Simulations of photonic phase corrector for adaptive optics system

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1. Introduction

Adaptive optics (AO) systems improve the capabilities of ground-based observatories by correcting the atmospherically-aberrated wavefronts. Incorporating photonics helps simplify many aspects of a conventional AO system. The photonic integrated circuit (PIC) reported here is proposed as an alternative for deformable mirrors (DM) in AO systems. It uses grating couplers to couple the beams focused by a lenslet array into single-mode waveguides where the fields are phase-matched using phase shifters and then coherently combined using beam combiners. This combined field is then coupled from the output waveguide to a single-mode fibre (SMF).

This project is concerned with modelling the devices, specifically the SMFs, output tapered waveguide, beam combiners and the grating coupler based on the design used for the fabrication of the PIC. The models will help estimate the performance of the system before the experiments are carried out and would inform the design of the next-generation circuits.

2. Methods

RSoft photonics simulation package was used to simulate the field propagation through the designed model of the device. The package uses the Finite-difference time-method (FDTD) to solve Maxwell's equations and calculate the electromagnetic fields.

These models are then used in an end-to-end simulation of the complete AO system. It starts with the production of a turbulent field of the size of the telescope aperture of diameter (D = 0.4 m) using a phase screen generator. The atmosphere is modelled for Fried's parameter over a range. The generated field is then propagated from the atmospheric layer to the entrance pupil of the receiving telescope. Then, the spots at the focal plane of the square lenslet array is calculated using Fourier optics. A model of the grating coupler then couples each of the focal fields into single-mode beams. These coupled beams are then matched in phase and the corrected beams are coherently combined.

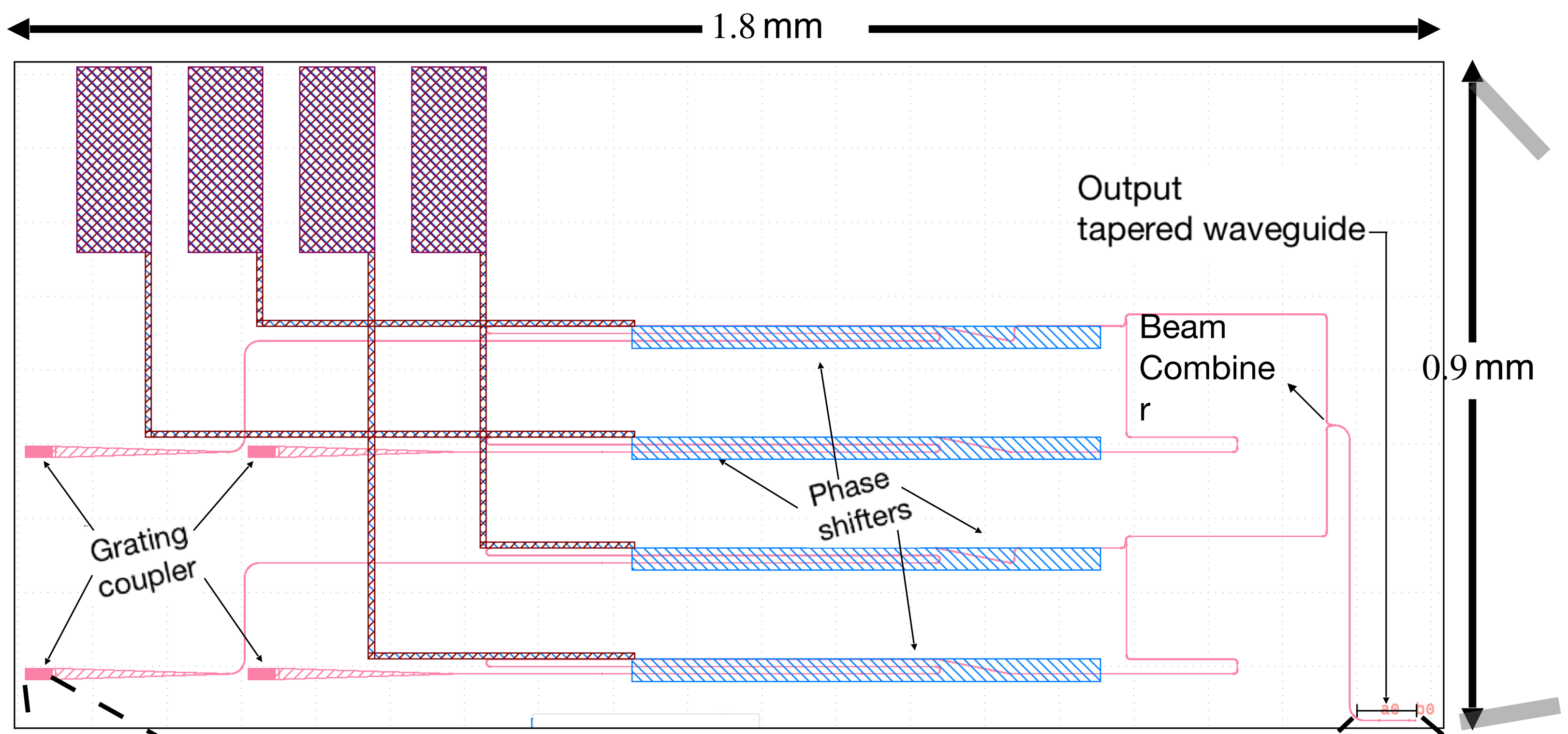

Fig 4: Mask layout of the photonic integrated circuit for a 2x2 device, with the grating couplers, phase shifters and the output tapered waveguide.

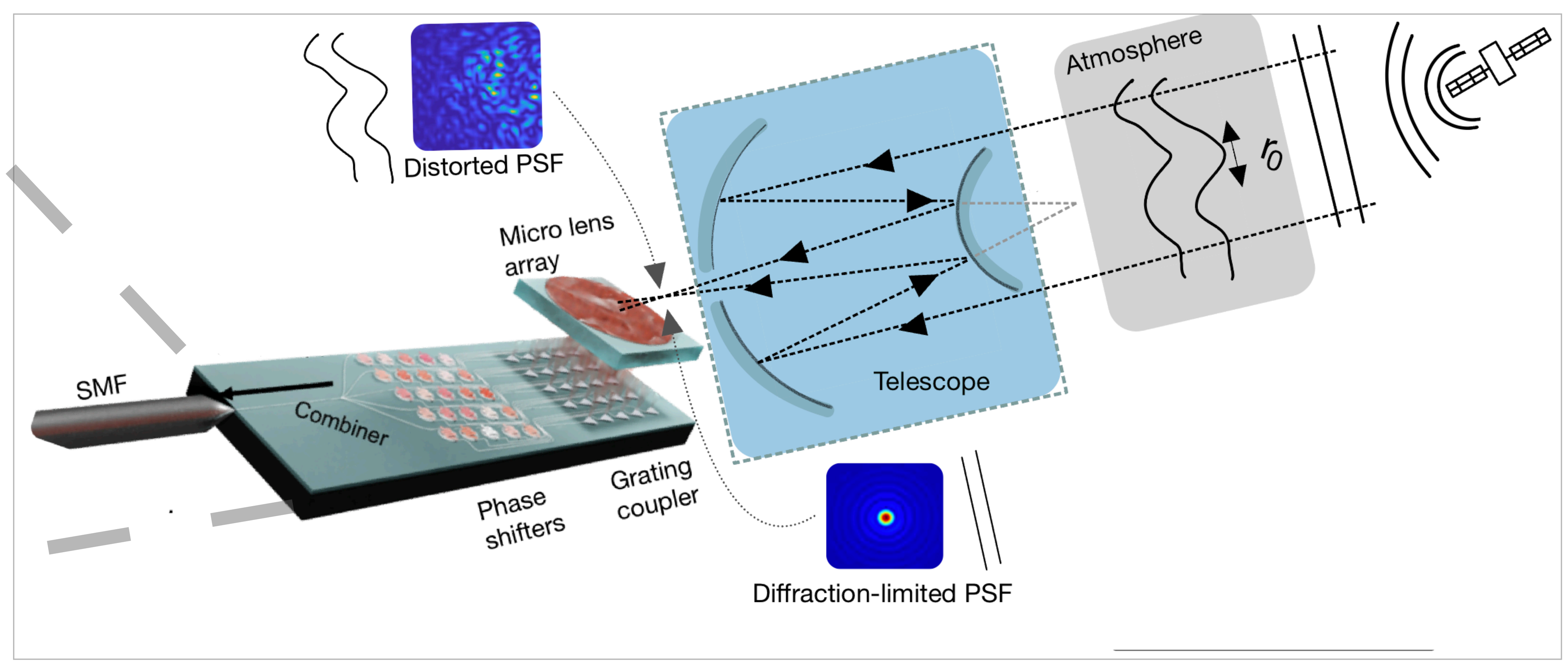

Fig 1. Schematic of the photonics based phase corrector in a free-space optical communication. The light from the from the LEO satellite star gets distorted by the aberrations introduced by the atmosphere, characterised by Fried's parameter (r0) is observed at a ground station which uses the phase corrector to couple the light in a single-mode fiber. The performance of the correction is characterised by the Strehl's ratio (SR).

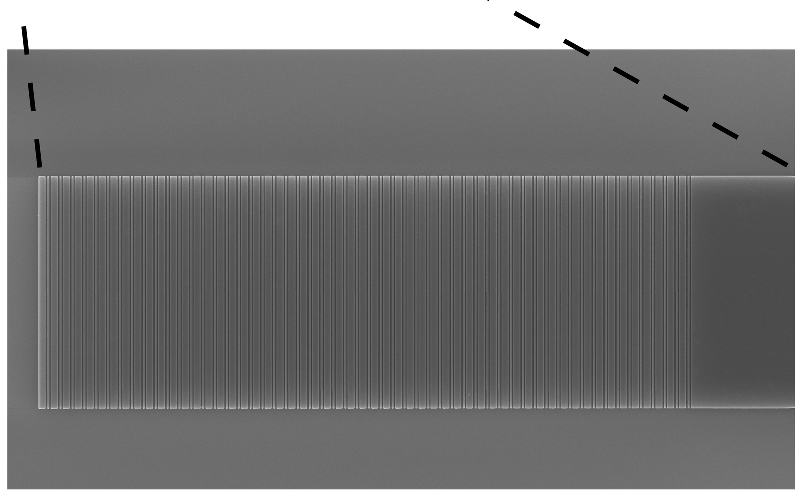

Fig 3: Scanning electron microscope (SEM) micrograph of a grating coupler

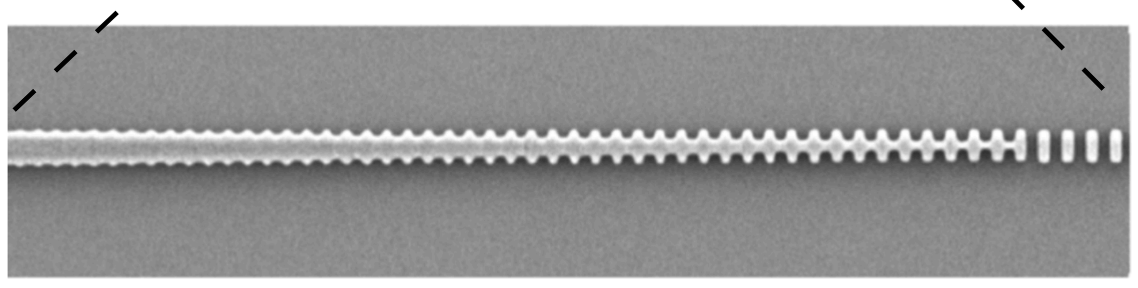

Fig 2: SEM micrograph of the output tapered waveguide.

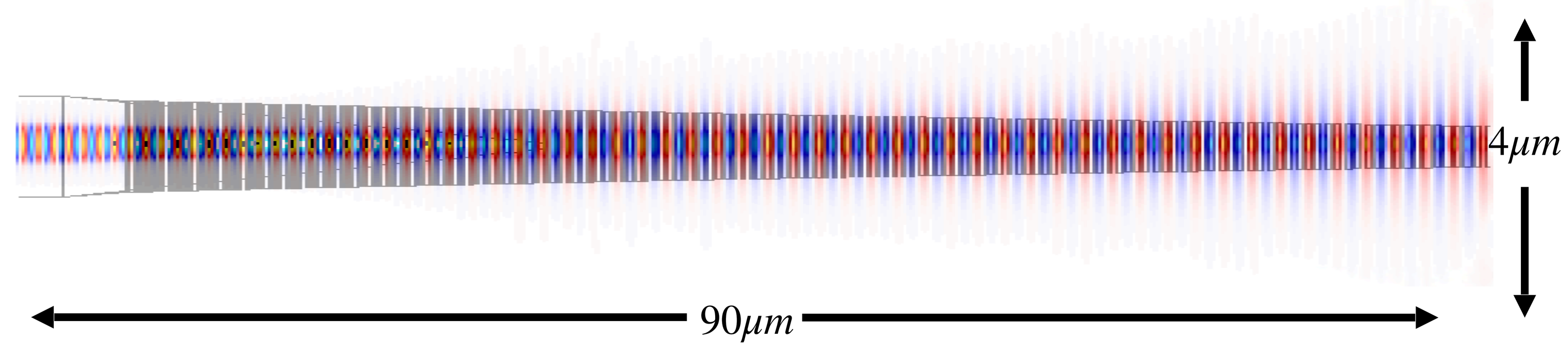

Fig 5: Simulation result of the E-field propagating through the sub-wavelength grating used to expand the mode of the output waveguide to match the mode of the single-mode fiber.

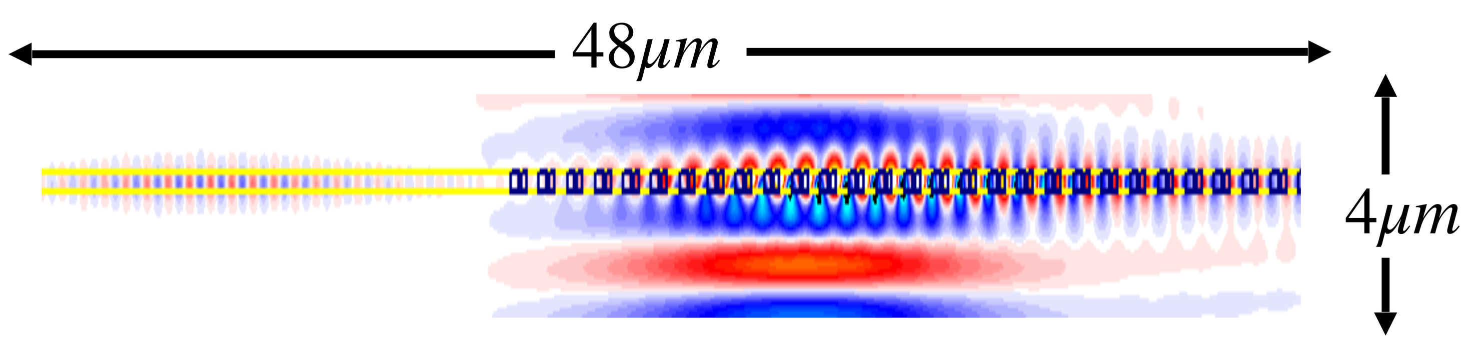

Fig 4: Simulation result of the E-field propagating through the grating coupler showing the field getting coupled from free-space to a waveguide.

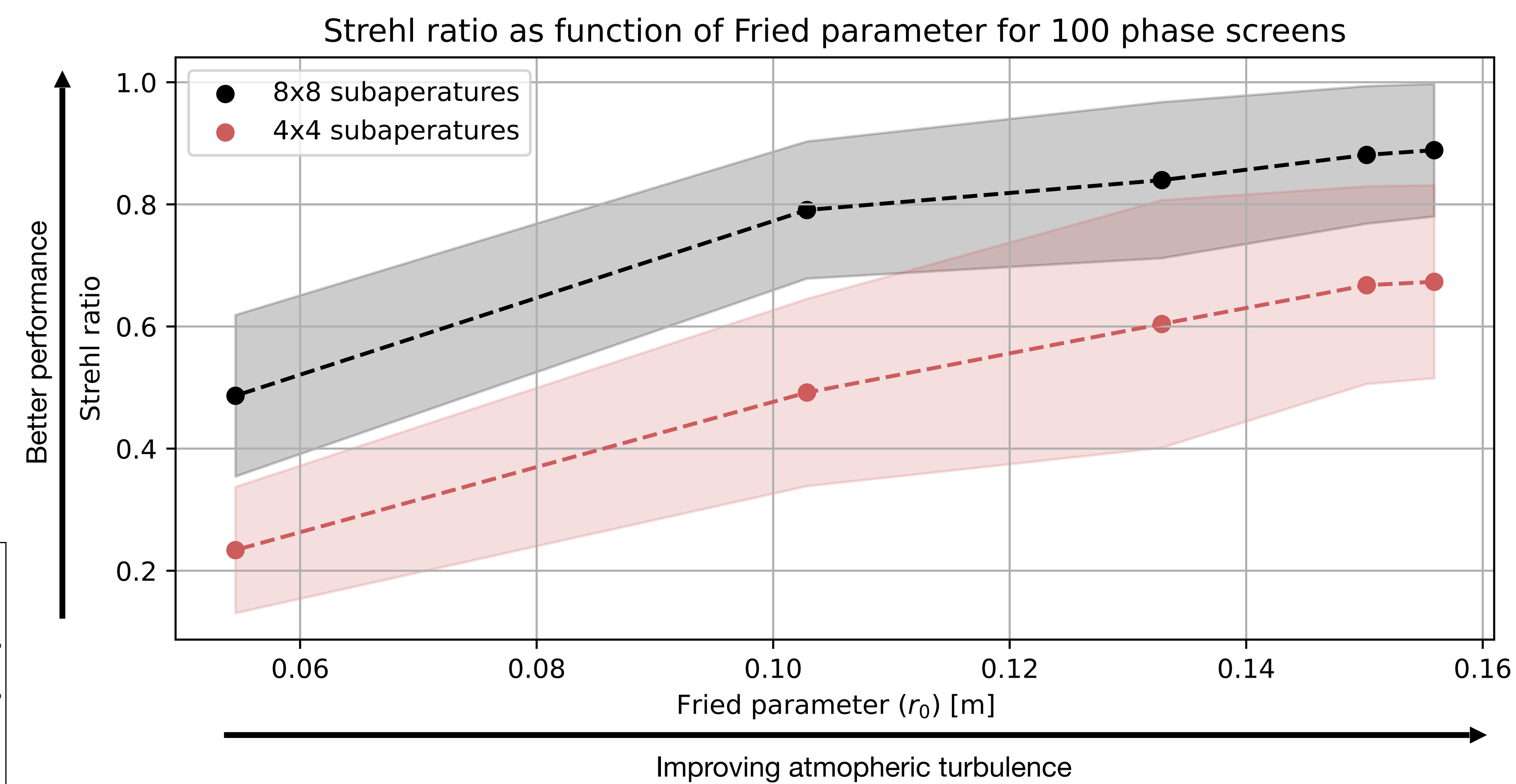

Fig 6 : Performance of the simulated PIC: Strehl ratio (SR) defined as the intensity measured at the output fiber from a distorted wavefront relative to that measured at the diffration-limit as function of the atmospheric turbulence (r0)

3. Results

The end-to-end simulation was done for Fried parameter ranging from 0.05m to 0.15m at wavelength of 1550nm for a telescope aperture of 0.4m. The simulations were done for the case of 4x4 and 8x8 sub aperture cases with there results from the two cases shown in figure 6.

References

Diab, M., Cheriton, R., & Sivanandam, S. 2022, in Adaptive Optics Systems VIII, ed. L. Schreiber, D. Schmidt, & E. Vernet, Vol. 12185, International Society for Optics and Photonics (SPIE), 121858Q, doi: 10.1117/12.2642529