

# A compact silicon nano-wire waveguide optic switch

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**Abstract:** Based on silicon nano-wire waveguides, a compact Mach-Zehnder interferometer type optic switch was demonstrated through thermo-optic effect. The maximum extinction ratio was 20-dB, and the switching speed reached 0.1-ms.

## 1. Introduction

A compact optic switch, as one of the most fundamental devices used in optic-electronic circuits, is always demanded by the development of the optical network systems, especially of the future photonic network systems. On the other hand, silicon photonics is now attracting more and more attentions due to the monolithic integration of optic and electronic devices, in addition to the device processing compatibility and the cost [1,2]. Further more, silicon nano-wire waveguide is considered as one promising platform in constructing optical devices [3-6]. Because of the large refractive-index-difference of silicon core ( $n=3.5$ ) and the cladding materials of silica ( $n=1.5$ ) or air ( $n=1$ ), silicon waveguide can provide strong light confinement, which greatly benefits the small (several-micrometers) bending radius of the devices and further achieves device compactness.

Here, we demonstrate for the first time a compact thermo-optic switch based on silicon nano-wire waveguides. We introduce the silicon nano-wire waveguide optic switch on its structure, fabricating processes and the optical characteristics we measured.

## 2. Structure and Fabrication

The silicon nano-wire waveguide optic switch was a Mach-Zehnder (MZ) interferometer type switch controlled through thermo-optic effect, as shown in Fig. 1. The switch was composed with two 40- $\mu\text{m}$ -long MZ interferometer branches, which were connected with two Y-splitters used for 3-dB couplers. The MZ interferometer branches and the Y-splitters were all made of silicon nano-wire waveguides with a  $0.3 \times 0.3\text{-}\mu\text{m}^2$  cross-sectional size. Over the two MZ branches, two micro-heaters were arranged for thermal controlling. One heater was active with a 26- $\Omega$  ohmic-resistance and was connected with electrode pads, while the other heater was a dummy one for constructing structure symmetry of the MZ interferometer branches. In

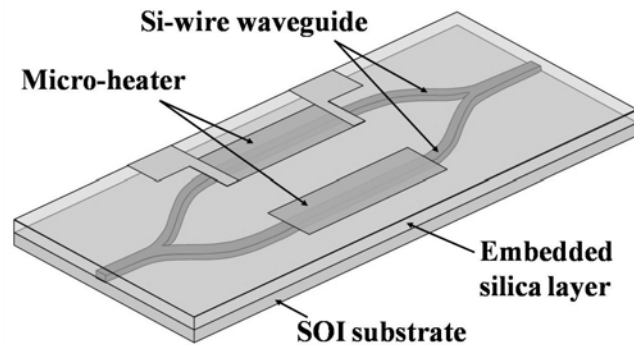


Fig. 1, Structure of Si nano-wire waveguide switch.

switching operation, the heating of the active heater, which could create temperature difference of 0~120-K between the two MZ interferometer branches, changed the refractive index of the silicon waveguide through thermo-optic effect, and further shifted the phase of the light-wave propagating through to achieve optic switching.

The silicon nano-wire waveguide switch was fabricated on a silicon-on-insulator (SOI) wafer with a 0.3- $\mu\text{m}$ -thick top silicon layer and a 1- $\mu\text{m}$ -thick buried-oxide (BOX) layer on a silicon substrate. In fabrication, the top silicon layer of the SOI wafer was at first patterned with electronic beam lithography to form the waveguide structure. Then, the silicon layer except the waveguide area was etched down to the BOX layer with an inductively coupled plasma (ICP) dry etcher. This waveguide-only structure was effective in isolating the heat diffusion for building the temperature difference between the MZ interferometer branches, due to the high thermal conductivity of silicon. Next, a 1- $\mu\text{m}$ -thick silica layer was embedded over the device patterns formed in silicon layer. Finally, metal thin-film heaters, together with gold electrode pads were sputtered on the MZ interferometer branches. Fig. 2 shows a microscopy view of the silicon nano-wire waveguide optic switch we fabricated. The device size was about  $160 \times 65 \mu\text{m}^2$ , excluding two electrode pads. The device length was about one order of magnitude shorter than semiconductor-based optic switches reported before [7].

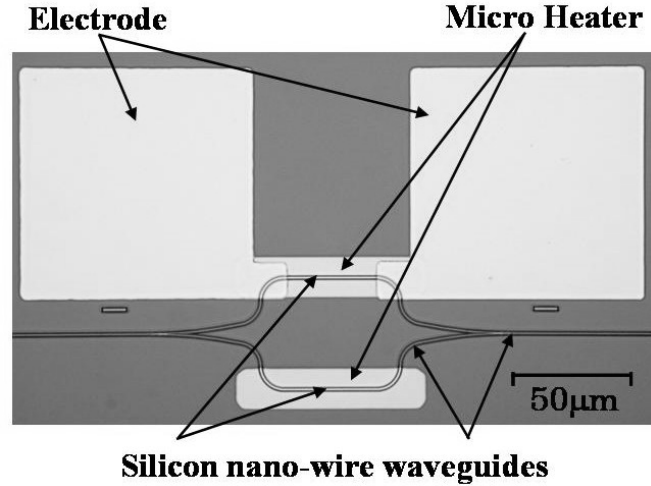


Fig. 2, Microscopy view of Si nano-wire waveguide optic switch we fabricated.

### 3. Measurements

The silicon nano-wire waveguide optic switch was measured with a tunable laser source and an optical spectrum analyzer. Two tapered optical fibers were used for coupling light into/from the end facets of silicon nano-wire waveguides, one for coupling incident light and the other one for collecting output light signal. A DC power supply was used to turn the heating current of the micro-heater.

At 1550nm, the extinction-ratio dependence of heating power of the optic switch was measured with TE/TM (electric-field vector parallel/perpendicular to the substrate) incident light, as plotted in Fig. 3. The data was normalized based on the minimum loss of about 15-dB of TM light, which included the total fiber coupling loss of about 14-dB. The maximum extinction-ratios were about 20-dB for TM light and 13-dB for TE light, respectively. The output peak at 20-mW-heating-power was arising from the inherent light-phase-difference due to the structure unbalance of MZ interferometer branches, which was not compensated sufficiently by the dummy heater. Ignoring

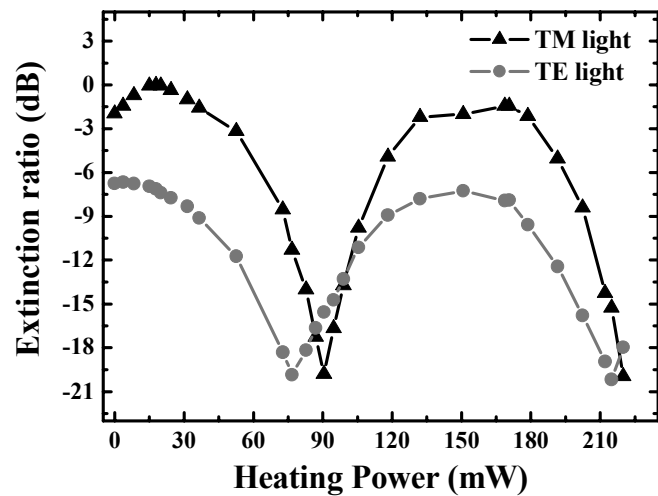


Fig. 3. Switching characteristics of Si nano-wire waveguide optic switch.

the heating power used for compensating this inherent light-phase-difference, the necessary switching power was estimated to be about 70-mW.

Fig. 4 shows obtained maximum extinction ratio plotted against wavelength under a fixed heating power. The switching bandwidth of obtaining more than 20-dB extinction ratio was about 20nm for TM light. The maximum extinction ratio obtained at 1545-nm indicated that the same extinction ratio should be obtained in measurement showed in Fig. 3, if the heating power could be adjusted finely.

The switching response speed was measured with a pulse current source. As showed in Fig. 5, the switching on/off speeds were both proximately estimated to be 0.1 ms, which was could be expected to be used in photonic network systems.

#### 4. Conclusions

Based on silicon nano-wire waveguides, a compact Mach-Zehnder interferometer type optic switch was for the first time demonstrated through thermo-optic effect. The maximum extinction ratio obtained presently was 20-dB and 13-dB at 1550-nm for TM/TE light, respectively. The necessary switching power was about 70-mW. The optical switching on/off speeds reached 0.1-ms. Further improvements in device performances are highly expected by improving device fabricating accuracy and optimizing the device structure.

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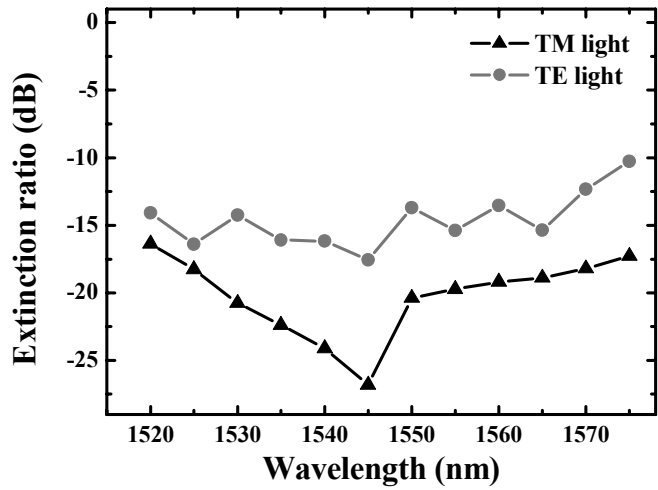


Fig. 4. Bandwidth of Si nano-wire waveguide switch

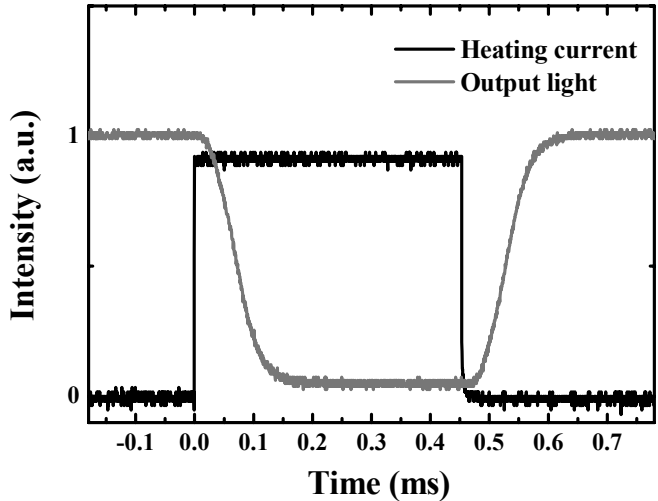


Fig. 5. Response of Si nano-wire waveguide switch