Optical Switching Using Free Carrier Effect in Silicon

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Abstract：Recording and operation and control for data processing and are conducted using electricity in conventional computers. Optical computers only work on light. Since amount of data to be processed has dramatically increased in recent years, it is difficult to continue to develop computers only with technology based on the extension of semiconductor electronics. Therefore, it is necessary for the computing technology to be based on a new concept. Concerning about optical information technology increases from such a background. Various proposals for optical switching using various materials have been conducted until now. Our group has proposed an optical switch using the free carrier effect in silicon phonic waveguide by computer simulation. In this time, we report on an experimental succession of optical switching using the carrier effect of silicon. Signal light was switched by injecting violet light for control on silicon.

1. Introduction

Due to developments in technology of digital computer, the range of the application has expanded and the amount of data to be processed has dramatically increased [1,2]. As a result, the need to improve the computational capability of computers has increased. However, the demand for high processing and handling of enormous quantities of data will always exist even if the capability of computers improves to a cuttlefish. In particular, large-capacity high-speed computers are required in fields, such as knowledge information processing (pattern information processing, e.g., image or sound processing), automatic translation or the expert system, and technology calculation. Miniaturization integration technology, based on microelectronics technology developed for semiconductor LSIs, have supported the development of conventional computer hardware. This tendency continues for a while, and it is thought that the computer technology continues developing smoothly. Development of submicron super nano-fabrication technology and three-dimensional Just use the full term of “IC” since you only use it once in this paper. IC technology is necessary. New architectures and algorithms suitable for high-speed processing, parallel computation, and hierarchical structure architectures and pattern recognition and association have been developed in these techniques by a clue. It is difficult to continue developing computers by only using conventional semiconductor electronics technology. Therefore, we discuss information processing from a totally different view point in terms of both hardware and software. There is also a need of a computing technology based on a new concept. Therefore, we have been attracted a new technique for calculation using light signals, which is alternative to one using electrical signals.

In recent years, researches on fast optical switching has been performed because an increase in the amount of calculation due to advanced information technology. Optical computation can be processed in parallel. Various proposals for optical switching using new materials have been conducted until now. Our group has proposed an optical switch using the free carrier effect in silicon optical waveguide by computer simulation [3-5]. Electron-hole pairs (free carriers) are generated by irradiating control light on silicon to control signal light, and the signal light is attenuated by the free carriers [6-8]. Thus, optical switching occurs using this free carrier effect. We are also conducting research on the emission of visible light from sintered Si nanopolycrystals [9]. In this time, we researched if the optical switching device can be realized experimentally. Control light was irradiated on a high-purity silicon, and an optical switching of signal light was conducted.

2. Optical Computer

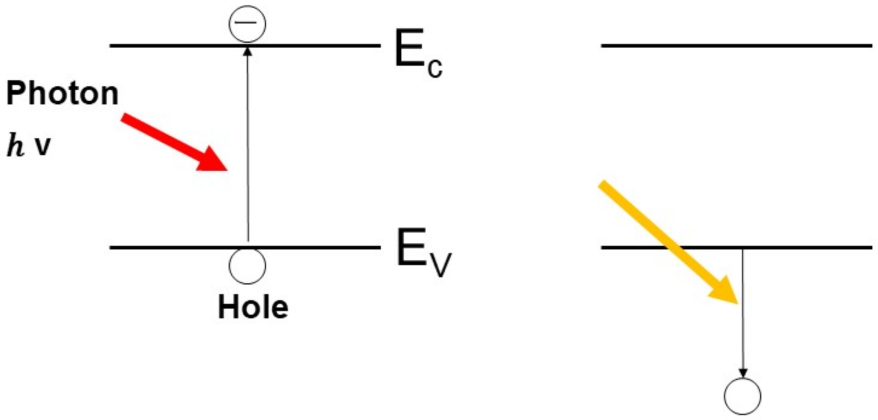
Advantages of light include what is put on there being much information. Conventional computers process records and information by moving and controlling electrons, but optical computers function only by light. Three-dimensional integrated circuitry is possible with light, which conserves energy.

3. Free carrier effect

Electro-optic silicon switch was proposed and fabricated by Lorenzo and Soref[7]. Our group aims to realize Si optical switch using free carrier effect controlled by light signal.

The mechanism of light absorption and carrier generation in silicon is shown in Fig.1. Here, we assume that there are two levels of a valence band and a conduction band of a semiconductor, such as genuine silicon. The band gap exists, and the band-gap energy is E_g, if light having a photon energy exceeding the band gap energy enters from outside, absorption of light occurs.

Electrons are excited and holes are generated. This is a normal process for light absorption in silicon. When light having photon energy less than the band-gap energy injected to silicon from the outside, the light is absorbed by electron and hole carriers [6]. The energy diagram of the semiconductor for the absorption is shown in Fig.1(b).



(a) (b)

Fig.1(b) Light absorption in silicon. (a) Normal, (b) Free carrier effect.

The absorption coefficient of silicon at 1.55 μm, which is the wavelength for optical communication due to the carrier effect, is obtained by the following equation[5].

$$\Delta\boldsymbol{\alpha} = \Delta\boldsymbol{\alpha}_e + \Delta\boldsymbol{\alpha}_h = \mathbf{8.5} \times \mathbf{10^{-18}} \cdot \Delta\boldsymbol{N}_e + \mathbf{6.0} \times \mathbf{10^{-18}} \cdot \Delta\boldsymbol{N}_e \tag{1}$$

For an example, when N_e and N_h are both 1×10^{18} cm^{-3}, α is 14.5 cm^{-1}.

4. Experimental setup

The experimental setup for the optical switching using free carrier effect is shown in Fig. 2. An ultraviolet light pulses (the peak wavelength is 405 nm) was repeatedly irradiated on the bulk silicon as control light. A microchip Nd:YVO_4 CW laser (the lasing wavelength is 1064 nm) was used as a light source for signal light. The incident angle of the control light was about 15 ° to the optical axis. The CW laser passed through high-purity silicon. Finally, the light was detected by a Si Pin diode. The temporal waveform of the signal light was observed with an oscilloscope. The temporal waveform of the control light with a repetition rate of 100 Hz and an input amplitude of 100 mV is shown in Fig.3.

The temporal waveform of the controlled signal light by irradiating control light on silicon are as shown in Fig.4. When the modulation frequency of the control light was both 50 and 100 Hz, the voltage signals are attenuated by the free carrier effect of silicon. It has been proved in this experiment that pure silicon can be used as an optical switch by irradiating light with a wavelength of 405 nm.

However, switching signal light by control light with the frequency of 200 Hz is not successful because the switching becomes unstable. This will because carriers are accumulated in the silicon. The carrier concentration in silicon results in causing signal light absorption and instability of periodical absorption of signal light.

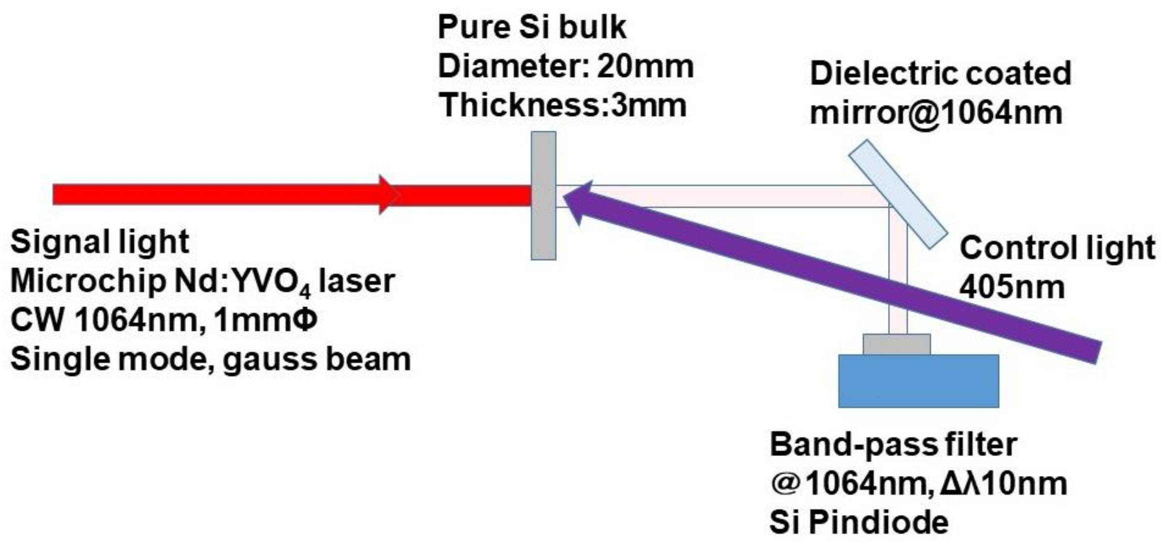


Fig.2 Experimental setup.

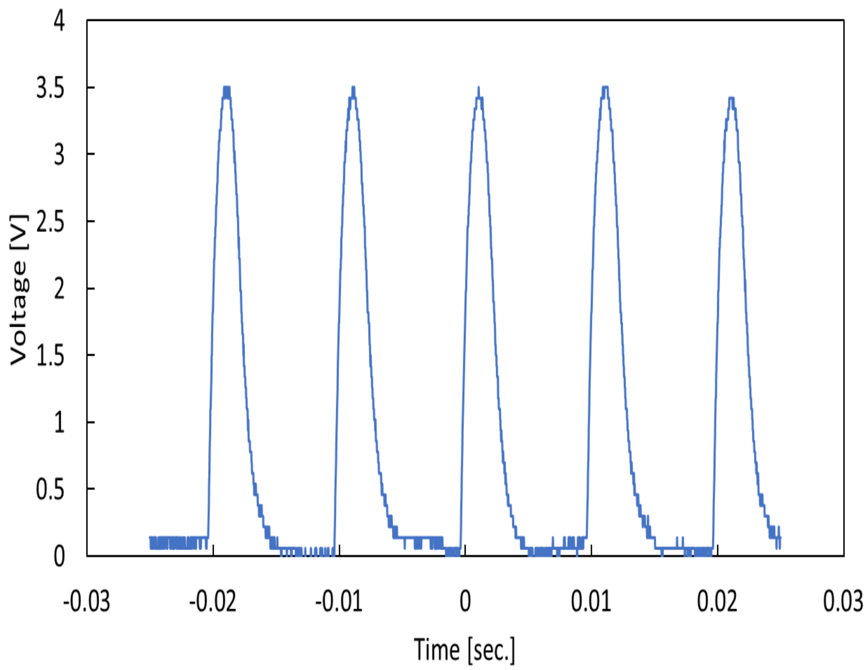
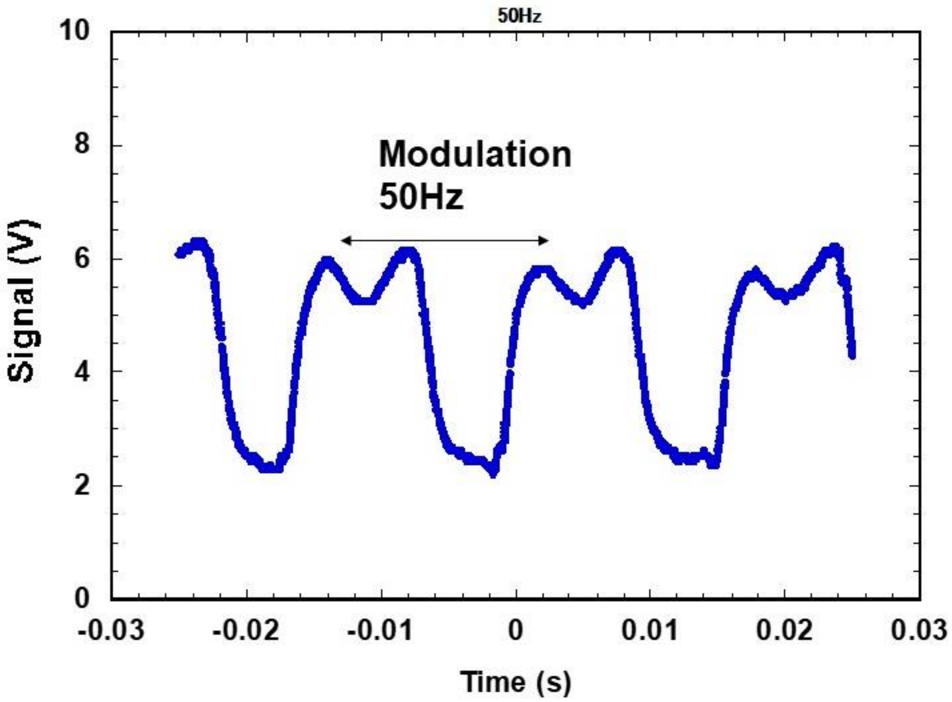
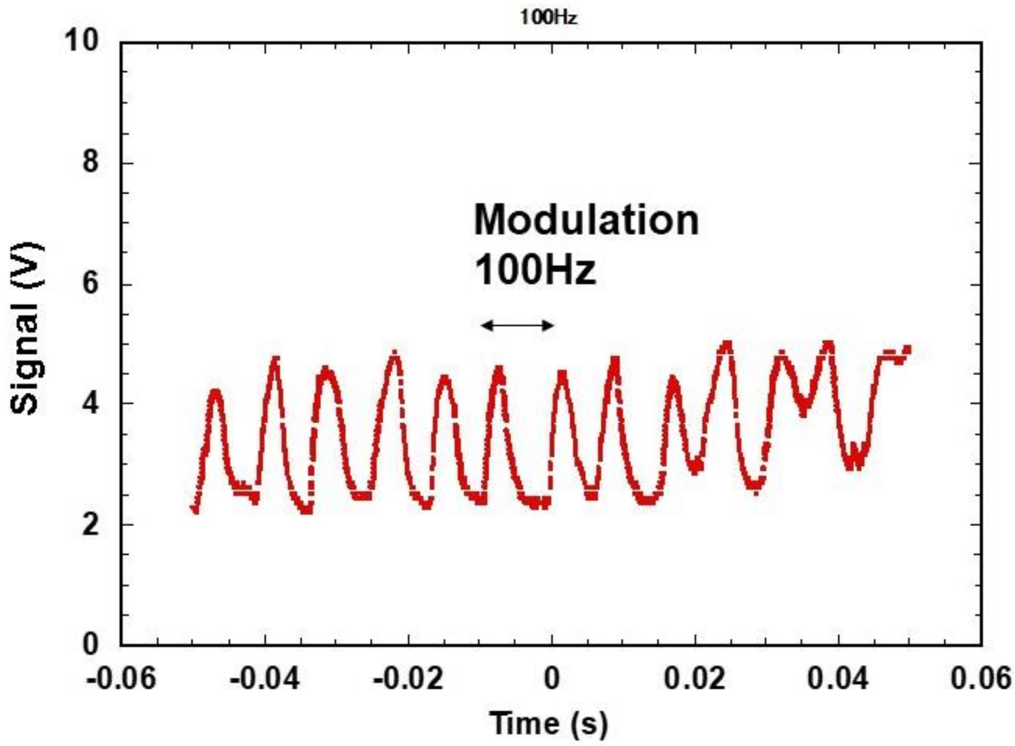


Fig.3 Temporal wave form of control light.



(a)



(b)

Fig.4. Temporal wave form of signal light. (a) Frequency of control light: 50Hz, (b) Frequency of control light: 100Hz.

5. Summary

Our group has proposed an optical switch using the free carrier effect in silicon phonic waveguide by computer simulation. In this time, we had succeeded in optical switching using the carrier effect of silicon experimentally. Signal light with 1064nm wavelength has been switched by irradiated pulsed control light with 405nm wavelength and the frequency of up to 200Hz on silicon.

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