A Simple, High sensitivity, Wideband Wavefront Sensor

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Wavefront sensing and control is a critical technology for wide array of photonics systems, particularly gravitational wave (GW) detectors and their ongoing development. For example, ultra-high precision and accuracy differential Hartmann wavefront sensors (HWS) [1] are used to monitor absorption-induced wavefront distortion and the compensation systems within the Advanced LIGO [2] and Virgo GW detectors. Additionally, novel low-scatter reflective adaptive optics (AO) [3,4] are being currently being installed in the LIGO detectors to enable improved matching of the laser beam shape to the optical cavities. While the AO actuators are pre-calibrated, they are not completely isolated from their surroundings and thus it would be useful to independently monitor their operation to enable close-loop operation. However, vacuum-compatible compact wavefront sensors with a suitable bandwidth are not currently available.

We describe here the development of a simple low-cost high-sensitivity wideband Hartmann-type wavefront sensor that uses an array of quadrant photodiodes (QPD) to determine the shape of the wavefront incident on the Hartmann plate rather than a pixelated camera. The voltages from each QPD are used to calculate the centroid location for each Hartmann spot, which are then combined to determine the wavefront change. Here, we present a four-aperture 'quad quadrant photodiode' (QQPD) sensor that can measure prism, and spherical and cylindrical power with a bandwidth of 50kHz.

The sensitivity and dynamic range of the QQPD to a change in wavefront curvature were measured by reflecting a probe beam from a "compression-fit mirror" (CFM), the curvature of which is adjusted by changing its temperature and which was calibrated using a HWS as described in [3]. The expected change in probe beam curvature (red curve) and that measured by the QQPD are plotted in Figure 1, which shows that the QQPD sensitivity is ca. 10 μm^{-1} RMS. The dynamic range of the QQPD is ca. 0.5 m^{-1}.

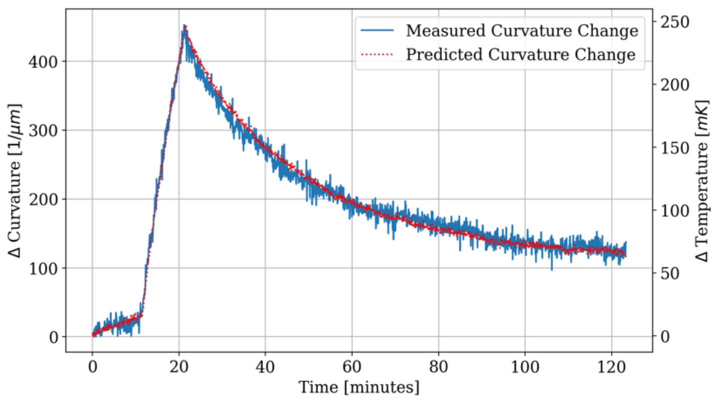

Figure 1: Plot of measured and predicted wavefront curvature change.

[1] A.F. Brooks, T-L Kelly, P.J. Veitch and J. Munch, *Opt. Express* **15**, 10370 (2007)

[2] A.F. Brooks et al, *Appl. Opt.* **55**, 8256 (2016).

[3] H.T Cao, S.B.S Ng, M. Noh, A. Brooks, F. Matichard and P.J. Veitch, *Opt. Express* **28**, 38480 (2020)

[4] V. Srivastava et al, *Opt. Express* **30**, 10491 (2022)