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Development and error analysis of a 2 µm-centered polarimeter for complete Stokes' vectors measurements

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Abstract

Developing a device to retrieve the full Stokes' vector at high-speed requires a careful design. We present an analysis of the measurement error of a polarimeter as a function of all optical component defects.

Main text

The polarization of light is an important parameter for many applications, such as multiplexing in light-based communication systems or encoding qubits in orthogonal States of Polarization (SOP). However, the 2 µm wavelength region lacks systems for complete measurements of this SOP. Commercial systems for this wavelength are limited to measuring the polarization extinction ratio (PER), and are therefore restricted to the ratio between the orthogonal linear components of a polarization state. Thus, a PER meter cannot provide the exact position of a polarization vector (or Stokes vector) on the Poincaré sphere, and are mostly suitable for linearly polarized light, which account only for the equator of said Poincaré sphere.

To measure the complete SOP of any incoming light, the main polarimeter technique uses the rotating quarter wave plate (QWP) method, where the incoming light passes through said rotating QWP and a polarizer. By sampling the output power of this system and performing the relevant Fourier transforms, the four components of the Stokes vector can be retrieved [1]. However, this method requires a stable motor with low vibrations, and the Fourier transform are time-consuming and limited to the sampling speed, which depends on the motor speed.

In order to develop a fast 2 µm polarimeter, we considered another method based on a four-armed system inspired from [2], each with different fixed polarization components, see figure 1. The four components of the Stokes vector (S_0 through S_3) can be retrieved from simple algebra on the four measured intensities in a single-time measurement, therefore the setup is limited by the electronics rather than motorized components, allowing for an increase in acquisition speed. [2] accounts for several kHz with their original setup and a high-speed camera.

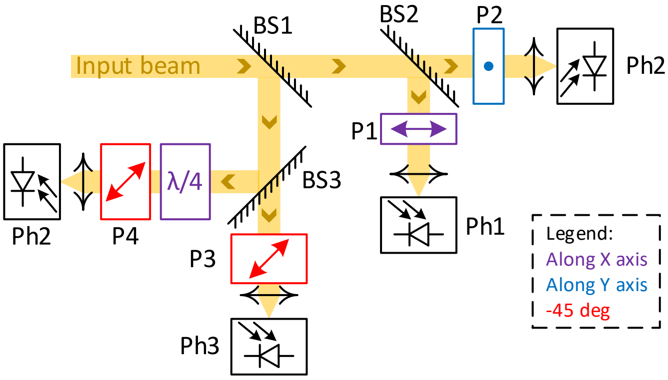

Fig. 1. Setup schematic of the polarimeter.

The setup uses three non-polarizing 50/50 beam splitters (BS), four polarimeters (represented according to their orientation with respect to the propagation plane), and a QWP. Intensities are retrieved from photodiodes (Ph), and therefore used to compute the Stokes vector over time. It allows to obtain the full SOP, as well as the degree of polarization (DOP), defined as $\sqrt{S_1^2 + S_2^2 + S_3^2}/S_0$ [1] accounting for the ratio between polarized and unpolarized light.

A system in its ideal form (perfect optical components) can obviously produce accurate results for any given input polarization state. However, errors are inherent to a physical system. Concerning the polarimeter these errors can be identified as angular misalignment between optical components, the 50/50 beam splitting ratio, and the phase delay difference between polarization axis. Some of these errors can be compensated through additional calculation/calibration, e.g. the beam splitting ratio. Though the others are intrinsic to the system and their effect on the polarimeter's performance need to be estimated. Such study is necessary to define the acceptable performance range of the system.

Therefore, we studied these errors through a numerical calculation, similar to the misalignment analysis for the rotating QWP setup presented in [3]. To do so, the Poincaré sphere is homogeneously sampled, and each sample vector will be propagated through the erroneous system. All sources of errors can be represented as angles (transmitted and reflected phase delay difference for the BS, fast axis angle and retardance for the QWP, and angular misalignment for the polarizers). Hence, only one of these parameters is chosen as the error, and ranges between ±2° of its ideal value, chosen accordingly with an estimation of the worst-case alignment error. The maximum error, calculated as the absolute angle between the expected and measured Stokes vectors, is displayed as a heatmap on the Poincaré sphere in Figure 2 as a function of the Stokes parameters. The three main polarization states visible are labelled for simplicity: left circularly polarized (LCP), linear horizontally polarized (LHP), linearly 45° polarized (L45P). We observe that the maximum error varies between 0° and 4.15° for a misalignment of P1, and between 0° and 5.00° for P4, which are acceptable values considering the complexity of the system. From these measurements, we also observe that the error displays either a point symmetry centered at the origin (figure 2a) or a planar symmetry (figure 2b), different for each component. For P1, the maximum error occurs for linear polarization at ±45°, and the minimum is mostly in the region where S_2 is minimal. For P4, the horizontal and vertical linear polarization induce the maximum error, and the minimum is where S_1 is minimal, with a wider region around circular polarizations (north and south poles). These two figures where obtained from error on a single polarizer. The other three main polarizations (right circular, vertical, and −45°) are their respective antipodal points on the sphere.

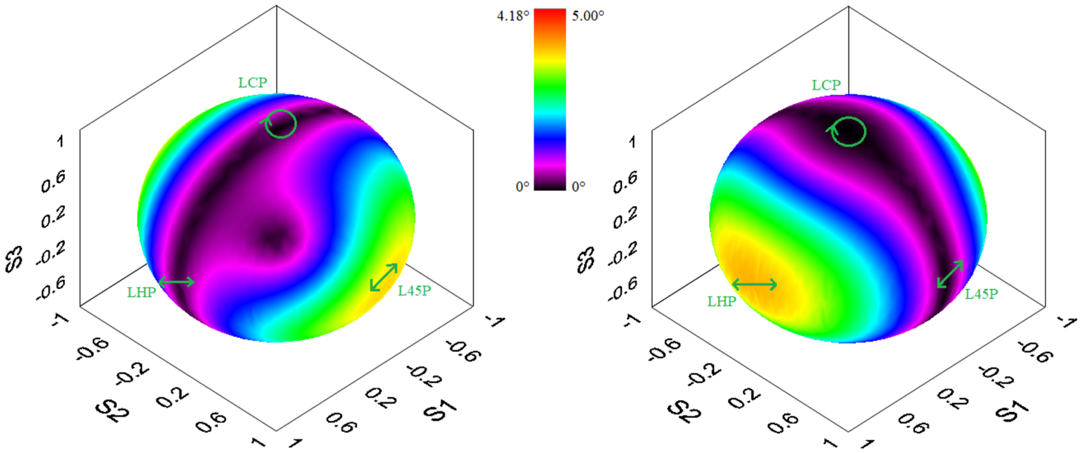

Fig. 2. Maximum error induced by a misalignment ranging within ±2° for different optical components and all SOP. Left: polarizer P1. Right: polarizer P4.

In order to define the useful range of the device, we define the maximum acceptable error as 10°. It is found that the estimated error could be used in parallel with calibration polarizations to improve the alignment of the various components, by targeting the components more likely to introduce an error at a given test input. Certain errors can also undergo an algorithmic correction, such as specific wavelength-dependence, therefore narrowing the overall error.

Finally, we apply the error analysis to a real setup we designed and assembled for a wavelength of 2 µm. The wavelength range to have a maximum error lower than 10° is determined and presented.

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