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Mach-Zehnder interferometric optical switch using MEMS phase shifter

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***Abstract*-We propose a novel type Mach-Zehnder interferometric optical switching device using micro-electro mechanical systems (MEMS) as a phase shifter.**

As the analytical result, the amount of stretch length is 70nm at the applied voltage of 60 V per one phase shifter. The π–shift is achieved using cascade connections of 4-7 shifters.

I. INTRODUCTION

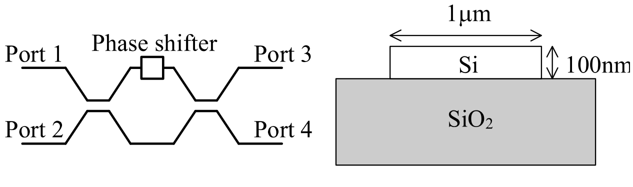
Optical cross-connect switches are very important for optical fiber communications. Typical optical switches have an OE/EO converter. However, a switching delay and power consumption become a problem in OE/EO converter. All-optical switching is attractive to solve the problems. In particular, the optical switch integrated with waveguides has been studied intensively.

Silicon-on-insulator (SOI) waveguides are very promising for realizing dense photonic integrated circuits [1]. The large refractive index difference between the silicon layer and the oxide layer provided high optical confinement. Mach-Zehnder interferometric SOI optical switches with thermo-optic (TO) phase shifter have been reported [2],[3]. Phase shift with TO effect is obtained to change the refractive index in the waveguide by using a thin film heater. This switch has low switching speed and high power consumption.

In this paper, we propose a novel type of the optical switching device with micro-electro mechanical systems (MEMS) phase shifter. SOI waveguides are also suitable for MEMS device because silicon has good mechanical characteristics.

II. MEMS PHASE SHIFTER

Figure 1(a) shows the 2×2 Mach-Zehnder interferometric optical switch integrated with the MEMS phase shifter. The cross-sectional silicon optical waveguide of 1μm × 100 nm was designed for single-mode propagation (Fig.2 (b)).



(a)MZ optical switch (b) Cross-sectional view of Si waveguide

Fig. 1 Mach-Zehnder interferometric optical switch.

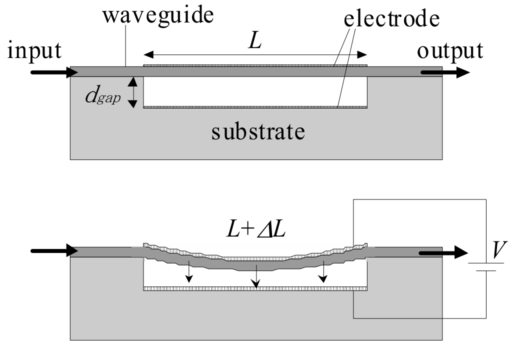


Fig. 2 The mechanism of the MEMS phase shifter.

The schematic mechanism of MEMS phase shifter is shown in Fig. 2. The phase shift in this MZ interferometer is caused by the control in the length of the waveguide. The waveguide of MEMS phase shifter region has an air-bridge structure for movable waveguide. When voltage is applied between the air-bridge waveguide and the substrate, the bridge is bended and stretched by electrostatic attractive force. The optical path lengths for input light are controlled by applied voltage. Therefore, this structure is available as the phase shifter. Moreover, the low power consumption can be expected by using this phase shifter because the steady current doesn't flow at ON state.

III. MEMS MODELING

We simulated the MEMS phase shifter performance to use an approximation model in the waveguide stretching. Figure 3 shows the approximation model of the waveguide under the applied voltage. A fixed-fixed beam as the MEMS phase shifter can be regarded as a parallel-plate capacitor. The electrostatic attractive force between the parallel-plate is expressed as,

$$F_e(z) = -\frac{\varepsilon L V^2}{2z^2}$$

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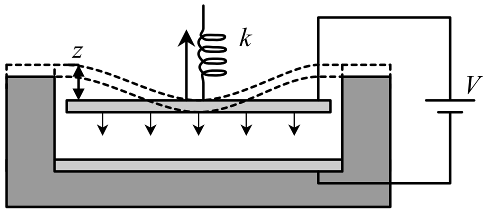

Fig. 3 The approximation model of the waveguide bridge.

where, ε is dielectric constant, L is the bridge length, V is the applied voltage.

The waveguide bridge is replaced with a plane electrode that is sustained by a spring. The spring force is a replacement of the restoring force of the bridge. The restoring force $F_r(z)$ and a spring constant k is expressed as,

$$F_r(z) = kz, \qquad k = -\frac{384Y^E I}{L^3}$$

where, Y^E is the Young's modulus, I is the Geometrical moment of inertia.

An amount of deflection z_{max} was determined from the balance between the above forces ($F_e(z_{max})=F_r(z_{max})$).

IV. ANALYTICAL RESULTS

The size of the bridge architecture in this analysis was L-mm-long, 100-nm-thick and 1-μm-wide. The air-gap between the bridge and the substrate was 4μm.

Figure 4 shows the bridge deformation distribution under applied several voltages at 30 μm-long bridge. The amount of deflection was increased with the increasing voltage. The deflection of 1μm was obtained at applied voltage of 100V.

Figure 5 shows the applied voltage dependence of the stretch length of the bridge. The maximum stretch length was longer with increasing bridge length. However, the high voltage was needed in deflection at short length bridge. The maximum stretch length of 60-100 nm was obtained.

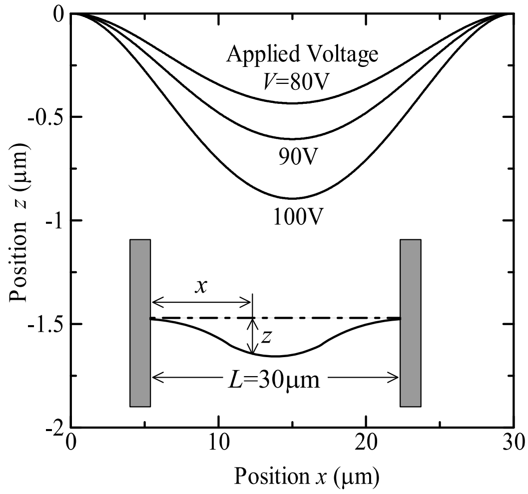

Fig. 4 The deformation distribution of the bridge under the applied voltage.

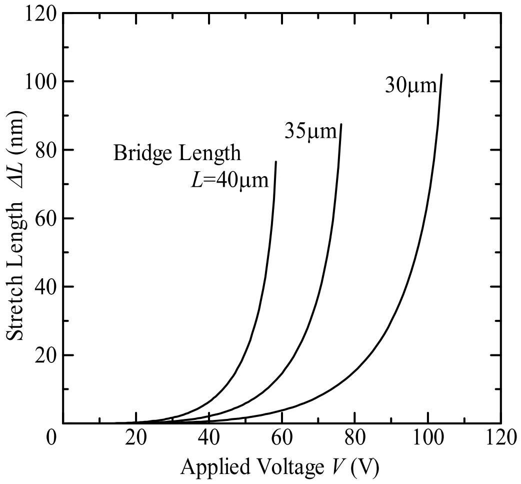

Fig. 5 The applied voltage dependence of the stretch length.

An optical path difference needed to π-phase shift was estimated. An equivalent refractive index n_{eq} was 2.0. The estimated optical path difference was 388 nm at wavelength of 1.55 μm. Therefore, the π-shift was achieved by the serial connection of 4-7 phase shifter sections.

V. SUMMARY

We proposed and simulated the novel type MZ interferometric optical switching device with the MEMS phase shifter. The phase shift of π was obtained by cascade connection of 4-7 phase shifters. This switching device is very promising for the realization of low power consumption photonic integrated circuits.

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