SECOND-HARMONIC DOUBLE STOKES-MUELLER FORMALISM OF COLLAGEN-BASED SAMPLES: EXPERIMENT VS. THEORY

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Second harmonic generation (SHG) polarimetry constitutes a useful tool for a complete characterization of the second-order susceptibility tensor of collagen-based biological tissues. The polarization properties of the sample are contained in a general 4x9 matrix named as a 4x9 double Stokes-Mueller matrix (DSMM) [1]. This DSMM has been successfully used in the calculation of susceptibility component ratios and orientations of molecules in the ordered aggregates [2] or the detection of changes of collagen in breast cancer tissues [3]. However, this general DSMM can be noticeable simplified assuming both Kleinman and cylindrical symmetries in collagen [3]. This is interesting since the non-null elements of the first row of the matrix, responsible for the SHG intensity emerging from the sample, are reduced from 9 to 4 (i.e. m_{00}^{SHG}, m_{01}^{SHG}, m_{02}^{SHG} and m_{03}^{SHG}). This leads to the fact that only 4 independent incident polarization states are required to compute those elements. From these elements the diattenuation (D) or polarization sensitivity to incident polarization can be computed as:

$$D = \frac{1}{m_{00}^{SHG}}\sqrt{\left(m_{01}^{SHG}\right)^2 + \left(m_{02}^{SHG}\right)^2 + \left(m_{03}^{SHG}\right)^2}$$

The aim of this work is to use our previously reported far-field SHG theoretical model [4] to calculate the analytical expression of those DSMM elements. These were computed as a function of different phyical parameters such as the incident wavelength, the objective numerical aperture and the sample's ratio of hyperpolarizabilities, ρ (directly related to the degree of collagen internal order). To corroborate the theoretical results, experimental SHG microscopy images of tissues presenting different collagen patterns were acquired and the corresponding DSMM elements computed. As an example the relationship between D and ρ is depicted in Figure 1. A fairly good agreement between our both experiment and theory is observed. D values were found to increase with ρ values. As a consequence, a loss of regular organization of the collagen fibrils (lower values of ρ) implies a reduction of the SHG polarization sensitivity (i.e. a decrease in D).

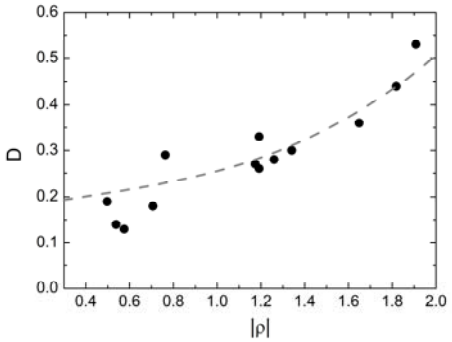

Figure 1: Experimental (dots) and theoretical (dashed line) values of D as a function of the ratio ρ.

[1] Shi et al, *Phys. Rev. A* **49**, 1999 (1994).
[2] Samim et al., *J. Opt. Soc. Am. B* **32**, 451 (2015).
[3] Golarei et al., *Biomed. Opt. Express* **7**, 4054 (2016).
[4] Avila et al., *J. Biomed. Opt.* **20**, 086001 (2015).

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