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Charge inversion of polarization correlation vortex

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ABSTRACT

Optical Speckles has many extraordinary applications like subwavelength focusing, aberration-free imaging, etc. which are not possible even with a highly coherent optical field. This makes it necessary to study the fundamental properties of such Optical Speckle fields. In the recent past, the polarization correlation vortex phase was experimentally realized in vector speckle field generated by scattering of Poincare beam. Higher-order correlations have also been studied in such vector speckle fields. Moving further into this direction, we have studied the first-order polarization correlations in the focused vector speckle field. We have generated a vector speckle field by scattering of Poincare beam. Which is then allowed to be focused using a spherical and a cylindrical lens. The focused vector speckle field intensities at different planes around the focal plane were recorded to get polarization correlations at each plane. It was observed that the charge of the input vortex beam before scattering is still present in the polarization correlation of the focused vector speckle field. We have also observed charge inversion of polarization correlation vortex focused through a cylindrical lens. The importance of this study relies in the fact that it provides, with supporting experimental and simulation results, that the polarization correlation obeys the wave equation. It could find application in optical image processing while analyzing any optical data, to find information about the source of the speckles, etc.

Keywords: Correlation Optics, Polarization, Singular Optics, Statistical Optics, Speckle, Vortex Charge, Poincare beam

1. INTRODUCTION

Optical speckles are stochastic electromagnetic fields[1], i.e., the field having random intensity and phase distribution. Optical speckles are obtained when coherent light is scattered by the medium having wavelength scale irregularities[2]. Being random in nature, speckles were considered as a noise in the optical system having a coherent source, suppressing the useful information in the observations and hence limiting the system performance. Therefore, sufficiently high number of efforts were made by the researchers and engineers to eliminate speckles from the recorded data[1].

In the efforts to eliminate speckles from the experimental data, there emerged some extraordinary applications of optical speckles, which were not possible even with highly coherent optical fields. Such applications are subwavelength imaging[3], subwavelength focusing[4], aberration-free imaging[5], etc. Therefore, the field of optical speckles grabbed much attention and numerous[6-10] fundamental studies on optical speckle field were carried and more need to be done.

One of the most useful tools to study optical speckles is the Correlation function. Statistical correlation has proved its importance in many fields for data processing and information extraction. Some of the important applications those become possible due to statistical correlation are: ghost imaging[11], study of ultra-short pulses[12], correlation holography[13], super resolution microscopy[14], etc.

Statistical correlations like intensity correlations, first-order field correlations[15], Stokes field correlations[16], etc. have been studied earlier. Considering the importance of correlation study in information processing, we investigated the first-order polarization correlation in the field propagating through a spherical and a cylindrical lens.

In this paper, an experimental method to study polarization correlation in propagating vector speckle field is described in detail. The speckles are propagated through spherical and cylindrical lenses and the polarization correlations are determined at various planes before and after the focal plane of the lens. The experimental data, with supporting simulation results, showed that the polarization correlation obeys wave equation. It was also observed that the charge of the polarization correlation vortex gets inverted while speckle field propagates through a cylindrical lens.

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2. EXPERIMENTAL METHOD

The experimental set-up for the study of propagation of first-order polarization correlation is as shown in figure 1. A diode-pumped solid-state laser, *Coherent-Verdi-V10*, having Gaussian beam output with vertical polarization is used as a source. Operational wavelength of the laser is 532 nm.

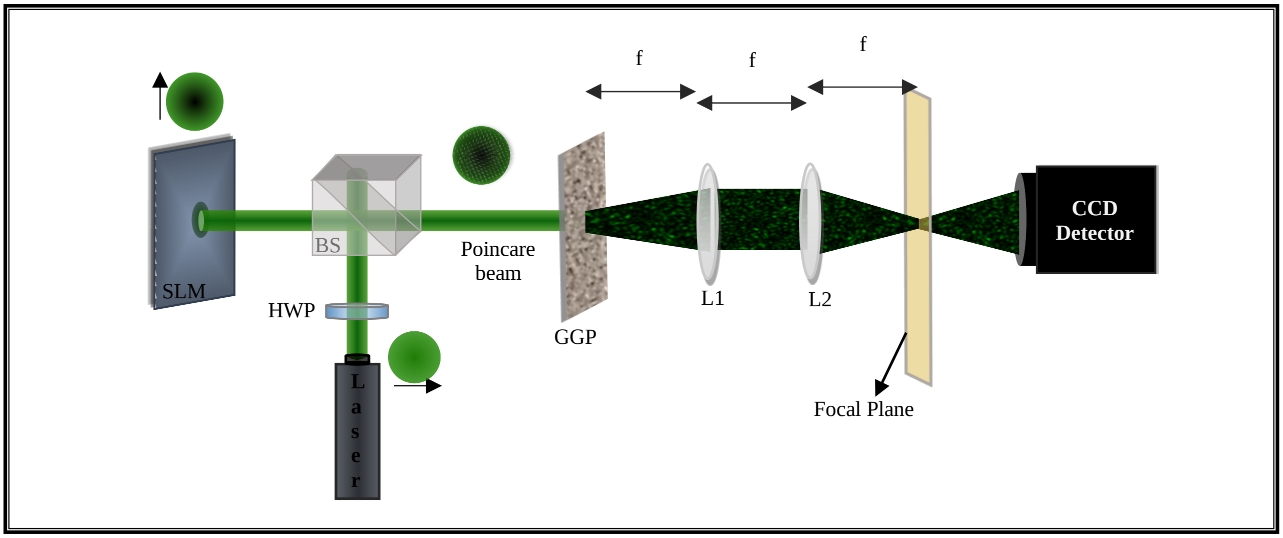

Figure 1. Experimental set-up to study polarization correlation in propagating vector speckle field. SLM: Spatial Light Modulator; BP: Beam Splitter; GGP: Ground Glass Plate.

A vertically polarized Gaussian beam of laser, after passing through adjusted HWP, will contain an equal amount of horizontally and vertically polarized components. A portion of this light is allowed to fall onto a y-polarization sensitive spatial light modulator (SLM), using a beam splitter (BS). The SLM is programmed with a vortex phase. Therefore, y-polarization component of the incident light will be modulated with the vortex phase, giving a y-polarized vortex beam. y-polarized vortex beam and x-polarized Gaussian beam co-axially superpose to give Poincare beam[17] (PB) at the output of the BS. This PB is allowed to pass through a ground glass plate (GGP) having wavelength scale irregularities. Hence, we get polarization speckles at the output of GGP due to scattering of the PB.

The polarization speckles[18] or the vector speckle field is then allowed to pass through lenses L1 and L2 to study the polarization correlation in propagated speckles. Here, the L2 lens is the element of our interest. We kept a spherical and a cylindrical lens in place of L2 for our study. While lens L1 is a spherical lens only, used for mathematical simplicity of the analysis[19]. Both the lenses are having an equal focal length of 20cm.

The polarization speckle field can be mathematically expressed as:

$$\vec{E}_{sc}(\vec{r}) = F\left(\vec{E}_{PB}e^{i\phi_R(\vec{r})}\right) = \vec{E}_{Sc(x)}(\vec{r}) + \vec{E}_{Sc(y)}(\vec{r}) \quad (1)$$

Here, $\phi_R(\vec{r})$ is the random phase introduced by the GGP to the input field of the Poincare beam, $\vec{E}_{PB}$, given by

$$\vec{E}_{PB} = E_x e^{i\phi_x}\hat{e}_x + E_y e^{i\phi_y}\hat{e}_y = \left(\hat{e}_x + re^{i|l|\theta}\hat{e}_y\right)e^{-\frac{r^2}{2w_0}} \quad (2)$$

where, $r = \sqrt{x^2+y^2}$, $\theta = (y/x)$, and w_0 is the beam waist.

We recorded intensities of the speckle field propagated through L2 at planes before and after the focal plane of L2. The first-order polarization correlations defined as[15]

$$S_{xy}(\vec{r}_1;\vec{r}_2) = \langle\{\left|E^*_{Sc(x)}(\vec{r}_1)\right|\}\{\left|E_{Sc(y)}(\vec{r}_2)\right|e^{i\Phi_{xy}(\vec{r}_2)}\}\rangle. \quad (3)$$

were determined for these fields using Stokes polarimetry[20]. Here, $\Phi_{xy}(\vec{r}_2)$ is Stokes phase, giving the phase difference between orthogonally polarized components of the speckle field.

3. RESULTS AND DISCUSSION

The experimental results for propagation of polarization correlation and corresponding MATLAB simulations are as follows:

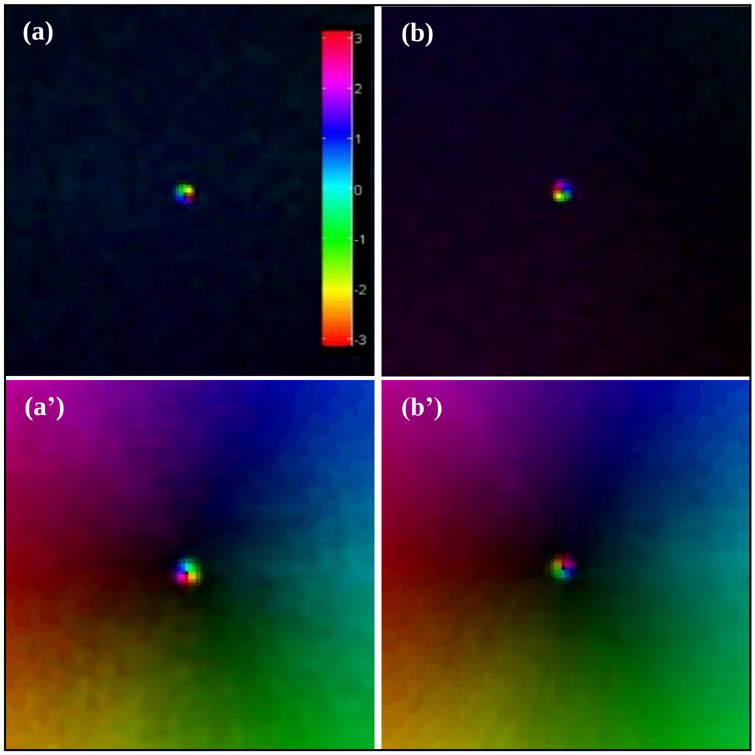

Figure 2. Intensity modulated Polarization correlation vortex for the speckle field (a) 4cm before the focal plane and (b) 4cm after the focal plane of the spherical lens. (a') and (b') are corresponding simulation results. Colorbar is the same for all as shown in figure 2(a).

It can be noticed from figures 2(a) and 2(b) that the polarization correlation vortex[22] at the planes 4cm before and 4cm after the focal plane are almost similar, except a phase difference of 180^o. It is clear from the figure that the experimental and simulation results are in good agreement. Some constant phase difference between experimental and corresponding simulation results is because of different initial phase conditions.

Figure 3 shows the polarization correlation vortex propagated through a cylindrical lens. It can be noticed that the polarization correlation vortex at the plane before and after the focal plane are having opposite topological charge analogues to free space propagation of optical vortex through cylindrical lens[21]. It is clear from the figure that the experimental and simulation results are in good agreement. A constant phase difference between experimental and corresponding simulation results is because of the different initial conditions.

It was observed that the polarization correlation vortex is behaving in the similar manner as the vortex beam while propagated through lenses[21]. The main difference between both these vortices is, the first one is the vortex arising due to first-order polarization correlation while the second one is the vortex phase associated with the field itself. Since vortex beam propagation obeys the wave equation, we can conclude that the polarization correlation defined by equation 3 also obeys the wave equation.

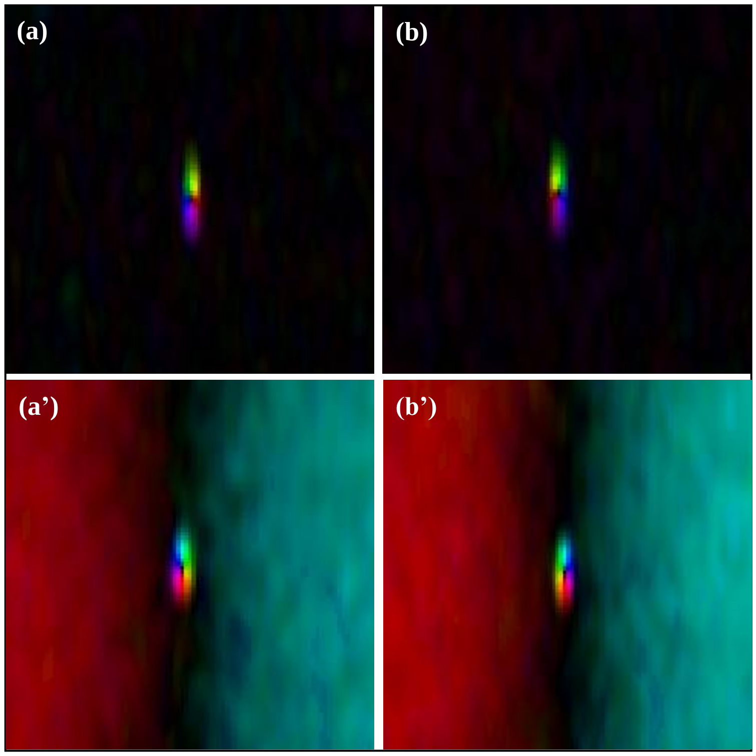

Figure 3. Intensity modulated Polarization correlation vortex for the speckle field (a) 4cm before the focal plane and (b) 4cm after the focal plane of the cylindrical lens. (a') and (b') are corresponding simulation results. Colorbar is the same for all as shown in figure 2(a).

4. CONCLUSION

This paper contains a detailed explanation of the experimental method to study polarization correlation in propagating vector speckle fields. We showed charge inversion of polarization correlation vortex when the speckle field is focused through a cylindrical lens. We have experimentally proved with supporting simulations that the polarization correlation defined by equation 3 is behaving in the similar manner to the vortex beam while propagated through lenses. Hence, defined polarization correlation also obeys the wave equation. This kind of fundamental study could be useful to better understand the polarization correlations in vector speckle fields. It could find application in optical image processing while analyzing any optical data to find information about the source of the speckles. Hence, it could be applied to biomedical imaging techniques to astronomical data analysis techniques, wherever speckle field is arising.

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