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Analysis of optical response characteristics of memory waveguides with photochromic material

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Abstract

The optical waveguides containing photochromic material "diarylethene" in the core have been fabricated to reduce the response time. From the analysis and modeling of the optical response a method to reduce the response time in millisecond order has been proposed.

1. Introduction

As a next generation computer, a neural network is attracting much attention [1]. The model of the neural network is shown in Fig. 1, where the more frequently the synaptic connection occurs the connection strength becomes stronger. This function is simulated by the photochromic material "diarylethene" [2], where the transmittance for the green light is decreased by UV irradiation and recovered by green light (Fig. 2). We reported the similar function by the optical waveguide containing diarylethene in the cladding layer [3]. The typical characteristics are shown in Fig. 3 where the green light transmittance is determined by the total amount of the green light energy passed through. However, the response time was min order, whereas millisecond order is required in practical. In this paper we have fabricated the waveguide containing diarylethene in the core to reduce the response time. From the analysis and modeling of the optical response we have proposed a method to shrink the response time in millisecond order.

2. Fabrication of waveguide mixed diarylethene in core

The structure of the fabricated waveguide and its fabrication process are shown in Fig. 4 (a). The core material is UV curable resin and the diarylethene is mixed into it. The sample is fabricated by photolithography and dry etching. Diarylethene of 2.6 mg was dissolved in 600 μl of propylene glycol methyl ether acetate, and then diluted with 0.24 g of UV curable resin. The microphotograph of the fabricated sample is shown in Fig. 4(b).

3. Measurement

The green laser (λ =513 nm) was input to the waveguide through lensed fiber. The output light was detected by a Si photodetector and recorded to computer. The UV light (365 nm) was irradiated from the top of the sample about 3.6 cm far, where the irradiation area is ~ϕ 7 mm. In order to avoid the UV irradiation to the lensed fibers the cone-shaped optical shield was set between the UV LEDs and the sample.

4. Results and Discussions

The transmittance for the green light (396 nW) is shown as a function of UV irradiation time in Fig. 6 (initial condition is ~transparent by irradiation of enough green light). As increasing the UV power, the attenuatin time is shortened. In Fig. 7, the recovery characteristics are shown as a function of green laser irradiation time for various green laser powers (initial condition is ~opaque by enough UV irradiation). The recovering is quick for lager input light power in the time region longer than 0.2 s. The small difference in short time may be due to the poor measurement accuracy. Anyway in both cases the response time is not so quick compared with the required millisecond order. In order to shrink the response time physical modeling was made. The diarylethene molecule has two states: one is (A): absorber for green light another is (B): transparent. Time change of the number of molecules in the these states is expressed by the following equations,

$$\frac{dn_1}{dt} = k_2 I_G n_2(t) - k_1 I_{UV} n_1(t) \quad (1)$$

$$\frac{dn_2}{dt} = k_1 I_{UV} n_1(t) - k_2 I_G n_2(t) \quad (2)$$

$$T = \exp(-k_3 n_1), \quad (3)$$

where n_1 and n_2 are the number of molecules in A and B states, respectively. I_G and I_{UV} are the intensities of the green and UV lights, respectively. T is the transmittance for the green light. k_1, k_2, and k_3 are the coefficients. The dotted lines in Figs. 7 and 8 show the simulated transmittance obtained by solving the diffrential equations (1) and (2) under the appropiately given initial conditons. In Fig. 7 the simulation and experimetanl results well fit together, while their fitting is poor in Fig. 7 because in the modeling UV and green light intensities are assumed to be uniform in the sample. However, it is not the case for the green light but it is true in the UV light which is irradiated from the top. It was found from the equations that the light intensity decay time τ by UV irradiation is given by $1/\tau = k_1 k_3 n_1 I_{UV}$ and for the recovering time τ by green light is given by $1/\tau = k_2 k_3 n_1 e^{-k_3 n_1} I_G$. Therefore in Figs. 9, the experimental time constants are plotted as a function of I_{UV} and I_G. For the UV response the I_{UV} = 4 W gives ~10 ms, which is sufficient enough because the UV light is used for the simultaneous erase of the memory data. However for the recovering time constant by green light $k_2 k_3 n_1 e^{-k_3 n_1} I_G$ should be about 1700 to 4400 times larger than the present value. Then this value is plotted as a function of $k_3 n_1$ in Fig. 10. It turns out that the time constant becomes 25 times when n_1 is reduced to $1/6$ from the present value, i.e. the redcuction of diarylethene concentration is effective.

6. Conclusion

The optical waveguides containing photochromic material "diarylethene" in the core layer have been fabricated to reduce the response time. The physical model for the optical response was established and a method to reduce the response time has been proposed.

Acknowledgement

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References

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[2] I. Masahiro *et al*., J. Appl. Phys, **33**, 1550 (1994).
[3] K. Tanimoto *et al*. Jpn. J. Appl. Phys. **57**, 04FH02 (2018).

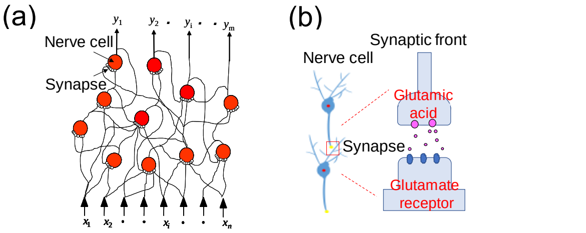

Fig. 1. (a) Schematic of neural network. (b) Model of neural network consisting synapse.

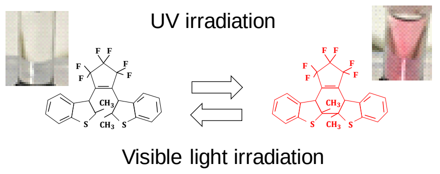

Fig. 2. Reversible reaction of diarylethene.

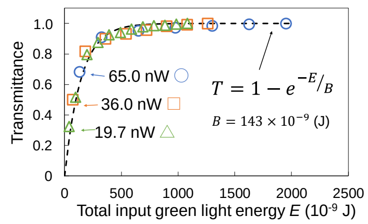

Fig. 3. Transmittance as a function of total amount of input energy of the green light.

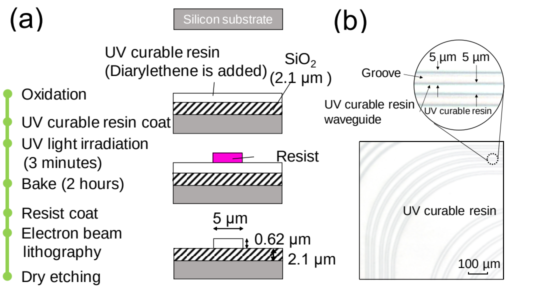

Fig. 4. (a) Fabrication process of optical waveguides with memory effect. (b) Optical microscopy image of the fabricated waveguides.

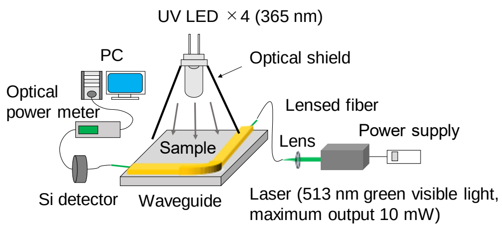

Fig. 5. Schematic of measurement system.

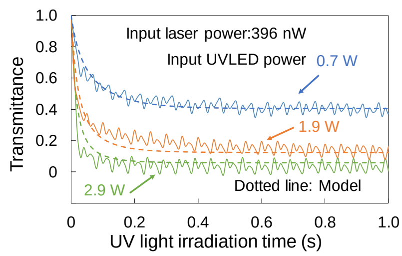

Fig. 6. Transmittance as a function of UV irradiation time.

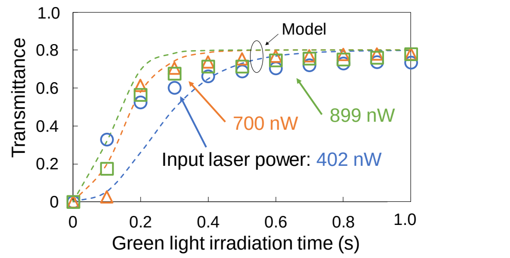

Fig. 7. Transmittance as a function of green light irradiation time.

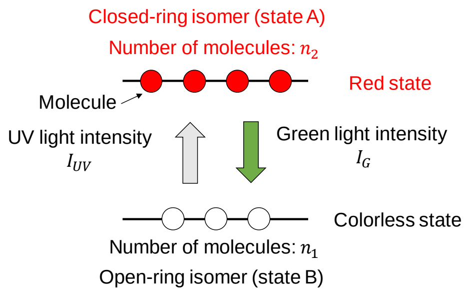

Fig. 8. Photoisomerization model of diarylethene

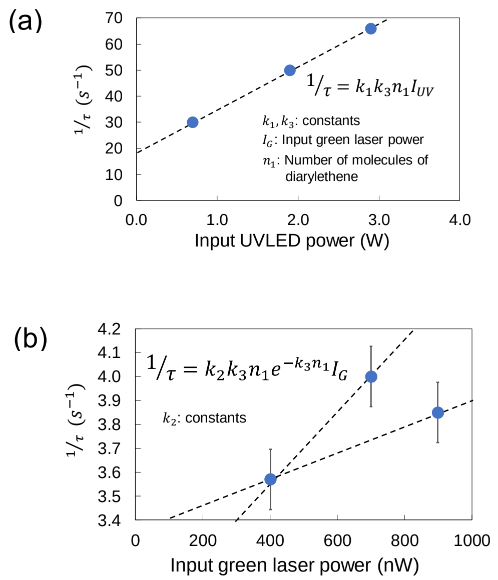

Fig. 9. (a) Reciprocal of time constant of attenuation. (b) Reciprocal of time constant of recovery.

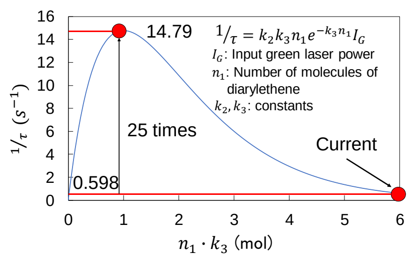

Fig. 10. Reciprocal of time constant as a function of diarylethene.