Polarization and phase shifting interferometry for the simultaneous measurement of phase and polarization.

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Optical components manipulating both polarization and phase of wave fields find a lot of applications in todays optical systems. In several cases it is useful to characterize such optical elements with respect to their impact on the polarization and the phase of an incoming light wave simultaneously. An interferometric approach for a spatially resolved measurement of phase and polarization in one measurement procedure is introduced. This is achieved by introducing a new method where a set of algorithms similar to the well established ones used in PSI with an additional variation of a reference polarization is applied. For the minimal algorithm only five interferograms are sufficient to calculate all unknown variables.

1 Introduction

The spatially resolved polarization and the phase of a wave front are two important quantities of a light beam. The characterization of polarization is generally made with a measurement of the Stokes parameters, resulting in the local phase retardation, but not the global phase. On the other side, for the phase measurement the well established method of the phase shifting interferometry (PSI) can be used, but without measuring any polarization results. Furthermore the PSI method can fail by spatially variant polarization.

Therefore a new method, the "polarization and phase shifting interferometry" (PPSI) was developed. The measurement strategy is based on the idea to change the polarization of the reference wave, in addition to common phase shifting, as by PSI.

With the first algorithms it was possible to measure, additional to the phase front, the spatially resolved orientation of the locally linearly polarized light [1, 2] in one measurement procedure. The next generation of the PPSI algorithms [3, 4] allowed the full field measurement of any polarization and phase distribution with nine detected intensities.

In this work a further development of the PPSI-algorithms is presented. For the complete calculation of all five unknown variables with a new set of algorithms just six detected intensity distribution are needed.

2 Theory

It is useful to start with a description of the theoretical background by a shortly introducing classical PSI.

2.1 PSI

In an interferometric setup the observed object beam with an unknown phase Φ interferes with the reference beam with known and adjustable phase Φ'. [5] The resulting intensity distribution can be described by the Michelson-formula given in Eq. 1 .

$$I = I_0(1 + V \cos(\Phi - \Phi')) \tag{1}$$

I_0 is the sum of the both intensities and V is the usual visibility. The interference term is a function of Φ and Φ'. The measurement strategy of the PSI is the detection of different intensity patterns by the variation of the reference phase.[6].

The interference pattern of the object beam with a locally varying linear polarization and a linearly polarized reference beam can lead to regions with low or even vanishing contrast caused by the orthogonality of both polarizations. This limits the classical full field phase analysis.

2.2 PPSI

Equation 2 is the advanced interference formula of the superposition of the unknown object and known reference beam with an additional polarization information given by the angles α/δ and α'/δ' respectively. [7]

$$I = I_0(1 + V \cdot IT(\Phi, \alpha, \delta, \Phi', \alpha', \delta')) \tag{2}$$

The definitions of I_0 and V are the same as in PSI. The interference-term IT is now a function of six values representing phase and polarization of both beams. The measurement strategy of PPSI is the detection of different intensity patterns by variation of polarization and phase of the reference. Various measurement algorithms with different numbers and values of steps were investigated. The minimal algorithm needs just six intensities to calculate the full description of the object phase and polarization in addition to I_0 and V.

3 Experimental setup

The measurement setup is a folded Mach-Zehnder interferometer (see Fig. 1) with some special metrological modifications.

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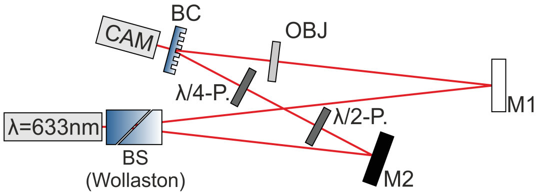

Fig. 1 *Sketch of the experimental setup*

The variation of the polarization and the phase of the reference beam is done by two rotatable polarization elements (HWP and QWP) and a movable mirror (M2), respectively. An almost normal incidence on the mirrors is necessary to suppress the influence of the mirror reflections on the polarization states, as the Fresnel coefficients indicate.
As a beam splitter (BS), a Wollaston prism is used, that allows to adjust the visibility of the interferograms by controlling the intensity ratio between object and reference wave. To conserve any polarization patterns present in the incident beams a specially designed phase grating is used as a beam combiner (BC).

4 Experimental results

The spatially variant polarization distribution in the object beam was generated by a polarization converter from the firm ARCoptix . This device, based on liquid crystals, converts a linearly polarized light beam into a beam with an axially symmetric radial or azimuthal polarization distribution (`http://www.arcoptix.com`).
Figure 2 shows the measured phase and polarization values of the generated radial polarization behind the device.

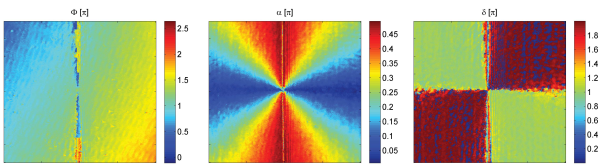

Fig. 2 *Measured phase Φ and polarization angles α/δ of the radial object polarization.*

For the second measurement (see. Fig. 3) the generated polarization was changed to azimuthal polarization.

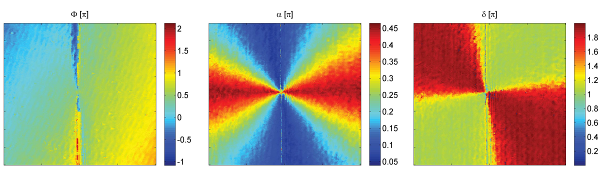

Fig. 3 *Measured phase Φ and polarization angles α/δ of the azimuthal object polarization.*

The presented results were calculated with a method we call $(3/2/1)$, that means that a set of three interferograms with an equidistant phase step of $\frac{2}{3}\pi$ was done for two reference polarization states, namely a horizontally and vertically linear polarisation. Both measured values of the phase front have the same plane shape. The vertical line in the centre of both phase distributions is caused by an integrated phase shifter in the converter. The active area of this phase retarder covers only half the useful aperture and the phase results are disturbed by this defect line.
The measured polarization angles α and δ represent the expected radially and azimuthally polarized light. These two values can be combined to one ellipse plot (see Fig. 4) for more comprehensible visualization of the measured polarization. The areas with blue and red ellipses represent some deviations in the ellipticity from the ideal polarization states with local ellipticity zero.

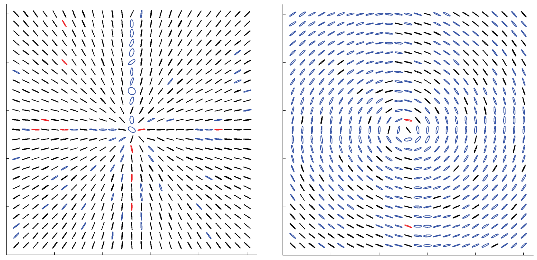

Fig. 4 *Resulting ellipse plots representing the measured polarization states.*

5 Summary

A new interferometric method for the simultaneous measurement of arbitrary spatially variant phase and polarization was introduced. The used experimental setup and some results were shown.

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