Absorption-induced circular dichroism in metamaterials consisting of chiral molecules and non-chiral dyes

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Abstract

We experimentally demonstrate that circular dichroism (CD) is induced in visible region by chiral metamaterials consisting of chiral molecules and non-chiral dyes. More interestingly, multilayer-type metamaterials shows a polarity reversal of a CD peak when measured from opposite direction. Theoretical consideration was carried out by constructing a model of a chiral medium connected to a non-chiral medium. Analytical and numerical calculation explains the enhancement of optical activity of the chiral medium by attaching a non-chiral medium.

1. Introduction

Optical activity (OA) of materials leads to a rotation of linearly polarized plane of light. If the materials are absorptive, the rotation accompanies circular dichroism (CD) due to the absorption difference between right- and left-handed circularly polarized lights. Glucose, which is a well know OA chiral molecule in the ultraviolet (UV) region, does not show CD in the visible region owing to very low absorption. In this contribution, however, we report that, by making a composite of glucose and absorptive dye, rhodamine-6G, a CD peak is induced in the visible region. The composites are of great interest in terms of chiral metamaterials, which are able to realize negative refraction of light even without a negative index of refraction.[1, 2].

In addition to composites, CD of multilayers consisting of glucose and rhodamine layers is studied. Transmission of circularly polarized lights through normal OA medium is symmetric, which means that the rotation angle is independent of propagation directions of lights. In terms of ellipticity, this results in identical CD angle in CD spectra even though the lights are transmitted from top or bottom of the materials. In this contribution, however, we demonstrate anti-symmetric transmission of circularly polarized lights through meta-interface between glucose and rhodamine layers in the multilayer-type chiral metamaterials.

2. Experimental Procedures

We first prepared a mixture of rhodamine-6G and UV curable resin. For composite-type chiral metamaterials, glucose is added to the mixture. The resin with both rhodamine and glucose was dropped onto a quartz, and sandwiched with another quartz substrate. By irradiating UV light for 40 min, resin was cured and composite-type chiral metamaterial was prepared. For multilayer-type, a resin mixed with rhodamine-6G was dropped onto a quartz. By irradiating UV light for 40 min, the resin was cured, and a rhodamine layer was formed. Another resin mixed with D/L glucose was prepared. The resin was dropped onto the rhodamine layer, covered by another quartz substrate, and irradiated by UV light.

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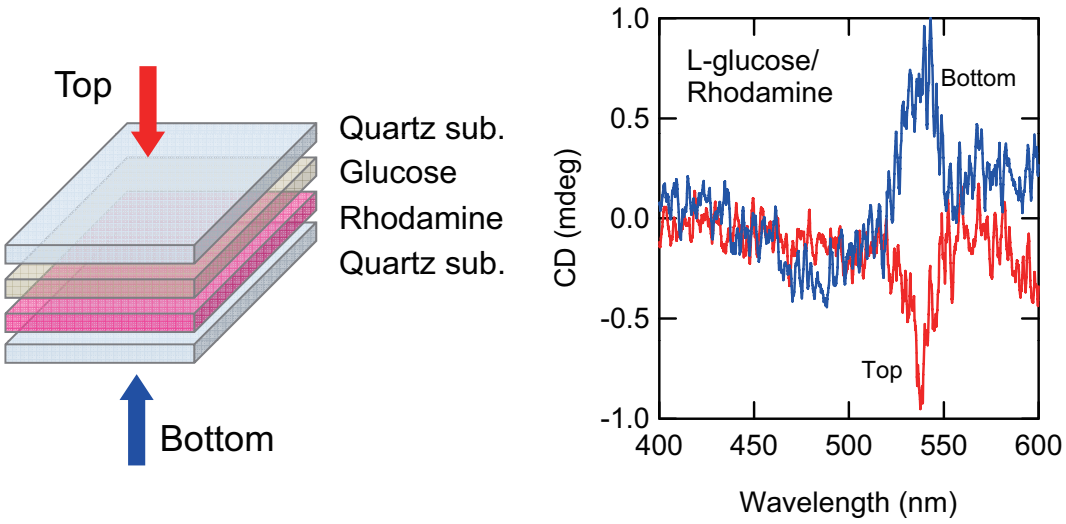

Fig. 1: (a) Illustration of a multilayer-type chiral metamaterial. Arrows indicate the transmission direction. (b) CD spectra of the multilayers using L-glucose and rhodamine-6G. Red (blue) line corresponds to a spectrum measured from top (bottom).

This experimental procedure results in a multilayer of D/L glucose and rhodamine sandwiched by quartz substrates as illustrated in Fig. 1(a). CD of the metamaterials was measured using JASCO J-820.

3. Results and Discussion

Glucose is silent in CD spectra of the visible region because of small absorption. Contrastingly, a CD spectrum of a composite-type chiral metamaterial consisting of L-glucose and rhodamine-6G shows a positive CD peak at about 540 nm, where rhodamine-6G exhibits absorption.[3] This result indicates that the weak CD of L-glucose is enhanced by the absorption of rhodamine-6G.

Fig. 1(b) shows CD spectra of a multilayer-type chiral metamaterial consisting of L-glucose and rhodamine-6G layers. Red line corresponds to a spectrum measured from top; the light transmits from L-glucose to rhodamine-6G layers. A negative CD peak is observed at about 540 nm, which is originated from absorption by rhodamine-6G. We see that absorption-induced CD is observed also in multilayer-type chiral metamaterials. As shown by blue line in Fig. 1(b), when the measurement is carried out from bottom, a positive CD peak is observed around 540 nm. These results demonstrate anti-symmetric transmission of circularly polarized light between the glucose and rhodamine layers.

We should mention that, although not shown in this paper, multilayers with D-glucose, which is the enantiomer of L-glucose, shows a positive (negative) CD peak when measured from top (bottom); the anti-symmetric transmission is observed. We should notice here that, when measured from top, the polarity of the CD peak is reversed between L-glucose and D-glucose. These results indicate that the anti-symmetric transmission is caused by the chirality of L/D glucose.

Physical origins of results obtained in experiments were theoretically considered. The ratio of transmission coefficient for right-handed polarization and left-handed polarization is analytically calculated by using a transfer matrix method. We suppose a multilayer-type chiral metamaterial; a chiral medium is connected to a normal (non-chiral) medium. The calculation result suggests that the OA of chiral medium is enhanced by connecting to a normal medium. What is important in this model is a directional difference of refractive indices and an interface between chiral and normal media. Due to this directional

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difference at the interface, the non-chiral normal medium can enhance the optical activity even though it has no intrinsic circular dichroism. Such an enhancement mechanism is a characteristic property of our model and physically distinct from the planar-chirality mechanism [4, 5]. Numerical calculation to explain the anti-symmetric transmission of circularly polarized lights is now underway.

4. Conclusion

In conclusion, we studied CD of composite- and multilayer-type chiral metamaterials consisting of chiral D/L-glucose and non-chiral absorptive rhodamine-6G. In a composite-type, a CD peak is observed where the rhodamine shows absorption. Also in multilayer-type, the absorption-induced CD is observed. More interestingly, anti-symmetric transmission of circularly polarized lights was found. Theoretical consideration was carried out by constructing a model of a chiral medium connected to a non-chiral medium. Calculation shows an enhancement of OA of the chiral medium. The meta-interface opens an avenue to circulator in optical domain.

References

[1] J. B. Pendry, *Science,* vol. 306, p. 1353, 2004.
[2] V. G. Veselago, *Sov. Phys. Usp.,* vol. 10, p. 509, 1968.
[3] Y. Kosaka et al., submitted.
[4] M. Kuwata-Gonokami et al., *Phys. Rev. Lett.,* vol. 95, 227401, 2005.
[5] E. Plum et al., *Appl. Phys. Lett.,* vol. 90, 223113, 2007.

