Broadband Compact Single-Pole Double-Throw Silicon Photonic MEMS Switch

(Student Paper)

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ABSTRACT

We demonstrate a photonic Single-Pole Double-Throw (SPDT) switch based on electrostatically actuated MEMS waveguides implemented in IMEC's ISiPP50G silicon photonics platform with custom MEMS release post-processing. An average Extinction Ratio (ER) > 23 dB is maintained over a 70 nm bandwidth with a peak ER of 25 dB at 1550 nm while an actuation voltage of 22 V is applied to the curved electrode electrostatic actuator of the device. A compact footprint of 30 µm × 60 µm and a low Insertion Loss (IL) allow for device integration in larger switch networks.

Keywords: Microelectromechanical Systems, Photonic Integrated Circuits, Silicon Photonics, Photonics

1. INTRODUCTION

An elementary, yet important function in Photonic Integrated Circuits (PIC) is the ability to actively switch and re-route optical signals on-chip. Switching in PICs is commonly implemented by exploiting the electro-optic, thermo-optic, or free carrier dispersion effect. However, since the magnitude of these effects is typically weak in silicon, conventional switches tend to occupy significant area or require bandwidth-limiting resonant photonic structures and exhibit significant power consumption, thereby prohibiting the scaling to very large PICs. In contrast, mechanically displacing waveguides is a physical mechanism for low-power and scalable approach for implementing photonic switches [1, 2]. Microelectromechanical systems (MEMS) technology provides a convenient means to obtain the desired mechanical translation. Previous demonstrations of large-scale silicon photonic MEMS switch networks exploiting multi-layer, out-of-plane actuated waveguides have shown scalability up to 240 × 240 in- and output ports [3].

Here we present an electrostatic, in-plane 1×2 silicon photonic MEMS switch with a Singe-Pole Double-Throw (SPDT) topology. The device is designed within IMEC's iSiPP50G silicon photonics platform and we make use of a custom post-processing step to provide freestanding MEMS waveguides [2]. This approach allows integration of the silicon photonic MEMS switch with a wealth of standard passive and active components such as low-loss waveguides, electrical wiring, modulators and high-speed detectors. Our device has a compact footprint and exhibits broadband behaviour making it suitable for inclusion in large-scale on-chip optical switch networks.

2. WORKING PRINCIPLE, DESIGN AND SIMULATION

SPDT switches are well known in the field of electronics for providing three states: (1) an OFF state, (2) input to a first output, and (3) input to a second output. Oberhammer et al. implemented a MEMS-based SPDT switch for electrical signals with three cantilevers moving in-plane under the influence of two curved electrodes, which provide an optimal force-to-size balance [4]. Here we introduce the photonic equivalent of the SPDT switch: as shown in Fig. 1a), the "single-pole" refers to the one physically movable input waveguide and the "double-throw" is represented by the two static output waveguides. The movable waveguide is anchored on its left side and is free to move in-plane under the influence of an applied actuation voltage to the top or bottom electrodes. Mechanical stoppers limit the maximum deflection of the input to prevent pull-in of the MEMS actuator. The anchors are designed to minimize optical losses when transiting from the suspended air-clad waveguide region to the fully oxide-clad region. The coupling regions on each waveguide (i.e., free ends) are adiabatically tapered to reduce coupling length and achieve broadband behaviour. In the OFF state, the input waveguide is separated by a 400 nm gap from either output waveguide and residual power coupling is equally split between the two outputs. After actuation, the gap between the input and the respective output decreases while the complementary gap increases, thereby transferring power to one branch only. Optical simulations Fig. 1b) confirm efficient power transfer from the input to the first output while keeping the optical mode well confined.

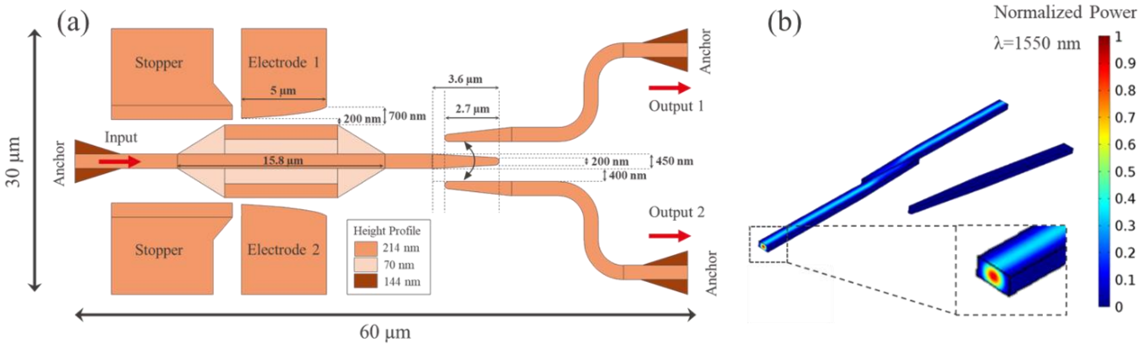

Figure 1. a) Geometry of the MEMS-based photonic SPDT switch exhibiting a compact footprint (dimensions not to scale), and b) optical simulation showing efficient power transfer from the input waveguide to output 1.

3. FABRICATION

The silicon photonics structures are fabricated in IMEC's iSiPP50G technology and the MEMS release process is performed at EPFL at the Center of MicroNanoTechnology (CMi). The release employs a previously demonstrated process sequence of protective alumina layer deposition, etch window opening, and vapour-phase HF sacrificial oxide etch [2]. An optical microscope image of the chip area showing the switch, the grating couplers serving as optical interfaces, the electrical metal wiring (to electrical contact pads outside of the visible area), as well as the opening in the alumina passivation is provided in Fig.1a). The metal ring, which partially obstructs the view of the underlying waveguide routing is implemented in the final top-metallization and is intended for a later sealing step of the MEMS not used here. Figure 2b) shows an SEM image of the final, released device with the suspended input waveguide well centred between the two output waveguides.

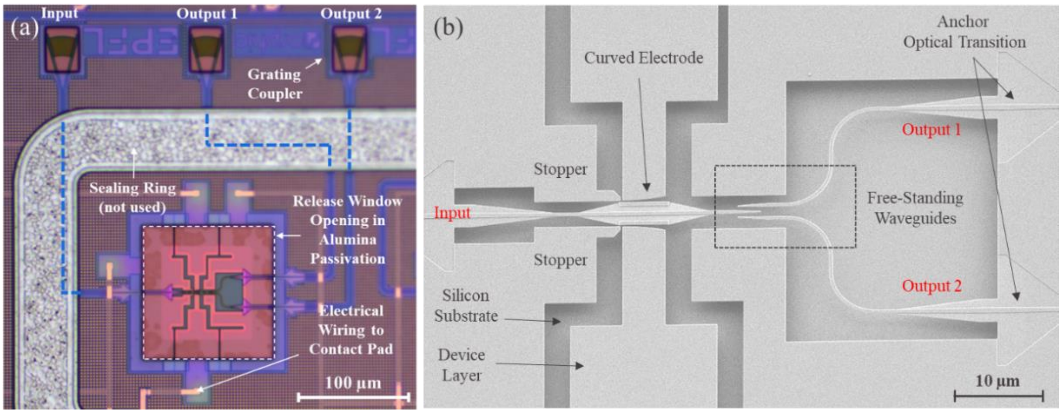

Figure 2. a) Optical microscope image showing an overview of the device, including grating couplers, electrical wiring and MEMS release window opening. b) SEM image of the released optical SPDT switch, highlighting the freestanding silicon waveguides, curved electrostatic actuation electrodes, and mechanical stoppers.

4. EXPERIMENT

Characterization is performed using a tuneable wavelength laser that is connected to a fibre array, which couples light into and out of the chip by means of the on-chip grating couplers shown in Fig. 2a). Power transmission to the two output ports is read using photodetectors and is recorded for a wavelength sweep from 1510 nm to 1580 nm. Electrical probe tips allow for the application of an actuation voltage in the range of 0 to 22 V to contact pads wired on-chip to either electrode 1 or electrode 2 to produce the desired actuation.

As shown in Fig. 3, when no actuation voltage is applied, passive power coupling is observed in both waveguides. The amount of coupled residual power can be designed by appropriate distance and direction of the coupling waveguides. Under ideal conditions, the power split should be even, however, we observe a difference of typically 3 dB in residual power coupled to the two output ports. We attribute this disparity to differences in the mechanical boundary conditions at the anchor points after release that cause the input waveguide to bend preferentially to output port 1 without any applied voltage. In addition, there may also be loss variations in the optical path between the two outputs related to the transitions or grating couplers. Such asymmetry also provides an explanation as to why the power transfer to the active port is not exactly the same for the two ON states. By increasing the applied voltage on electrode 1 or 2, the input waveguide is electrostatically pulled towards the respective output port where most of the power is transferred through direct coupling. Removing the actuation voltage allows the input waveguide to return to its initial state and by applying an actuation voltage to the opposite electrode, the power transfer characteristic is reversed.

Measurements indicate excellent broadband behaviour, as indicated by an average ER > 23 dB that is maintained over almost the entire wavelength sweep of 70 nm for both actuation states. We observe an ER of 25 dB at 1550 nm, the central wavelength for which this device has been designed to operate. Simulations predict an IL of less than 0.1 dB, yet measurements of such low insertion loss proved not reliable with our measurement setup due to variations in the coupling of the fibre array to the grating couplers.

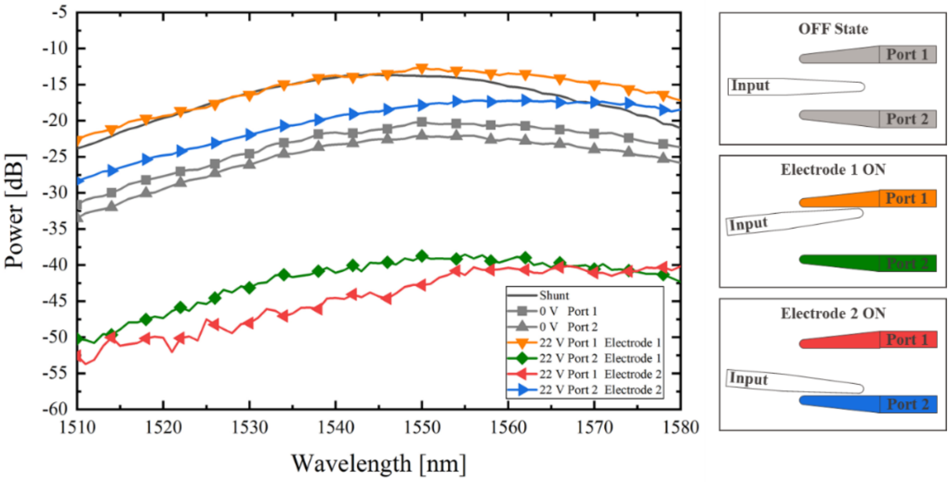

Figure 3. Transmission spectrum of the Silicon Photonic MEMS Single-Pole Double-Throw switch for the respective OFF, and the two ON states, redirecting the light to either output 1 or output 2.

5. CONCLUSION

We present the design, fabrication, and characterization of a novel SPDT Silicon Photonic MEMS switch in an established silicon photonics platform with custom MEMS post-processing. The device can transition between three distinct states by applying an actuation voltage of 22 V to generate an electrostatic force that induces mechanical modulation of the coupling behaviour between input and output waveguides. The device exhibits > 23 dB ER over a 70 nm bandwidth and an ER of 25 dB at the designed 1550 nm wavelength for both ON states. The IL, although not definitively quantifiable in the current experimental setup due to non-uniformity in the grating couplers is expected to be very low from simulations and initial qualitative measurements. As demonstrated, the unique SPDT topology allows this device to be used as a digital switch to completely redirect optical power from the input to either output port. This device could also potentially be used as an analog power coupler to vary the power distribution between the input and output ports by applying intermediate voltages between 0 and 22 V. Overall, the broadband and compact characteristics of our switch, combined with the high ER and low IL, make it a promising new component for large-scale on-chip photonic switch networks.

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REFERENCES

[1] C. Errando-Herranz, A. Y. Takabayashi, P. Edinger, H. Sattari, K. B. Gylfason, and N. Quack, “MEMS for Photonic Integrated Circuits,” IEEE Journal of Selected Topics in Quantum Electronics, vol. 26, no. 2, pp. 1–16, Mar. 2020, doi: 10.1109/JSTQE.2019.2943384.

[2] N. Quack et al., “MEMS-Enabled Silicon Photonic Integrated Devices and Circuits,” IEEE Journal of Quantum Electronics, vol. 56, no. 1, pp. 1–10, Feb. 2020, doi: 10.1109/JQE.2019.2946841.

[3] T. J. Seok, K. Kwon, J. Henriksson, J. Luo, and M. C. Wu, “Wafer-scale silicon photonic switches beyond die size limit,” Optica, OPTICA, vol. 6, no. 4, pp. 490–494, Apr. 2019, doi: 10.1364/OPTICA.6.000490.

[4] J. Oberhammer, M. Tang, A. Q. Liu, and G. Stemme, “Mechanically Tri-Stable In-Line Single-Pole-Double-Throw All-Metal Switch,” in 19th IEEE International Conference on Micro Electro Mechanical Systems, 2006, pp. 898–901, doi: 10.1109/MEMSYS.2006.1627945.