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# Measurement of the anisotropy factor with azimuthal light backscattering*

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The potential capability of low coherence backscattering (LBS) is explored to determine the anisotropy factor based on azimuthal light backscattering map. The scattering intensity signal measured at azimuthal angle $\varphi$=0° is extracted for analysis. By performing nonlinear regression fitting on the experimental signal to the Henyey-Greenstein phase function, the anisotropy factor is determined. The experiments with tissue phantom consisting of the aqueous suspension of polystyrene microspheres are carried out. The results show that the measured anisotropy factor is well described by Mie theory.

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Light scattering technique has been widely applied to measure local optical properties of tissue[1-4]. In tissue optics, the directional tendency of the scattered light is represented by the anisotropy factor $g$, which is defined as the average cosine of the scattering angle. The studies have shown that the anisotropy factor of tissue is a valuable intrinsic marker of disease[5]. The determination of anisotropy factor based on the analysis of laser Doppler power density spectra of liquids has been reported[6]. Wang[7] presented the measurements of spatially resolved scattering mean free path and anisotropy factor for entire biopsies, and demonstrated the direct correlation of anisotropy factor with tumor presence. The inverse model was proposed to determine the anisotropy factor using low-coherence enhanced backscattering spectroscopy[8,9] and optical coherence tomography[10,11]. The determination of the anisotropy factor was also demonstrated by a reconstruction scheme[12] and a fast perturbation method[13] from measured signals. All these methods involved complex system or inverse problem to determine the anisotropy factor. In this paper, we propose a simple and practical approach to obtain anisotropy factor based on azimuthal backscattering map which is achieved from low coherence backscattering (LBS) technique.

The schematic diagram of the experimental setup is shown in Fig.1. The broadband light from xenon (Xe) lamp is collimated by a 4f system with divergence angle of 0.4°. The beam is polarized by a polarizer P1, and its diameter is reduced to 2 mm by a field diaphragm A2. The mirror M deflects the beam through the beam splitter onto the sample, which is mounted on a sample stage. The incident beam is oriented at an angle of 15° approximately to the normal for avoiding the specular reflection from tissue surface. The backscattering light from the tissue is collected by the lens L3, and the angular distribution is mapped onto the CCD camera detection chip. The map records the scattered angle $\theta$ (between the incident light and scattered light directions) and the azimuthal angle $\varphi$ (between the incident light polarization and scattering plane). The intensity is the integration of all the wavelengths. Another polarizer P2 is positioned before the lens to independently collect co-polarized component light $I_{//}(\theta, \varphi)$ and the cross-polarized component $I_{\perp}(\theta, \varphi)$ of the scattered light. The background intensity is subtracted from $I_{//}$ and $I_{\perp}$ to remove the stray illumination and the background noise. Then the differential polarization intensity angular map, which is calculated as $\Delta I=I_{//}-I_{\perp}$, is used for the analysis to eliminate the multiple scattering.

The experiment with tissue phantom which consists of the aqueous suspension of polystyrene microspheres with refractive index of $n$=1.59 is carried out. The co-polarized signal $I_{//}$ and the cross-polarized signal $I_{\perp}$ are recorded, and the differential polarized intensity $\Delta I$ is calculated by subtracting $I_{\perp}$ from $I_{//}$. The scattered intensity of a sphere illuminated by polarized light is a function of diameter $d$,

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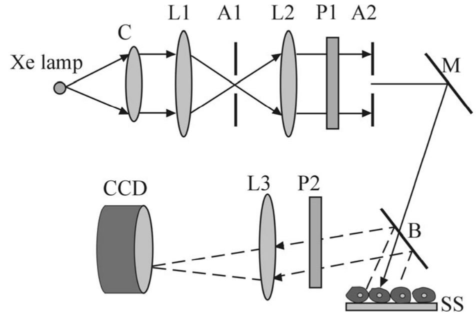
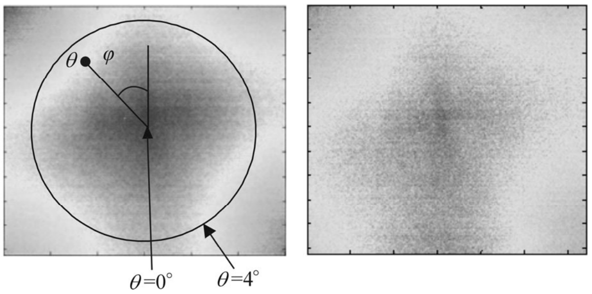
scattering angle $\theta$, azimuthal angle $\varphi$ and particle refractive index relative to the surrounding medium $m$. Fig.2 shows the scattering intensity angular maps of microspheres with the diameters of 4.3 μm and 3.2 μm.



C: condenser; L1, L2, L3: lens; A1, A2: aperture; M: mirror; B: beam splitter; P1, P2: polarizer

**Fig.1 Schematic diagram of experimental setup**



(a) 4.3 μm (b) 3.2 μm

**Fig.2 Scattering intensity angular maps of the light scattered by the aqueous suspension of microspheres**

It can be seen from Fig.2 that the two angular maps have the similar pattern. The strongest intensity is observed in the backward direction ($\theta$=0°). For the particles, the scattering intensity $\Delta I$ exhibits azimuthal symmetry, and the scattering angle is from –4.2° to 4.2°. Due to the azimuthal symmetry of the angular maps, the scattering intensity at $\varphi$=0°, i.e., $\Delta I_{\varphi=0°}(\theta)$, is extracted for the determination of the anisotropy factor. Using Henyey-Greenstein (H-G) function for backscattering, an empirical approximation for Mie scattering is described as sufficient accurate prediction of backscattering, which is expressed as

$$F(\theta)=\frac{1-g_{\mathrm{HG}}^{2}}{(1+g_{\mathrm{HG}}^{2}-2g_{\mathrm{HG}}\cos\theta)^{3/2}}\,. \tag{1}$$

According to H-G function, the nonlinear regression is applied to fit the phase function model of the measured scattering intensity. The tissue phantom consisting of suspension of microspheres with diameter of 4.3 μm is tested. The differential polarization signal at $\varphi$=0° is extracted, and the scattering angle is from –4.2° to 0°. By iteratively performing nonlinear regression fitting on the experimental signal to the phase function, the anisotropy factor is determined as 0.883. The experimentally measured $F(\theta)$ and the $F(\theta)$ obtained from the H-G phase function are in good agreement as shown in Fig.3. It also can be seen that H-G phase function matches well with the backscattering signal simulated by Mie theory. It demonstrates that the H-G phase function has a good prediction on the backscattering signal.

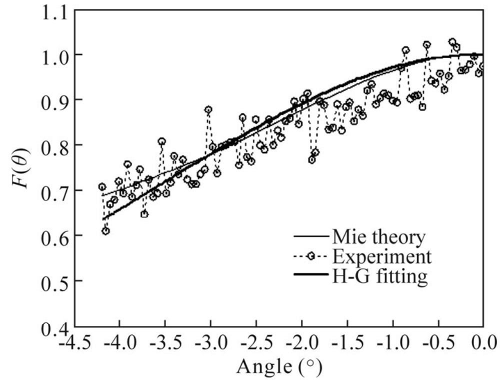


**Fig.3 Experimentally measured *F*(*θ*) compared with the *F*(*θ*) obtained by the H-G phase function and Mie simulation**

In order to investigate the capability for determining the anisotropy factor, the experiments with aqueous suspension of polystyrene microspheres with various sizes are carried out. The optical properties of the scattering media are calculated with Mie theory. In terms of anisotropy factor, the scattering medium with $g$=0.88 can be considered to be close to the biological tissue. So four different sizes of microspheres with the diameters of 3.2 μm, 4.3 μm, 5.0 μm and 9.0 μm are chosen, which correspond to anisotropy factors of $g$=0.863, 0.882, 0.889 and 0.904 at $\lambda$=550 nm, respectively. Tab.1 compares the anisotropy factors of $g_{\mathrm{HG}}$ obtained by nonlinear regression fitting of backscattering signal with the true value $g_{\mathrm{m}}$ calculated by Mie theory. The uncertainty in $g_{\mathrm{HG}}$ is 95% confidence interval of nonlinear regression fitting. The resulting $g_{\mathrm{HG}}$ interval includes $g_{\mathrm{m}}$, thus indicating an accurate measurement.

**Tab.1 Comparison of the anisotropy factors $g_{\mathrm{m}}$ calculated by Mie theory and $g_{\mathrm{HG}}$ from nonlinear regression fitting the experimental signal to the H-G phase function for polystyrene spheres**

| Diameters of polystyrene spheres | $g_{\mathrm{m}}$ | $g_{\mathrm{HG}}$ |
|---|---|---|
| $d$=3.2 μm | 0.863 | 0.868±0.007 |
| $d$=4.3 μm | 0.882 | 0.883±0.006 |
| $d$=5.0 μm | 0.889 | 0.884±0.011 |
| $d$=9.0 μm | 0.904 | 0.901±0.012 |

We present the measurement of anisotropy factor based on azimuthal light backscattering map. By nonlinear regression fitting the scattering signal at $\varphi$=0° to the

H-G phase function, the experimental anisotropy factor $g_{HG}$ is obtained. The results show that the measured anisotropy factor is in good agreement with the value calculated by Mie theory. Future work will explore the diagnostic abilities of azimuthal light backscattering map for tissue using LBS technique.

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