Polarization-sensitive phase contrast microscopy for optical data storage

Enhanced polarization contrast with a phase contrast objective

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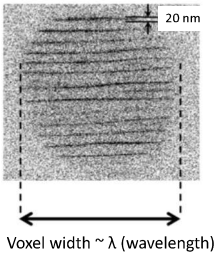
'5D' optical data storage

Encode information in local birefringent retardance and azimuth in glass.

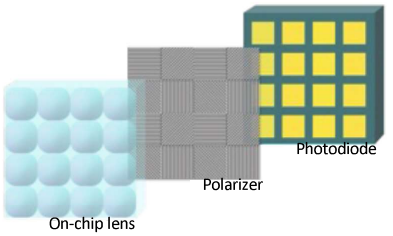
- Self-assembled birefringent structures ('voxels') in sub-micron size [1,2].
- Written by femtosecond laser with polarization control.
- Voxels arranged in 3D with different birefringent retardances and azimuths.
- Ideal for large-scale cold data storage for next-generation cloud infrastructure.

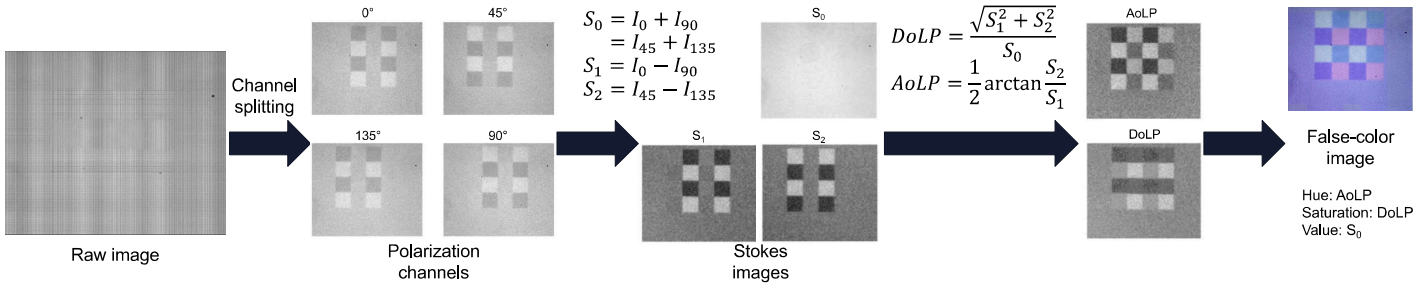


Single-shot polarimetry for linear components

Imaging birefringence in a single shot using a polarization camera.

- Pixelated polarization camera (FLIR BFS-U3-51S5P-C) with Sony IMX250MZR Polarsens sensor [3].
- Micro-polarizer array analyzes optical field simultaneously in four linear states at (0°, 45°, 90°, 135°).
- Computational reconstruction of three Stokes images for S0, S1 and S2, hence degree of linear polarization (DoLP) and angle of linear polarization (AoLP).
- Upon circularly polarised illumination, DoLP signal yields linear birefringence.

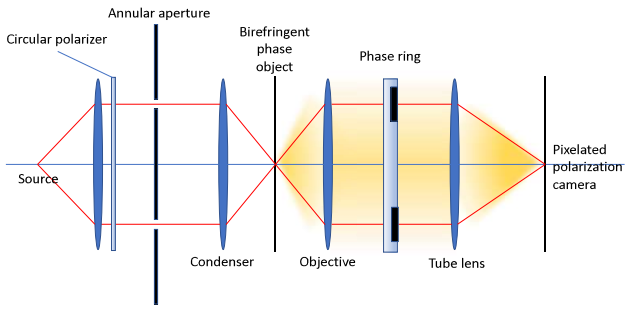


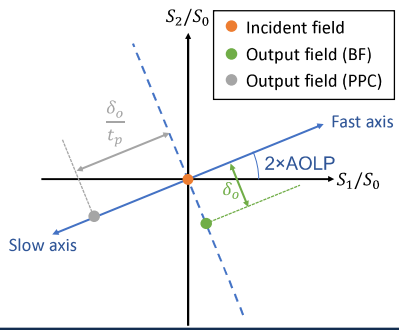


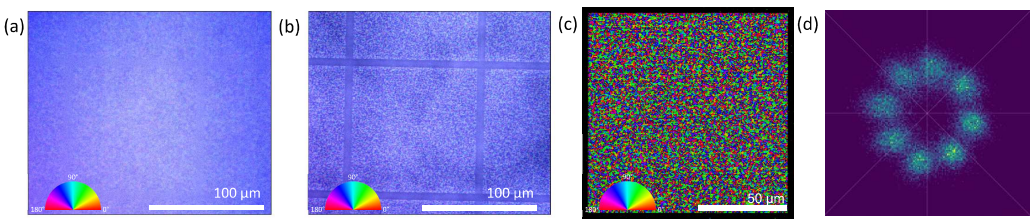
Polarization-sensitive phase contrast (PPC)

Phase ring attenuation enhances polarization contrast.

- Employs annular condenser aperture with a corresponding phase contrast objective (Olympus, LUCPLFLN 40x/0.60 Ph2).
- At the pupil plane, surround (S) and diffracted (D) waves split spatially, where the phase contrast objective imposes an amplitude and a phase modulation:
  - **Amplitude modulation**: S wave is attenuated with a transmission t_p<1,
    DoLP is **enhanced** by $1/t_p$ for objects with weak retardance ($\delta_o \ll 1$);
  - **Phase modulation**: D wave is delayed by λ/4 compared to S wave,
    AoLP is shifted by 45°.
- Therefore, PPC has a better sensitivity at detecting weak birefringence compared to brightfield (BF).







(a) Brightfield image and (b) PPC image of a data sector (162*162 voxels). Hue: AoLP; Saturation: DoLP; Value: S_0.
(c) Extracted birefringence data from PPC. Hue: AoLP; Saturation: 1; Value: DoLP.
(d) Constellation diagram in normalised Stokes plane demonstrating symbol distinguishability.

[1] Anderson P, et al. Glass: A New Media for a New Era? In: *10th USENIX Workshop on Hot Topics in Storage and File Systems (HotStorage 18)*. USENIX Association; 2018.p.1-6.
[2] Shimotsuma Y, et al. Self-Organized Nanogratings in Glass Irradiated by Ultrashort Light Pulses. *Physical Review Letters*. 2003;91(24). https://doi.org/10.1103/PhysRevLett.91.247405
[3] Sony Semiconductor Solutions. Polarsens; 2021. https://www.sony-semicon.co.jp/e/products/IS/industry/technology/polarization.html

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