Photonic Devices for Future Network Designs

Designing a Silicon Photonic MEMS Phase Shifter with Simulation

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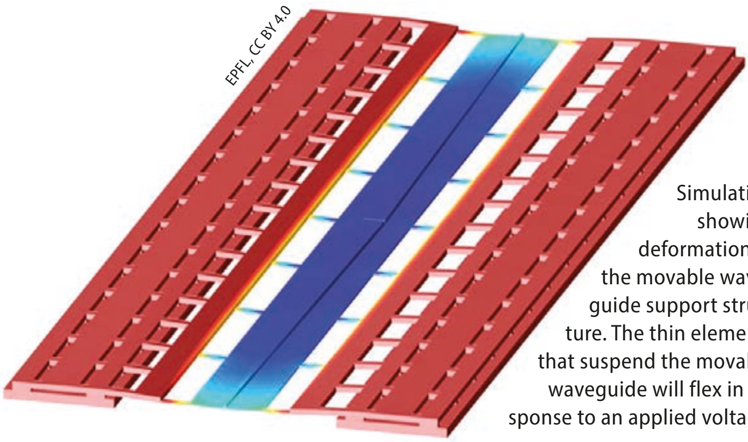
Optical fiber networks, which make up the backbone of the internet, rely on many electrical signal processing devices. Nanoscale silicon photonic network components, such as phase shifters, could boost optical network speed, capacity, and reliability. To design these small but powerful devices, a team at the Swiss Federal Institute of Technology Lausanne uses simulation to optimize both optical and electromechanical performance.



Simulation showing deformation of the movable waveguide support structure. The thin elements that suspend the movable waveguide will flex in response to an applied voltage.

The modern internet-connected world is often described as wired, but most core network data traffic is actually carried by optical fibers – not electric wires. Despite this, existing infrastructure still relies on many electrical signal processing components embedded inside fiber optic networks. Replacing these components with photonic devices could boost network speed, capacity, and reliability. To help realize the potential of this emerging technology, a multinational team at the Swiss Federal Institute of Technology Lausanne (EPFL) has developed a prototype of a silicon photonic phase shifter, a device that could become an essential building block for the next generation of optical fiber data networks.

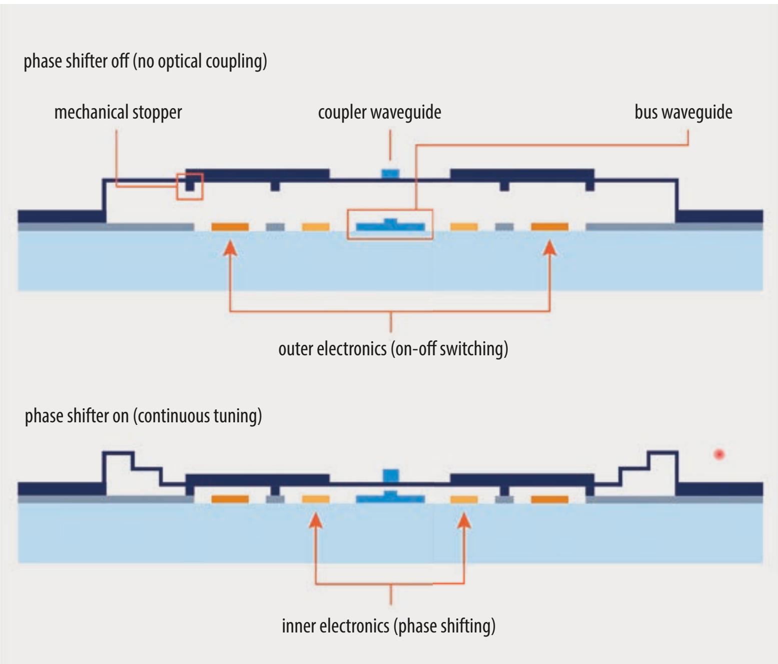


Fig. 1 Two stages of motion for the MEMS mechanism in the phase shifter

Lighting as a path

Using photonic devices to process photonic signals seems logical, so why is this approach not already the norm? Hamed Sattari, an engineer currently at the Swiss Center for Electronics and Microtechnology (CSEM) specializing in photonic integrated circuits (PIC) with a focus on microelectromechanical system (MEMS) technology, was a key member of the EPFL photonics team that developed the silicon photonic phase shifter [1, 2]. In pursuing a MEMS-based approach to optical signal processing, Sattari and his colleagues are taking advantage of a new and emerging fabrication technology. "Even ten years ago, we were not able to reliably produce integrated movable structures for Silicon photonics and MEMS are becoming more achievable with the current manufacturing

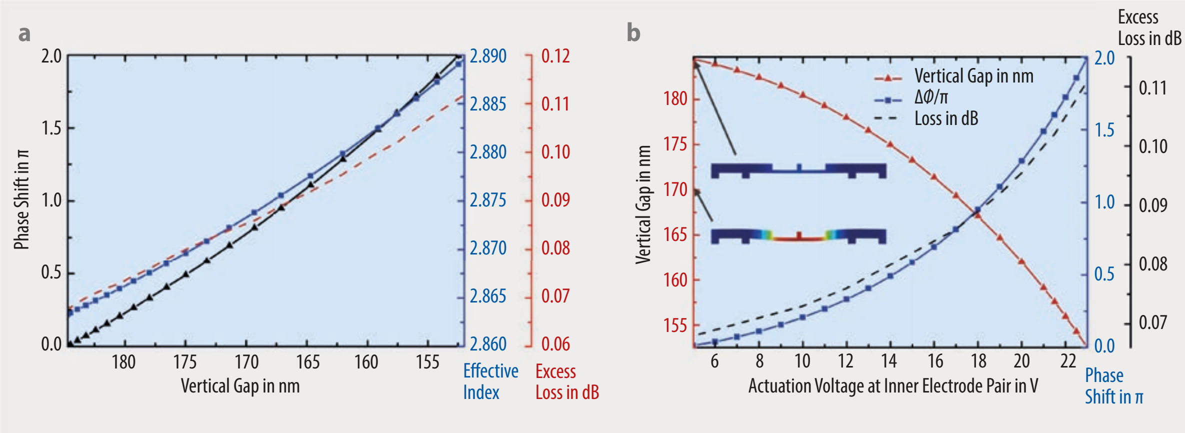


Fig. 2 The optical simulation established the vertical distance between the coupler and waveguide that would result in a desired phase shift in the optical signal (a). The electromechanical simulation determined the voltage which – when applied to the MEMS mechanism – would move the coupler waveguide to the desired distance from the bus (b).

capabilities of the microelectronics industry. This might transform the optical fiber network infrastructure.

The phase shifter design project is part of EPFL's broader efforts to develop programmable photonic components for fiber optic data networks and space applications. These devices include switches, chip-to-fiber grating couplers, variable optical attenuators (VOAs), and phase shifters, which modulate optical signals. For this application, existing optical phase shifters tend to be bulky or suffer from signal loss. MEMS actuation of movable waveguides could modulate an optical signal with low power consumption in a small footprint.

How to modulate optical signals

The MEMS phase shifter is a sophisticated mechanism with a deceptively simple-sounding purpose: It adjusts the speed of light. To shift the phase of light is similar to slow it down. When light is carrying a data signal, a change in its speed causes a change in the signal. Rapid and precise shifts in phase will thereby modulate the signal, supporting data transmission with minimal loss throughout the network. To change the phase of light traveling through an optical fiber conductor, or bus waveguide, the MEMS mechanism moves a piece of translucent silicon called a coupler into close proximity with the bus.

The design of the MEMS mechanism in the phase shifter offers two stages of motion (**Fig. 1**). The first stage provides a simple on-off movement of the coupler waveguide, thereby engaging or disengaging the coupler to the bus. When the coup-

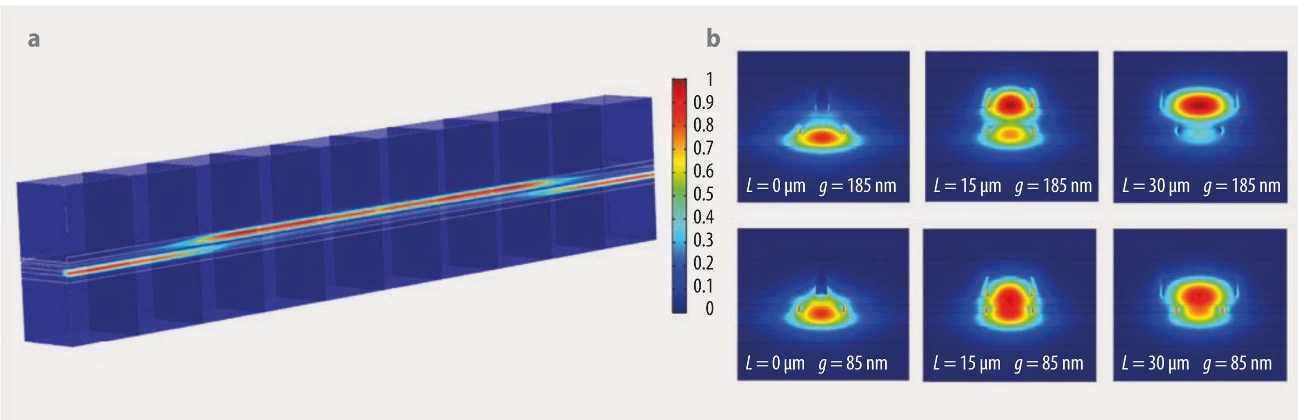


Fig. 3 Light passes from left to right through a path composed of an optical bus and a coupled movable waveguide (a). The cross-sectional slices of a simulated light waveform as it passes through the coupled device show that, by adjusting the distance between the two optical elements in their simulation, the EPFL team could determine how that distance affected the speed, or phase, of the optical signal (b).

ler is engaged, a finer range of motion is then provided by the second stage. This enables tuning of the gap between the coupler and bus, which allows precise modulation of phase change in the optical signal (**Fig. 2**). The coupler is made from silicon with a high refractive index. When the two components are coupled, a light wave moving through the bus will also pass through the coupler, and the wave will slow down. If the optical coupling of the coupler and bus is not carefully controlled, the light's waveform can be distorted, potentially losing the signal – and the data.

Designing at nanoscale

The challenge for Sattari and his team was to design a nanoscale mechanism to control the coupling process as precisely and reliably as possible. As their phase shifter would use electric current to physically move an optical element, Sattari and the EPFL team took a two-track approach to the device's design. Their goal was to determine how much voltage had to be applied to the MEMS mechanism to induce a desired shift in the photonic signal. Simulation was an essential tool for determining the multiple values that would establish the voltage versus phase relationship. To solve this complex multiphysics problem, the COMSOL Multiphysics® software provided many options for breaking the large problem into smaller tasks. The EPFL team conducted simulations in two parallel arcs, using the RF Module for optical modeling and the Structural Mechanics Module for electromechanical simulation.

The optical modeling (**Fig. 3**) included a mode analysis, which determined the effective refractive index of the coupled waveguide elements, followed by a study of the signal propagation. The light was to enter and exit the device with only the desired change in its phase. Thus, the team determined the eigenmode of the system in COMSOL®.

Along with determining the physical forms of the waveguide and actuation mechanism, simulation also enabled Sattari to study stress effects, such as unwanted deformation or displacement caused by repeated operation. Every decision about the design is based on the simulated results.

Adding to the foundation

The goal of this project was to demonstrate how MEMS phase shifters could be produced with existing fabrication capabilities. The result is a robust and reliable design that is achievable with existing surface micromachined manufacturing processes, and occupies a total footprint of just 60 µm × 44 µm. Now that they have an established proof of concept, Sattari and his colleagues look forward to seeing their designs integrated into the world's optical data networks. The building blocks created for the future will soon show their potential.

[1] *H. Sattari* et al., Optics Express **27**, 18959 (2019)

[2] *T. J. Seok* et al., Optica **3**, 64 (2016)

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