Wavefront measurement by using photonic crystals

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ABSTRACT

This paper presents a novel method of wavefront measurement for adaptive optic systems by using a photonic crystal. In adaptive optics the wavefront shape of the incident wave is measured and used to set a reconfigurable mirror array to compensate for the aberration, reduce distortion and improve image and beam quality. In a 2D approach, the tilted wavefront at each pixel enters a V-shape structure of waveguides in a photonic crystal. By measuring and comparing the output power in the two waveguides, we can determine the tilted angle of the incident light at that pixel. This method can also be applied in a 3D approach.

Keywords: optical measurement, wavefront sensing, photonic crystals, adaptive optics

1. INTRODUCTION

When light travels through a turbulent environment, resulting from thermal or wind in the atmosphere, distortions are introduced into the beam or image.[1] Adaptive optics use a closed-loop control system to compensate for aberrations actively.[2,3]

Adaptive optics usually consists of a wavefront sensor,[4] a deformable mirror array,[5] a control system and other components. Fig. 1 shows the basic components in an adaptive optic system. The wavefront sensor measures the wavefront shape, which contains the distorted information. There are many ways to measure wavefront, including direct and indirect methods, phase sensing and intensity-based wavefront sensing. We will show a new method to do this by using photonic crystals.

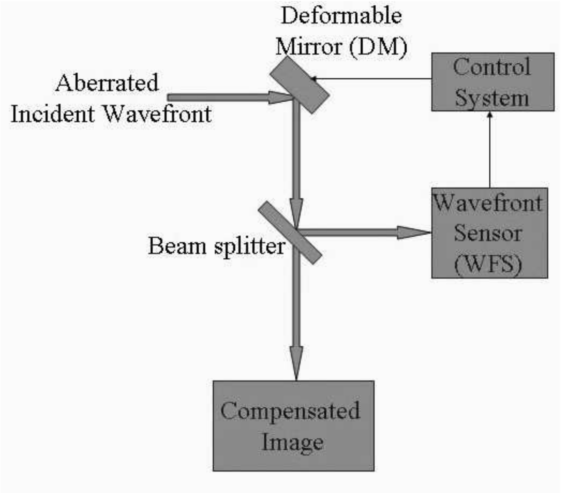

Figure 1. Basic configuration of an adaptive optics system

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2. PHOTONIC CRYSTALS STRUCTURE

Photonic crystals have drawn attention in recent years due to their unique bandgap structure. The periodicity gives photonic crystals special dispersion characteristics. When carefully designed, the photonic crystal device will show a forbidden bandgap that prohibit lights within a frequency range to pass through.[6,7] This has been used for confinement of light and to guide light. Photonic crystals have been employed for a different problem, wavefront correction of a beam to suppress wander in optical free-space communications.[8]

In this paper we use a two-dimensional hexagonal photonic crystal, whose lattice structure is constructed by air holes in a dielectric substrate, to build the wavefront sensing device. The dispersion characteristics can be calculated using the finite difference time domain (FDTD) method or plane wave expansion method.[9] Fig. 2 shows the bandgap structure of the hexagonal photonic crystal device, including both TE & TM polarizations.

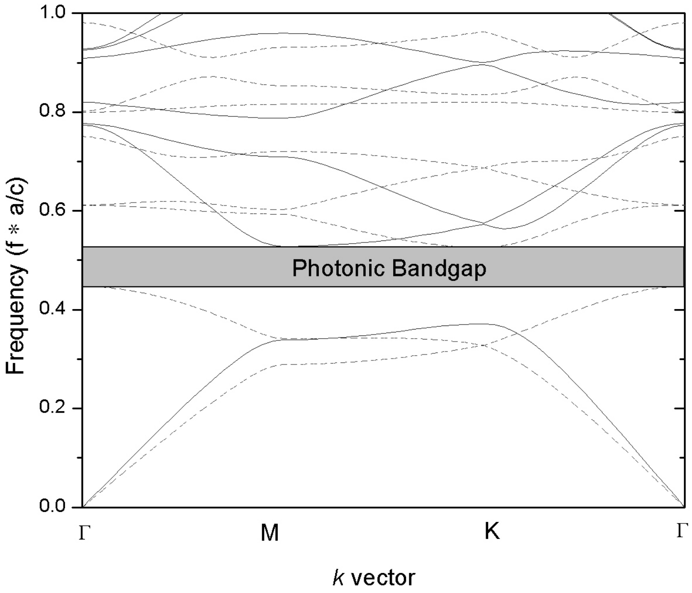
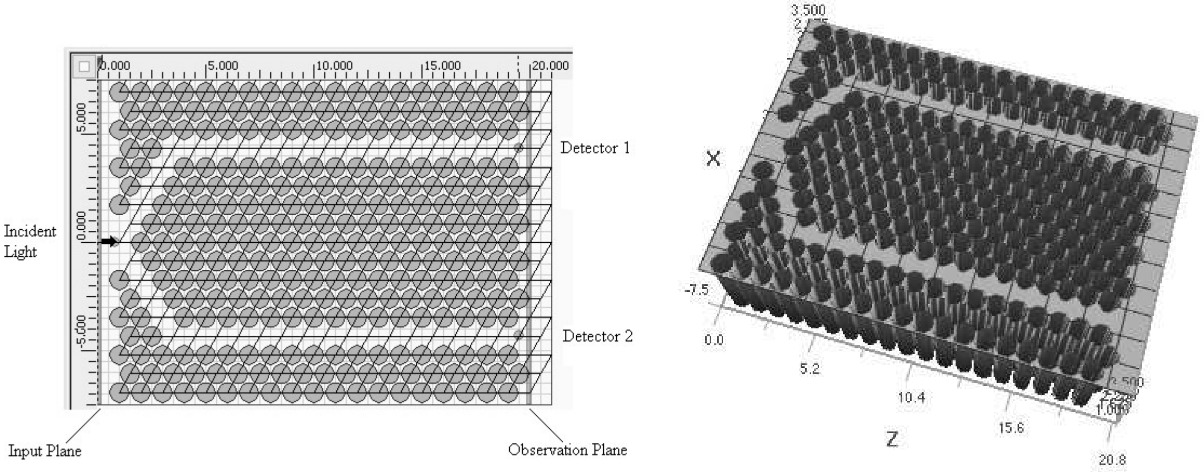


Figure 2. Band structure of photonic crystal. The dash lines represent TE bands and the solid lines represent TM bands

The dielectric constant of the substrate ϵ is chosen to be 13. The radius of the air holes is chosen to be $0.477\mathsf{a}$ (a is lattice constant) so that the overlapped bandgap for both TE & TM polarizations has maximum width. Fig. 3 shows the layout of the refractive index profile.

In Fig. 3, the tilted incident light comes from the left, enters the V-shaped defect of the photonic crystal through an aperture, and splits into two beams. Both beams travel along the photonic crystal waveguides and reach the detectors at the right. By measuring and comparing the power at the detectors, we can determine the slope of the incident wavefront.



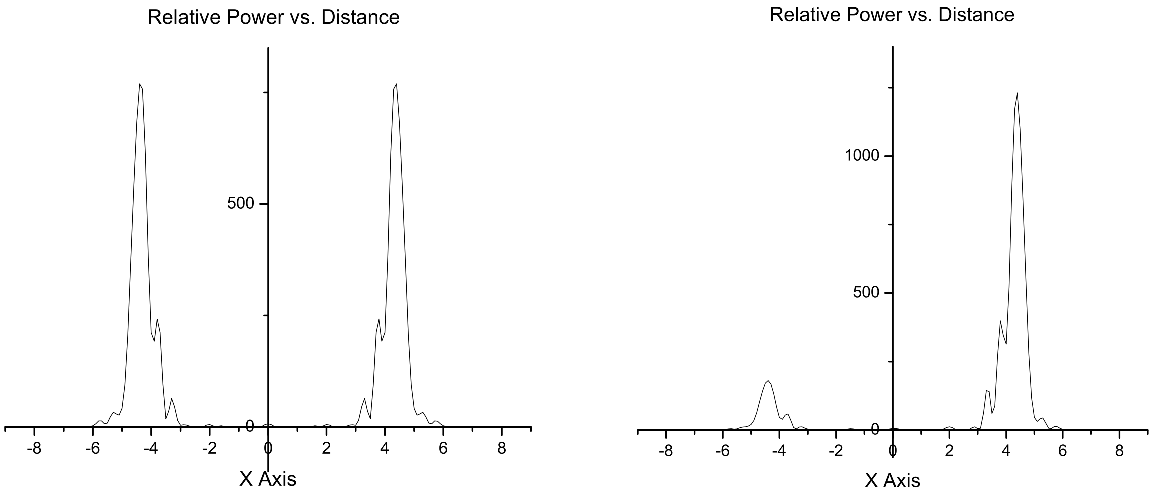
(a) Top View

(b) 3 D View

Figure 3. Photonic crystal device structure for wavefront measurement

3. SIMULATIONS AND RESULTS

We used the FDTD method for the simulation. Fig. 4 shows the power output along the observation plane in Fig. 3.



(a)

(b)

Figure 4. Relative Power along the observation plane: (a) incident light comes normally on the device, and (b) incident light tilted 10 degree)

The ratio of the output power from the two channels vs. tilting angle is shown in Fig. 5. This figure shows that our method gives a very good resolution for measuring the tilting angle of wavefront within ±22 degree. When the tilting angle becomes negative, the power ratio is less than 1. Since the device is symmetric, we can use the reciprocal of the ratio for better resolution.

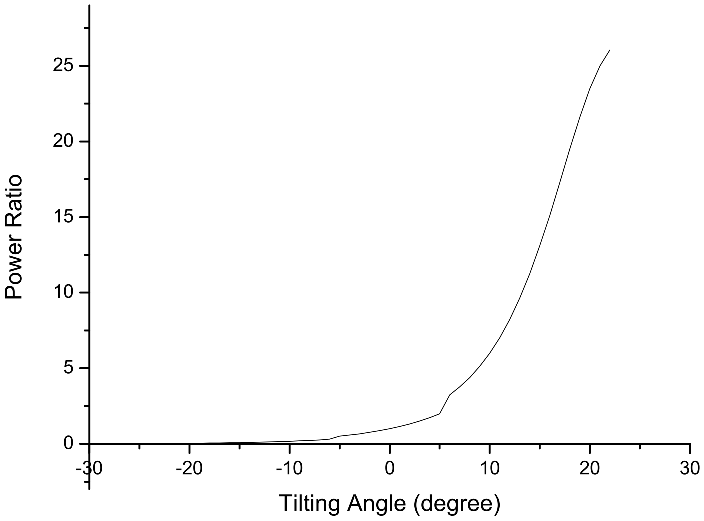


Figure 5. Power ratio vs. incident angle of wavefront

4. CONCLUSIONS

To measure the wavefront of incident light, we have proposed a novel method that uses the light confinement characteristics of photonic crystals. Since the photonic crystal structure is extremely compact and scalable, it is most suitable to be used with CCD detectors and micromachined deformable mirrors to achieve high resolution for reconstruction of wavefront.

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