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MEMS Optical Switches Using Slot Ring Resonator for Low Voltage Operation

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Abstract

We have improved the MEMS optical device using slot ring resonator for low voltage operation. From the simulation, more than 10 dB extinction ratio at low voltage 0.2 V are estimated by improving the waveguide width. We also succeed in the improvement of quality factor (from 6400 to 14000) and the switching operation with the extinction ration of 2 dB at 10 V.

1. Introduction

Silicon photonics devices have been applied to optical interconnection of chip-to-chip and moreover to inside of large-scale integration (LSI) chip. The structure of ring resonator is used for optical modulator, wavelength filter device and so on, where the resonance wavelengths are changed by some mechanisms: carrier-plasma effect [1,2], thermo-optic effect [3], etc. We have investigated the other type device where the operation mechanism is physical and mechanical [4]. This is well known as Micro-Electro-Mechanical-Systems (MEMS) but generally device size is large and operation voltage is relatively high [5], while low voltage of less than 1 V is necessary for optical interconnection in LSI chip. For this purpose, we originally propose the slot-ring resonator type MEMS optical device with narrow slot width shown in Fig. 1. By an electrostatic force, waveguides are deformed and the slot width is changed shown in Fig. 2. This change causes an effective refractive index and also a resonance wavelength change. Input light is switched and output optical intensity is modulated. In this device, device size is small for the structure of ring resonator and low-voltage operation is expected because of large refractive-index difference between 3.48 for silicon and 1.00 for air, while the difference in a carrier-plasma effect is an order of 10^{-2} when the carrier concentration is 10^{19} cm^{-3}.

In previous study, we investigated the proposed device where the slot waveguide width of one side is fixed to be 500 nm and the lithography processes are not optimum [4]. The measurement result of extinction ration was low (0.5 dB at 10 V). In this study, waveguide width dependence of extinction ratio is evaluated and lithography processes are improved for the further high performance.

2. Experimental

For the estimation of the voltage dependence of extinction ratio, the effective refractive index of slot waveguide is simulated and the deflection of slot waveguide Δd by applied voltage is calculated. The simulation is curried oud using the finite difference method (FemSIM, RSoft Design Group). In this simulation, the cross-sectional device structure is shown in Fig. 3. The slot waveguide width of one side, slot width, central rib height and thickness of the slab layer are 150-500 nm, 50 nm, 300 nm and 50 nm, respectively. The voltage dependence of the deflection of slot waveguide is calculated where the proposed device is approximately set to be a double-clamped beam structure.

The proposed device was fabricated using silicon-on-insulator wafer. Waveguides and slot ring resonators were formed by electron-beam (EB) lithography and reactive ion etching. For a narrow slot width, variable-shaped beam EB lithography is changed to point beam EB lithography (the slot width was 150 nm in the previous processes). For the reduction of the sidewall roughness of waveguides and high quality factor, positive-tone resists are changed to negative-tone resists. Al electrodes were formed by sputtering, maskless UV lithography and wet-etching. The lower SiO_2 layer was selectively etched by HF solution and the beam structure was formed. Optical measurements were carried out using an infrared tunable semiconductor laser (1480-1540 nm) and an InGaAs photo-detector.

3. Results and Discussion

Simulation for Extinction Ratio

The simulated effective refractive index change of slot waveguide is shown in Fig. 4(a) for 1 nm slot width change when the slot width is 50 nm. The largest point of waveguide width is ~250 nm and the effective index change is > 4×10^{-3} per 1 nm. This change is obtained at less than 1 V of applied voltage, which is found from Fig. 4(b) where the length l between clamped points is fixed at 10 μm. Here, mean values are plotted because the deflection of the slot waveguide is different at each position. The extinction ratio is estimated from these results. Figure 5 shows that more than 10 dB extinction ratio is obtained at low voltage 0.2 V where the quality factor is set to be realistic value 15000. The difference between the values of 250 nm and 150 nm is small, because the mean deflection of 150 nm is larger than that of 250 nm while the effective index change of 150 nm oppositely becomes small compared with that of 250 nm.

Switching Measurement

For the easiness of a fabrication and high extinction ratio, we fabricated the device with waveguide width 250 nm. The fabrication of narrow slot width less than 50 nm is succeeded. Figure 6 shows the typical example of scanning electron micrograph image. The resonance characteristics of the fabricated device is shown in Fig. 7. The maximum values of quality factor are improved to be 14000 (in the previous device, the quality factor is 6400 [4]). The measurement result of the switching behavior is shown in Fig. 8. The extinction ratio is 2 dB at 10 V which is improved from 0.5 dB of the previous value. The considerable reasons for low extinction ratio compared with the simulation result are a carrier-trap in the uncovered sidewall of waveguide, existence of lower cladding layer by ununiformity of etching process and so on.

4. Conclusions

We have investigated the performance of the MEMS optical device for low voltage operation. From the simulation, more than 10 dB extinction ratio at low voltage 0.2 V are estimated when the slot waveguide width is ~250 nm. We succeed in the fabrication of the proposed device structure and the switching operation with extinction ration of 2 dB at 10 V. This low extinction ratio is originated from defectiveness of etching process and so on. The optimization of fabrication process is necessary for further high performance.

Acknowledgements

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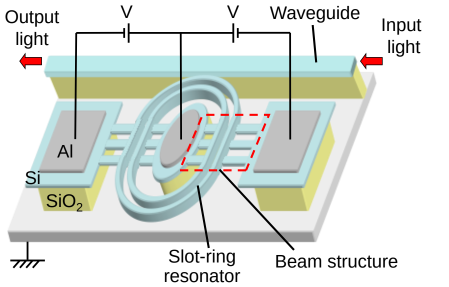

Fig. 1. Schematic structure of the proposed MEMS optical device, where SiO_2 layer below slot waveguide is removed.

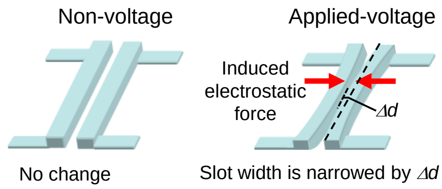

Fig. 2. Operation mechanism. Applied voltage induces an electrostatic force, and slot width is narrowed.

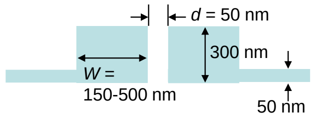

Fig. 3. Simulation condition of cross-sectional structure for the proposed device.

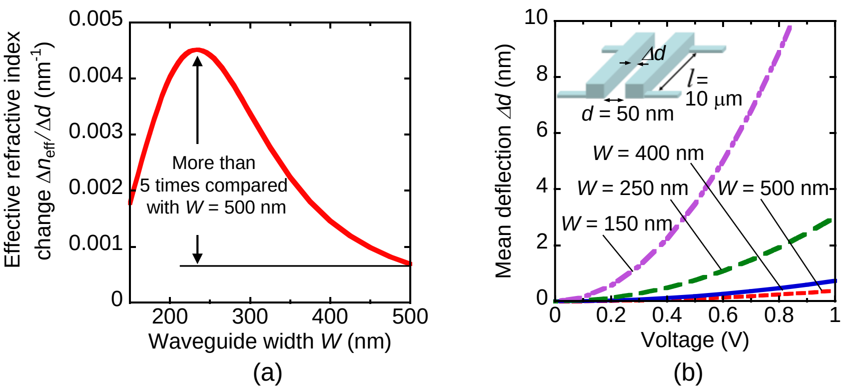

Fig. 4. (a) Simulated effective refractive index change and (b) voltage dependence of mean deflection of slot waveguide where the slot width is 50 nm and the length l between clamped points is 10 μm.

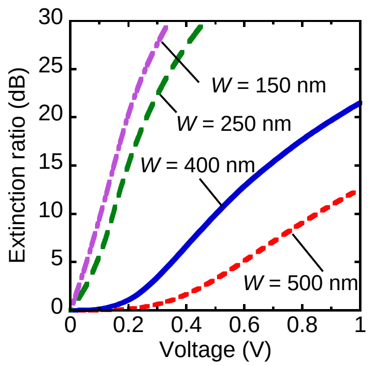

Fig. 5. Simulated voltage dependence of extinction ratio where the quality factor is assumed to be 15000.

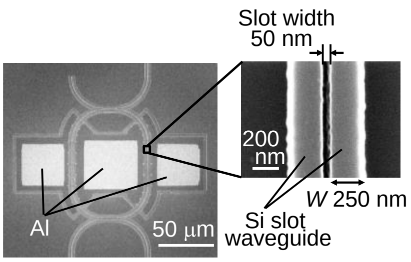

Fig. 6. Typical example of scanning electron micrograph (SEM) image of the fabricated device.

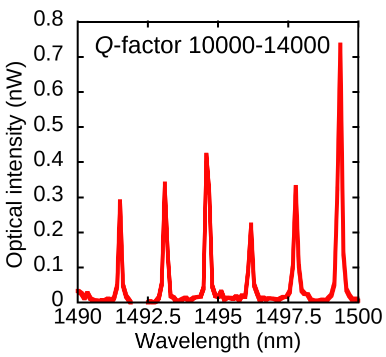

Fig. 7. Resonance characteristics of the fabricated device where the waveguide width is 250 nm and the slot width is 50 nm.

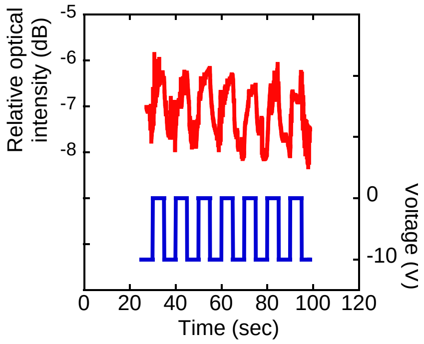

Fig. 8. Switching behavior of output light by applied voltage.