Low depth $N \times N$ optical switches using a generalized Mach-Zehnder interferometer on a 2D/3D hybrid waveguide platform

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A fast, high fidelity, low loss optical switch is a key component in many proposals for both classical and quantum optical technologies. In quantum linear optics, spatial multiplexing is an important tool and typical requires $N \times 1$ switches [1], however *relative multiplexing* (RMUX) requires the use of $N \times N$ switches [2].

A generalized Mach-Zehnder interferometer (GMZ) can act as an $N \times N$ switch with an optical depth of just one phase shifter and $2\log_2 N$ balanced 2×2 couplers [1]. They are constructed from of an array of N phase shifters placed between a pair of balanced $N \times N$ couplers. These devices have been realized with $N \times N$ couplers made with multimode interference devices [3] but never with a decomposition into 2×2 couplers, as proposed in [1], despite such couplers being demonstrated in 3D femtosecond written waveguide structures [4].

Here we propose a hybrid approach for realizing such a GMZ using 3 modules (see Fig 1a) in which a pair of *coupler chips* sandwich a *phase shifter chip*. It is desirable for the phase shifter chip to have low propagation and coupling losses, and have fast switching times.

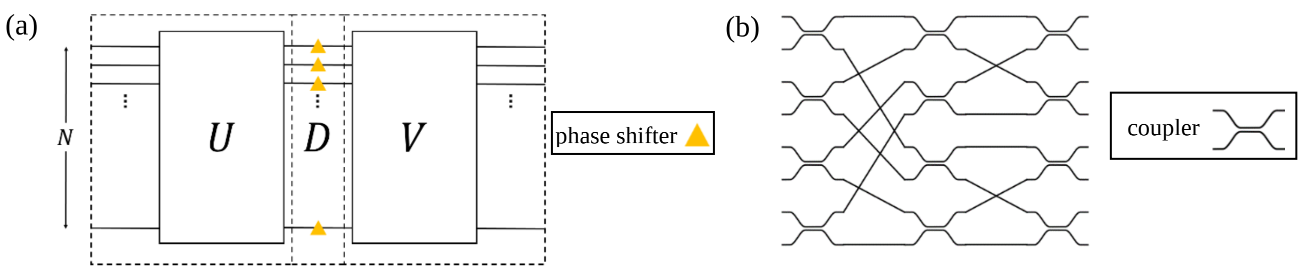

Figure 1: (a) An $N \times N$ GMZ made from 3 chips, U and V are the unitaries which describe the transformation of balanced coupler chips. We propose an implementation using 3D femtosecond waveguides. The phase shifter chip applies a diagonal unitary transformation, D. (b) An example of an FFT style 8×8 balanced coupler made from 3 layers of balanced 2×2 couplers. The complex interlayer permutations make 3D waveguide structures appealing for realizing these splitters.

When the number of modes, N, is a power of 2, a balanced coupler can be constructed using a decomposition inspired by the fast Fourier transform [5], shown in fig 1b. In this decomposition, none of the optical paths will interfere with themselves. This leads to an important advantage of this decomposition: internal phases, coming from differences in the optical path lengths, do not need to be matched for the coupler to remain balanced. Without any control over internal phases, we can still achieve *single route* $N \times N$ switching in a GMZ. By appropriately programming the phase shifters, any light coupled in to a given input mode will be completely routed to a given output mode. This is sufficient for RMUX. When the internal phases can be controlled, we can create GMZ devices which can implement a set of N, N mode permutations on the modes. The cyclic permutations can be implemented when the two coupler chip unitaries implement DFT_N and DFT_N^{-1} respectively. In this case, we can program any circulant unitary matrix. This comes from the standard result that DFT diagonalizes any circulant matrix.

In future work we plan to further investigate how the unitary transformation of the coupler chips affect the structure of the unitary matrices that the GMZ can implement. Experimental work is underway and progress will be reported at the conference. By using the full programmability of this device, it may find application for quantum photonics beyond switching, such as for multiphoton interference experiments.

References

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