CARBON NANOPARTICLES FOR DIAGNOSTIC OF RANDOM SPECKLE-FIELDS. HILBERT TRANSFORMATION APPLICATION

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INTRODUCTION

A new approach of carbon nanoparticle using for the optical diagnostics of a complex scalar optical field obtained by scattering and diffraction of radiation on a surface with roughness is suggested in this paper. Luminescence of carbon nanoparticles made it possible to register their coordinate position in time. The algorithm for the reconstruction of scalar optical field intensity distribution through the analysis of nanoparticle position was proposed in the paper. The phase map of the optical speckle field was analyzed by a Hilbert transform filter to restore the phase of the entire object. A special attention was paid to the restoration of the phase singularities of the speckle field of the scattering studied object.

STUDY OF OPTICAL SPECKLE FIELD BY CARBON NANOPARTICLES

The search for ways to recover the intensity distribution through processing of recorded tracks of carbon nanoparticle motion in the complex optical field, which is obtained at the light scattering on the surface with roughness[1,2] are analyzed in this part of paper.

Cuvette with carbon nanoparticles of about $\lambda/_{10}$, with known properties, in water solution, is placed in an optical field. Randomly suspended particles move in this field as a result of the internal optical flows action, and localize in regions of minimum intensity with singularities. It is possible to reconstruct tracks of nanoparticle motion and intensity distribution. Motion of particles is visualized due to their bright luminescence.

The ratio of the gradient and scattering components of the optical force for different size of carbon nanoparticles at a wavelength of 633 nm for nanoparticles in a speckle field is shown in the Figure 1.

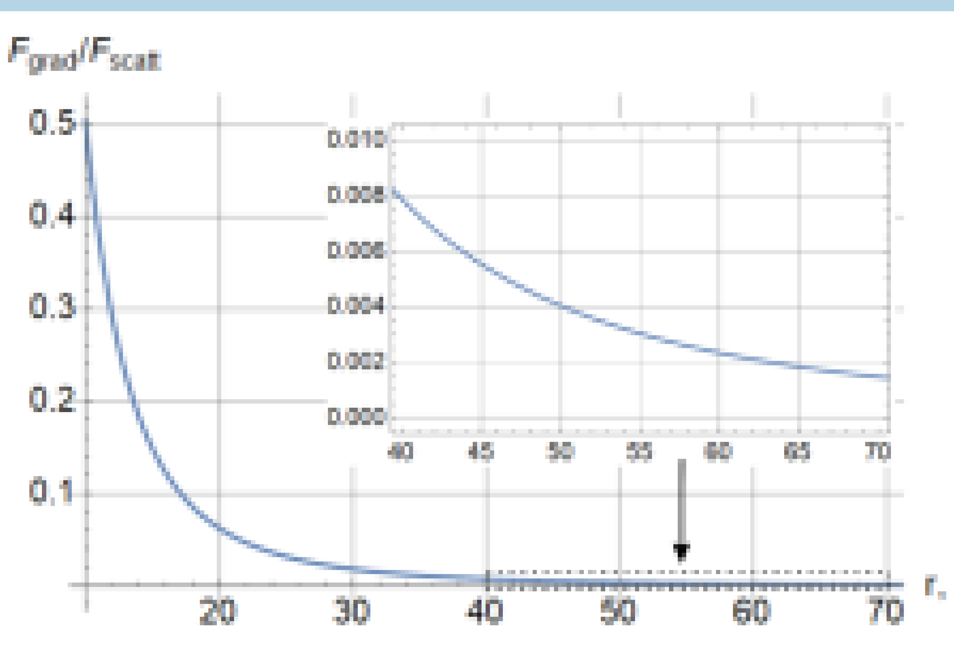

Fig. 1 Ratio of optical force components as a function of the size of carbon nanoparticles

The distribution of the gradient force is analyzed in x(y) directions, i.e. in the cross section of the beam. The scattering and absorbing components exert their effect in the direction of the action of the Pointing vector (longitudinal z-direction). Therefore, when analyzing the distribution and influence of these forces in the transverse plane, the action of the gradient component of the optical power is highlighted. An analysis of the magnitude of the active component of gradient force shows that the minimum regions with singularities determines such a force value that can change the particle position in time.

Equation of motion of an i-particle (i=1..N, where N – total number of nanoparticles analyzed in the speckle field) under the action of optical force can be written down as:

$$m\frac{d\vec{v}_i}{dt} = \vec{F}_{opt_i} + \vec{F}_{st_i}$$

where $\vec{F}_{opt_i}$– the resulting optical force (components of which are gradient, scattering and absorbing components), $\vec{F}_{st_i} = 6\pi r_i \eta \vec{v}_i$ – Stokes force, $m_i = \frac{4}{3}\pi {r_i}^3 \rho$ – mass of carbon nanoparticle, r_i – particle radius, $\rho = 2,26\,\frac{g}{sm^3}$, $\eta = 8,9 \cdot 10^{-4}\ Pa \cdot sec$ – dynamic viscosity of the medium (water) at T=25°C.

When computer simulation is performed (Fig.2) the observation interval for each nanoparticle is determined by the time of capture of the nanoparticle by the intensity minimum with singularities (Fig.3). Figure 2 demonstrates the changes in carbon nanoparticles position in time.

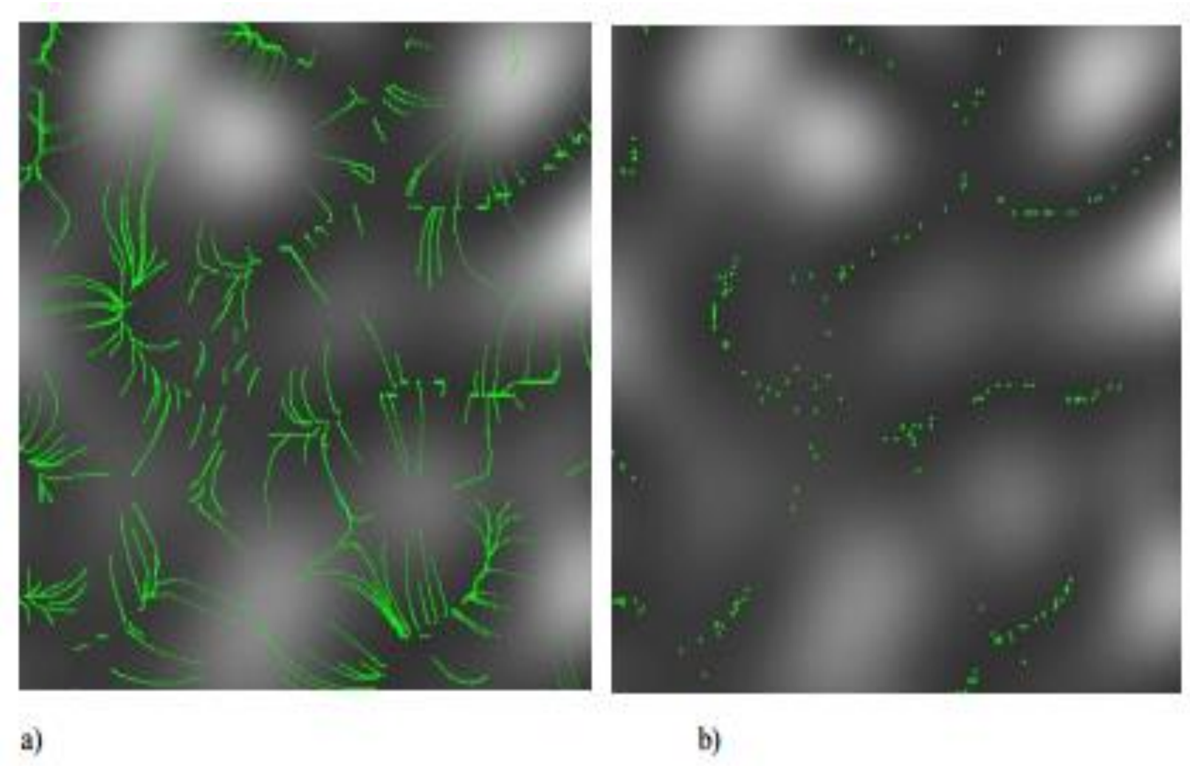

Fig. 2. The particles position in time: tracks of nanoparticles during their motion (a); the position of the particles in the speckle field after their redistribution into the areas of intensity minimum (observation time 5 second) (b).

SINGULARITY POINTS RESTORATION

Figure 3 (a, b) presents the distribution of intensity gradient lines (white lines with arrows) in simulated speckle field (the size of analyzed region is 1.8x1.8 μm^2 (Fig. 3a (red square), b, c)). Singularity point is marked by a red point (Fig.3 a, b). In 30 second (Fig. 3c) carbon nanoparticles redistribute into the minimum area with singularities moving along the gradient lines of intensity (green tracks).

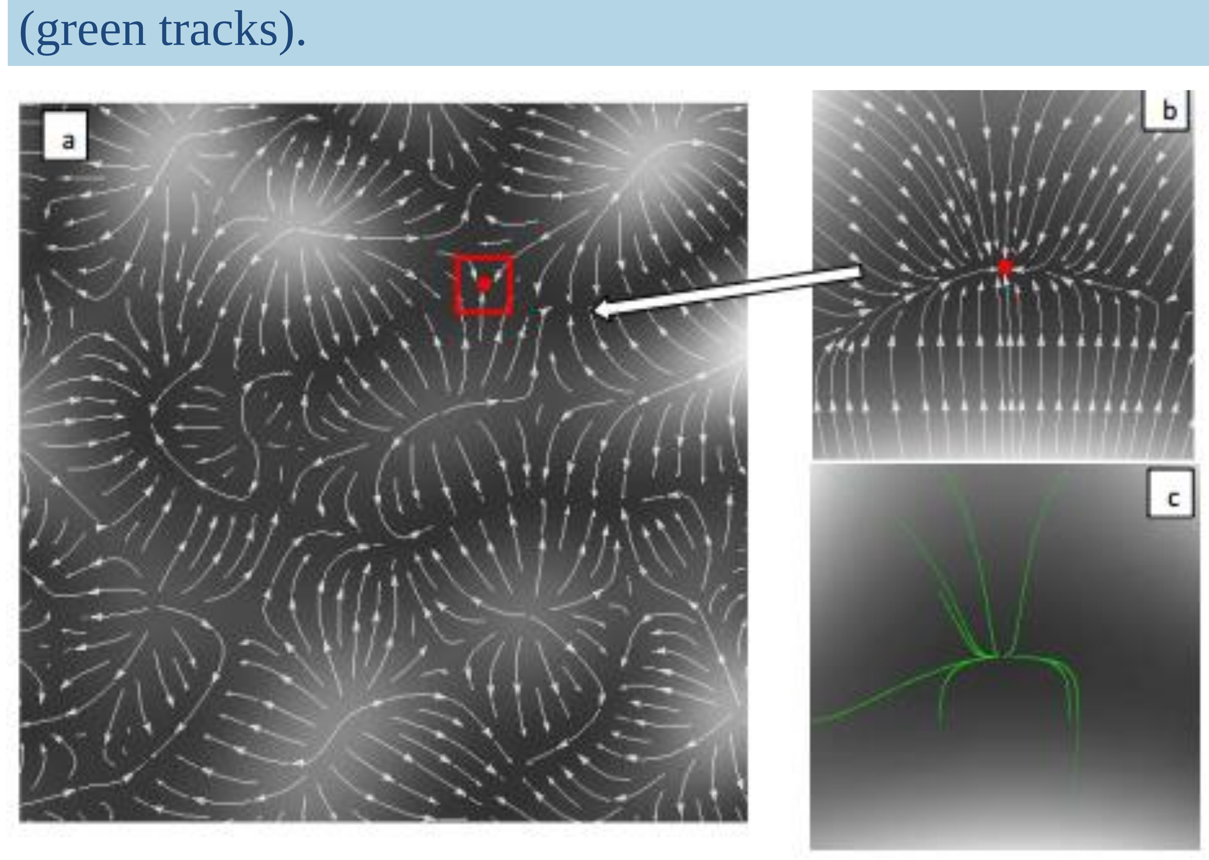

Fig. 3 Speckle field (a, b, c) with gradient lines of intensity (white lines with arrows) determining the motion of carbon nanoparticles (green tracks) (c) into the areas with singularities (red point) (a, b).

The final step of our investigation is to restore a phase information[3-7] from the reconstructed intensity distribution. Mathematica software product offers, in order to restore phase distributions, to use the Hilbert filter, which is processed the intensity distribution of the studied speckle field. Specific speckle-field points as intensity zeros, phase singularities, which need to be analyzed and reconstructed, can be extracted from the obtained phase map. The resulting phase map is shown in the figure 4. For comparison the same points are obtained through the intersection of real and imaginary parts of complex field amplitude (Fig. 4, green and blue lines). The error of singularity diagnostics in our case is 85 %

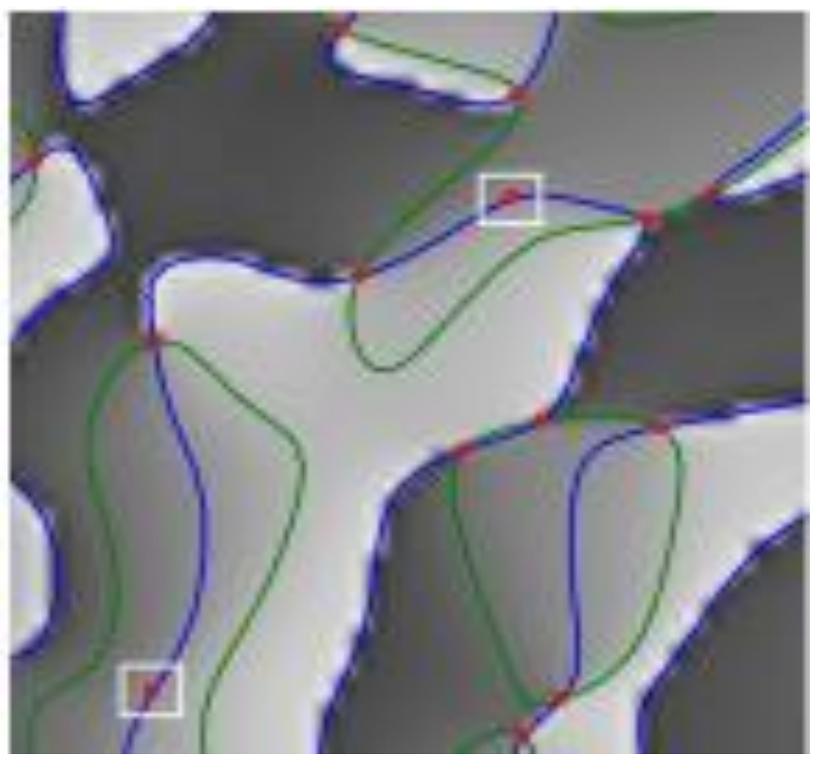

Fig. 4. Localization of phase singularities (red points) and minimum of intensity (red points in white square) obtained from the restoring phase map. Green and blue lines correspond to the distribution of real and imaginary parts of complex field amplitude.

CONCLUSIONS

New approach of carbon nanoparticles using to study the optical field obtained as a result of diffraction on a random scattering non-stationary object is demonstrated. The carbon nanoparticles of about $\lambda/_{10}$, used in investigation, are characterized by strong absorption and luminescence at yellow-green wavelengths and weak absorption at He-Ne wavelength laser irradiation, where a speckle field is formed. Visualization of singularity points by carbon nanoparticles, their moving in the optical field due to internal optical flows action, gives it possible to reconstruct intensity distribution of analyzed optical field. Applying of Hilbert transform for phase retrieval of investigated optical field, provides the information about the phase map with the determination of phase singularities of the object optical field.

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