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Fully integrated stokes snapshot imaging polarimeter

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Abstract. We present a new concept for a fully integrated nano-optical snapshot imaging polarimeter. It consists of a nano-optical retarder and polarizer array with various orientations combined with a microlens array and crosstalk module. That facilitates a fast, robust, and compact stokes imaging polarimeter without moving parts for applications at 450 nm wavelength.

1 Introduction

Polarized light metrology can be used for many applications to perform non-contact, non-destructive, and fast measurements, e. g. in the semiconductor industry for wafer inspection [1], in tissue characterization [2, 3], chemistry [4], biomedical diagnosis [5] or more.
A full Stokes-polarimeter measures all four terms of the Stokes vector:

$$\vec{S} = \begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix} = \begin{bmatrix} I_0 + I_{90} \\ I_0 - I_{90} \\ I_{+45} - I_{-45} \\ I_R - I_L \end{bmatrix}, \qquad (1)$$

Where I is the total intensity of the input light, Q the intensity ratio of 0° and 90° linear polarized light, U for +45° and -45° polarization, and V for right circular and left circular light. Various methods are established [6] to measure the full stokes vector. In our approach we modified the proposed 2 x 2 x 3 design by Alenin et. al. [7], which consists of a polarizer array with 0° and 90° orientation and retarder array with 126° retardation and 15°, 45° and 75° orientation. To achieve a snapshot polarimeter, we implement all three orientations of the retarder directly on top of the imaging sensor, resulting in a 3 x 4 design. The whole setup consists of a bandpass filter for 450 nm wavelength (design wavelength of the retarder array), nano-optical retarder and polarizer array as well as microlens array and crosstalk module (see figure 1).

In general, these compact imaging polarimeters consist of only a polarizer array (e.g. the Sony IMX250MRZ sensor) and can only measure linear polarized light (I, Q, V) or use a rotating or liquid crystal retarder, which is bulky and need additional hardware (motors, electronic controller, etc.). Our approach of a full stokes division of focal plane (DoFP) polarimeter offers many advantages: we achieve

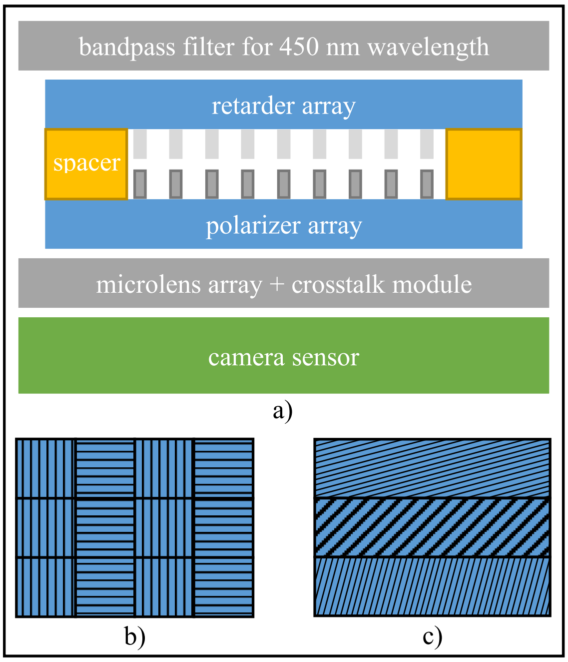

Fig. 1. a) Schematic drawing of the imaging polarimeter setup, b) polarizer array and c) retarder array.

a robust construction without moving elements and due to the parallelization, a fast measurement becomes possible. In addition, thin element sizes are feasible. Each array (polarizer, retarder, microlens + crosstalk) is fabricated on a 0.5 mm thin substrate and are aligned to and placed directly on top of a CMOS sensor with 2560*1920 pixels, thereby high flexibility and integration in various systems for different metrology tasks is possible.

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2 Setup and fabrication of the nano-optical elements

The nano-optical retarder array and wire grid polarizer are grating type metasurfaces with periods smaller than the applied wavelength. Their fabrication is well established in our work group [8, 9]. For applications in the visible wavelength regime we use a broadband iridium wire grid polarizer. The nano-optical retarder array consists of a titanium oxide grating, which can be understood as an effective, birefringent medium [10]. The iridium wire grid polarizer array consists of four columns with alternating 0° and 90° orientation. The titanium oxide retarder array consists of three retarder elements with orientations of 15°, 45° and 75°, arranged in three rows. For increased mechanical stability and to protect against environmental influences, the polarizer and retarder arrays are integrated in such a way that the structured areas face each other. A physical contact of the nanostructured areas is prevented by means of spacers (see figure 1). Also, this allows a simplified manufacturing process, as each array can be fabricated individually. During the assembly of all components, they are aligned with the camera sensor and firmly fixed in a holder, so that no adjustment is required after assembly.
A fist image taken by the imaging polarimeter during the calibration is shown in figure 2 and a real-world image is displayed in figure 3.

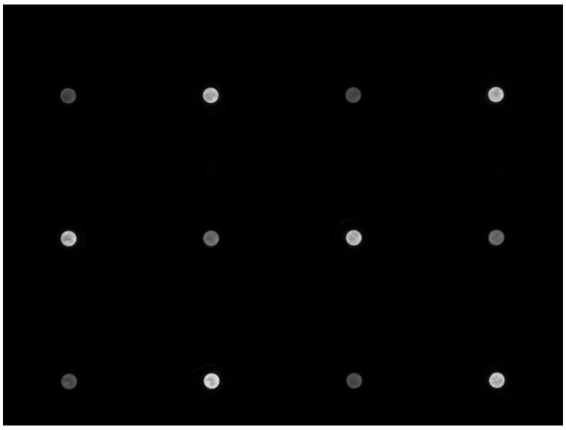

Fig. 2. Image taken during the calibration of the polarimeter. The incoming light is 0° linear polarized. Different intensities are transmitted through the polarizer and retarder array.

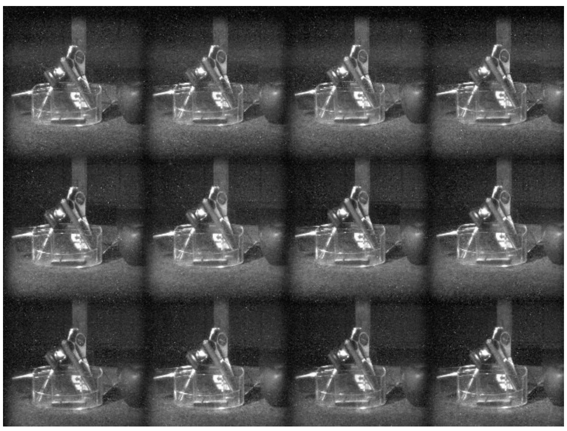

Fig. 3. Real-world image of office objects taken by the imaging polarimeter.

Detailed information about the system design, estimations of the uncertainty budget of the entire polarimeter, and first measurements will be presented at the conference.

3 Conclusion

We presented a concept of a highly integrated full stokes imaging polarimeter using nano-optical elements as analyser and retarder. We fabricate these metasurface gratings via nanostructuring technology and various orientations can be realized within one element. This facilitates parallel measurement by replacing any rotating or electrooptical elements resulting in a compact and robust setup.

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