Title

Review of "Application of circularly polarized light for non-invasive diagnosis of cancerous tissues and turbid tissue-like scattering media "

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Author

Chang, Josiah

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Effect of polarized light in optical imaging

JOSIAH CHANG

Polarization-based imaging allows for high quality imaging for biological tissue that is otherwise difficult to obtain with conventional techniques by analyzing the polarization state of back-scattered light. In particular, circularly/elliptically polarized light as opposed to linearly polarized light can be used to better determine the size and refractive index of turbid tissue. In this paper, the difference between linearly and circularly/elliptically polarized light will be explicitly explored, as well as the processes by which polarization can change when traversing a medium.

1. INTRODUCTION

Different materials possess different thicknesses and indices of refraction. Therefore, imaging can be produced by analyzing the properties of light that is back-scattered by the objects of interest[1]. However, most biological tissue is turbid, or highly anisotropic, meaning it scatters light to the point where the back-scattered light becomes inseparable from diffused background light[2]. Therefore, polarization-based imaging attempts to solve this problem by using polarized light; as a result, the back-scattered light from the object will be polarized, which means it can analyzed separately from the background light[1]. Research has shown that using circularly/elliptically polarized light rather than linearly polarized light can further improve polarization-based imaging of turbid biological tissue because circular polarization is less affected than linear polarization in this medium[2].

2. STATES OF POLARIZATION

To begin with, linearly polarized light must be clearly defined apart from circularly/elliptically polarized light. Polarization refers to how an electric field E changes as it propagates through a medium[3] (suppose it propagates in the z-direction). The polarization of an electric field can be described by the parameters φ, the phase difference between the field components of E (E_x and E_y), and α, the magnitude ratio of E_x and E_y (Eq. S1 [3]):

$$\varphi = \varphi_y - \varphi_x, \qquad -\pi < \varphi \leq \pi,$$

$$\alpha = \tan^{-1}\frac{|\mathcal{E}_y|}{|\mathcal{E}_x|}, \qquad 0 \leq \alpha \leq \frac{\pi}{2}. \tag{S1}$$

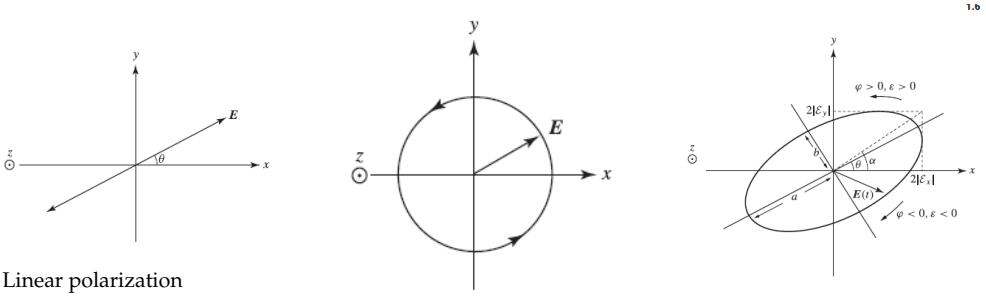
From different specifications of φ and α, there are generally three different states of polarization; linear, circular, and elliptical[3].

Linearly polarized light is defined as light where $\varphi = 0$[3]. Therefore, when looked at from the direction of propagation, the E vector will appear to be constantly shrinking/expanding across one "line" as seen in Fig. S2a; hence the name of linear polarization.

For circularly/elliptically polarized light, $\varphi \neq 0$. Therefore, the tip of the E vector will appear to spin as time passes. The polarization is called circular when $\varphi = \pm\,\pi/2$ and $\alpha = 1$ because the electric field will exactly trace a circle, as seen in Fig. S2b. Furthermore, circularly polarized light is classified as either right-handed (RHCP) if it rotates clockwise or left-handed (LHCP) if it rotates counter-clockwise/left-handed[3]. All other combinations of φ and α are considered elliptical polarization (Fig S2c).

3. POLARIZATION MODULATION IN A MEDIUM

In the paper, it is shown that circular polarized light can maintain its polarization longer than linearly polarized light when scattered in highly scattering biological tissue[2]. In order to explore this, the process by which polarization changes in this kind of medium must be explored first.



(a) Linear polarization

(b) Circular polarization

(c) Elliptical polarization

Fig. S1. Graphs of the 3 general states of polarization from the viewpoint of the propagation direction. Taken from *Principles of Photonics*[3]

A. Birefringence and Dichroism

Permittivity ϵ and susceptibility χ are two properties of any material that determine how an electric field changes as it traverses that material, corresponding to D and P. respectively. The ϵ and χ of highly scattering media, such as turbid tissue are second-order tensors[3]. As a result, The D and P vectors change the electric field in not only direction but polarization as well. These ϵ and χ tensors are diagonalizable matrices, so they can be fully described by a set of eigenvalues and eigenvectors[3]. Indices of refraction can be defined in Eq. S2 to describe how these eigenvectors affect how light travels in a medium:

$$n_x = \sqrt{\frac{\epsilon_x}{\epsilon_0}}, \quad n_y = \sqrt{\frac{\epsilon_y}{\epsilon_0}}, \quad n_z = \sqrt{\frac{\epsilon_z}{\epsilon_0}}. \tag{S2}$$

If the ϵ eigenvectors are different values, there will be a difference in indices of refraction across the different axes these eigenvectors correspond to. Birefringence occurs when there is a difference in the real parts of these indices[4]. Dichroism occurs when there is a difference in the imaginary parts of the indices[4], resulting in different rates of optical loss for different polarization axes or modes. Because birefringence and dichroism can affect the phase difference in the polarization states of light, both are key factors in depolarization in turbid tissue.

B. Scattering

Another principal factor in polarization modulation in turbid tissue is the scattering of light. As light enters the tissue, the photons will scatter and interfere with itself at different amplitudes and phases[2]. If enough scattering occurs, the values of φ and α will become completely lost, resulting in weak to little polarization.

The observation that circularly polarized light maintains its polarization longer than linearly polarized light in turbid tissue can be partially explained by a difference in depolarization between linearly and circularly polarized light. Circularly polarized light becomes depolarized in scattering not only due to randomization in direction but in helicity (right-handed or left-handed) too[2]. In turbid tissue with larger sized scatterers, it is more difficult to change this helicity because the scattering angle needed to flip the helicity becomes larger as well[2]. As a result, it is more difficult to depolarized circularly polarized light than linearly polarized light in turbid tissue.

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