Optical Masks for Imaging Exoplanets with Large Ground-Based Telescopes

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Primary CNF Tools Used: ASML DUV stepper, Oxford ICE-RIE etcher

Abstract:

A stellar coronagraph is a telescope instrument that enables direct imaging of extra-solar, or exoplanets, from the ground or in space. Some components of the coronagraph system we use require microfabrication techniques to be manufactured. We report on the progress of fabricating optical masks known as complex focal plane masks for stellar coronagraphs, as well as their uses at the Subaru telescope so far.

Summary of Research:

In recent years, astronomers have used telescopes attached with instruments to estimate that approximately 50% of stars have a habitable planet (an Earth-size planet with surface temperature able to sustain liquid water). Current detection limits only allow for the radius, orbit and mass of the planet; identifying if life has developed on the planet requires direct imaging and spectroscopy. This is extremely challenging: the planet can be about a billion times fainter than the star it orbits and is located very close to it on the sky. The key to performing direct imaging and spectroscopy is a telescope instrument called a stellar coronagraph. A stellar coronagraph is designed to access light from the planet for observation by blocking, reducing, or in some way suppressing incoming starlight using a series of carefully designed optical masks.

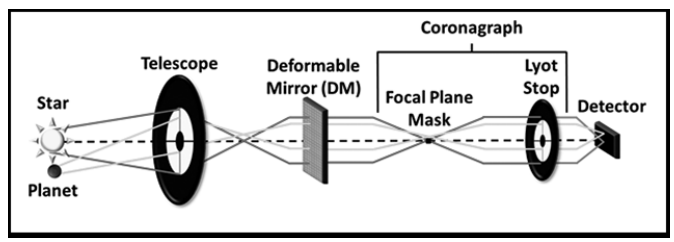

Figure 1. A stellar coronagraph. After entering the telescope, light from the planet passes through the chain of optical masks (focal plane mask, Lyot stop) unchanged, while the starlight is altered in amplitude and phase to allow the collection of planet light from the detector. The deformable mirror can be used to improve the performance of the coronagraph. Image courtesy of Kelsey Miller, University of Arizona.

Each mask is responsible for changing the starlight amplitude and phase to induce deep destructive interference, or cancellation, of the starlight to collect the planet signal possibly buried underneath. A simple coronagraph architecture is shown in Figure 1. It consists of optics after the telescope which focus and collimate the incoming beam at various points; doing so allows for the optical masks to suppress the starlight as discussed.

The stellar coronagraph we developed for the Subaru Coronagraphic Extreme Adaptive Optics (SCExAO) bench at the Subaru Telescope on Mauna Kea, HI, is known as the Phase-Induced Amplitude Apodization Complex-Mask Coronagraph (PIAACMC). It consists of several custom-fabricated optical masks including a "complex" focal plane mask. Figure 2 shows an example of a fabricated complex mask designed to modulate the amplitude and phase of starlight coming to a focus. The fabrication process for this mask used the ASML DUV stepper and an Oxford ICP-RIE etcher.

These masks consist of a tessellated pattern of hexagonal zones which vary in height; the hexagons are responsible for producing the destructive interference of the starlight

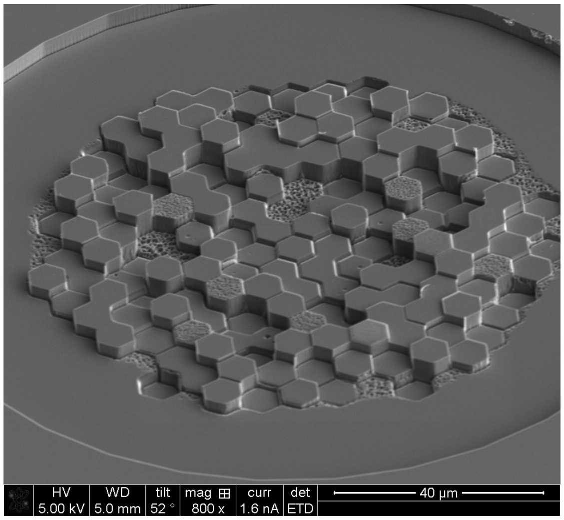

Figure 2: An early iteration of a fabricated complex mask.

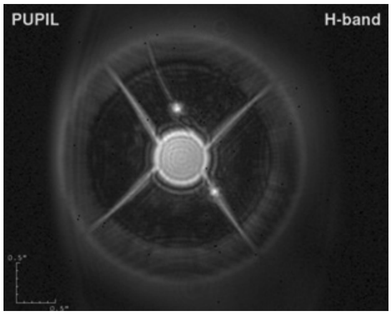

Figure 3: An image of a fabricated complex-mask aligned at SCExAO in the plane before the Lyot stop. Starlight passing through the complex-mask has been changed, but still propagates through to the features of the telescope architecture. This light will be blocked by the Lyot stop, after which the performance of the coronagraph can be measured.

on a detector. This type of focal plane mask must be fabricated using microfabrication techniques as each hexagon is typically on the order of 10 μm wide and a few microns or less deep. Tolerances of these devices are being investigated, but the better they are made to match the original design, the better they can destructively interfere starlight at several wavelengths simultaneously.

The masks from this fabrication effort will be installed and tested at SCExAO soon, but for now only some other masks have been put into the system. Figure 3 demonstrates the intended effect an aligned focal plane mask has in only allowing light to gather in places where it can be blocked by another optical mask. We report on some of these activities in references [1] and [2].

References:

[1] Julien Lozi, et al., "SCExAO: new high-performance coronagraphs ready for science," Proc. SPIE 10706, Advances in Optical and Mechanical Technologies for Telescopes and Instrumentation III, (Publication pending).

[2] Justin M. Knight, John Brewer, Ryan Hamilton, Karen Ward, Tom D. Milster, Olivier Guyon, "Design, fabrication, and testing of stellar coronagraphs for exoplanet imaging," Proc. SPIE 10400, Techniques and Instrumentation for Detection of Exoplanets VIII, 104000N (12 September 2017).