Chip-Integrated Full-Stokes Polarimetric Imaging Sensor

Jiawei Zuo[1,2,3], Jing Bai[1,2], Shinhyuk Choi[1,2,3], Ali Barsiri[1,2], Xiahui Chen[1,2,3],Chao Wang*[1,2,3], YuYao*[1,2]

[1]School of Electrical, Computer and Energy Engineering, [2]The Center for Photonics Innovation

[3]Biodesign Center for Molecular Design &Biomimetics

Arizona State University, Tempe, Arizona,85247, United States

* wangch@asu.edu; yuyao@asu.edu

We report a chip-integrated, dual-wavelength (red: 630-670 nm and cyan: 480-520nm) full Stokes polarimetric complementary metal-oxide-semiconductor (CMOS) imaging sensor based on sub-wavelength scale metasurface polarization filter arrays (MPFA). MPFA composes of 168×56 full Stokes filter units (Fig. 1A), each consists of four linear polarization (LP) filters and two sets of chiral metasurface(CM). As illustrated (Fig. 1B), amorphous silicon (a-Si) nano gratings (top) were designed to introduce artificial birefringence that converts circularly polarized light (CPL) to linearly polarized light (LPL)[1]. The LPL is further filtered by LP gratings (bottom). Our CM design has a unique dual-color use, achieving a maximum circularly polarized light extinction ratio (CPER) over 600 with a transmission efficiency of 61.5 % at 650 nm and a CPER of 170 with an efficiency of 24.5 % at 510 nm. Moreover, this design can operate over a broad wavelength range of 600nm to 700 nm and 450nm to 525 nm with a CPER over 10, with the bandwidth comparable to grating diffraction-based designs[2].

The key device fabrication steps are shown in figure 1C: First, nano-gratings with period of 297nm and 90nm of width was patterned by electron beam lithography (EBL) onto 130nm thick a-Si thin films deposited on fused silica substrate by Plasma Enhanced Chemical Vapor Deposition (PECVD), followed by inductively coupled plasma (ICP) etching of a-Si to form a-Si gratings. 520nm thick SiOx spacer layer was then sputter-deposited onto a-Si gratings by physical vapor deposition (PVD), followed by a second EBL to pattern gratings with duty cycle of 50% and period of 210nm on SiOx spacer layer. Then the spacer layer was etched by 110nm via reactive ion etching (RIE) etching, followed by electron-beam evaporation of 80nm thick aluminum (Al) , leaving 30nm gap in between top and bottom Al double layer grating for near field coupling. 200nm of SiOx caption layer was then sputtered onto double layer grating. Finally, we spin coated ultraviolet light (UV) resist onto a commercial CMOS sensor (IMX477) and use homemade transfer setup to align and bond the MPFA onto the CMOS sensor. Using the packaged sensor, 7 polarization states were measured at both the red and cyan wavelengths, the average measurement error of S1, S2, S3 were measured

---

[1] Basiri, A., et al., *Nature-inspired chiral metasurfaces for circular polarization detection and full-Stokes polarimetric measurements.* Light: Science & Applications, 2019. **8**(1): p. 1-11.

[2] Rubin, N.A., et al., *Polarization state generation and measurement with a single metasurface.* Optics express, 2018. **26**(17): p. 21455-21478.

less than 2% for red and 3% for cyan, which is much lower than the state of the art diffraction grating based design[2]. The exemplary full Stokes polarization images show images of logo of Arizona State University (ASU) made of LP films with a quarter-wave plate (QWP) in optical path to convert logo 'fork' and 'S' into CP light, as shown in the degree of circular polarization (DOCP) image in Figure 1D-a. In addition, the birefringence induced by internal stress of a plastic protractor causing highly non-uniform DOCP and angle of polarization (AOP) images is shown in Figure 1D-b. Our sensor could be widely adopted in applications requiring polarization information for sensing and imaging such as enhanced small object (e.g., mirror defects) detection in solar power plants, remote sensing , biomedical imaging, etc.

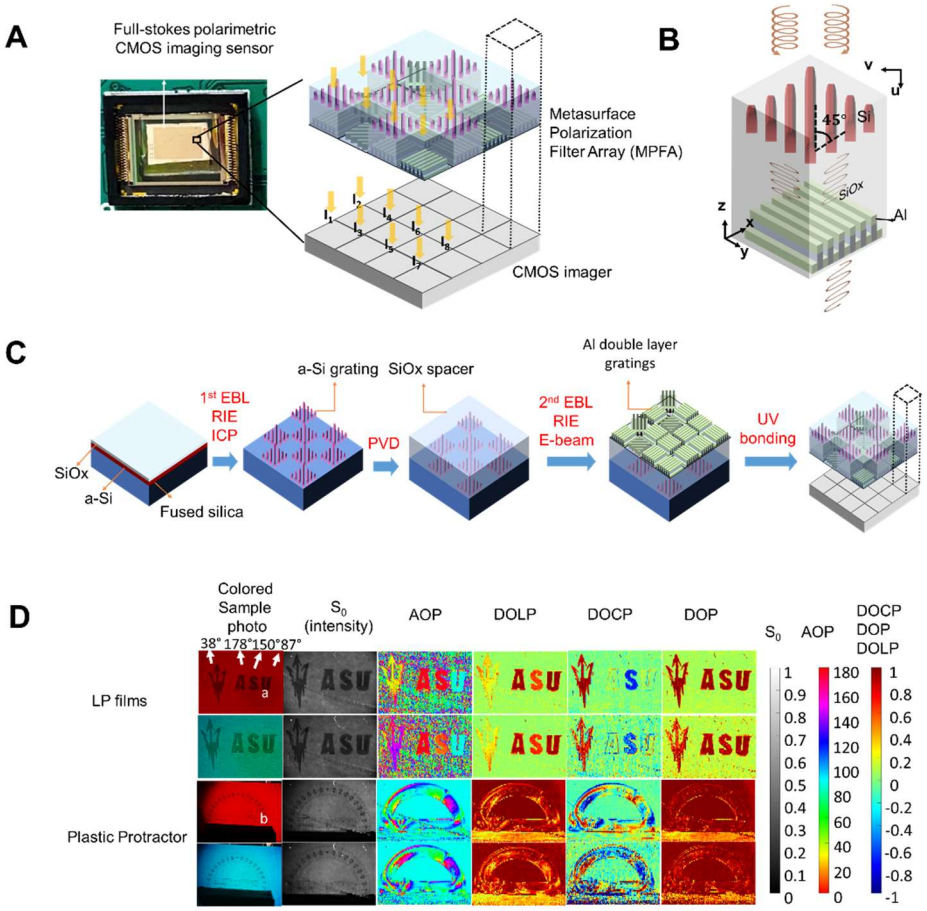

Figure.1 Design concept, full Stokes polarization detection, and polarization imaging. (A) The design concept of full Stokes polarization imaging sensor. I_1,I_5 denotes transmitted intensity of right handed circularly polarized (RCP) component of incoming light. Likewise I_4,I_8 corresponds to left handed circularly polarized (LCP) component, I_2 , I_3 , I_6 , I_7 corresponds to 45°, 135° , 90° , 0° LP component. (B) 3D schematic of the chiral metasurface (C) Fabrication process of the MPFA (D). Full Stokes parameter polarization imaging of objects under red and cyan light illumination. a: LP films cut into Arizona State University logo, each with polarization axis 38°,178°, 150°, 87° respectively. b. plastic protractor with 0° LP as input background. S_0: intensity of the image. AOP: angle of polarization; DOLP: degree of linear polarization; DOCP: degree of circular polarization; DOP: degree of polarization;