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Optical Waveguides with Memory Effect Using Photochromic Material for Neural Network

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Abstract

Optical waveguides having a memory effect were fabricated using cladding containing photochromic material “diarylethene”. The transmittance of the green light is decreased by the irradiation of UV light and recovered by the green light passing through the waveguide. The fatigue characteristics were also investigated and the long irradiation of green light was found to partly heal the UV induced damage. And an optical neural network using the waveguide and CMOS circuits was proposed.

1. Introduction

As a next generation of computer, a neural network is attracting much attention [1]. In this work, we conduct fundamental research to fabricate optical neural network using photochromic materials for which the optical transmittance is changed depending on the amount of light that passed through [2]. The schematic model of the neural network is shown in Fig. 1 [3], where the synapse takes an important role, i.e., the more frequently the synaptic connection occurs the connection strength becomes stronger. This function of the synapse is simulated by the photochromic material “diarylethene” [2].

2. Neural circuit using photochromic material

Our optical neural circuit model is shown in Fig. 2 where the synaptic connection strength is controlled by optical waveguides containing photochromic material. The function of the nerve cell, i.e., firing at a certain integral of the input signal, is implemented by the CMOS circuit after converting the input light signal to the electric one. The output of the circuit is converted to the light signal by LED and it is delivered to the other synapses through waveguides.

As the photochromic material we use “diarylethene” which molecular structure is shown in Fig. 3 [2] with the photograph of the ethyl acetate solution mixed with diarylethene. The solution has initially transparent but after irradiation of UV light (e.g. 360 nm) the color is changed to pink. And after irradiation of visible light (e.g. 532 nm) it is again back to colorless [4]. This phenomenon is repeatable.

3. Fabrication of waveguide with memory effect

The structure of the waveguide with memory effect is shown in Fig. 4(a). The core material is silicon nitride which is transparent for the green (532 nm) light, and the diarylethene is mixed into the cladding (spin on glass: SOG). The sample is fabricated by photolithography and dry etching. Diarylethene of 1 mg was first dissolved in 200 μl of ethyl acetate, and then added to 1 ml of SOG solution.

4. Measurement

For visible light, green pulsed laser light (λ=532 nm) was used and put into the waveguide through lensed fiber. The output light was detected by a silicon photodetector and recorded to computer through A/D converter. For the UV light, a high pressure Hg lamp (100 W) was used and irradiated from the top of the sample about 10 cm far.

5. Results and Discussions

Memory effect of the waveguide

The output signal for various laser power of input green laser is shown in Fig. 5. After UV light irradiation for 20 s the output quickly goes down to zero, and it gradually recovers to the initial intensity. For the strong input green light the output is quickly recovered, whereas for the weak input light recovery is slow. However, as shown in Fig. 6, the output recovery characteristics is almost fit to the following universal curve irrespective of the input power,

$$I = A(1-e^{-E/B}) \quad (1)$$

where I is output, E is total energy of the input light, A and B are constants. This memory effect is just what we wanted to apply to the optical neural network shown in Fig. 1.

Fatigue and repairing characteristics

Initially the response of the waveguide is reproducible as shown in Fig. 7. However, after a long strong UV irradiation the response is changed presumably because the diarylethene receives the UV induced damage. After accumulated UV irradiation time of about 20 h the response of the waveguides is changed as shown in Fig. 8. Initially the recovery is quick but it is followed by the very slow component. The two time constants were derived from the response curve and plotted as a function of the number of the experimental run (Fig. 9). These time constants are increased after a few experiment runs as shown in Fig. 9, which is in contrast to Fig. 7. In order to repair this fatigue phenomenon, a strong green light (20 μW) was irradiated for 30 min after each experiment. The result is shown in Fig. 10, where the fatigue phenomenon seems to disappear. However, it is not complete, i.e., the same result as shown in Fig. 9 is reproduced without the strong and long green light irradiation. This may be due to the short wavelength (254 nm) component from the UV lamp, and the fatigue problem may be reduced by eliminating this wavelength component by the filter.

6. Conclusion

The optical neural network using photochromic material and CMOS circuits was proposed. It was demonstrated that the photochromic material “diarylethene” has the suitable properties for the optical memory devices for simulating the function of synapse connection.

Acknowledgement

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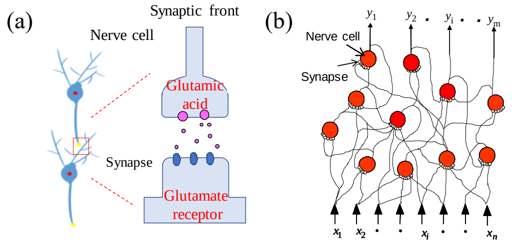

Fig. 1. (a) Model of neural network consisting of synapses. (b) Schematic of neural network .

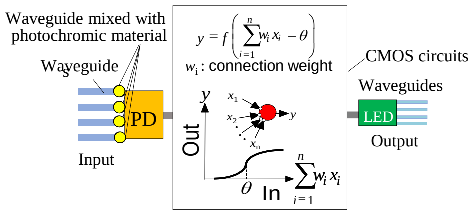

Fig. 2. Model of a unit nerve cell using photochromic material.

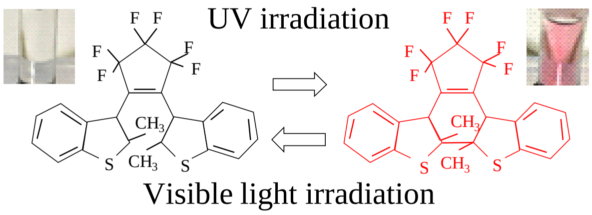

Fig. 3. Reversible reaction of diarylethene.

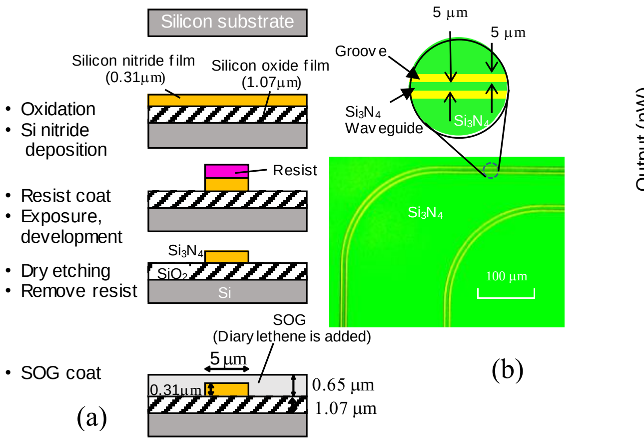

Fig. 4. (a) Fabrication process of optical waveguides with memory effect. (b) Optical microscope image of the fabricated waveguides.

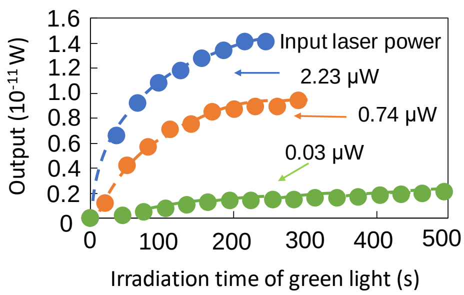

Fig. 5. Output recovery characteristics for various input laser power after UV irradiation for 20 s.

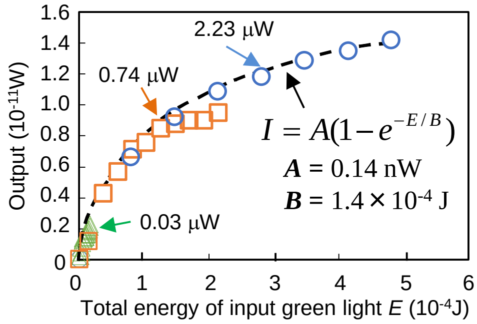

Fig. 6. Output recovery characteristics as a function of total amount of input energy of the green light.

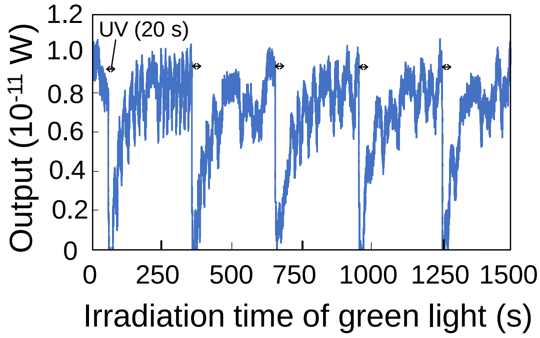

Fig. 7. Typical output signal behavior (UV is irradiated for 20 s).

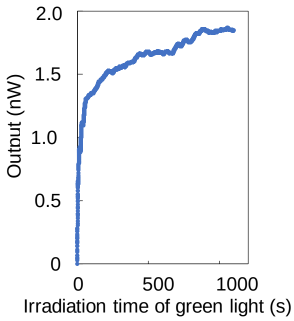

Fig. 8. Output signal behavior after long strong UV irradiation.

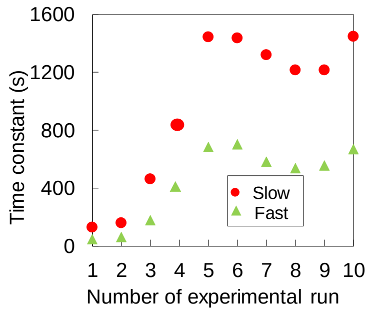

Fig. 9. Change in time constant (UV irradiation: 10 s, green light irradiation:1~10 min).

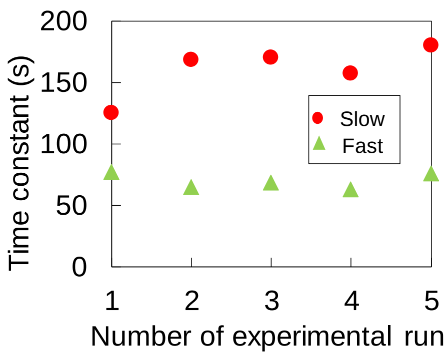

Fig. 10. Recovery time constant versus number of experiment when long (for 30 min) irradiation of green light is carried out after each experiment.