Fabrication of ISHELL Immersion Gratings

UT Si Diffraction Grating Group

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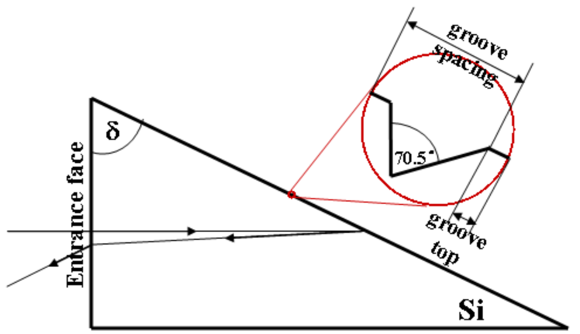
Principle of an immersion grating: (Fraunhofer 1823)

Infrared immersion gratings are an enabling technology because they can shrink instrument volumes by about an order of magnitude.

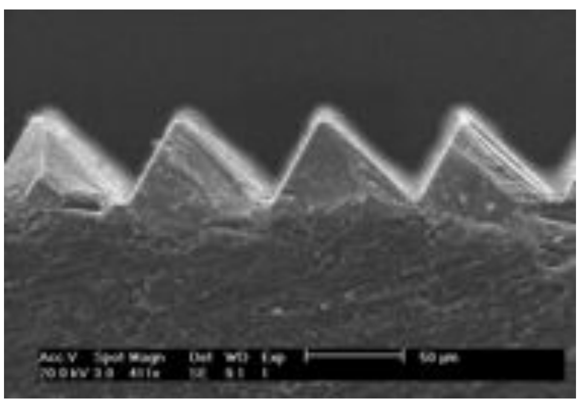


$\Delta x \Leftrightarrow \Delta\phi = (2\pi n/\lambda)\Delta x$

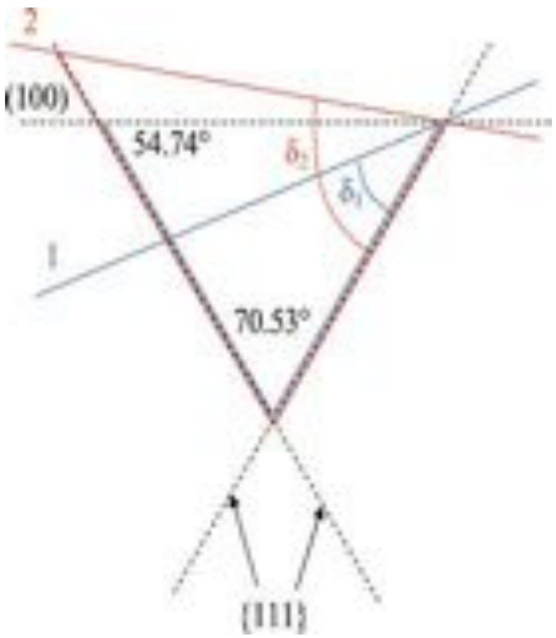
$$m\lambda = n_G \sigma(\sin\alpha + \sin\beta)$$

$$R_{\max} = \frac{2n_G L \sin\delta}{\lambda}$$

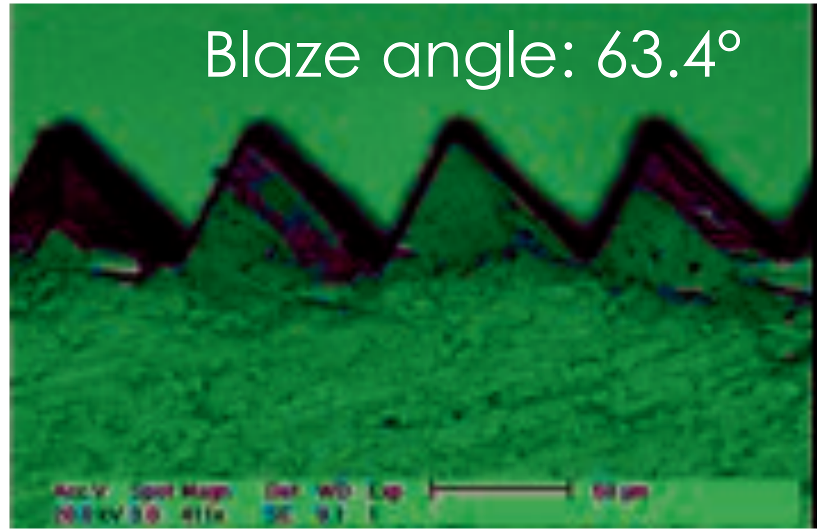
$$\frac{d\beta}{d\lambda} = \frac{2n_G \tan\beta}{\lambda}$$

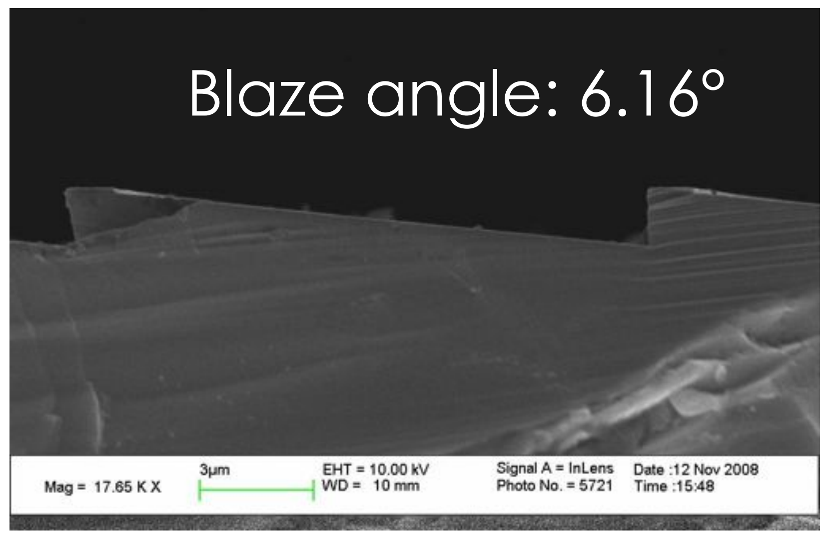


By cutting the crystalline silicon at the right angle, we determine the blaze.

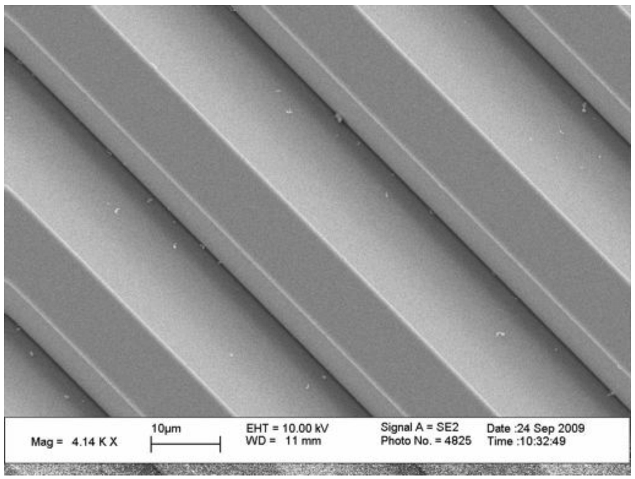


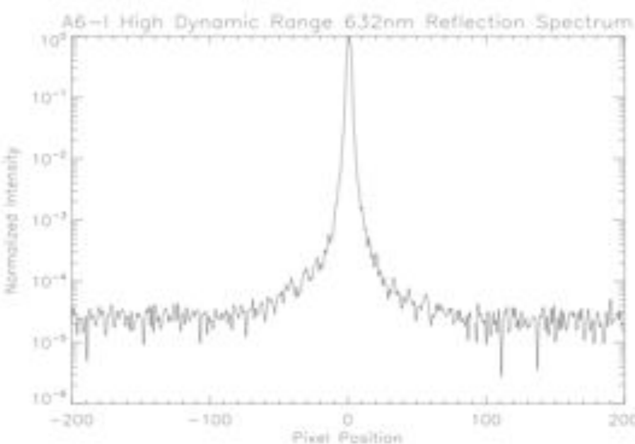
*Cutting angle depends on desired blaze angle **δ**





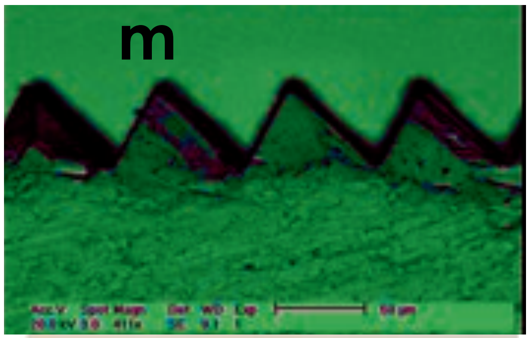
The perfect shape and low roughness of etched grooves means low scattered light levels.



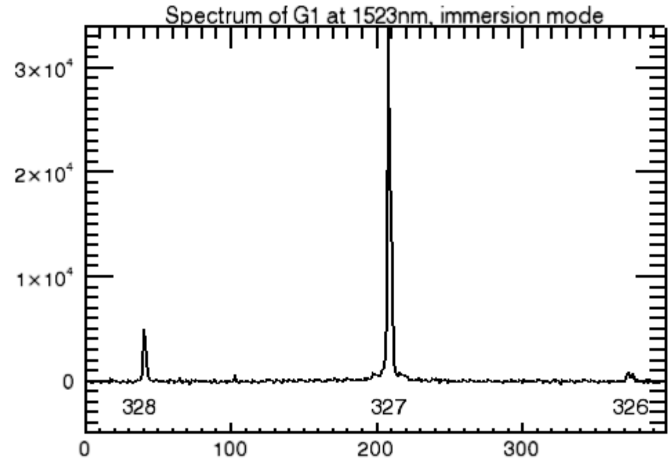


The high placement precision leads to high efficiency and spectral purity.

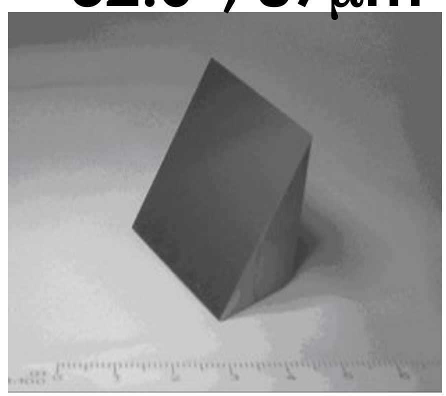
63.4°, 80μm



iShell grating G1 for NASA Infrared Telescope Facility

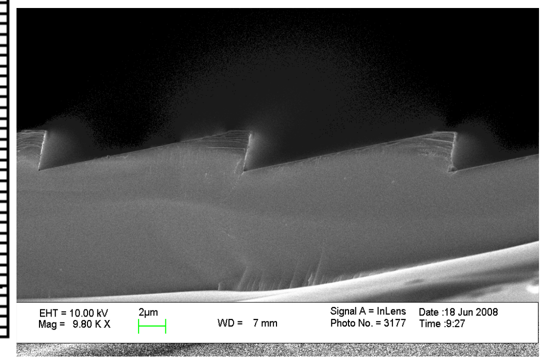


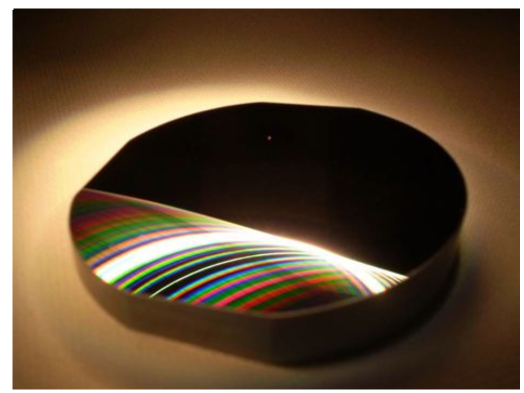
32.6°, 87μm



FORCAST grating G3 (mid/near IR camera for NASA's SOFIA airborne observatory)

6.16°, 15.36μ

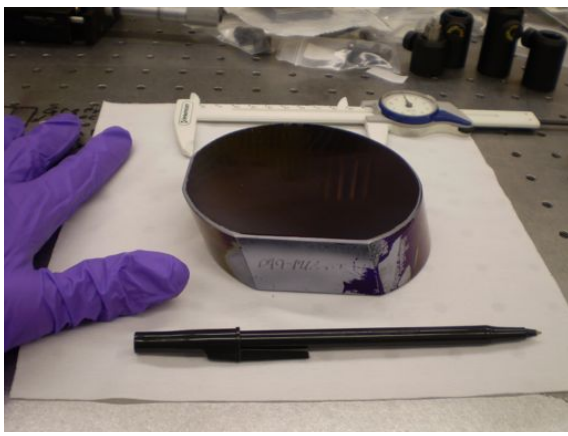
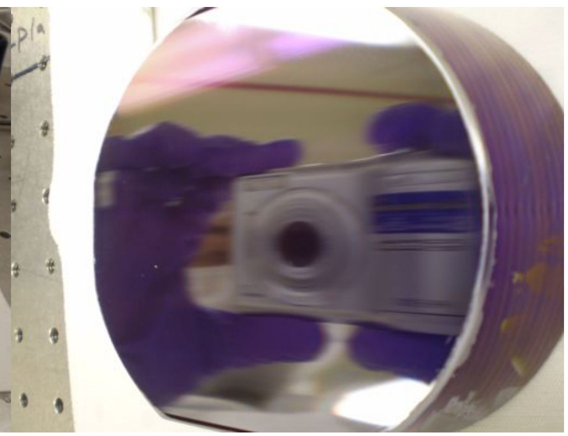
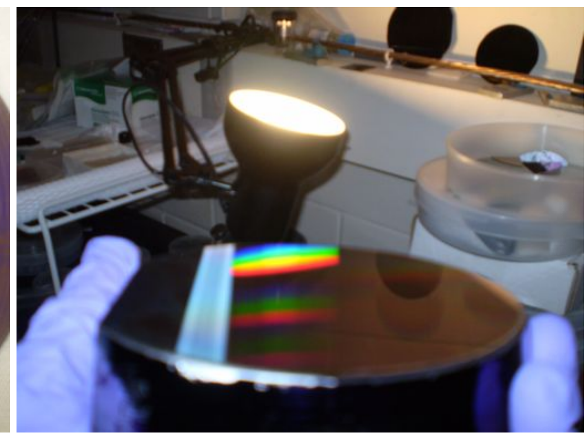




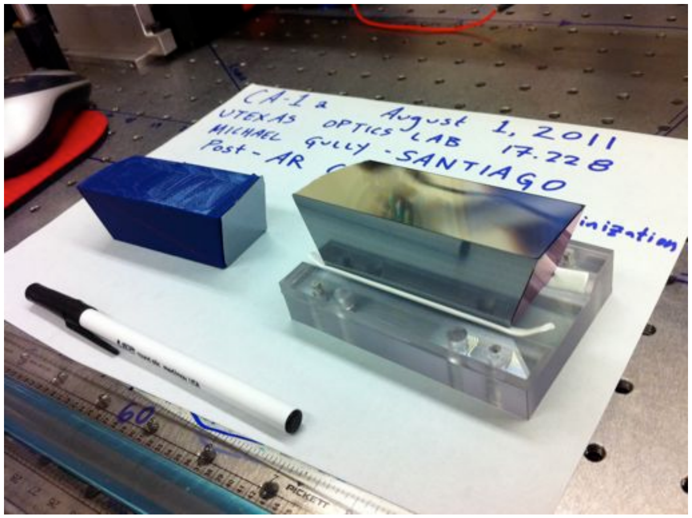
JWST NIRCam grism A6-F

Views of the CA1 (IGRINS Grating Completed Surface)

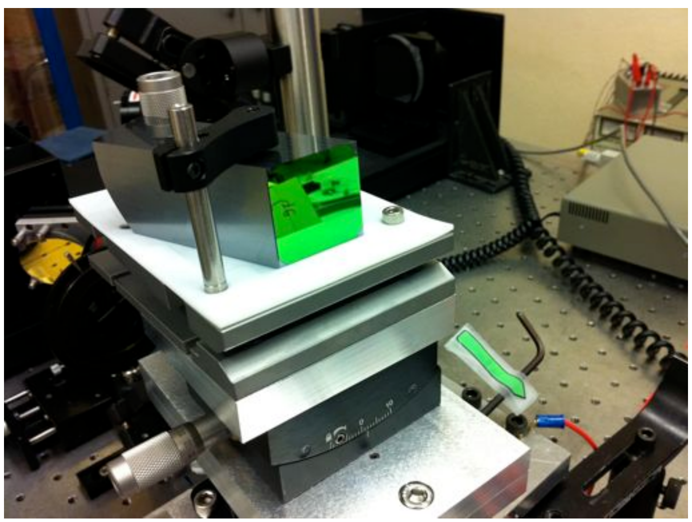
Images of CA1 post KOH etching, but before nitride stripping

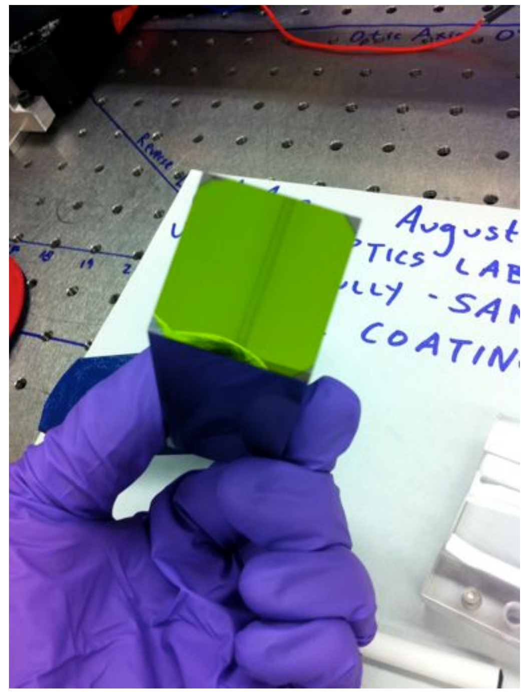




Immersion Grating CA1, After Coating, August 2011



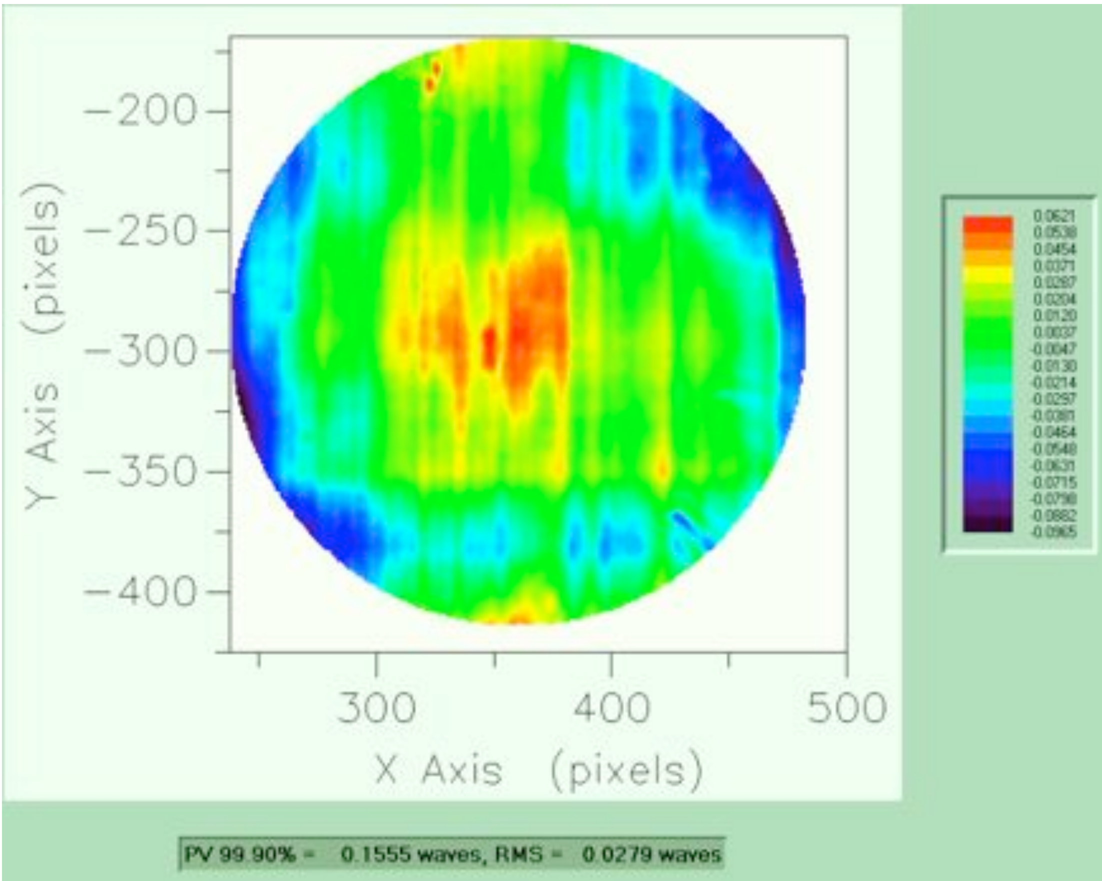
Grating along side a solid model mockup





View of the AR coated entrance face

Front-Surface Interferogram of CA1

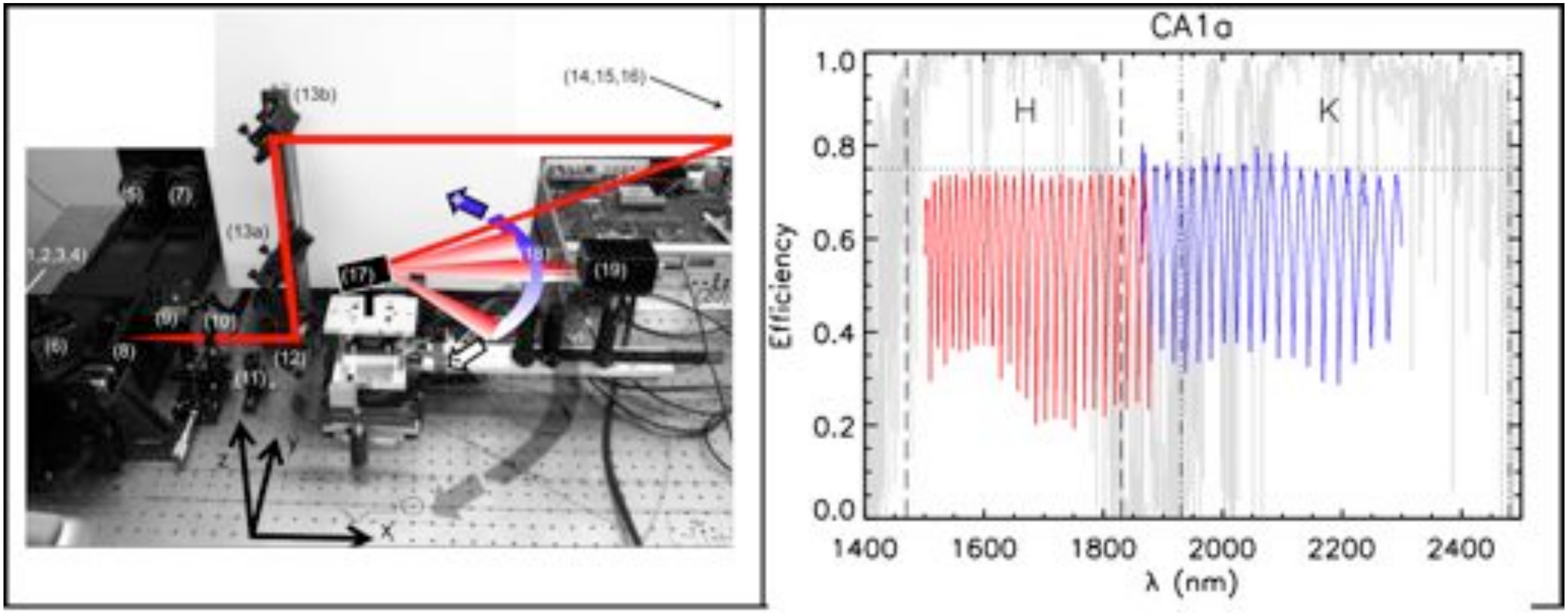


Interferogram with a 25 mm beam, front surface at 632 nm

Peak to Valley deviation is 0.16 waves

5nm repetitive error leads to 0.2% ghosts

Measured efficiency in immersion:

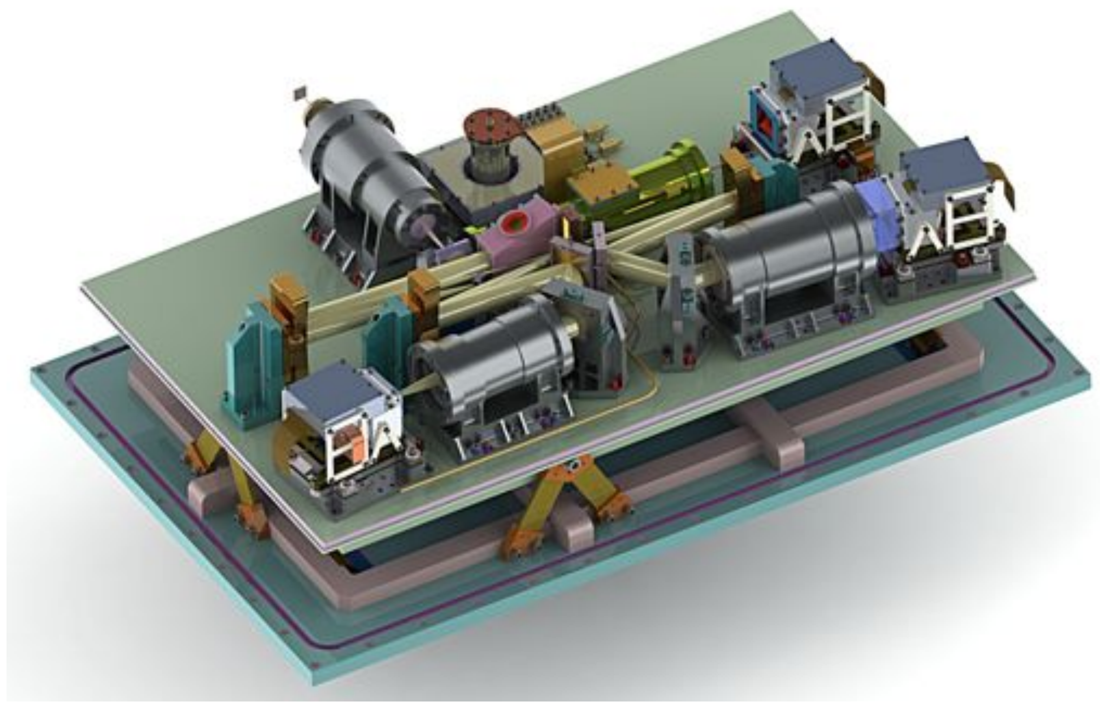


Measured efficiency at 1.523 (close to the
blaze but not on it) is 79 +/-6%

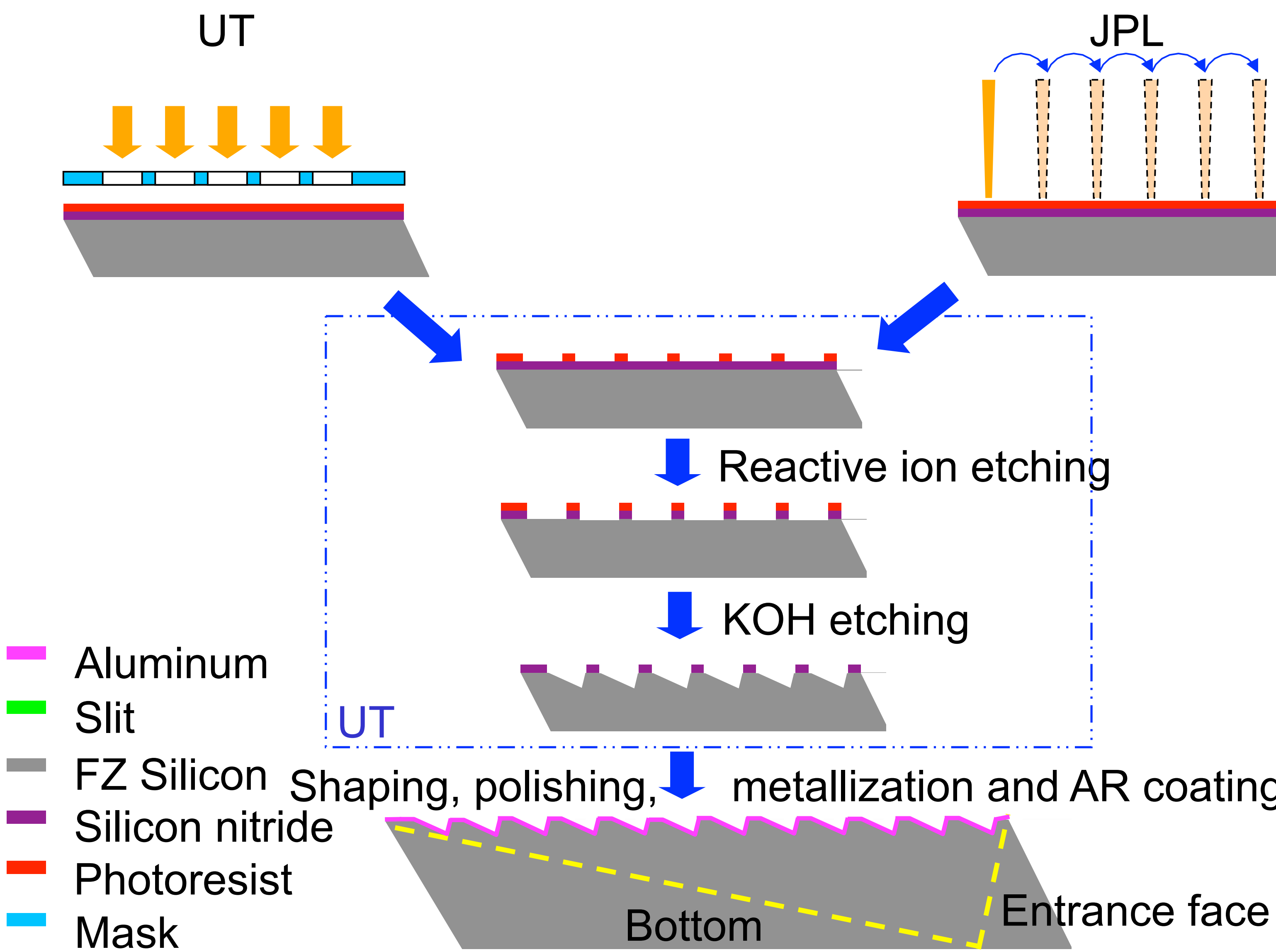
IGRINS Concept of the Instrument

IGRINS is a high resolution near-IR spectrograph:
R= 40,000
Slit 1"x 15" on the McDonald 2.7m, proportionally smaller on larger telescopes.
Stable and simple to use:
no moving parts

Very large spectral grasp
(all of H and K at once)
Good efficiency/sensitivity
Slit viewing camera for efficient observations
Pipeline reduction software for normal use.

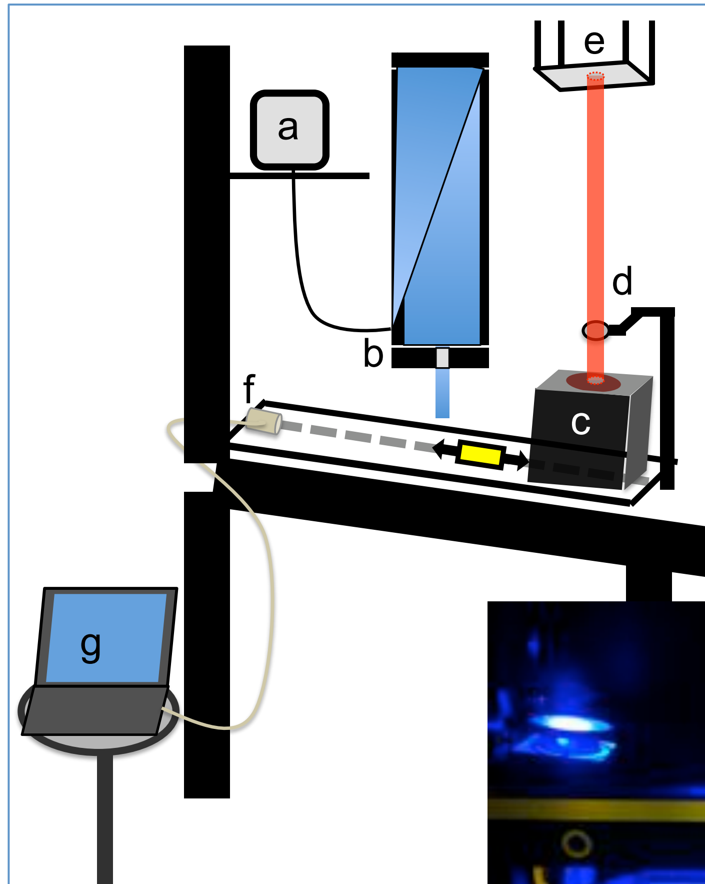


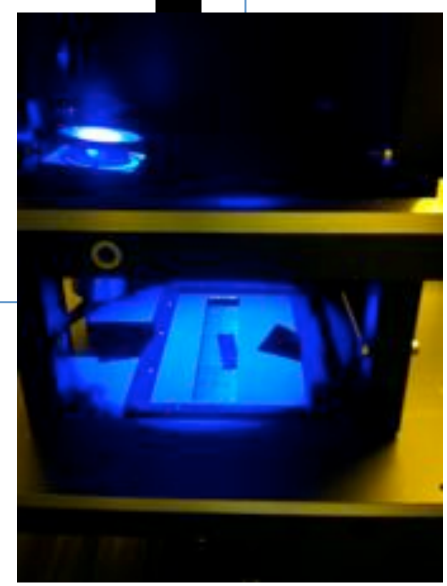
University of Texas immersion grating process and development



UV patterning of photoresist

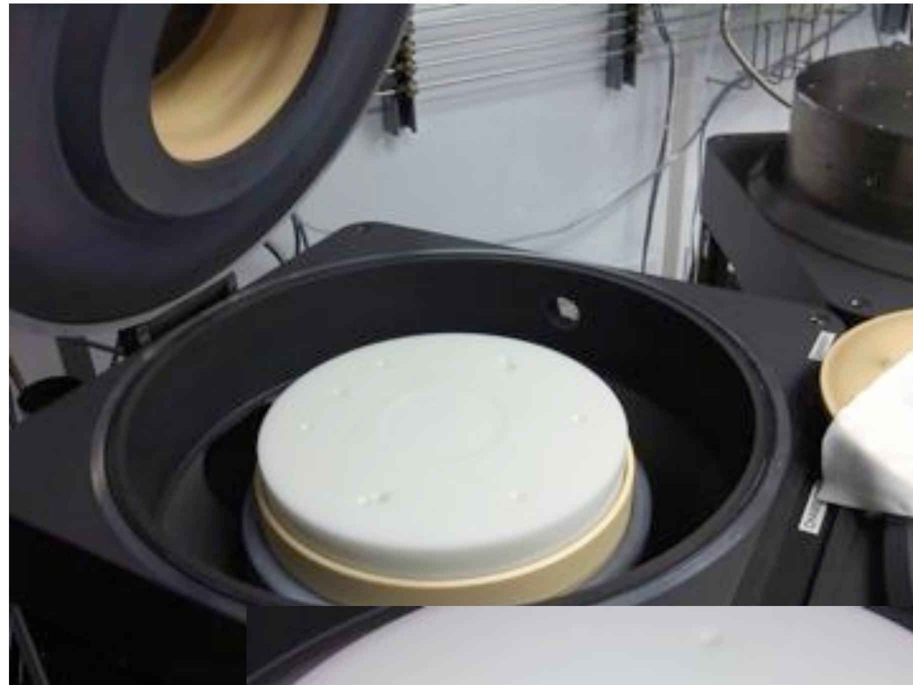
- The UV exposure system operates by moving the mask-substrate unit beneath a stationary UV light source.
- The exposed photoresist is then developed out in the wet processing bench in our main lab

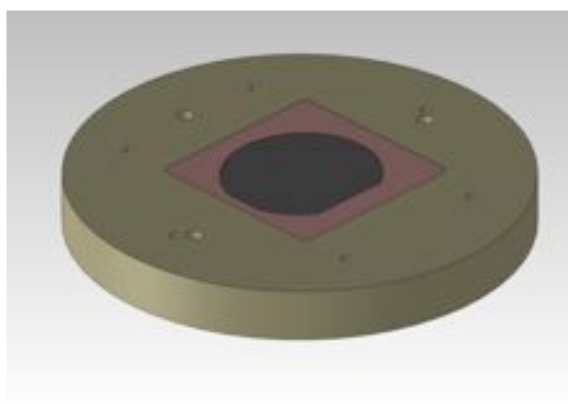




Plasma etching of silicon nitride mask

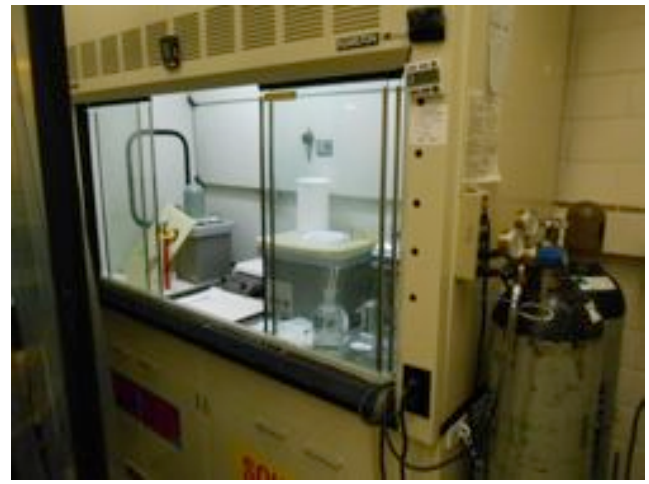
- After patterning the photoresist, a silicon nitride layer is etched using a Trion Oracle inductively-coupled plasma (ICP) etch system.
- The interior of the etch chamber has a custom cathode cover manufactured to hold our thick silicon disks





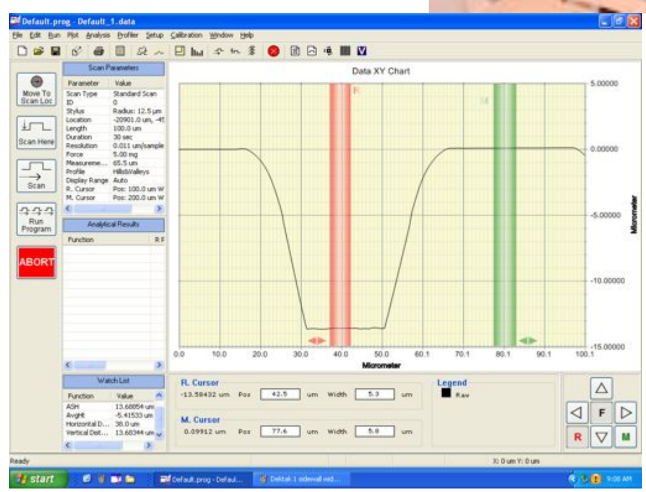
Etching grating into silicon

- The grating surfaces are etched into silicon using a solution containing potassium hydroxide (KOH). The silicon nitride film previously etched asks as a hard mask during the silicon etching.
- The KOH setup includes a circulating chiller for temperature control of the ultrasonic batch in which the KOH etching solution is immersed



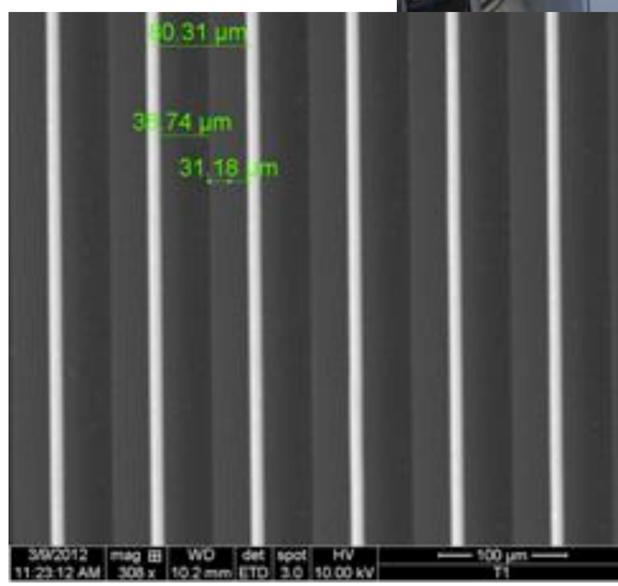
Metrology during processing

- A number of instruments are used for *in situ* process monitoring
- Non-destructive film thickness is measured using a Woollam ellipsometer and feature profile is measured using a Dektak profiler



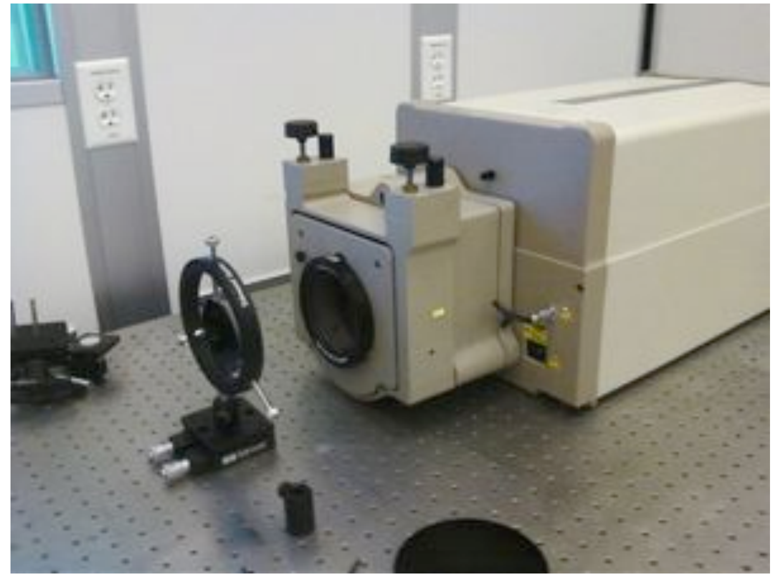
Electron microscopy

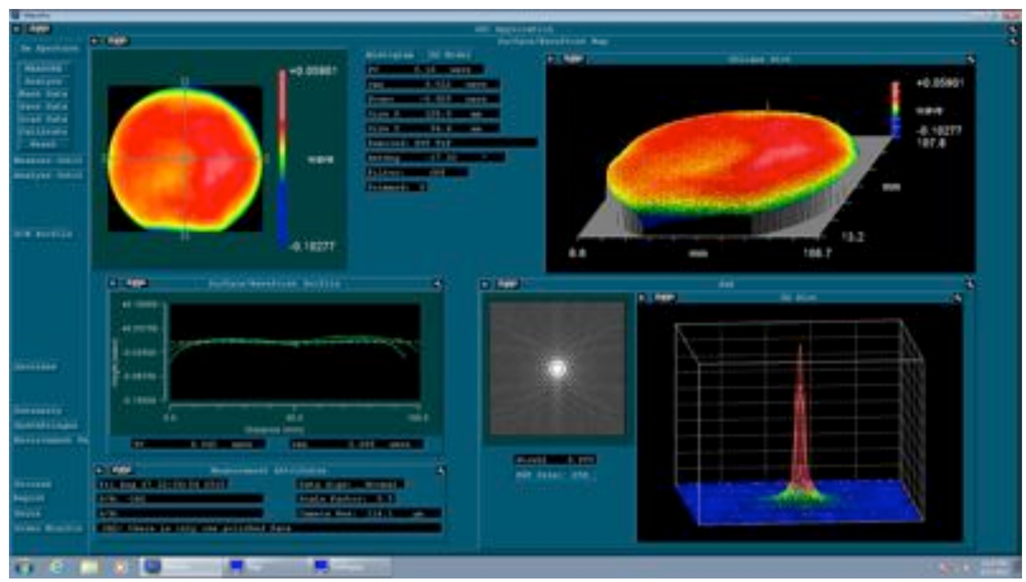
- The TMI houses a Quanta environmental scanning electron microscope
- This SEM has a large sample chamber so that we can place the entire thick silicon substrates in the chamber allowing us to non-destructively image the gratings.



Optical interferometry

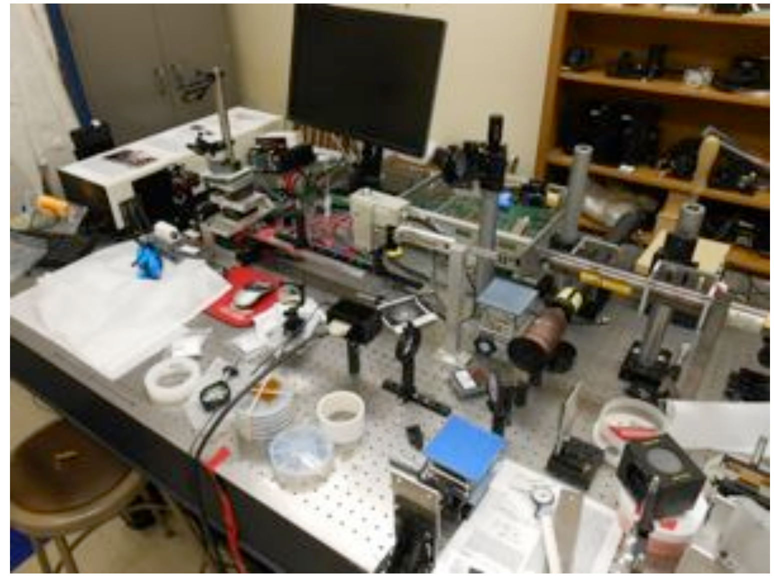
- We have recently purchased a Fizeau-type laser interferometer manufactured by Zygo corporation that is housed in the CNM
- This tool creates an optical interferogram that we use to characterize the quality of the grating after patterning is completed.

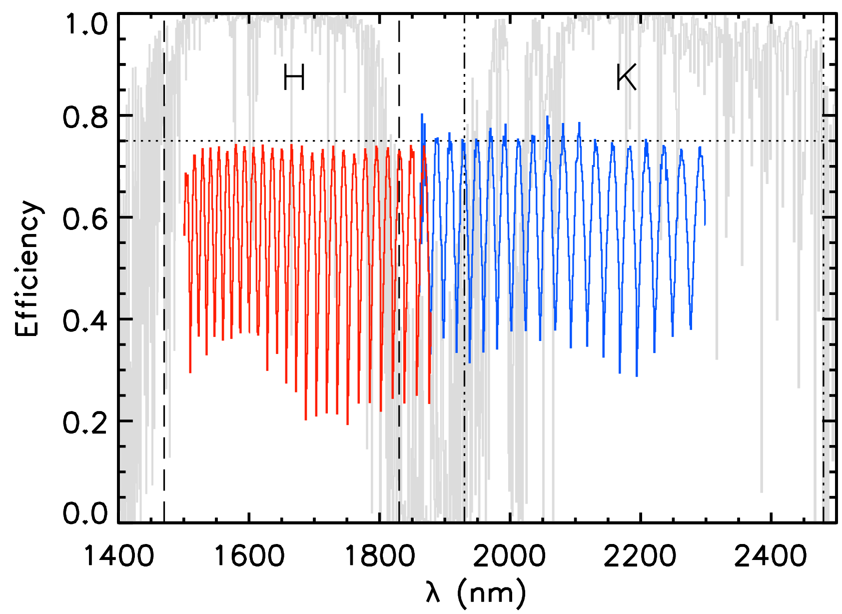




Efficiency characterization

- The efficiency measurement setup is located in our main lab
- This measurement compares the signal from the immersion grating to that of an aluminum mirror





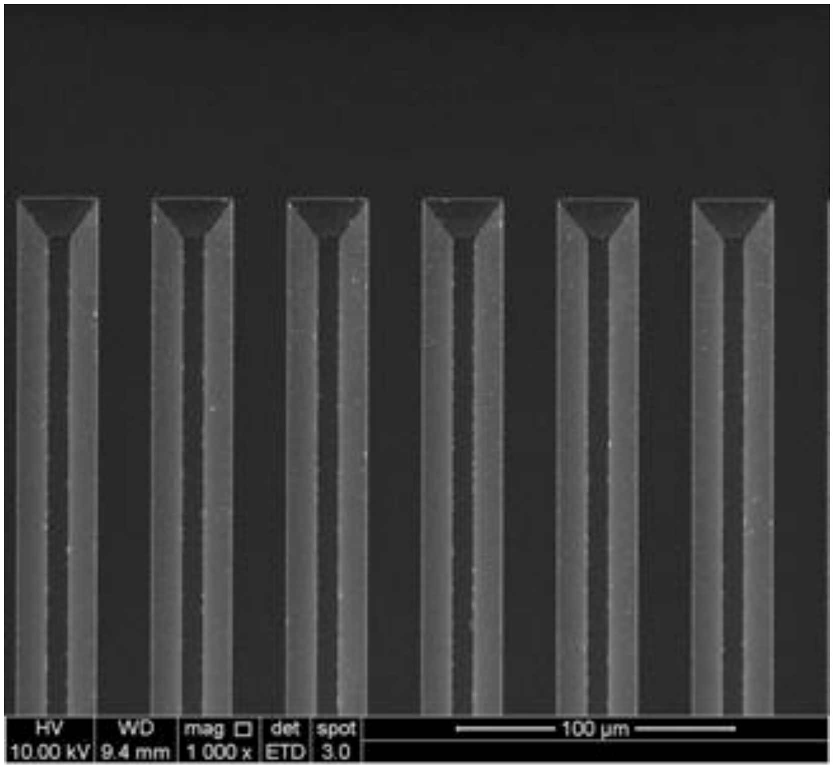
ISHELL Requires two immersion gratings:

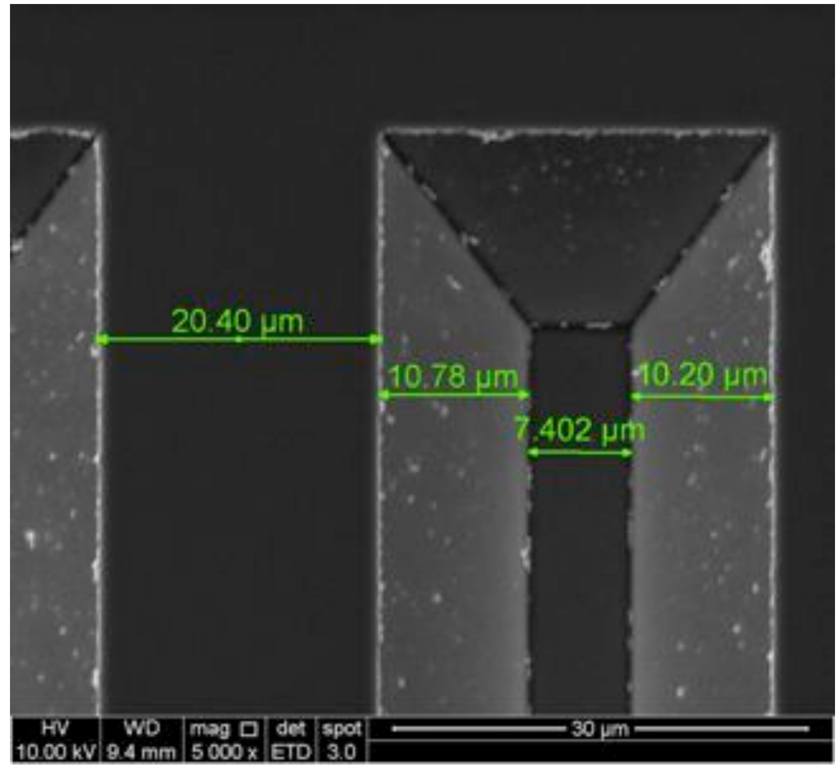
Long wave: (2.7-5.4 microns): 80 micron period
Short wave: (1.15-2.5 microns) 48.5 micron perid

Both are R3 with a 30.5x35 mm entrance face.

The plan is to fabricate the long wavelength grating using contact lithography (a la CA1) but to fabricate the short wavelength grating using e-beam lithography with the JEOL writer at JPL.

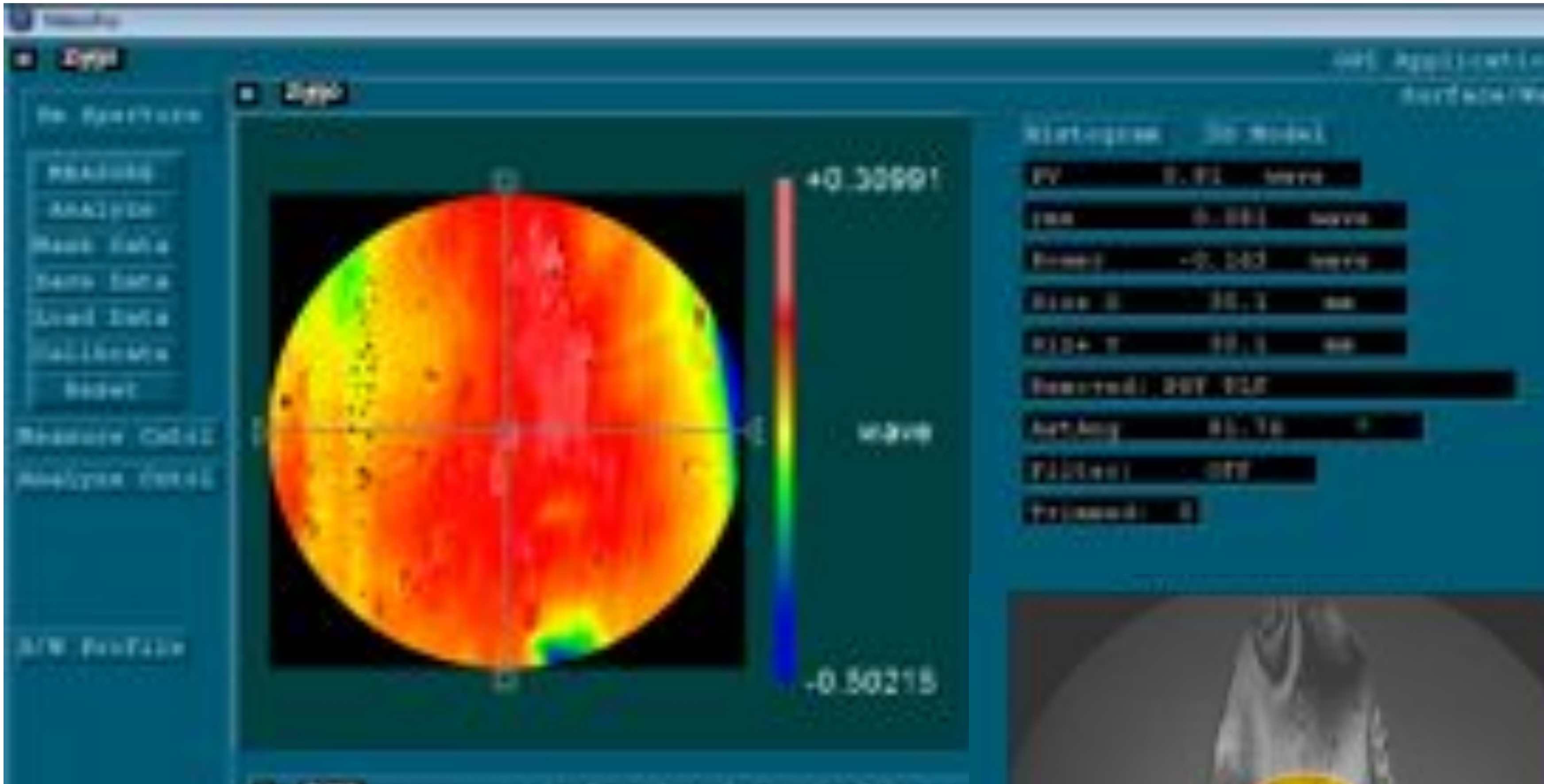
ISHELL JHK Part: E-beam trial SEM images after etching

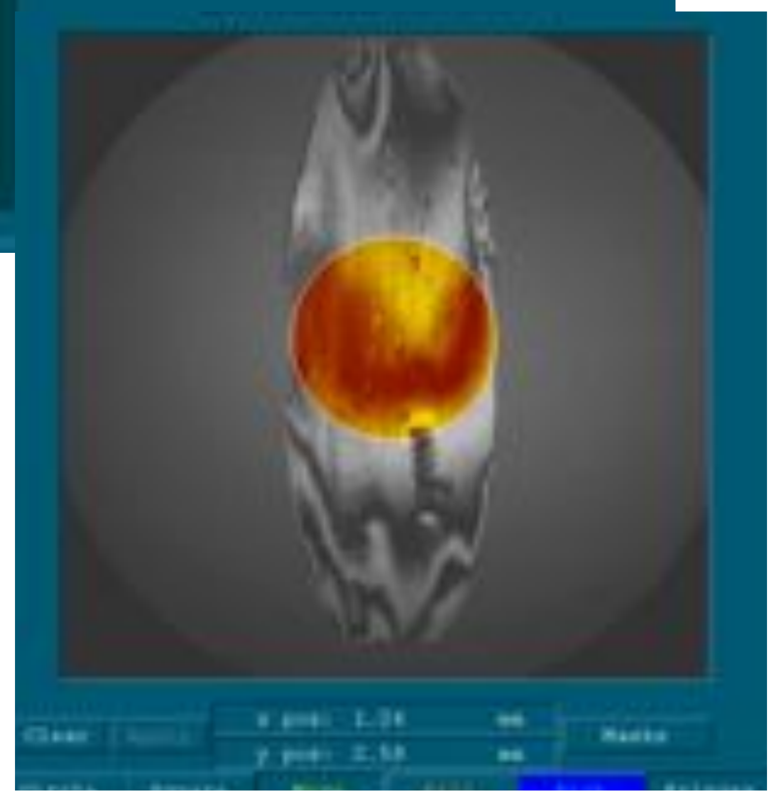




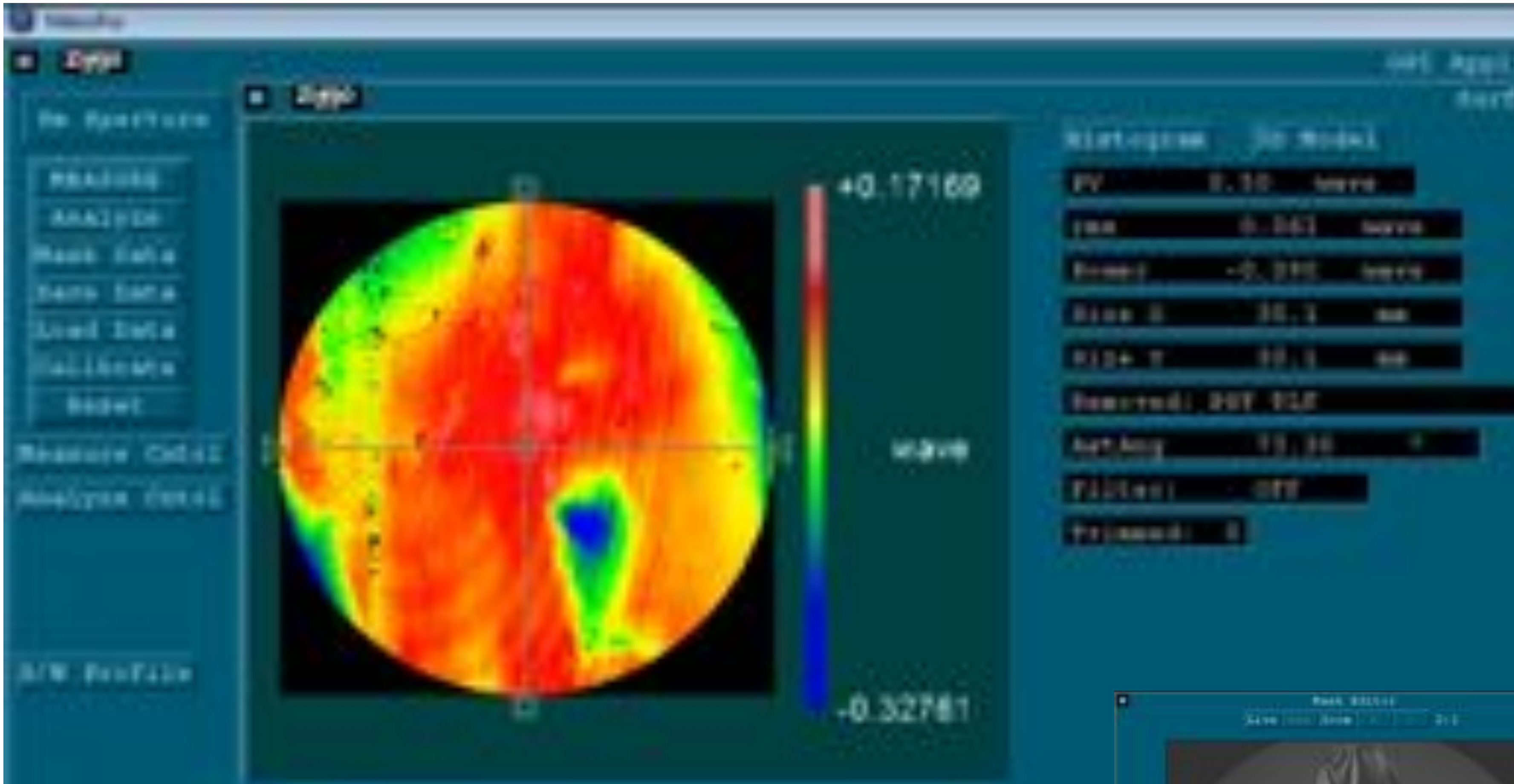
Residue is from undercut of nitride mask; part has not been cleaned yet.

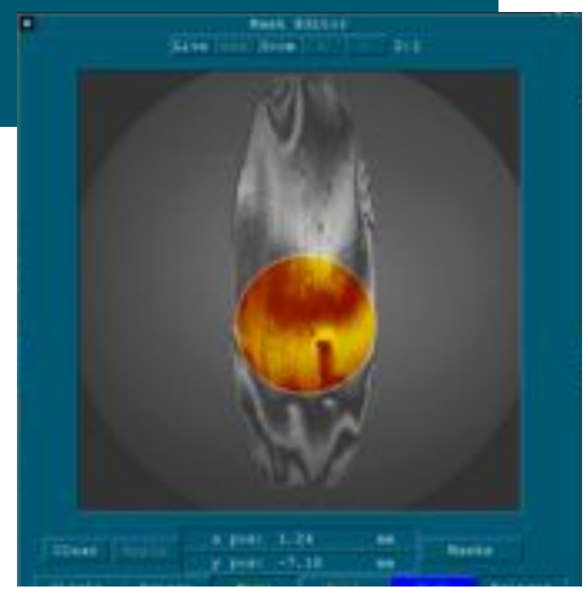
Left-right asymmetry due to slight tilt on SEM.





Interferogram of E03 30mm thick piece for ISHELL L&M grating. This is a 30mm diameter aperture at 633 nm. This is about lamda/3 p to v in immersion at 4 microns on a 25mm aperture.





ISHELL possible grating

Same piece (G03) at a slightly different position. This realization would be lambda/4 over a 30mm aperture but note that the entrance face cannot be that perfect all the way to the edge.

Status and plans:

L&M: We have a marginally acceptable surface now. We are making tests now to our setup to understand the origin of the large-scale errors. This will involve sacrificing a 30mm thick part. After that, we should be able to re-make the part.

JHK: Has been in recovery from the destruction of a 100 hour write ISHELL part last year. We now understand the process issues that caused this and the groove samples you see demonstrate that we can safely write a thick part. The one issue remaining is to test this sample for ghosts.

Expect to write both types of parts in the next 2-3 months.