Multicast 4x20 Silicon Photonic MEMS Switches
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Abstract: We report on monolithic 4x20 silicon photonic MEMS switches capable of multicast functions. The switch has small footprint (1.2x4.5mm²), low optical insertion loss (<4.0dB), fast switching (9.6µs). 1x2 and 1x4 multicasts were successfully demonstrated.

OCIS codes: (130.4815) Optical switching devices; (250.5300) Photonic integrated circuits

1. Introduction
Fast optical circuit switches (OCS) can provide reconfigurable high-bandwidth paths in datacenter networks. Previously, we have reported two high-port count (50x50) OCS using silicon photonic MEMS technology [1,2], the largest monolithically integrated OCS. Those switches, however, only provide one-to-one connections between input and output ports. In many applications that require high-bandwidth transmission from one source to multiple destinations, such as videoconference and video streaming, optical multicast switching is desired. Previous multicast switches with broadcast-and-select architecture have unnecessary high loss [3]. It is desirable to supply the input to just the selected set of output ports.

In this paper, we report on 4x20 multicast silicon photonic switch with variable switching ratios. The multicast switch uses the same architecture (passive crossbar) as our 50x50 switch [1,2], but the switching elements are replaced by continuously variable couplers. Instead of digital switching, we use continuously tunable directional couplers that can select any arbitrary switching ratios from 0 to 100%. In addition to the 1-to-1 switching, we also demonstrate 1x2 and 1x4 multicast operation on the 4x20 switch. Light is only delivered to the selected 2 (or 4) ports without wasting power in other ports. The isolation of non-selected ports is greater than 50 dB. The rise and fall times are 9.6 and 4.8 µs, respectively. The chip area is 1.2x4.5 mm², and the maximum on-chip propagation loss is 4.0 dB. In addition to datacenters, this analog switch also has applications in integrated quantum optical information processing [4].

2. Design and Simulation Results

Figure 1(a) shows the architecture of our silicon photonic MEMS switch. It consists of a 4x20 passive optical crossbar network with 80 MEMS-actuated variable couplers. At 0% coupling, light is passed on to the next cell with almost no loss (0.087 dB/cell). This is the “bar” state. At 100% coupling, light is redirected to the orthogonal waveguides through a pair of directional couplers. This is the “cross” state. With coupling ratio between 0 and 100%, partial light can be tapped to a selected set of waveguides. Figure 1(b) shows the optical micrograph of a unit cell with two variable couplers. Each variable coupler consists of a fixed and a movable waveguide. Both movable waveguides are attached to a MEMS electrostatic combdrive actuator, similar to [5]. Figure 1(c) shows the simulated transfer curve of the variable coupler. The power to the Drop port is changed by over 50 dB by moving the waveguide over a distance of 700nm, which can easily be achieved with combdrive actuators.
3. Fabrication and Experimental Results

The switch was fabricated on 220nm-thick silicon-on-insulator (SOI) wafers at Berkeley Marvell Nanolab. There are three main steps: (1) shallow etch (70nm) for patterning ridge waveguides, crossing, and grating couplers; (2) full etch that defines strip waveguides, variable directional couplers, and combdrive actuators; (3) metal lift-off. The combdrive has 44 finger pairs with 300 nm width and 400 nm spacing. The waveguide is 500 nm wide. All structures are patterned with a deep-UV stepper with 250 nm resolution. After fabrication, the actuators and the variable couplers are released by selective-etching the buried oxide in vapor HF. The size of the 4x20 switch chip is 1.2x4.5mm².

Figure 2(a) shows measured transfer characteristics of 17 unit cells. Maximum switching occurs at 9.7V with excellent uniformity across different switching cells. Figure 2(b) shows the measured insertion loss of different light paths. The loss per unit cell is extracted to be 0.087 dB from the slope of the linearly fitted line. The Y-intercept (1.38 dB) represents the switching loss of variable couplers and the propagation loss of the waveguide connections between the switch and the grating couplers. The on-chip loss for the longest path is 4.0 dB. Figure 2(c) shows the measured temporal response of the switch. Under-damped MEMS actuators usually exhibit ringing. We used a two-step voltage waveform to suppress the ringing. The rise and fall times of the switch were measured to be 9.6 μs and 4.8 μs, respectively.

Figure 3(a) shows image of the fabricated 4x20 switch array with red dotted lines denoting the light paths of the 1x2 multicast measurement. Light from the 4th input waveguide was split equally to the 19th and 20th output waveguides by adjusting the voltages of the actuators in <4,19> and <4,20> cells. The excess loss is 3.75 dB. The 1x4 multicast function is illustrated in Fig 3(b). The excess loss is 5.5 dB. The excess loss here can be lowered by separately controlling the two variable couplers in the same unit cell. The second variable couplers should be 100% for all selected cells. Currently, they have the same coupling ratios as the first couplers due to sharing of actuators.

4. References