AFTA-WFIRST Coronagraph Fabrication and Specifications Plan

Architecture: Hybrid Lyot

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Key Components per Architecture

As per Peter Lawson's ACW 2 TRL presentation, the following list are the key components we would like detailed information. These are the components believed to be the lowest TRL in your systems. Please use one page per component when responding.

Hybrid Lyot Architecture

- Hybrid Lyot Focal Plane Mask is the single key component for our technology.

Scope

- **Description**
  - The hybrid Lyot focal plane mask, together with the pupil plane Lyot stop and deformable mirrors, creates a high contrast dark field of view in which exoplanets can be imaged and their spectra isolated from the glare of the central star.
  - Details of the mask design, including K. Balasubramanian's spreadsheet, are provided on the following slides.
- **Manufacturer**
  - The hybrid Lyot mask is manufactured in Trauger's JPL laboratory, using a vacuum deposition system dedicated to this task only.
  - The method of manufacture is by the vacuum deposition of thin film layers of nickel and MgF_2 on a fused silica substrate, with thickness profiles .
  - Heritage: vacuum deposition of optical thin film materials on glass is an industry standard and a highly mature technique. Our techniques have been perfected over the past five years and validated in HCIT performance demonstrations as part of the ASMCS and SAT/TDEM programs.
- **Acceptance Criteria**
  - The vacuum deposition process is monitored in real time, calibrated with reference to metal and dielectric test patterns, and perfected through repeated fabrication/calibration cycles.
  - Specifically, we measure the optical properties of the metal layer with a scanning fiber photometer and dedicated microscope/camera, and the dielectric layer using interference fringes under a dedicated microscope/camera. These calibration techniques have been refined and validated over the past five years.

TRL 5 Schedule

- **Show a development schedule for each key component. Show at minimum the following milestones on a timeline so that durations are visible:**
  - Manufacturing design completed and tolerances defined: October 2013.
  - Circular mask fixture to be completed: November 2013.
  - Manufacturing and process calibrations begin: December 2013
  - Final component delivered to HCIT: March 2014.

- **Nick's schedule in the Appendix will show how the key technologies can be brought to TRL 5 by FY17. If your key component deliveries fit into his schedule and you generally agree with the timescales and testing approach then you can just say the TRL 5 schedule look reasonable for your mask. If your delivery schedule does not fit then explain how you expect to meet the TRL 5 milestone with less demonstration time.**
  - The mask fabrication, as indicated above, will produce high quality masks ready for testbed validation by mid-2014. Refining the design and the cleanroom fabrication facility for flight components will be straightforward. Therefore, the TRL5 schedule is reasonable for the hybrid Lyot mask.

TRL 6 Technical Concerns

- **What risks exist in your key components not passing environmental testing for a TRL 6 assessment? The following are possible tests:**
  - The hybrid Lyot mask, composed of thin film layers of nickel and MgF_2 on a fused silica substrate, is actually a two-layer variation of an optical interference filter, an optical technology already known to be robust for flight.
  - In flight, the hybrid Lyot mask will reside internal to the coronagraph instrument, where it will be subjected to well-known environmental conditions typical for an optical interference filter in a space telescope. As such, the hybrid Lyot technology is robust against expected levels of: charged particle radiation, survival temperatures between +5 to +50 C, humidity, vacuum, random vibration and acoustics, shock expected internal to an optical instrument.
  - Further, the hybrid Lyot mask is a monolithic component, requiring no internal alignments.

- **Any other environmental exposure risks that could damage a flight part?**
  - As with any optical component at or near an instrument focal plane, contamination due to particulates must be minimized.

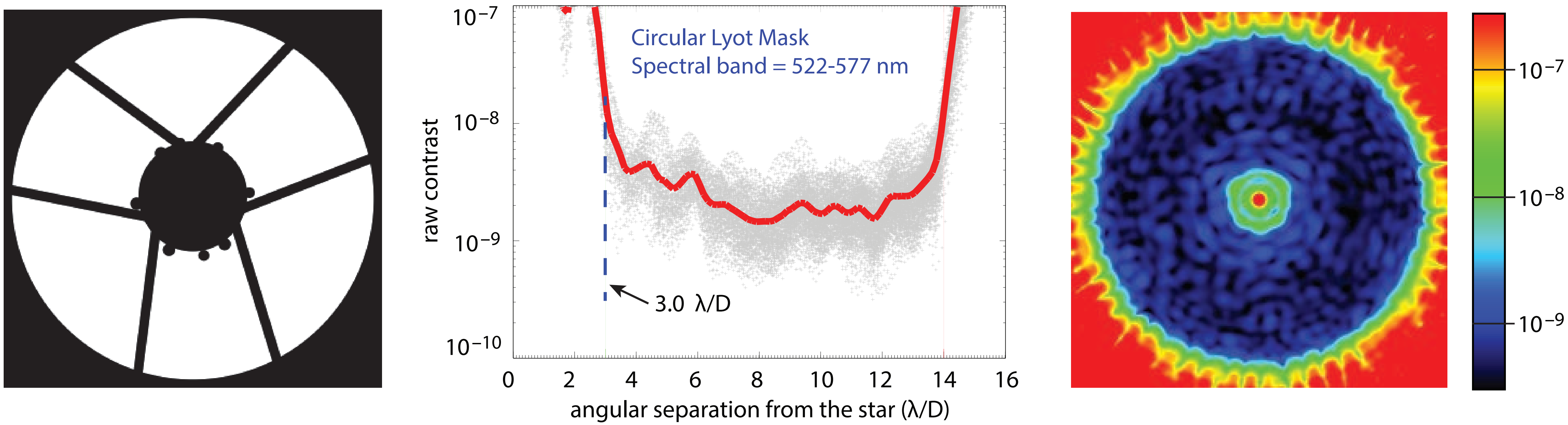
- **Are there any concerns in fabricating your key components to meet TRL 6 fit, form, and function requirements by FY19.**
  - The hybrid Lyot mask is a compact monolithic component that can be formed on a glass substrate of arbitrary shape and size, therefore we have no concerns in meeting the fit, form, and function requirements well in advance of FY19.

Concerns and Risks

- **List and explain your concerns to fabricate and deliver your key components to meet your schedule.**
  - The vacuum deposition fabrication process is well established in the industry, straighforward and familiar to the investigators, and therefore we do not expect difficulties in meeting our schedule.

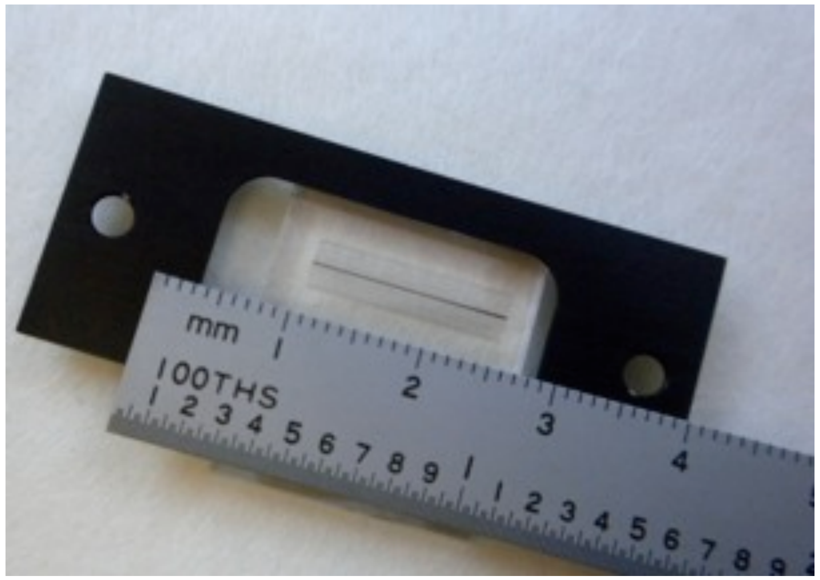
- **List any other concerns or risks re the manufacturability of your key components.**
  - The fundamental vacuum deposition technique is well established. We are building a new and improved fabrication fixture, specifically for circular hybrid Lyot masks, to be installed into our mature vacuum deposition system which is dedicated to this task only, using commercial parts and straightforward mechanical design. We consider the risk in this process to be minimal, with many off-ramps.

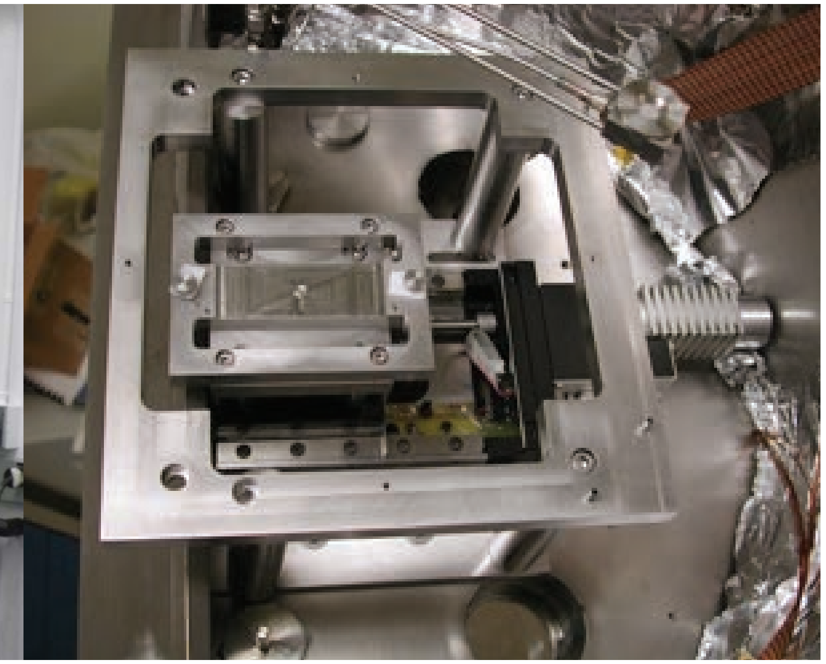
Now the details: hybrid Lyot masks



- *Shown is the representative image contrast and coronagraph dark field for a hybrid Lyot coronagraph tailored to the partially obscured AFTA telescope pupil.*
- *The focal plane mask consists of two superimposed thickness-profiled thin film layers on a fused silica substrate.*
- *Design process simultaneously manipulates both layer profiles and DM settings to optimize performance over specified inner and outer working angles, spectral bandwidths, and pupil configurations.*

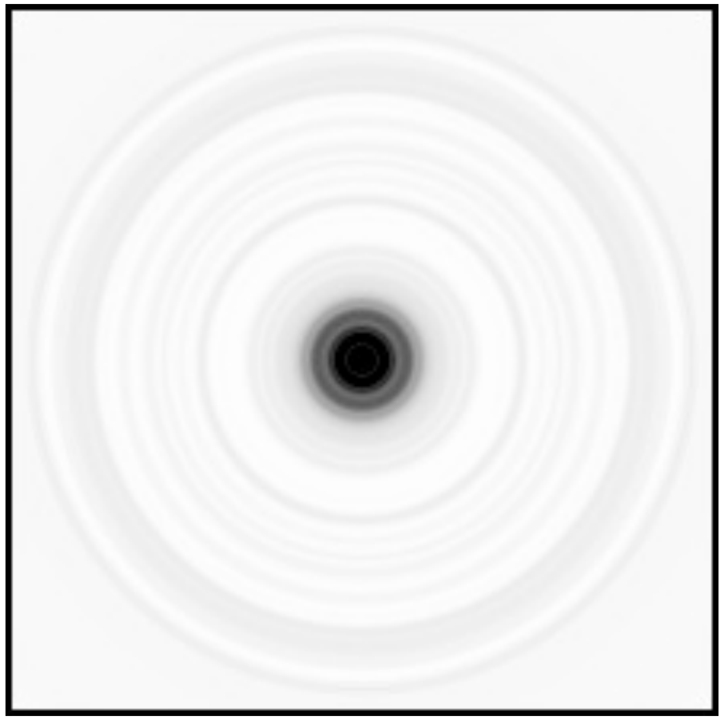
Fabrication heritage - linear masks

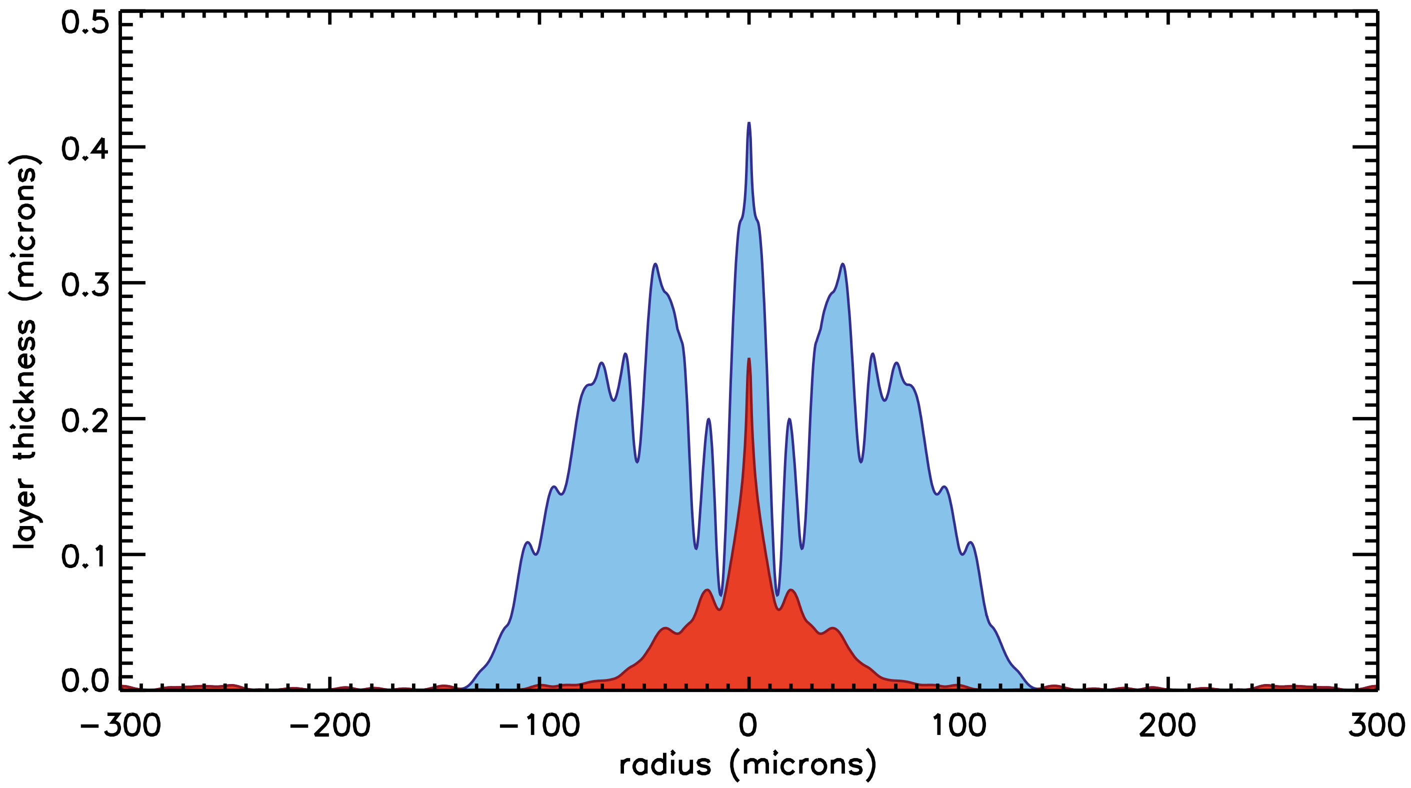




- ***Our fabrication technique*** *has been developed, refined, and validated over the past few years on linear Lyot masks.*
- ***Thickness-profiled metal and dielectric thin films*** *are vacuum deposited through a 15 micron slit (slit is made at JPL's MDL) on a glass substrate.*
- *Substrate is scanned in 1 micron steps behind the slit during deposition, dwell times define the thickness profiles.*
- ***Performance predictions and manufacturing tolerances*** *are based on optical models that have been validated to the 2e-10 contrast level in TDEM/HCIT demonstrations (Trauger et al.).*
- *Finished masks are stable and robust,* ***a suitable technology for flight****.*

Circular hybrid Lyot mask



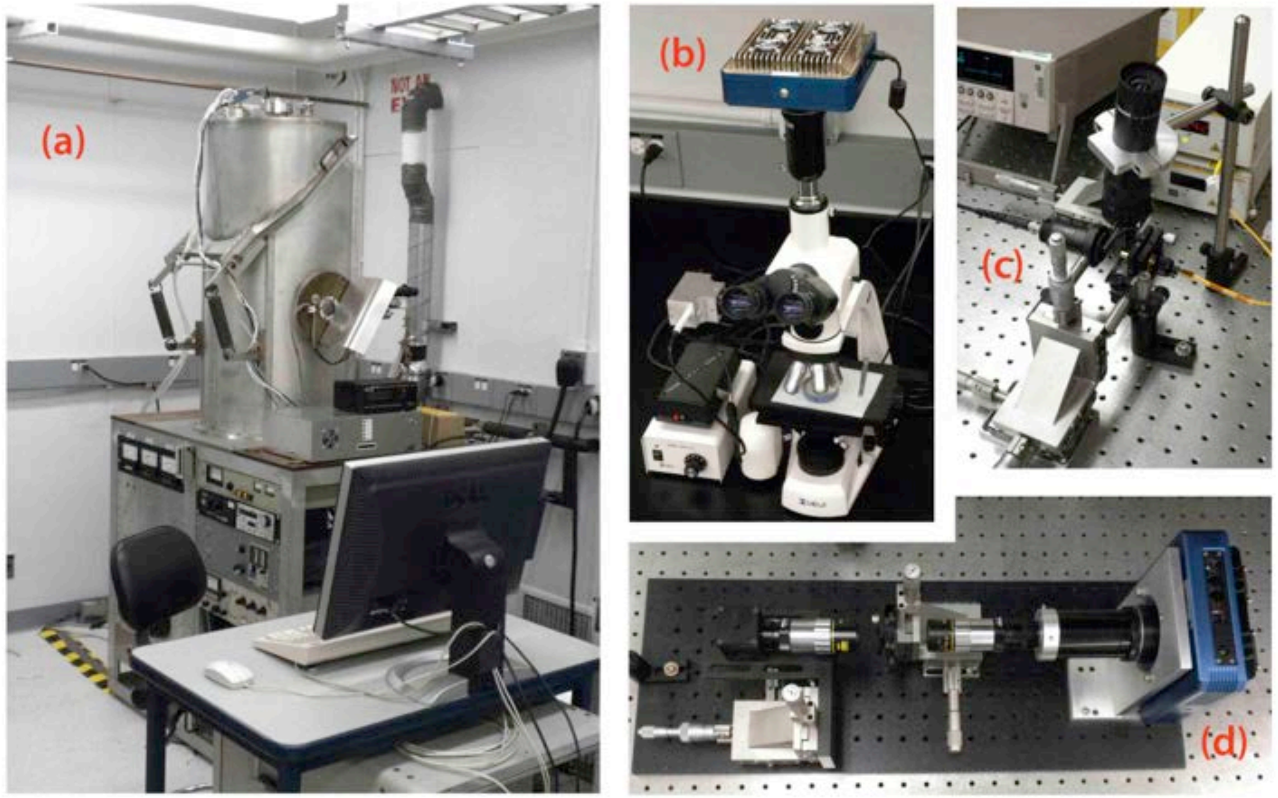


- *Above left, the attenuation pattern of a representative circular mask. Mask is designed for a 3 λ/D inner working angle, and optimized for the AFTA pupil.*
- *Above right, the radial cross section "sand diagram" of the superimposed, thickness-profiled metal (red) and dielectric (blue) layers. Note that the vertical axis has been expanded by a factor of 700 for clarity – the pattern is actually quite flat.*
- *Factoid: very little material is required:*
  - *Peak thickness of nickel layer is 0.24 microns. Total material volume = 920 cubic microns = 8.2 nanograms*
  - *Peak thickness of MgF2 layer is 0.28 microns. Total material volume = 6900 cubic microns = 19.5 nanograms.*

Description of the circular Lyot mask

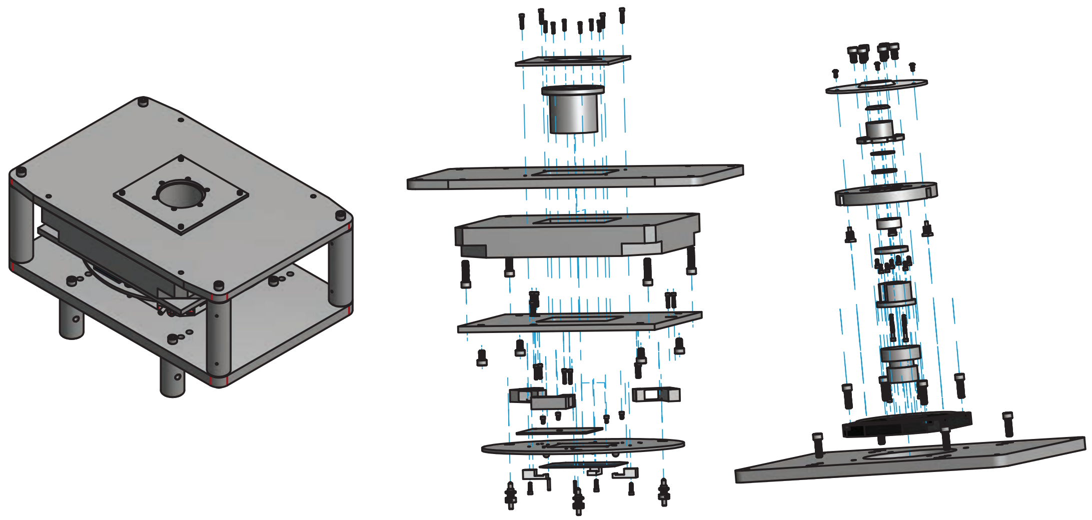
	Hybrid Lyot Coronagraph Mask
Geometry	Transmissive
Size / Shape	circularly symmetric
# of masks needed	One
Substrate Material	Fused silica
Substrate dimensions	One cm diameter or larger
Clear Aperture	Diameter of the selected glass substrate
Substrate wedge angle, or parallelism, if required or not	None required
Transmission	~95%
Transmitted wavefront	λ/20 PV at 550nm across 1 mm
Scratch and dig spec	Typical
Backside AR Coating	Yes, 500 to 600nm band or broader
Backside AR spec	< 0.25%
Mask Materials	Ni, MgF_2
Structure	Two layer coating
Illumination cone angle or F#	No constraint.
Wavelength band	550 +/- 27nm
Fab Technology or Vendor	Vacuum deposition at JPL
Mask Specs and measurements	See previous slide for typical profiles
OD vs radius and λ	Follow from the thickness profiles
Ni Layer thickness vs radius	See previous slide for typical
Dielectric Layer thickness vs radius	See previous slide for typical
ϕ vs radius and lambda	Follows from the thickness profiles
ΔOD vs r	5%
$\Delta\phi$ vs r	5%
Circularity or shape distorsion allowed	5%
Metallic or other particulates per sq mm	TBD
Size and distribution of particulates	TBD
# of pin holes, if any, allowed per sq mm	TBD
Size and location of pin holes	TBD
Other defects or errors, e.g., irregular features	
# of masks to be produced	4 or more
Desired target date	Mid April 2014

Circular Mask Fabrication – What is unchanged?



- *We use the same dedicated cryopumped vacuum deposition chamber (located in our 183-818 laboratory).*
- *Materials are the same: metal = nickel, dielectric = cryolite/MgF2, fused silica substrate.*
- *Our knowledge of material characteristics, adhesion, and thickness linearity with deposition rates is preserved.*
- *We use the same calibration procedure for metal layer: scanning fiber photometer.*
- *We use the same calibration procedure for dielectric layer: Fresnel fringes in a dedicated microscope*

Circular Mask Fabrication – What is different?



- *Mask design has rotational symmetry.*
- *Deposition mask is no longer a linear slit, instead a "microstencil" array now includes precisely located circular (and possibly annular) openings etched into a silicon wafer (at JPL's micro devices laboratory).*
- *Deposition fixture (designed by Brian Gordon, shown above) now includes a rotary stage for the substrate to enforce azimuthal symmetry and an x/y stage for alignment and selection of of the microstencils.*
- *Rotary stage is already in house at JPL. Its rotational runout has been verified as better than 1 micron rms (measured in our laboratory by Kent Wallace this week).*
- *The x/y stage for microstencil placement is a PI device with 0.1 micron positional encoding and +/- 0.3 bi-directional repeatability.*

Process improvements are based on past experience

- *Deposition fixture is easily demountable from the vacuum chamber: fixture and substrate fine alignments will be carried out under a microscope on the laboratory bench prior to insertion into the vacuum system.*
- *Fine x/y alignment of the microstencil mask will be carried out with the alignment microscope, making reference to the rotation axis of the substrate. Microscope improves repeatability of the alignment process and reliability of the calibrations.*
- *Fine z alignment, i.e. the separation between microstencil and substrate, will also be adjusted with reference to the alignment microscope.*
- *Higher capacity e-beam source will solve a number of inconveniences, increase deposition rates, and improve process reliability. Both metal and dielectric materials will be sourced from the same location in the vacuum deposition chamber.*
- *The x/y stage is a PI device with 0.1 micron positional encoding and +/- 0.3 micron bi-directional repeatability, is better than the Newport lead screw stage used for the linear mask fabrication.*

Conclusions

- *Circular hybrid Lyot mask fabrication is an extension of techniques refined and validated during the past six years.*
- *Lessons learned have been incorporated into the circular mask fabrication fixtures to improve process control.*
- *The linear hybrid Lyot mask is TRL 5. Circular mask readiness is close behind.*
- *We have a JPL-funded IRAD program scheduled to develop, by mid FY2014, circular hybrid Lyot masks suitable for AFTA coronagraph testbed demonstrations.*

End