact dimensions, and low-contrast shallow-etched star couplers for low-loss operation [5]. The PHASAR is made insensitive to the polarization of the light by proper choice of the waveguide width.

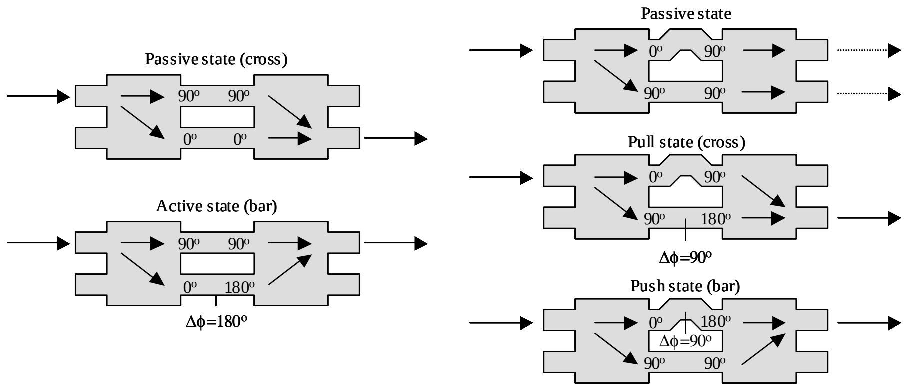

Figure 2: Required phase shift for switching in case of a standard (symmetric) MZI switch and a push-pull (asymmetric) MZI switch.

Compact MZI switches were realized by designing them for push-pull operation. By introducing an initial phase difference of 90° between both arms of the Mach-Zehnder interferometer, we can reduce the phase shift required to put the switch in its cross or bar state by a factor of two, as illustrated schematically in Figure 2. Reducing the necessary phase shift by a factor of two means a reduction of the length of the phase shifters by a factor of two and hence a more compact switch. The initial 90° phase shift is achieved by inserting an additional waveguide section in one of the arms.
Figure 3 shows the mask layout of the extremely compact WDM cross connect using the configuration with four low-loss compact PHASAR (de)multiplexers and four compact push-pull MZI switches.

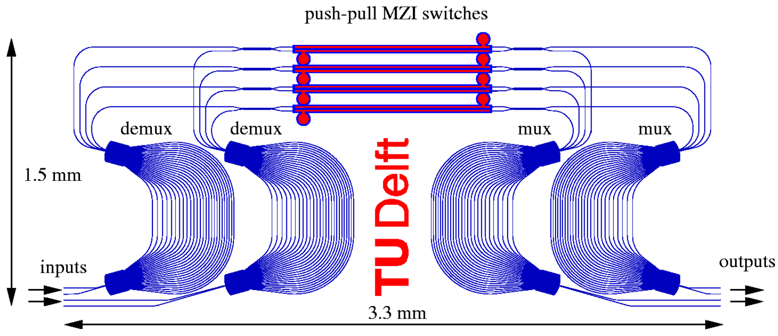

Figure 3: Layout of the compact WDM cross connect

To obtain polarization-insensitive switching operation, the whole WDM cross connect has been oriented under a 28º angle relative to the large flat of the wafer [6]. The complete WDM cross connect is deep etched (except for the star couplers in the PHASAR (de)multiplexers), in order to make the device as compact as possible. All crossings are made under a 90º angle and all curved connection waveguides have a bending radius of 100 µm. The device dimensions are 1.5×3.3 mm^2.

Fabrication

The WDM cross connect was fabricated in a CBE-grown layer-stack consisting of a 720 nm InGaAsP ($\lambda_{bandgap}$=1.25 µm) waveguide layer sandwiched between an InP substrate and a 1200 nm InP cladding layer. A 100-nm PECVD-SiN layer served as an etching mask for the waveguides. The pattern was defined using contact illumination with positive photo-resist and transferred in the SiN-layer by CHF_3 reactive ion etching. The waveguides were etched employing an optimized CH_4/H_2 etching and O_2 descumming process [7]. After the etch-depth for the shallow region was reached, a photo-resist mask was deposited, windows were opened at the regions where a deep etch is required, and the etching was using again a CH_4/H_2 etching and O_2 descumming process but this time optimized for photo-resist masking.

Experimental results

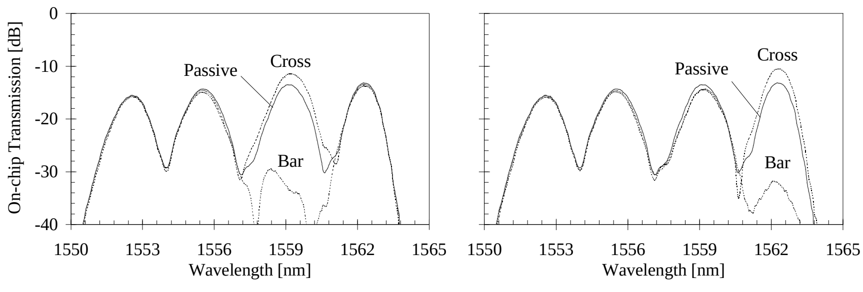

Figure 4: Measured spectral responses when the switches are activated that correspond to the third and fourth channel (left and right, respectively).

Figure 4 shows the measurements on the cross connect for TE-polarized light. In the passive state the signals are equally divided over both output ports (passive in the figure). When a voltage is applied to one of the phase sections of one of the switches, the signal increases in the cross-port (cross in the figure) and decreases in the bar-port (bar in the figure). In one of the four switches the phase shifters were electrically connected due to an error during lift-off, and one other switch suffered from a malfunctioning phase shifter. For this reason only two switches could be operated properly.

The crosstalk achieved, however, is better than –20 dB and the loss is <12 dB, which is comparable to that of the much larger WDM cross connects we reported earlier [1],[2]. The reason for the relatively low losses are the small bending radii and the compact four-PHASAR configuration which keep the on-chip length very short and compensate for the increased propagation losses of the deep etched waveguides.

Conclusions

A first version of an extremely compact WDM cross connect has been realized. Although the device did not perform optimally, the potential of the compact technology has been clearly demonstrated. A crosstalk of better than -20 dB with a single switch and an on-chip loss of less than 12 dB are comparable to the best results reported so far but, with a device dimension of only 1.5×3.3 mm^2. Obviously the higher losses of the compact components are (more than) compensated by the loss reduction resulting from the much shorter interconnection lengths between the components. We consider this trend, in which the dimensions are reduced without an accompanying reduction in performance, as very promising for future research.

Acknowledgements

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