Propagation of shaped light carrying orbital angular momentum through turbid tissue-like scattering medium

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We explore the potential of using shaped light carrying orbital angular momentum (OAM) in diagnosis of cells and biological tissues. So far, the spin angular momentum (SAM) of light has been employed extensively in various diagnostic applications [1,2]. Since recently much attention has been drawn to the laser beams carrying OAM. It has been demonstrated that this, so-called, complex structured light is able penetrate deeper into the turbid tissue-like scattering medium providing higher visibility contrast [3,4]. Nevertheless, the potential of OAM for practical biomedical diagnosis and tissue characterization is far from being fully explored.

In current report, utilizing Monte Carlo (MC) model developed in-house, we investigate evolution of OAM upon propagation within turbid tissue-like scattering medium. The developed MC modeling approach allows to track light waves propagation in the random scattering medium in terms of a number of MC-photon trajectories ($\sim 10^9$), with the possibility of involving up to 10^3 scattering events along each trajectory. The tracing cut-off is conducted according to the Beer-Lambert-Bouguer law, whereas the direction of Poynting vector after a scattering event is defined by using Henyey-Greenstein phase function [5]. The MC modeling of evolution of SAM is performed by assigning two instantaneous polarization vectors to each MC photon packet (representing partial component of the wave front) similar to the iterative solution of the Bethe-Salpeter equation [6]. Modeling of the OAM laser beam helical profile is defined by settings of initial spatial intensity distribution LG_p^ℓ, phase ψ_0 and unique direction $\mathbf{s}$, assigned for each MC-photon based on the corresponding trajectory of Poynting vector [7].

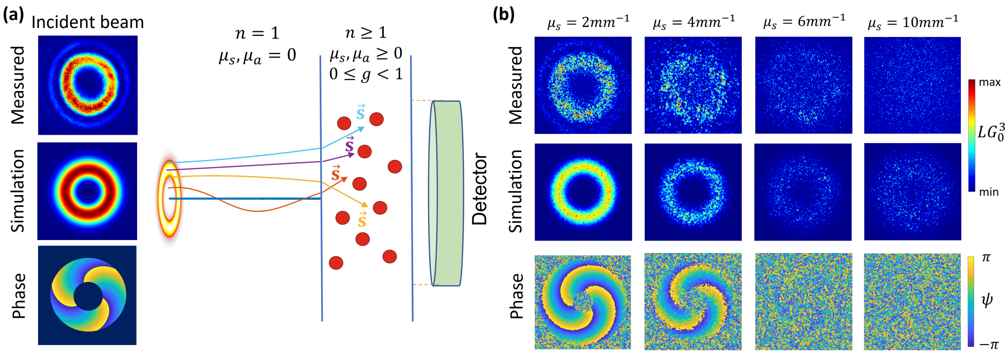

Fig. 1 **(a)** Schematic presentation of experiment/modelling geometry: LG_p^ℓ beam with phase twisted due to the presence of topological charge $\ell = 3$, radial index $p = 0$ is incident on the turbid medium defined by scattering μ_s and absorption μ_a coefficients, anisotropy g and refractive index n. **(b)** Measured intensity versus simulated intensity and simulated phase.

The developed MC model is used to imitate speckle patterns formation to explore how sensitive the Laguerre-Gaussian (LG) beams are to subtle alterations in biological tissues. The results of our modelling studies, acknowledged by experiment, confirm that along propagation of LG beam within turbid tissue-like scattering medium the OAM is preserved with the noticeably different phase shift – twist of light. Finally, we demonstrate, both theoretically and experimentally, that the twist of light is highly sensitive to the refractive index variations (Δn down to 10^{-6}) within the sampled medium. This offers fascinating opportunities for non-invasive monitoring of tissue analytes, including glucose, as well as a high potential in cells diagnosis.

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