Large-scale silicon photonic switches with movable directional couplers: supplementary material

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1. INSERTION LOSS MEASUREMENT METHOD

Figure S1(a) describes the measurement setup and the switch chip under testing. All input and output waveguides of the switch are routed to the grating couplers positioned at one edge of the chip to allow direct coupling with a fiber ribbon. We used a polarization-maintaining fiber ribbon polished at 13-degree angle, which was attached to an alignment stage capable of six-axis ($X, Y, Z, \theta_x, \theta_y, \theta_z$) motion for precise alignment. There were two pairs of back-to-back grating couplers: one pair at the outer edge and the other at the center of the grating coupler array. We used the outer pair for optical alignment and the center pair for characterizing the insertion loss of the grating couplers. The insertion loss was measured as 5.5 dB per grating.

The electrical connection to the actuators was provided by individual probes with 5- μm -radius tungsten tips. The switch chip was bonded on a carrier by indium, and the chip carrier was electrically grounded. Our fiber ribbon consists of a 1×24 array. To most efficiently test the large switch chip, we selected seven input, seven drop, and seven through waveguides for simultaneous measurement. Those waveguides were routed to grating couplers at the edge of the chip. The waveguides selected include the shortest and the longest paths. The measured insertion loss versus the optical path length (measured by the number of unit cells light passes through) is shown in Fig. S1(b). The insertion loss of the longest path, which includes 98 through-state cells and one drop-state cell, was 27.5 dB. By linear fitting, the insertion losses of through- and drop-states were extracted and their values were 0.253 dB (slope) and 2.47 dB (y -intercept), respectively, as shown in the graph.

To characterize the waveguide crossing loss, we fabricated a test structure with a large number of crossings. The measured insertion loss versus the number of crossings is shown in Fig. S1(c). By linear fitting, the loss per crossing was extracted as 0.038 dB.

2. FREQUENCY RESPONSE OF MEMS ACTUATOR

Figure S2 shows the measured frequency response of our MEMS actuator. We used a Laser Doppler Vibrometer (LDV) to measure the frequency response. Vertical movement of the actuator was measured while AC voltage with different frequencies were applied. The actuator showed maximum response at 163 kHz. The mechanical quality factor of the actuator was measured to be 2.19. The low-quality factor was mostly due to the air damping of the actuator, thus explaining the small ringing of the optical signal when the switch was turned on or turned off.

Fig. S1 (a) Switch chip on a chip carrier with fiber ribbon. (b) Insertion loss measurement of switch network. (c) Insertion loss measurement of waveguide crossing.

Fig. S2 Measured frequency response of the MEMS cantilever.