Fabrication of a band-limited mask for PHARO

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Extrasolar planets are many orders of magnitude fainter than the stars which they orbit and located within close angular proximity. To directly detect the presence of a planet, it is necessary to eliminate the bright glare of light from the star. A coronagraph is a device that performs this task in practice by attenuating the star and removing instrument diffraction. Its critical component is an occulting mask located in a focal plane. Such masks have small features and must be manufactured with nanofabrication technology to operate at visible and near-infrared wavelengths [1,2]. As the result of this research ``band-limited" coronagraphic K_s- and Y-band masks have been created and installed in a sensitive near-infrared instrument at Palomar observatory (PHARO) to enable direct imaging of young, massive, large-separation planets that orbit nearby stars.

The photograph (Fig.1) of a finished mask for K_s-band observations illustrates the challenges encountered in the mask manufacturing process. The most stringent requirement is to delineate opaque 200 nm thick metallic aluminum features that are varied in the characteristic size from a few tens of nanometers to a few tens of micrometers and are scattered over a square millimeter area of an electrically non-conductive substrate (Dow Corning model 1737 glass). Application of proximity correction software is absolutely crucial in such a case. Hydrogen silsesquioxane (HSQ) negative resist (Dow Corning XR1541), spin-coated and soft-baked (80^0C) over the aluminum film has been exposed on a JEOL-9300FS electron beam lithography tool at an acceleration voltage of 100 kV and beam current of 2 nA. Utilizing a continuous metallic film under the resist allows complete elimination of detrimental surface charging. The exposed resist is developed in a hot (80^0C) aqueous solution (25%) of tetramethylammonium hydroxide (TMAH). Chemically aggressive TMAH will also remove in the development process unprotected by the resist Al film areas thus no other manufacture steps such as plasma etch are required. The development time was selected as the time of complete dissolution of unprotected Al film. Unavoidable characteristic size reduction of the Al features due to the lateral chemical etch should be compensated during the feature design stage by a positive size biasing.

Figure 2 presents the mask diffracted light response. The bright ring around the center is a perfect match to theoretical predictions. The starlight will be blocked by an iris with the same shape, and the combination of the mask and pupil stop will remove starlight and pass the light from planets.

[1]. M.J. Kuchner, J. Crepp, J. Ge, ApJ, **628**, 466 (2005)
[2]. J.R.Crepp, J.Ge, A.D.V. Heuvel, S.P.Miller, M.J.Kuchner, ApJ, **646**, 1252 (2006).

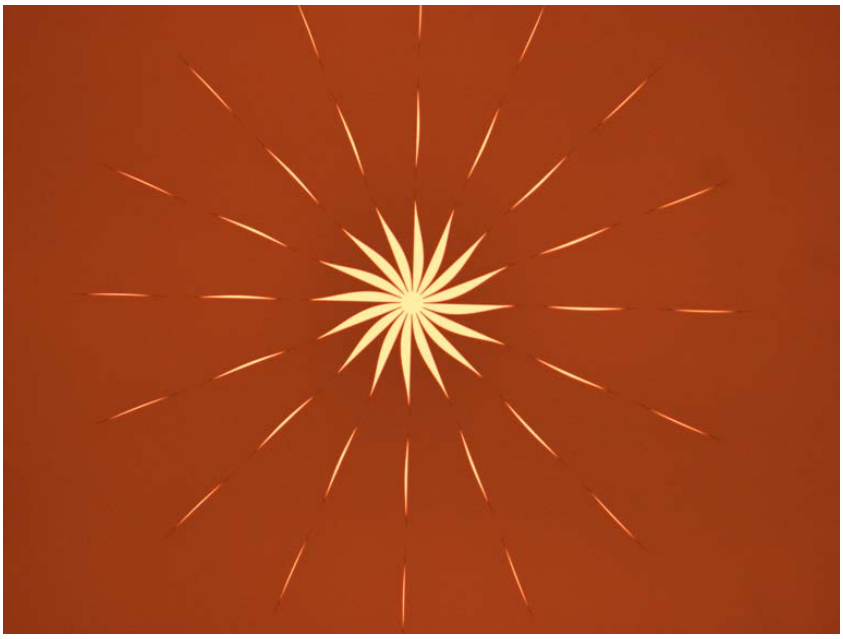

Figure1. Photograph of a finished K_s-band mask. The radius of the area covered by the mask elements is 0.52 mm.

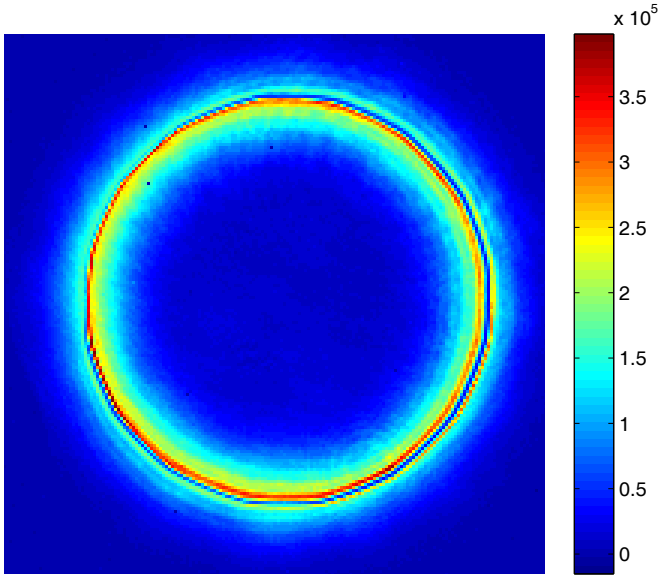

Figure2. An image of the pupil plane obtained during the mask testing.

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