

Wavefront sensing using a liquid-filled photonic crystal fiber

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Purpose

A novel wavefront sensor based on a microstructural array of fibers is proposed. The method is based on the sensitivity in light-coupling efficiency to the wavefront gradient present at the entrance aperture of each fiber in an array [1,2], and hence the amount of incident light that couples is influenced by wavefront aberrations [3]. The concept is illustrated using a liquid-filled photonic crystal fiber method (LF-PCF) [1].

Methods

The probed wavefront can be reconstructed from the coupling-dependent power attenuation measured in each fibre. For a single-mode waveguide $\Psi_m(x, y) = (2/\pi w^2)^{0.5} \exp[-(x^2 + y^2)/w^2]$, and for an incident field with a linearly expanded phase around the centre of each fiber $\Psi_m(x, y) = A_0 \exp[i(\phi_0 + \phi_x x + \phi_y y)]$, the power P_{mn} coupled to any given fiber (mn) can be estimated from [4]:

$$P_{mn}(\phi_x, \phi_y) = P_{mn}(0,0) \exp\left[-\frac{w^2}{2}(\phi_x^2 + \phi_y^2)\right] \quad (1)$$

where ϕ_x and ϕ_y denote first-order derivatives of the wavefront at the centre of the waveguide. The analysis of power may not distinguish between the phase gradient of the wavefront in two orthogonal directions as well as it makes no distinction between positive and negative derivatives of phase. However, if a bias angle (θ_0) is introduced in each orthogonal direction (θ_{0x}, θ_{0y}) the change in power can detect sign and relative values of the phase gradient in each orthogonal component, given by [4]:

$$\Delta P_{mn}(\Delta\theta_{mn}) = -\frac{k^2 w^2}{2} \sin(2\theta_0) P_{mn}(\theta_0) \Delta\theta_{mn} \quad (2)$$

where θ_{mn} is the angle of incidence related as $\phi_x^2 + \phi_y^2 = k^2 \sin^2 \theta$ and $k = 2\pi/\lambda$.

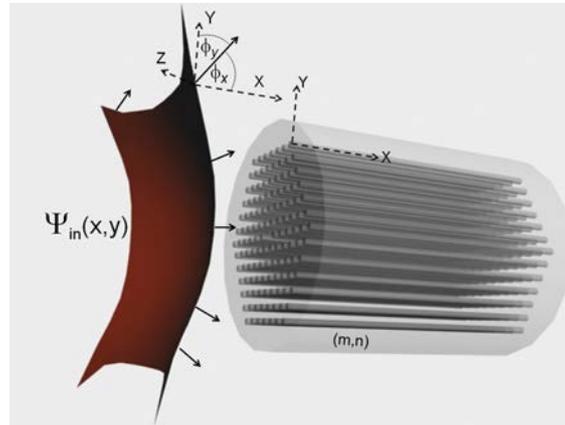


Fig. 1. Schematic of the wavefront sensing method using a photonic crystal fiber.

For the realization, a microstructured array of fibers is implemented using a commercially available photonic crystal fiber (LMA-20) and their air holes filled with Castor Oil. The LF-PCF is placed inside of a precision oven allowing thermo-optical control of its single- and multimode characteristics [1].

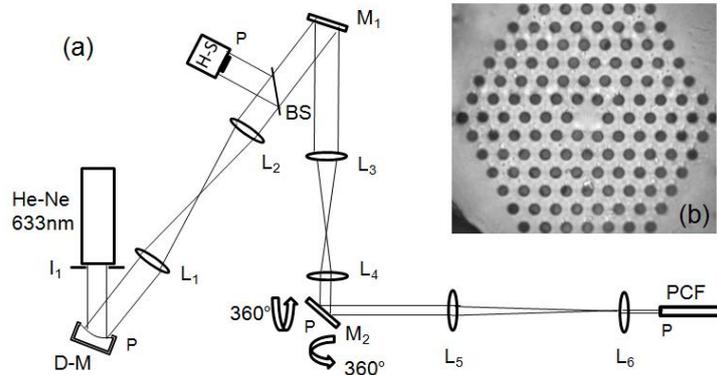


Fig. 2. (a) Optical setup. D-M: deformable mirror, BS: Beam splitter, H-S: Hartmann-Shack wavefront sensor, M_1 : fixed mirror, M_2 : rotatable mirror, PCF: photonic crystal fiber, and achromatic lenses are denoted by L_1 to L_6 . (b) Section of PCF fiber (LMA-20).

As represented in Fig. 2.a the bias angle and well-controlled optical aberrations are introduced using a flat mirror (M_2) and a deformable mirror (D-M), located at different conjugated planes of the coupling face of the LF-PCF. After propagating the light coupled is imaged by the objective on a CCD camera and the intensity of the light coupled is measured for each oil-filled hole at the end face of the LF-PCF.

Results

Experimental trials for different order aberrations are analyzed. As a first example, changes in the power coupled for different tilt aberrations are shown in Fig.3.

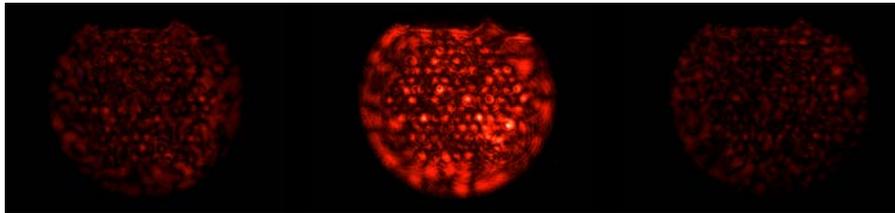


Fig. 3. Intensity of light propagated by the fiber for different introduced tilt values introduced, $Z_1 = 2\mu\text{m}$ (left), $Z_1 = 0\mu\text{m}$ (center), $Z_1 = -2\mu\text{m}$ (right).

The results are in agreement with the expectations based on numerical simulations, and are discussed in relation to measurements using the deformable mirror as wavefront generator measured and calibrated by the Hartmann-Shack wavefront sensor. The pros and cons of the PCF-based sensor and possible designs for different applications are discussed.

References

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