Dynamics of Optical Vortices in Speckle Patterns with Sub-Nanometric Spectral Resolution

A. Di Donato[1*], D. Mencarelli[1], G. Fabi[1], E. Pavoni[1], H. J. Christopher[1], L. Pierantoni[1], A. Morini[1] and M. Farina[1]

[1] *Dipartimeto di Ingegneria dell'Informazione,*
Università Politecnica delle Marche, Via Brecce Bianche
60131 Ancona, Italy *a.didonato@univpm.it@univpm.it

By exploiting a novel quantitative imaging technique based on Synthetic Optical Holography, we describe with nanometric spectral resolution the dynamic behaviour of optical vortices in a speckle pattern varying the laser wavelength.

Keywords: Optical vortices, Synthetic Holography

1. Introduction and Results

The study of the correlation properties of the speckle intensity distributions, generated by the superimposition of coherent random waves, is of noteworthy importance in many contexts, such as the estimation of size distribution of macromolecules and biological cells, the characterization of the motion of the constituents in dense complex media, or the interaction of electromagnetic waves with complex random media [1]. By studying the statistics of the displacement in time or frequency of specific features in the speckle pattern, it is possible to characterize the interaction between the wave and sample. The most distinctive features of those random patterns are the phase singularities at the intensity nulls of the speckle [2]. These optical entities exhibit the statistical proprieties of a stochastic random process known as random walk, when varying the wavelength of the incident wave field [1, 2]. In the proposed work, by exploiting a novel quantitative imaging technique based on Synthetic Optical Holography (SOH) [3], we retrieve, with nanometric spectral resolution without affecting the spatial resolution, the dynamic behaviour of optical vortices when the laser wavelength is varied over a finite range of frequencies. The speckle pattern is generated by the interference of light scattered by a random rough surface [4]. The presence of phase singularities, with the associated optical vortices, can be mapped only through a quantitative phase/amplitude imaging of the random scattered field. This goal is achieved by setting up a lens-free scanning probe microscopy system implementing the technique of Synthetic Optical Holography, recently introduced [5]. The acquisition of data were performed through a compact all-fiber system in which the scanning probe is a cleaved optical fiber fed by a Super-Luminescent Diode (SLED) at 850 nm, (bandwidth FWHM = 40 nm) as reported in [6]. The system is working in back-reflection mode and in common path configuration to guarantee an improved sensitivity. The definition of the spatial transverse resolution of the image is dependent on the Numerical Aperture (NA from 0.10 to 0.14) and Mode Field Diameter (MDF around 5.6 μm) of the scanning probe; whereas the spectral resolution is limited by the SLED intensity noise and the resolution of the spectrum analyser (0.1 nm resolution for the device used). This kind of configuration is a first step towards the implementation of SOH for quantitative broad-band imaging.

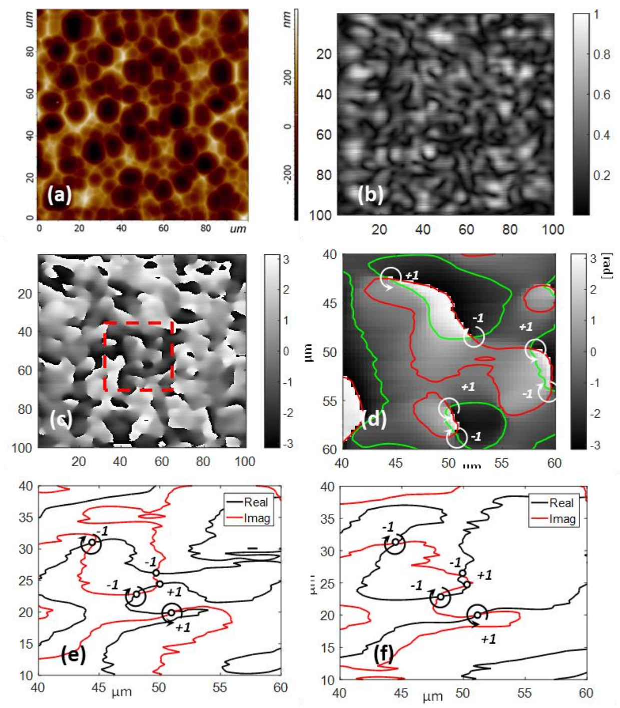

Fig. 1 (a) AFM topography, (b) Magnitude of the scattered field (c) Phase of the scattered field, (d) Detail of the phase map in which the zero contour plots of real and imaginary part of the scattered fields are highlighted. The intersection points define the position of phase singularities, each characterized by a topological charge, (e) The contour-zero lines of the real and imaginary parts of the complex scattered field are reported for the wavelength 836.4 nm and (f) 835.8 nm [7].

References

1. Cheng, X. et al. *Opt. Lett.*, 39, 11, (2014).
2. J. W. Goodman, *Speckle phenomena in optics* (2007).
3. M. Schnell et al. *Nat. Commun.* 5, 3499 (2014).
4. A. Di Donato et al. *J. Light. Technol.* 28, 10 (2010).
5. A. Di Donato et al. *AIP Adv.* 5, 117125 (2015).
6. A. Di Donato et al. *Opt. Lett.* 38, 23 (2013).
7. A. Di Donato et al. *AIP Adv.* 9, 015211 (2019).