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Study on Silicon Optical Switch with T-Shape SiO_2 Waveguide as an Optical Control Gate

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1. Introduction

Optical switches and optical modulators are basic components for silicon microphotonics applications. Silicon-on-insulator optical waveguide with MOS structure for the electrical transmission control [1] and optically controllable optical switch have already proposed. We here report simulation results for a silicon optical switch with T-shape SiO_2 waveguide as an optical control gate.

2. Switch structure and simulation model

The structure of optical switch is shown in Fig. 1. Device has a silicon rib waveguide designed for the single-mode propagation of $\lambda=1.55\,\mu$m signal light and a T-shape SiO_2 waveguide for control light of $\lambda=0.85\,\mu$m. When the core of the silicon waveguide is illuminated with a control light having a value hv lager than the bandgap energy of silicon, the electron-hole pairs are created. Since the absorption coefficient increases by the free-carrier effect [2,3], the signal light is attenuated. Thus, the signal light can be controlled by illumination of short wavelength light .

The finite difference time domain (FDTD) method is used for the electromagnetic field simulation. The dimension of unit cell are $\Delta x=\Delta z=27.8\,\mu$m, $\Delta y=37.5\,\mu$m. The time step is $\Delta t=0.058$fs. The dielectric constant of silicon is 12.1 for 1.55 μm and is 13.0 for 0.85 μm. That of SiO_2 is 2.1 for both wavelengths. The absorption coefficient of silicon (α) is 750cm^{-1} for 0.85 μm[4], and is null for 1.55 μm.

3. Simulation results

The magnetic field distributions on the y-z plane at $x=81\,\Delta x$, which locates at the center of silicon core are shown in Fig. 2. Figure 2(a) is obtained for $\alpha=0$, and Fig. 2(b) is for $\alpha=750$cm^{-1}. The electromagnetic field is heavily absorbed in the silicon core.

The frequency characteristics of the magnetic field amplitude in the silicon core are in Fig. 3. Figure 3(a) is obtained for $\alpha=0$, and Fig. 3(b) is for $\alpha=750$cm^{-1}. For both cases, the resonance phenomena based on the light reflection on interfaces between SiO_2 and silicon have appeared. The resonant frequency is about 350THz for both cases.

Evolution of the energy of the control light absorbed into the silicon core and that of the energy transferred by the SiO_2 waveguide through the reference plane at $z=40\,\Delta z$ are shown in Fig. 4 as a function of time. The transferred energy and the absorbed energy rise up from $t=100\,\Delta t$ and $200\,\Delta t$, respectively. The absorbed energy increases most at the resonance frequency. It should be noted that the transferred energy is consumed by 18% in the silicon core.

Much energy is consumed in the volume of crossing of two guides ($\sim 2\times10^{-12}$ cm^3). It is necessary to find the steady state in creation of electron-hole pairs and recombination under the illumination of control light. It is estimated that the density of electron-hole pairs created is about 1×10^{18} cm^{-3} for the control light of 0.5 μW when we assume that the lifetime of carriers is 1 μsec. This yields the change in absorption coefficient ($\Delta\alpha=27$ cm^{-1}) by the free-carrier effect, resulting in signal attenuation more than 36 dB for $\lambda=1.55\,\mu$m signal light.

4.Summary

Optical control operation of silicon optical switch with T-shape SiO_2 waveguide as a control gate is studied by using the electromagnetic field simulation. It has been shown that the resonance frequency is about 350THz in optical circuit for control light, and that signal light ($\lambda=1.55\,\mu$m) is attenuated more than 36 dB by the illumination of $\lambda=0.85\,\mu$m control light.

References

[1] Y. Omura, Y. Iida and Y. Nagayama, Proc. 2001 IEICE General Conference, C-11-12 (in Japanese).
[2] R. A. Soref and B. R. Bennett, IEEE Journal, Quantum electronics, vol.33, pp.123-129, 1987.
[3] P. D. Hewitt and G. T. Reed, IEEE J. Lightwave Tech., vol.18, pp.443-450, 2000.
[4] S. M. Sze, Physics of Semiconductor Devices, Chap.13, John Wiley & Sons, New York, 1981.

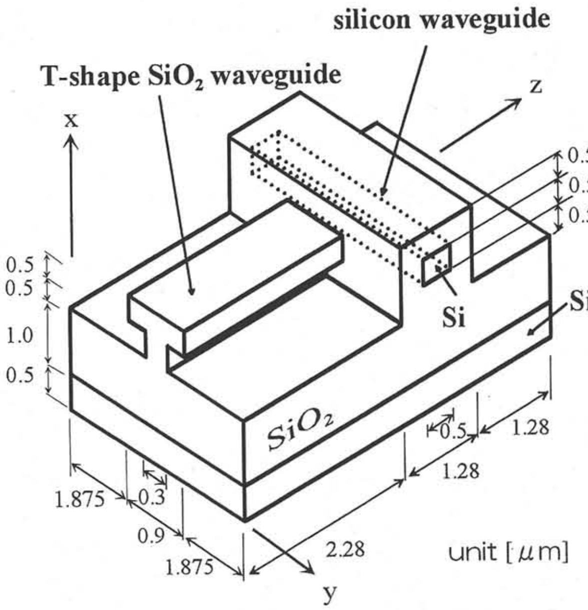
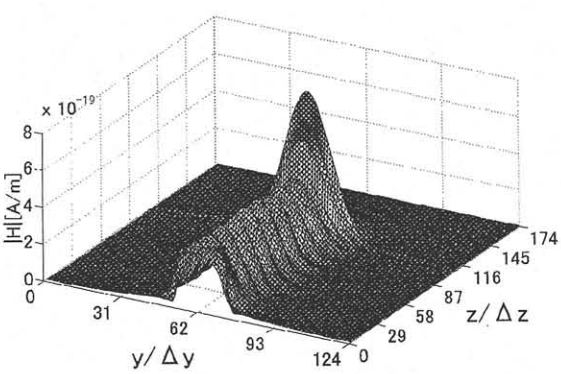
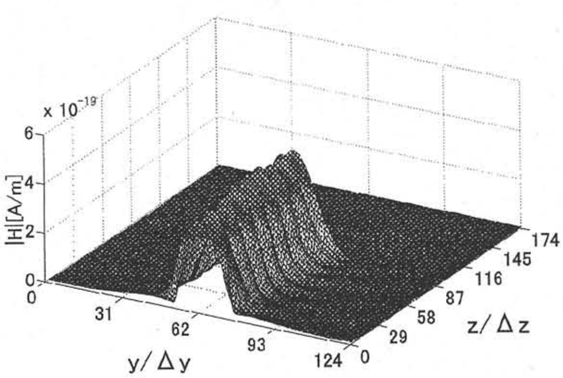


Fig.1 Structure of the optical switch.

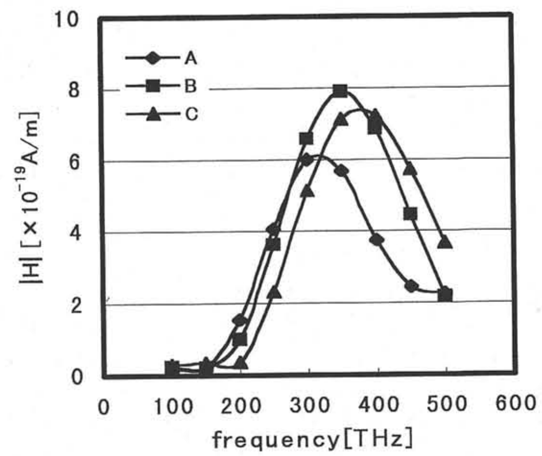


(a)

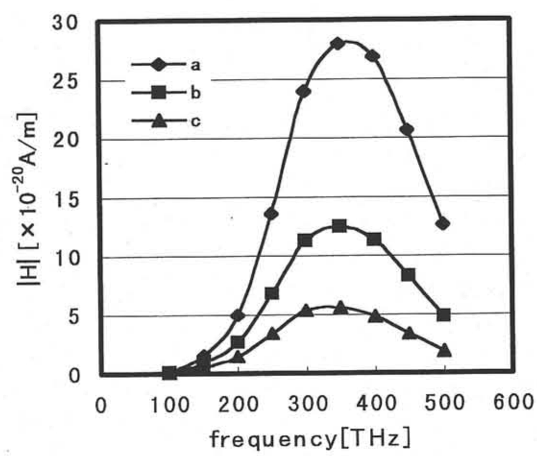


(b)

Fig.2 Magnetic field distributions on y-z plane crossing the center of silicon core. (a) α=0 and (b) α=750 cm $^{-1}$



(a) α=0. A:0.38 μm, B:0.41 μm, C:0.44 μm, from the interface at T-shape guide side.



(b) α=750cm $^{-1}$. a:0 μm, b:0.03 μm, c:0.06 μm, from the interface at T-shape guide side.

Fig.3 Resonance characteristics of the magnetic field amplitude in the silicon core.

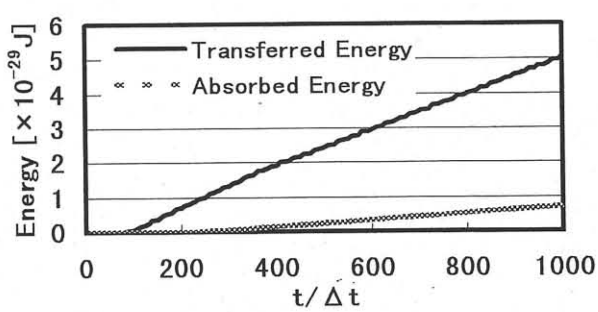


Fig.4 Absorbed energy of the control light in the silicon core and the transferred energy in the T-shape SiO_2 waveguide flowing through the plane at z = 40Δz.