Vector Diffractive Optical Element as a Full-Stokes Analyzer

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ABSTRACT: In this work, we achieve real-time characterization of the state of polarization of a ligth beam with a robust and fast device, a Vector Diffractive Optical Element (VDOE). From the simulations, our device is able to identify any polarization state with an averange uncertainty of 0.006%. Finally, we manufactured the VDOE and verify its performance.

MOTIVATION

The polarization state of light plays an important role in several fields like material analysis, astrophysics, medicine or defense as it determines how light interacts with matter. It can be studied through two main approaches:

JONES FORMALISM — Totally-Polarized light

MUELLER-STOKES FORMALISM — Partially-Unpolarized light

Therefore, many devices have been proposed to analyze the polarization state of a light beam such as a rotating linear retarder followed by a fixed linear polarizer or a set of beam-splitters generating four light beams which are measured with four photodetectors.

These instruments allow evaluating polarization states. However, they do not provide real-time measurements or they are bulky and expensive. We **propose a compact and fast polarization analyzer device**.

We use a **VECTOR DIFFRACTIVE OPTICAL ELEMENT** (VDOE) composed of polarizers and retarders spatially distributed in sectors (Fig 1) [1,2].

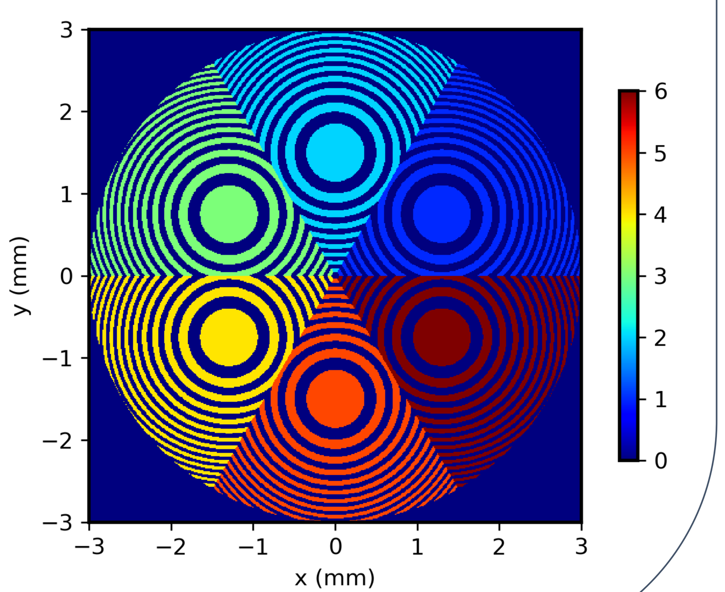

Figure 1: VDOE layout.

VDOE DESIGN

As shown in Figure 1, each sector of the VDOE is formed by a **Vector Fresnel Zone Plate (VFZP)** with the same focal length but de-centered with respect to the geometrical center of the VDOE (Δr). Therefore, this mask generates 6 focal points on the same plane.

Moreover, each VDOE sector has a different polarization state, shown with different colors in Figure 1. We have chosen four sectors with linear polarization at 0º, 90º, 45º, 135º and the remaining two with right and left-hand circular polarization. We have used this polarization states because they allow us to obtain **Stokes vector** $\vec{S}$ with less uncertainty (Eq. 1).

VDOE parameters	
Focal	F = 200 mm
Wavelength	λ = 632.8 nm
Radial displacement	Δr = 1.5 mm

$$\vec{S} = \begin{pmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{pmatrix} = \begin{pmatrix} I_T \\ I_0 - I_{90} \\ I_{45} - I_{135} \\ I_{RCP} - I_{LCP} \end{pmatrix} \quad (1)$$

VDOE PERFORMANCE

The intensity distribution at the focal plane is obtained using the vector Rayleigh-Sommerfled approach (VRS) implemented at *Diffractio* [3], an open-source Python library. Then, the light intensities reaching the six focci are detected by six photodetectors in order to determine the polarization of the incoming light beam.

As a first simulation, we have used incident beams corresponding to the autostate of each VDOE sector. The intensity distribution at the focal plane is shown in Figure 2. Here we can see **5 focci and a dark area**, which corresponds to the sector with inverse polarization to the incident one.

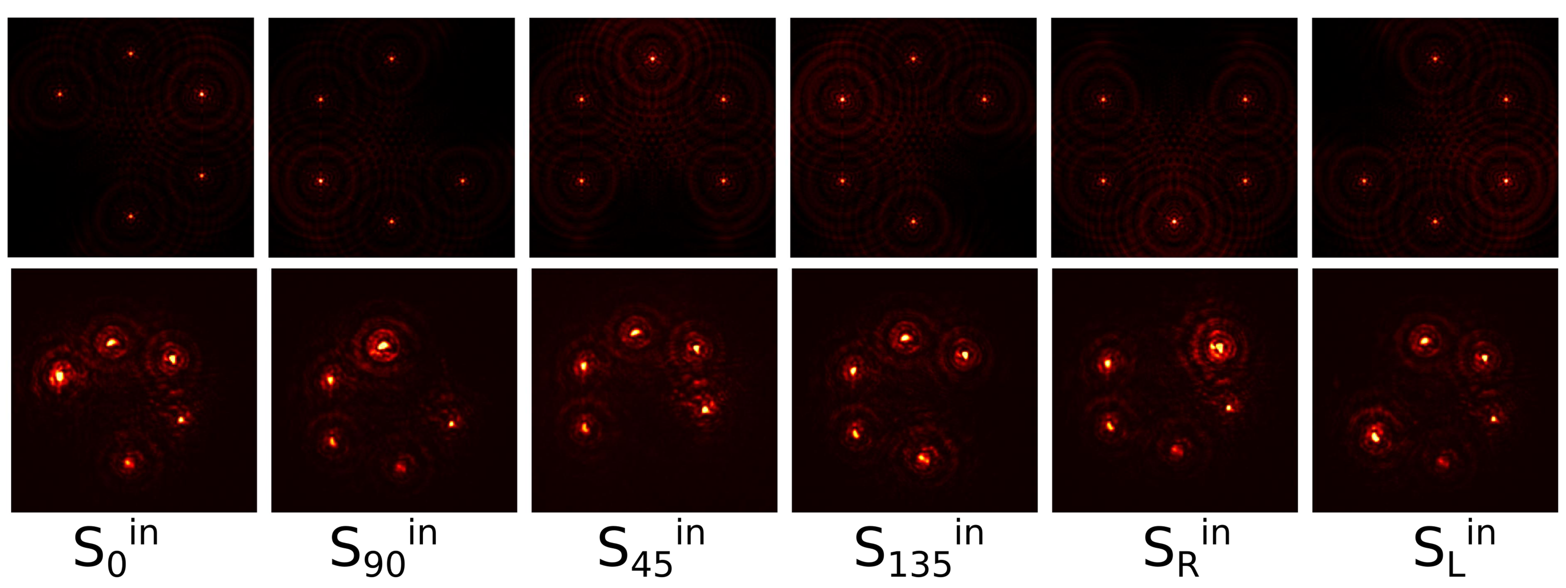

Figure 2: Intensity distributions at VDOE focal plane for simulations (upper row) and the experiment (lower row).

In order to analyze the differences between the Stokes vectors obtained from the intensities distributions and those of the incident beam, we have computed the distance between both Stokes vectors.

ANALYSIS OF UNCERTAINTY

Although the uncertainty for the examples shown in Figure 2 only range between 0.88% and 0.91%, we have analyzed **possible error sources**:

Normalization error — The intensity is not evenly distributed on the aperture of the VDOE.

Diffractive effects — A fraction of light scatters towards detectors undesired.

Systematic uncertainties — The error vary in an uniform way so we have performed a linear adjustment.

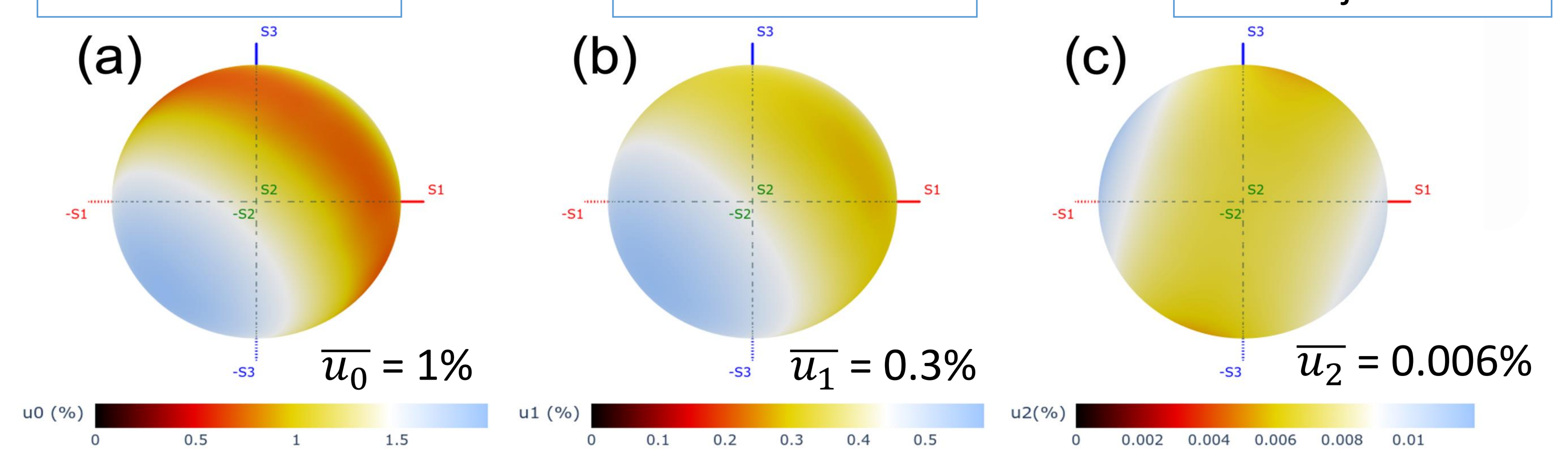

Figure 3: Total uncertainty (a) without corrections, (b) when normalization and diffractive effects are corrected, and (c) systematic errors are removed.

EXPERIMENTAL RESULTS

To validate the VDOE polarization characterization capabilities, we have **manufactured the device** (lower right corner of Figure 4). The experimental set-up employed has mainly an expanded He-Ne laser beam, a motorized rotating polarizer (R-P) and quarter wave plate (R-QW) to generate any input polarization state. Then, the beam iluminates the VDOE and the detection system (camera) capture the intensity.

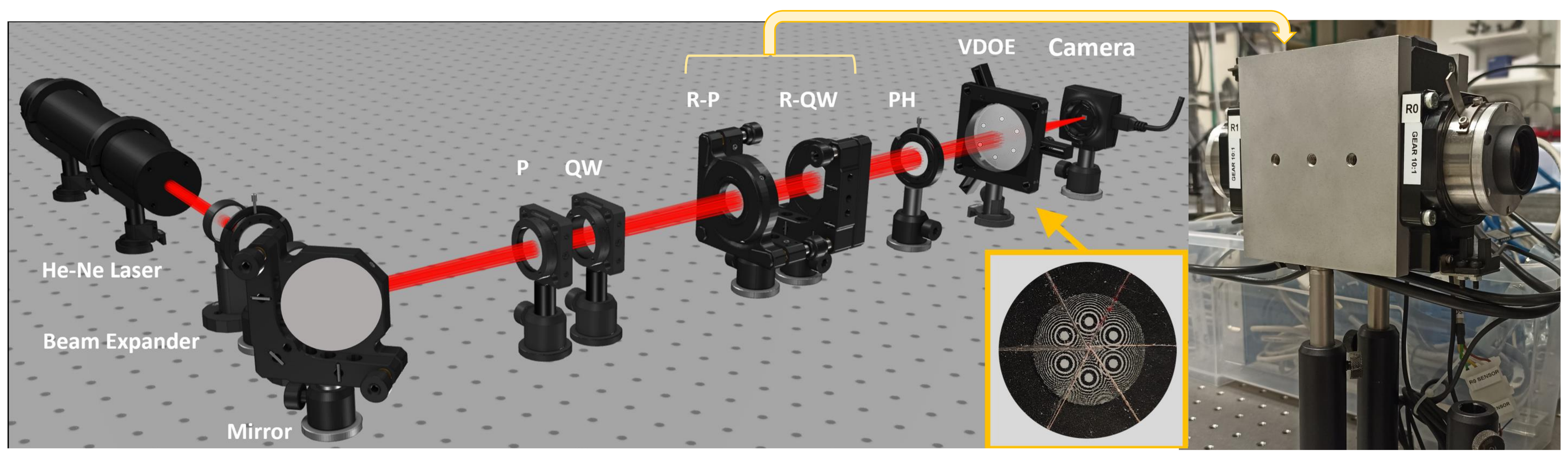

Figure 4: Set-up used to analyze the performance of the manufactured VDOE.

In addition to the previous uncertainty correction, in this experiment we have taken into account that polarizers and retardes are not perfect so we have measured the **Mueller matrix** for each sector with a polarimeter [4]. We have also studied fabrication defects. For this, we have replaced the VDOE by a **motorized quarter waveplate and polarizer** to simulate the mask sectors, reaching a lower error (Figure 5).

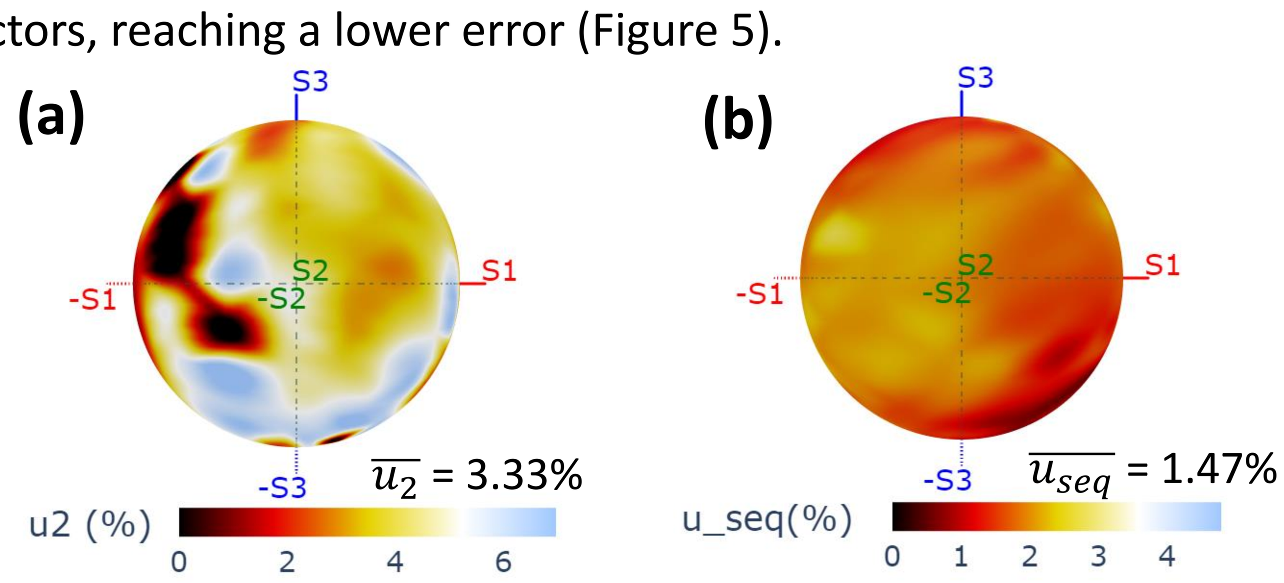

Figure 5: Experimental uncertainty with (a) VDOE and (b) motorized plates.

CONCLUSIONS

- We propose an **effective, robust and fast** Stokes analyzer using a sectorized Vector Diffractive Optical Element.
- We develope an **uncertainty procedure** with which the error is reduced significantly.
- The experimental device **behaves as expected** and it reproduces well the Stokes parameters of the incoming beam.

REFERENCES

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