Wavefront Image Sensor Chip

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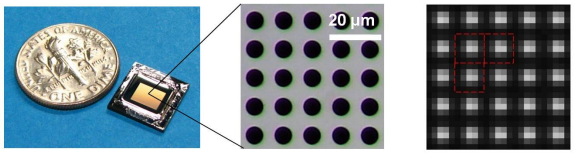
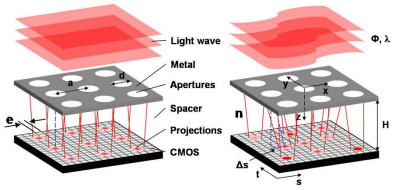
Motivation:

A light field contains two primary characteristics – intensity/amplitude and phase front variations. Now all image sensor chips are like our retina and only responsive to the intensity/amplitude variations of light. But the detection of the phase variations is also important as transparent organisms and cells only modulate the phase of light. The inability of image sensors to detect phase front variations forces us to resort to relatively complex bulk optics to translate phase front variations into intensity variations that are then detectable. We report a new class of compact image sensor chips, termed wavefront imaging sensors (WIS), that is capable of *simultaneously* measuring both the amplitude and the phase front variations of a light field *separately* and *quantitatively*.

Wavefront Image Sensor (WIS):

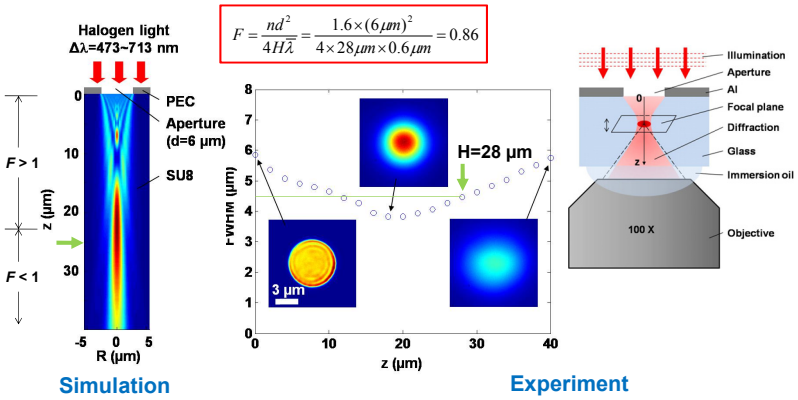




- **Pixels array:** 1944×2592
- **Pixel size (e):** 2.2 μm
- **Spacer:** SU 8 resin, n=1.6
- **Effective spacer thickness (H):** 28 μm
- **Aluminium thickness:**150 nm
- **Apertures array**: 280×350
- **Aperture diameter (d):** 6 μm
- **Aperture spacing (a):** 11 μm

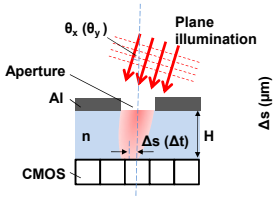
Self-focusing in High Fresnel Num Regime:

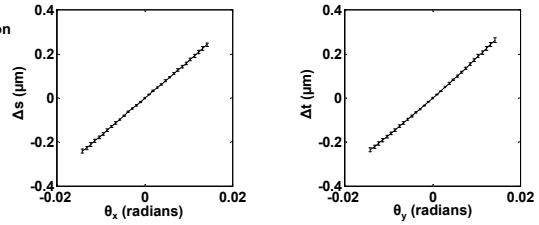
$$F = \frac{nd^2}{4H\lambda} = \frac{1.6\times(6\mu m)^2}{4\times 28\mu m\times 0.6\mu m} = 0.86$$



Simulation Experiment

Normalized Phase Gradient θ_x (θ_y):





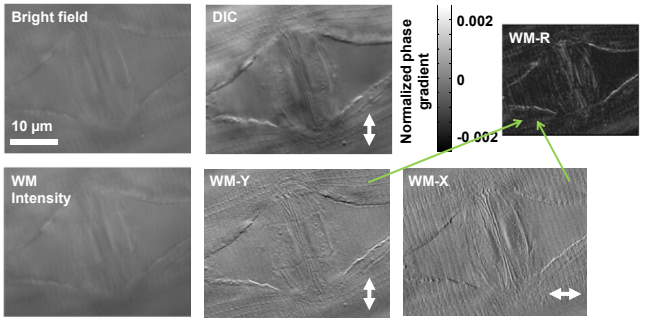
when $\Delta s(x,y) << H$

$$\Delta s(x,y) \approx \frac{H}{n}\frac{\lambda}{2\pi}\frac{\partial\phi(x,y)}{\partial x} = \frac{H}{n}\theta_x(x,y)$$

- **Linear over:** +/- 15 mrad
- **Variation among 350 apertures:** < 0.5 mrad
- **Sensitivity:** < 0.1 mrad (1 sec, 10 μW/cm^2)

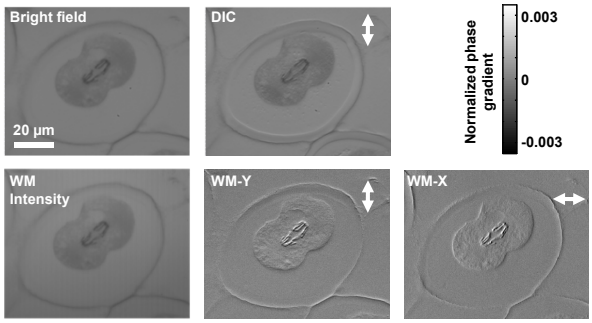
Wavefront Microscopy (WM):

Vulva of an Unstained wild-type hermaphrodite adult *C. elegans*:



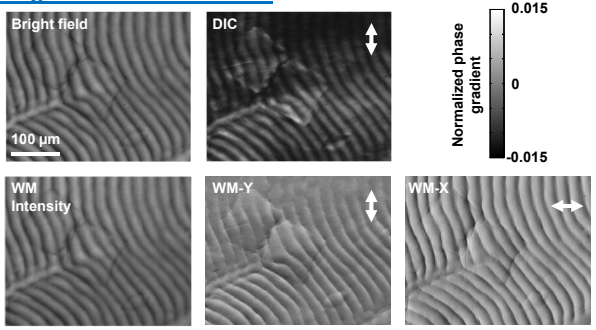
- WM images are consistent with those obtained separately by conventional techniques
- Orthogonal and complete WM phase gradient images

Stained *ascaris* undergoing cell division:



- The amplitude and phase information of the sample image are separated in the WM images

Birefringent ctenoid fish scale:



- WM images are free of birefringent artifacts

References:

1. Xiquan Cui, Guillermo J. Tearney, Changhuei Yang, 'Wavefront imaging sensor chip', submitted.
2. Xiquan Cui, Matthew Lew, and Changhuei Yang, 'Quantitative differential interference contrast microscopy based on structured-aperture interference', Applied Physics Letters, 93, 091113 (2008)

Funding sources: