Optical imaging featuring both long working distance and high spatial resolution by correcting the aberration of a large aperture lens

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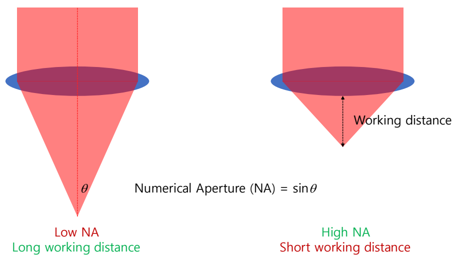
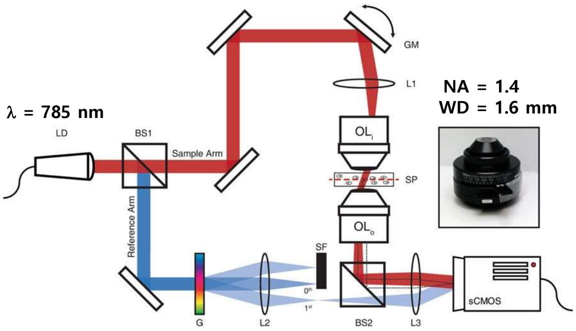
Introduction

$$(\text{resolution}) = \frac{\lambda}{(NA_{ill}+NA_{col})}$$



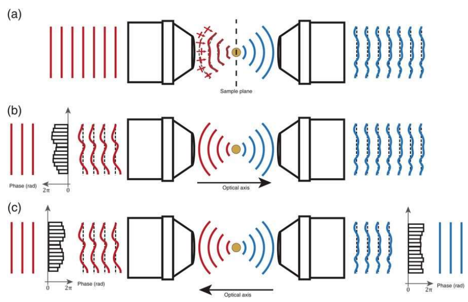
- ✓ High NA and long working distance is mutually incompatible.
- ✓ A physically large diameter lens has both long working distance and High NA.
- ✓ Fabricating such a large diameter lens is difficult since such a bulky lens is likely to introduce severe aberration.

Experimental setup



- ✓ Transmission coherent imaging system based on a Mach-Zehnder interferometer.
- ✓ To physically guarantee both long working distance and high spatial resolution, we employed two microscope condensers (MBL78700, Nikon; NA: 1.4, working distance: 1.6 mm) as illumination and imaging objective lenses.

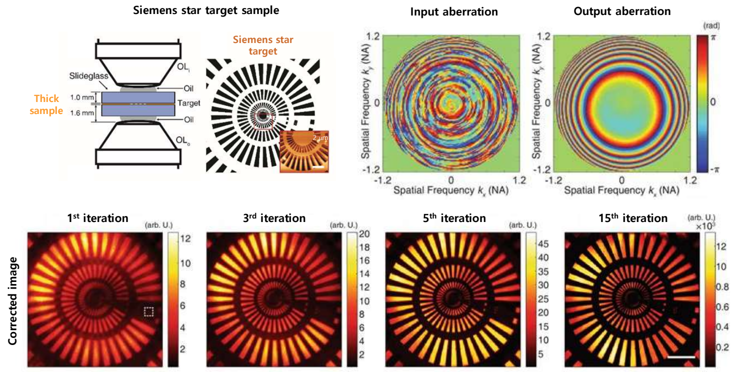
Algorithm for aberration correction



- ✓ Due to condenser aberration, the plane wave at the sample plane (red curved lines) acquires a different phase shift. This yields a blurred and distorted PSF.
- ✓ By placing a virtual SLM at the Fourier plane to compensate for the additional phase shift at different angles
- ✓ In a reversal of the previous process, a virtual SLM is placed at the output pupil to focus light at the sample plane to compensate for output aberration.

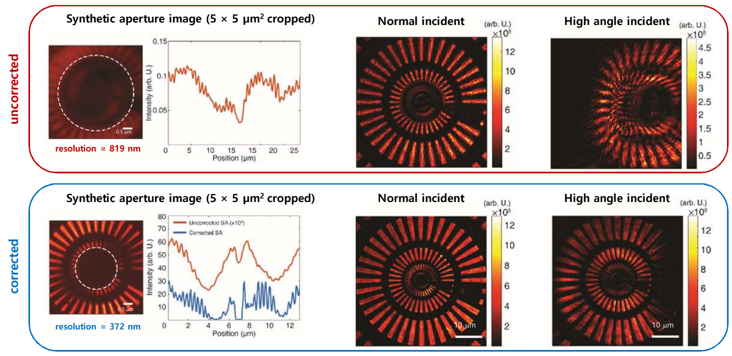
Results

Test target imaging



- ✓ Total sample thickness was about 2 mm.
- ✓ As the iterations continue, fine target structures progressively resolve.

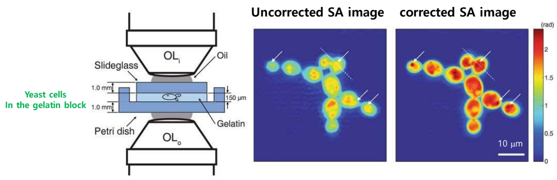
Resolution enhancement



$$\Delta = \frac{\lambda}{(NA_{ill}+NA_{col})} = 327 \text{ nm}$$

- ✓ the structure of 372 nm periodicity was resolved with aberration correction. As the iterations continue, fine target structures progressively resolve.
- ✓ This result confirms that our aberration correction algorithm almost perfectly compensates for system aberration.

Yeast cell imaging



- ✓ We applied the developed method to the imaging of biological cells.
- ✓ In the aberration-corrected image, granular structures were clearly visible.

Conclusion

- ✓ We developed a method to correct the aberration of an optical system. By using this method, microscope condensers turned into objectives with a longer working distance.
- ✓ This allowed us to image thick specimens with a spatial resolution of 372 nm, a value close to the diffraction limit set by 1.2 NA at the wavelength of 785 nm.