Use of polarization in interferometry after double passage through turbulence

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We report what are to our knowledge the first experimental results of coherence enhancement that use polarization to separate coherent and incoherent paths.

The phenomenon of coherence enhancement after double passage through turbulence has been predicted and observed (Ref. 1 and references therein). This phenomenon consists of the appearance of correlation in the backscattered field in regions around the illumination sources. In Ref. 2, the possibility of exploiting this effect to perform diffraction-limited imaging of deterministic objects is discussed and a method is proposed for increasing the correlation by separating the coherent part of the reflected light. This method is based on the manipulation of the polarization states of the illumination and the reflected light. In this Letter experimental results illustrating the potential of this method are given. These preliminary experimental results have been obtained for a mirror illuminated by two coherent point sources.

The experimental setup is schematically shown in Fig. 1. Two point sources were created by focusing two collimated light beams originating from the same linearly polarized He–Ne laser. The focused beams passed through the two circular apertures A and B in the opaque screen. The diameter of these apertures was 0.4 mm, and the distance between their centers was 1.9 mm. Behind the holes we installed two quarter-wave plates with fast axes oriented such that linear polarized radiation passing through them was transformed into circular polarized radiation with the electric vectors of beams A and B rotating in opposite directions. This is achieved by setting the angle between the fast axes and the direction of the incident beam polarization to be +45° and −45°. The circularly polarized light was directed to a plane mirror M with a diameter of 40 mm situated behind the turbulent layer. Turbulence in the glass cell was created in the distilled water layer lying between two heat exchangers and could be varied by changing the liquid layer height and the temperature difference between the heat exchangers. In this experiment, the coherence radius of the light reflected from the mirror in the plane of the sources was approximately 0.14 mm.

With illumination of the plane mirror by the two sources at A and B we can single out four possible paths of light propagation: AMA, AMB, BMB, and BMA. If the illumination at points A and B has vertical polarization, then after double passage through the quarter-wave plates along the mentioned four paths the polarization states will undergo the following transformations:

- **BMB**: vertically polarized → right circular (λ/4 at +45°) → horizontally polarized (λ/4 at −45°);
- **AMA**: vertically polarized → left circular (λ/4 at −45°) → horizontally polarized (λ/4 at +45°);
- **BMA**: vertically polarized → right circular (λ/4 at +45°) → vertically polarized (λ/4 at −45°);
- **AMB**: vertically polarized → left circular (λ/4 at −45°) → vertically polarized (λ/4 at +45°).

Apertures A and B are thus illuminated by light reflected from mirror M, part of which has vertical polarization, with the other part having horizontal polarization.

Since the beams AMB and BMA pass through the same inhomogeneities, the turbulence will introduce the same phase delay, and the beams will be coherent. The paths AMA and BMB go through different parts of the turbulent medium, their phase delays are uncorrelated, and, consequently, they are incoherent. Because the coherent beams (AMB and BMA) have vertical polarization and the incoherent beams (BMB and AMA) have horizontal polarization, we can separate the components of the reflected radiation with the help of a suitably ori-
Fig. 2. Time-averaged one-dimensional intensity observed in the focal plane with no turbulence present and no quarter-wave plates. The visibility of the fringes is 0.91. In all figures the vertical axis represents the intensity in arbitrary units and the horizontal axis represents the length in millimeters.

The measured visibility was $V = 0.91$. This visibility is unaffected by the presence or absence of the quarter-wave plates. In the presence of turbulence but without the quarter-wave plates the interference pattern is formed both by the coherent and incoherent parts of the incident light. In this case, as expected, we observe some blurring of the time-averaged interference pattern (Fig. 3)—the visibility is equal to 0.20. With the quarter-wave plates in front of A and B the visibility of fringes is significantly improved ($V = 0.56$; see Fig. 4), since in this case only the coherent components interfere. It should be noted that the theoretical prediction in this case for deltalike apertures is $V = 1$. The lower visibility obtained in the experiment is the result of a practical limitation of the experimental apparatus, namely, that the apertures have a larger diameter (0.4 mm) than the coherence radius of the turbulence (0.14 mm).

The polarizer was then rotated to the horizontal. In this instance only the light traveling the paths $AMA$ and $BMB$ is passed by the horizontal polarizer. These paths are coherent with respect to each other only if there is no turbulence. When the turbulence is switched on, we indeed observe the complete loss of interference fringes in the time-averaged pattern (Fig. 5). This is because we have only allowed the incoherent components of the light field to add.

The distribution of the time-averaged backscattered intensity in the source plane with the wave plates present was also measured. The detector array was placed behind the spherical lens in the

Fig. 3. Time-averaged one-dimensional intensity observed in the focal plane with turbulence present but no quarter-wave plates. The visibility of the fringes is 0.2.

Throughout our measurements, the linearly polarized illumination was defined to be vertically polarized. The polarizer was first rotated to the vertical. When the turbulence is switched off we observe an interference pattern (Fig. 2), the visibility of which is

$$V = \frac{I_{\text{max}} - I_{\text{min}}}{I_{\text{max}} + I_{\text{min}}}. \quad (1)$$

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Fig. 4. Time-averaged one-dimensional intensity observed in the focal plane with turbulence present and quarter-wave plates situated at the apertures A and B. The visibility of the fringes is 0.56.

Fig. 5. Time-averaged one-dimensional intensity observed in the focal plane under similar conditions to those in Fig. 4 but with the polarizer rotated to the horizontal. No interference pattern is visible.
When the polarizer is effectively opaque to directly backscattered radiation along paths $AMA$ and $BMB$ (i.e., a vertical polarizer), we observe a relatively uniform average intensity distribution in the source plane (Fig. 6). From our measurements above we know that this is the condition under which we observe coherence enhancement. With the polarizer horizontal we observe two intensity peaks, the position of the maxima of which coincides with the position of the sources (Fig. 7), yet obtain no enhancement of coherence. These results clearly demonstrate the difference between the effects of power and coherence enhancement under backscattering. Power enhancement is determined by intensity fluctuations, whereas the enhancement of coherence is caused primarily by phase correlation in the reflected waves.

We have illuminated a plane mirror through turbulence through two pointlike apertures and observed the time-averaged interference pattern in the image plane of the aperture after the return passage. It has been experimentally demonstrated that by manipulation of the polarization states of the illumination and reflected radiation one can improve the visibility of interference fringes. Physically this is due to the fact that we select only the coherent part of the light reflected from the object. The use of polarization has allowed us to distinguish between two related phenomena—power enhancement under backscattering through turbulence and coherence enhancement of the scattered field in the presence of turbulence.

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