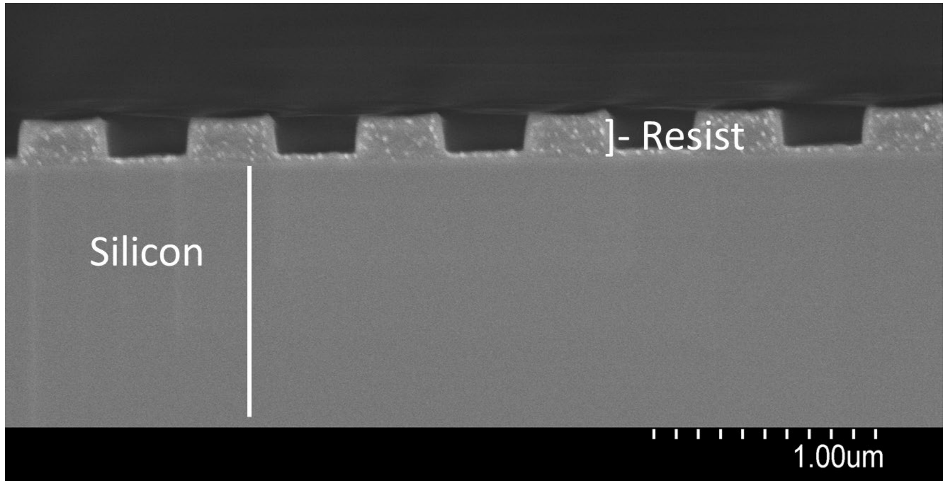
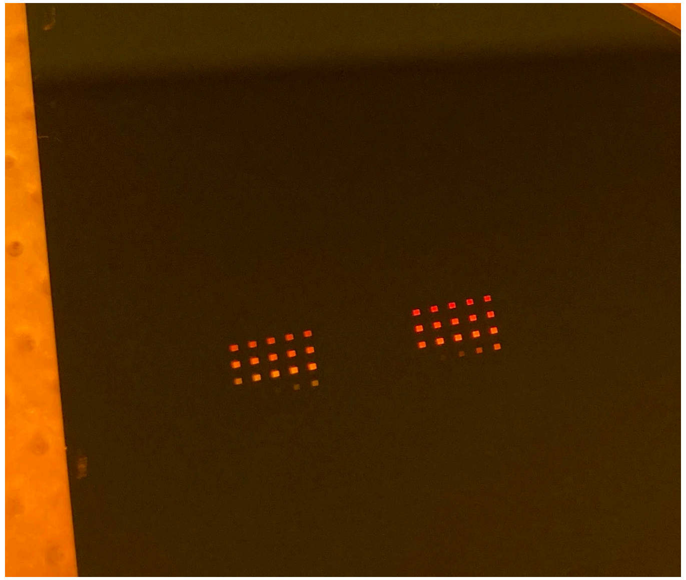
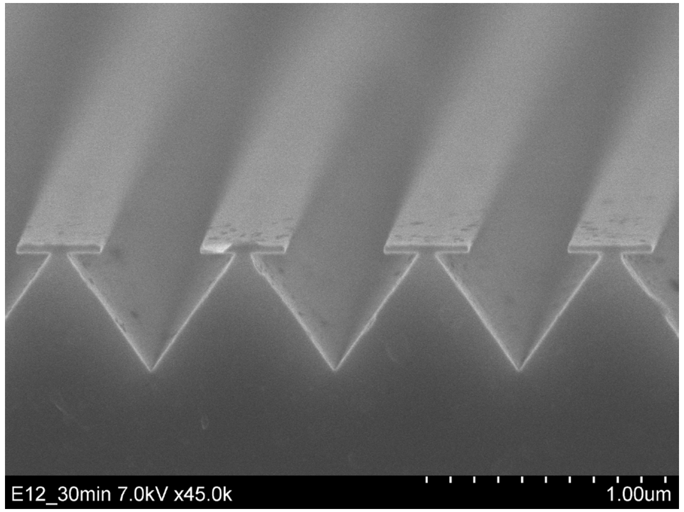
Advances in Diffraction Grating Fabrication for Space-UV Astrophysics







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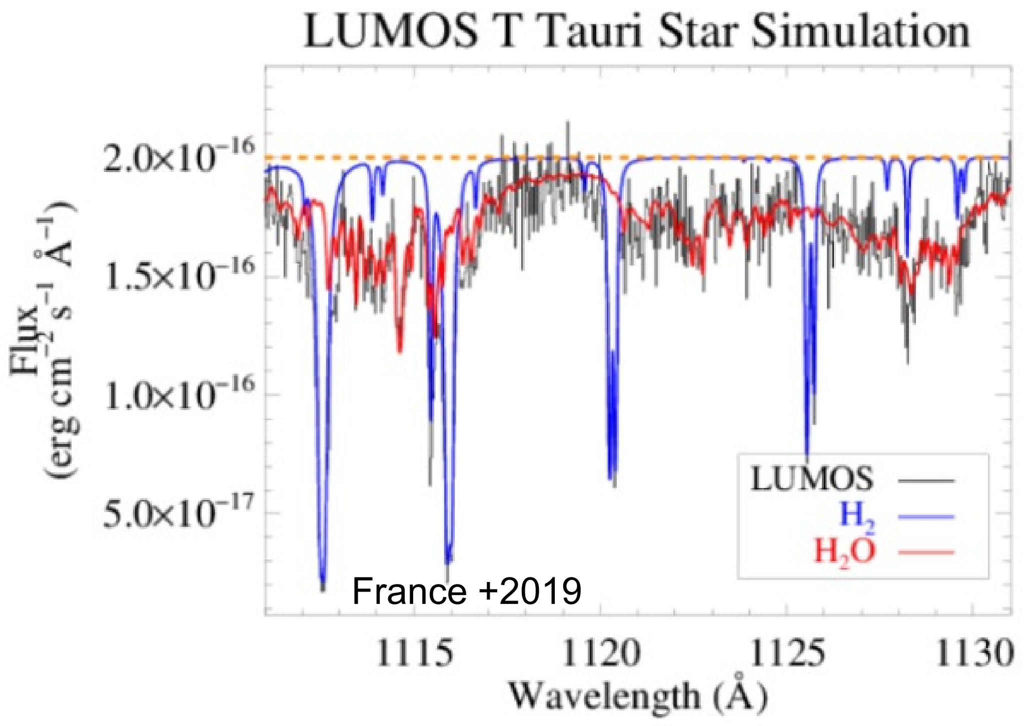
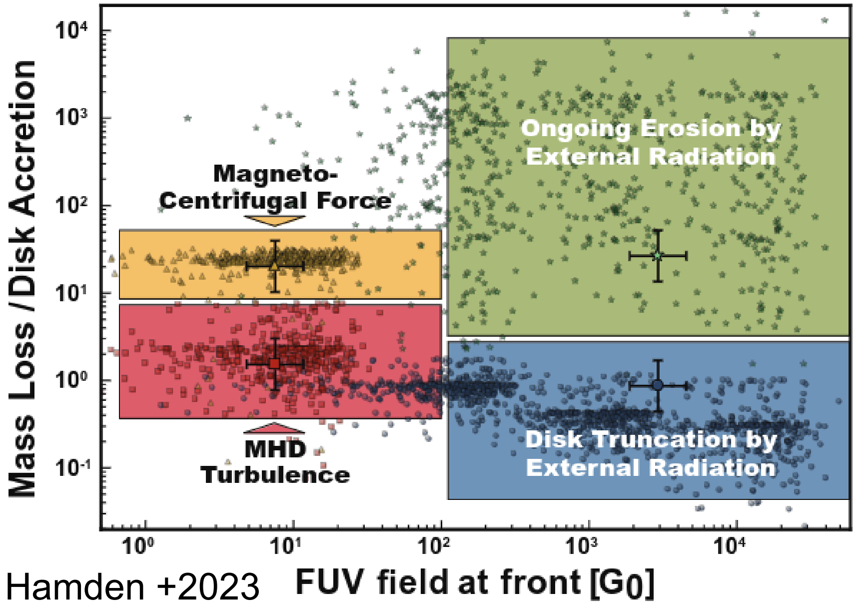
IOWA

High efficiency, Low scatter Gratings for UV Astronomy

- 2020 Decadal Survey large program priority: large IR/O/UV telescope (Habitable Worlds)
- Key drivers: "Worlds & Suns in Context", "Cosmic Ecosystems"
- Example: Lifetimes & dispersal of planet-forming disks
  - Co-spatial molecular abundances in terrestrial planet forming zones (absorption)
  - How is gas lost during dispersal and how much? (emission)
- Both require high spectral resolution (R>30,000) at space-UV wavelengths to address

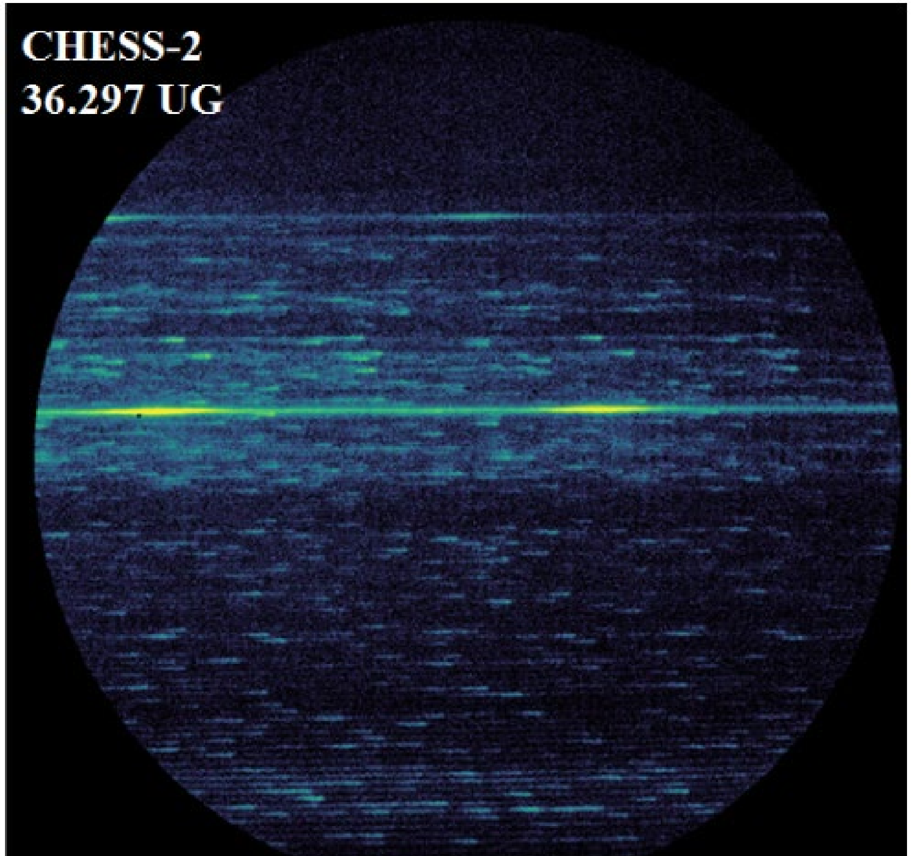




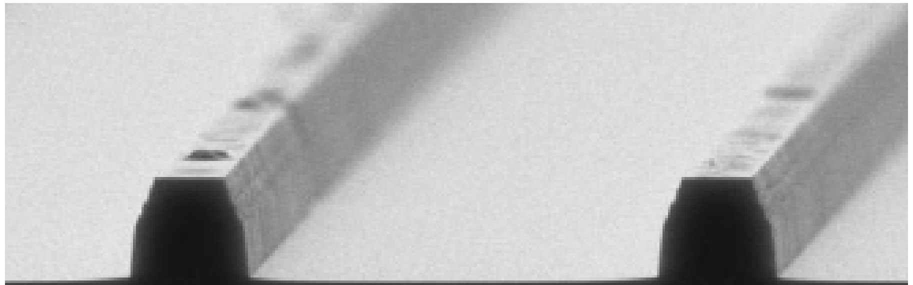
High efficiency, Low scatter Gratings for UV Astronomy

- What do we need to make high-resolution UV spectroscopy happen, both near-term and for Habitable Worlds?
- -> Large format, high efficiency, low stray light reflection gratings for space-UV

- Current standard industry grating fabrication:
  - Mechanical ruling
  - Ion beam etching
  - Photolithography



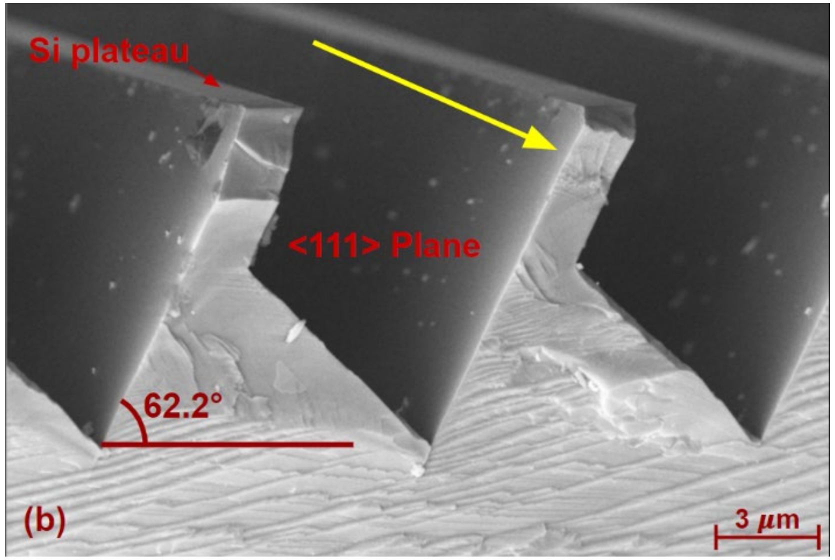
Hoadley +2020: Mechanically ruled echelle grating


Hoadley +2014: SEM of photo-lithographically ruled echelle grating facets for CHESS-1

High efficiency, Low scatter Gratings for UV Astronomy

- What do we need to make high-resolution UV spectroscopy happen, both near-term and for Habitable Worlds?
- -> Large format, high efficiency, low stray light reflection gratings for space-UV

- Emerging technology that shows promise to meet future UV grating needs: electron beam lithography (EBL) on silicon, with KOH etching for blazed gratings



SEM of KOH-etched Si to create blazed facet (Kruczek+ 2022)

INGRINS Immersion Grating Dynamic Range

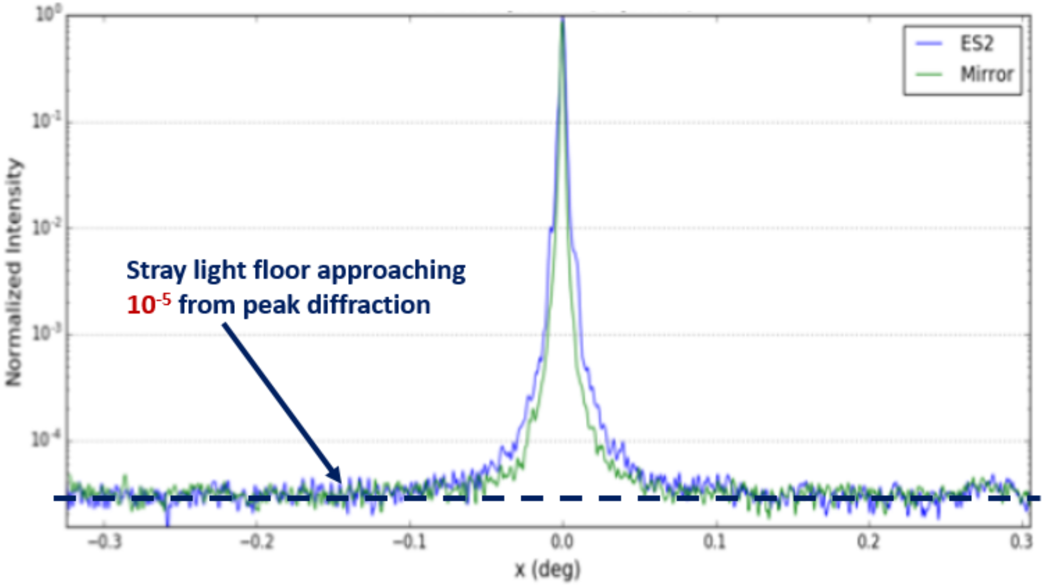
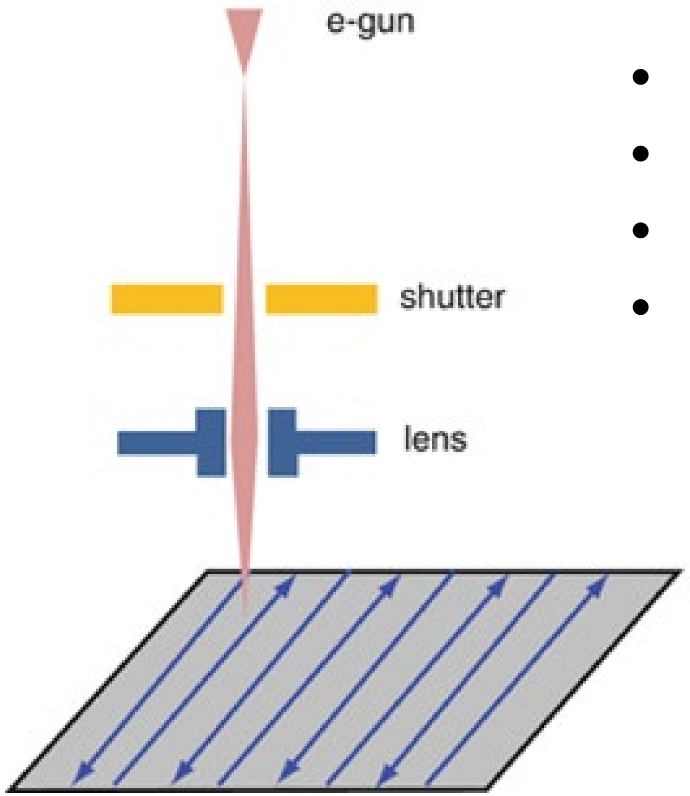


Figure credit: D. Jaffe/INGRINS/U. Texas Austin

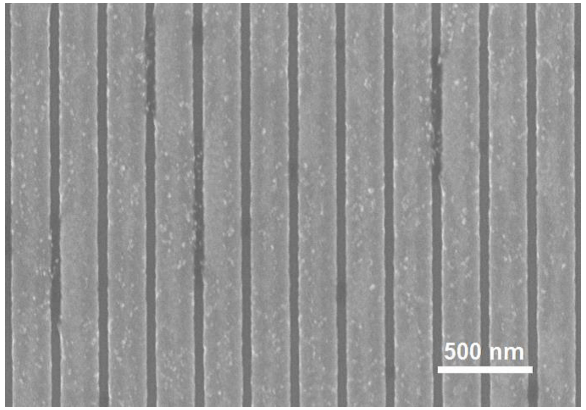
Electron Beam Lithography (EBL)

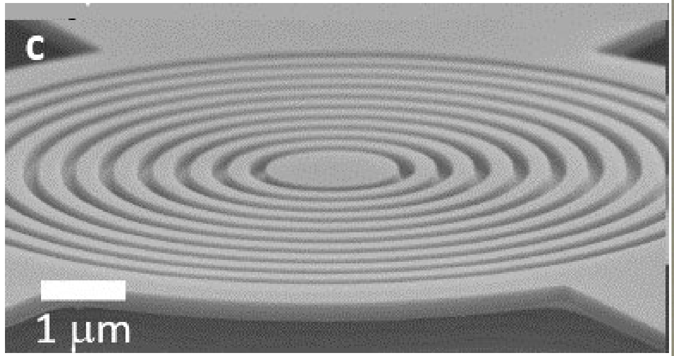
- EBL: rasters high energy e^- across resist changes solubility of resist in a developer

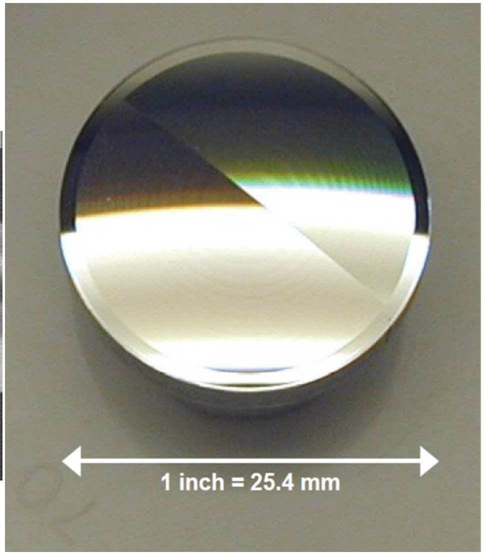


Pala & Karabiyik 2016

- Patterns periods ~100s nm (e.g., Grisé et al. 2021)
- Highly customizable patterns
- Large-format patterning (e.g., Miles et al. 2018)
- Curved substrate patterning (Wilson et al. 2003)







Process Steps

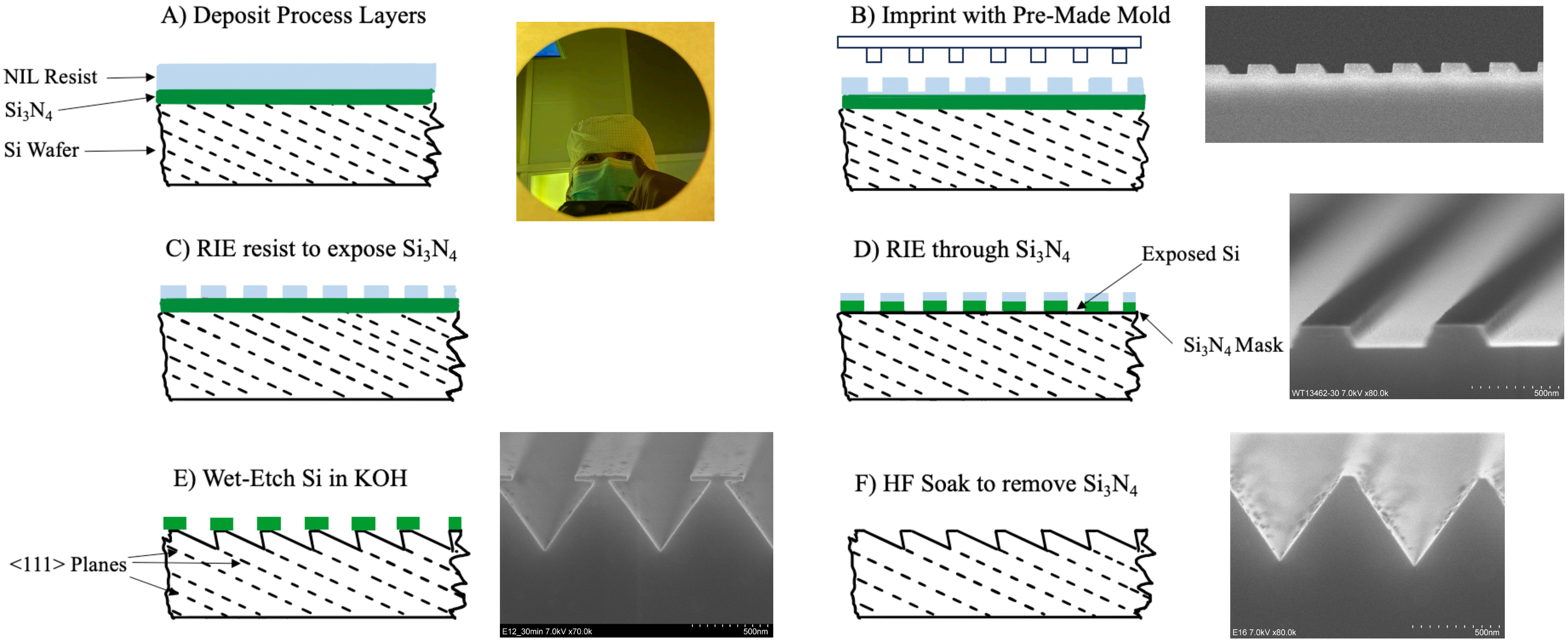
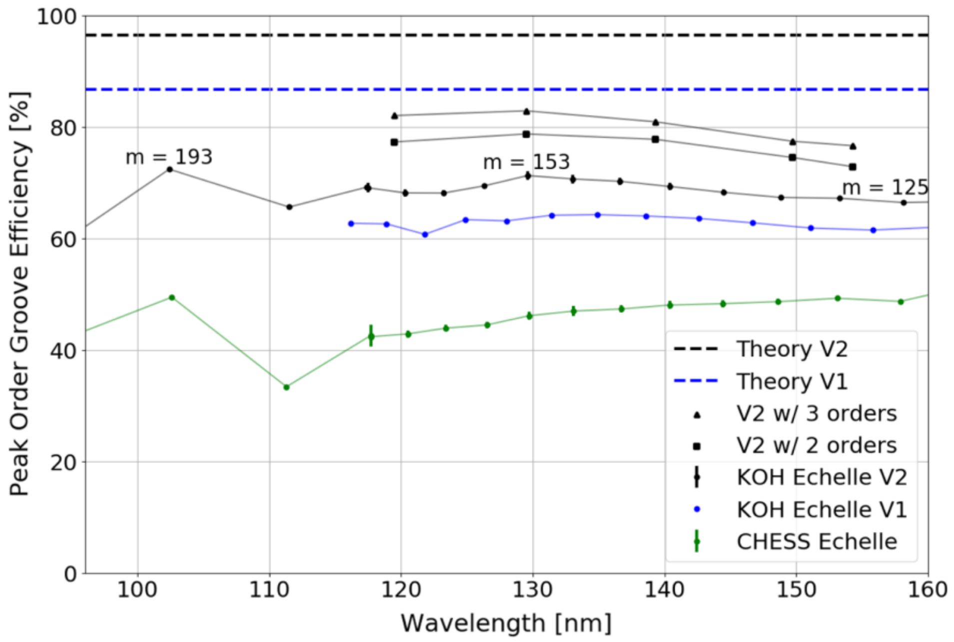


Figure credit: Cecilia Fasano, UI

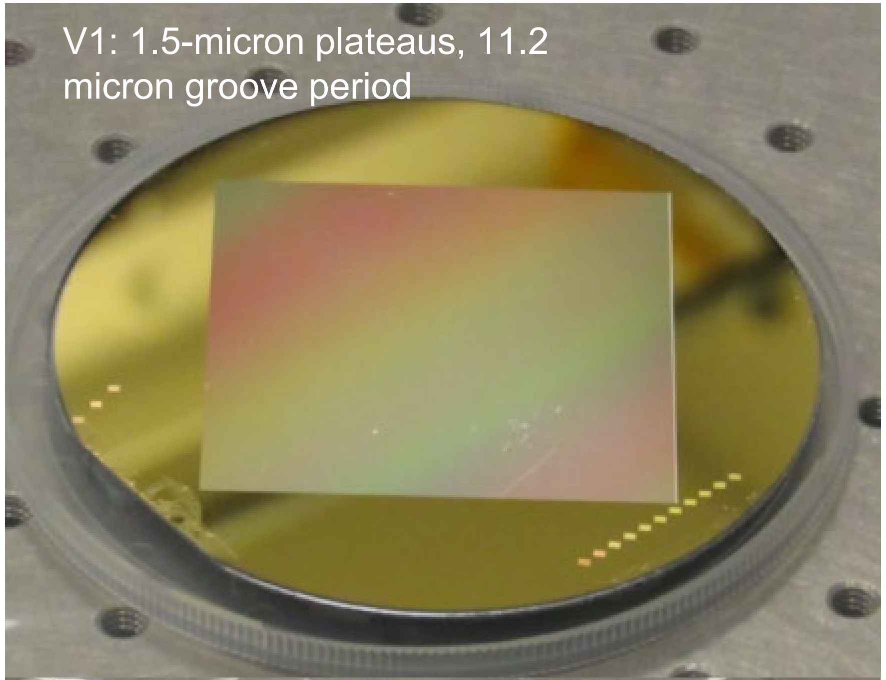
Performance of EBL/KOH gratings

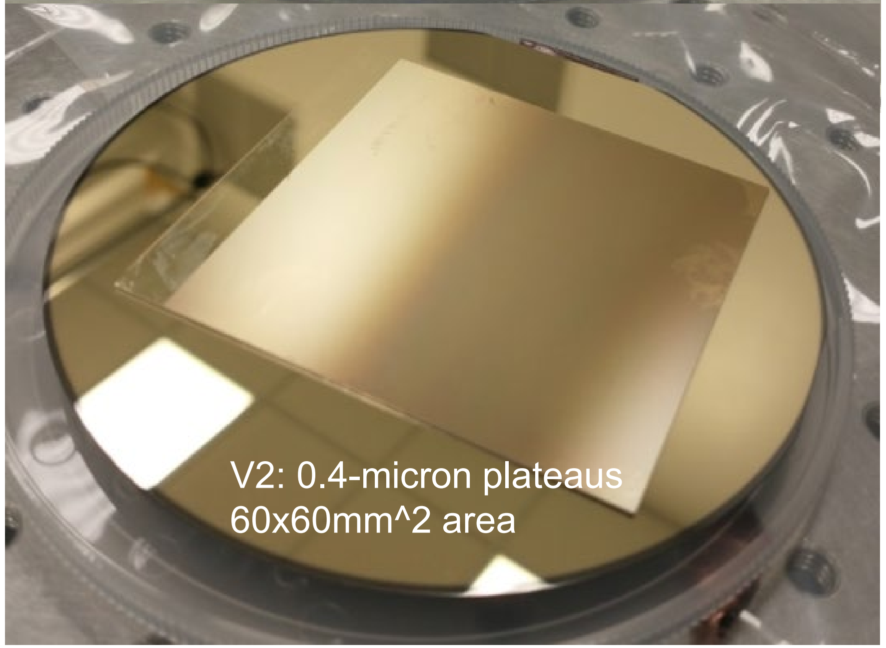
- Demonstrated groove efficiency from 100 – 160 nm for blazed (echelle) gratings is reaching >60%



- Large format grating areas viable

Kruczek+ 2022





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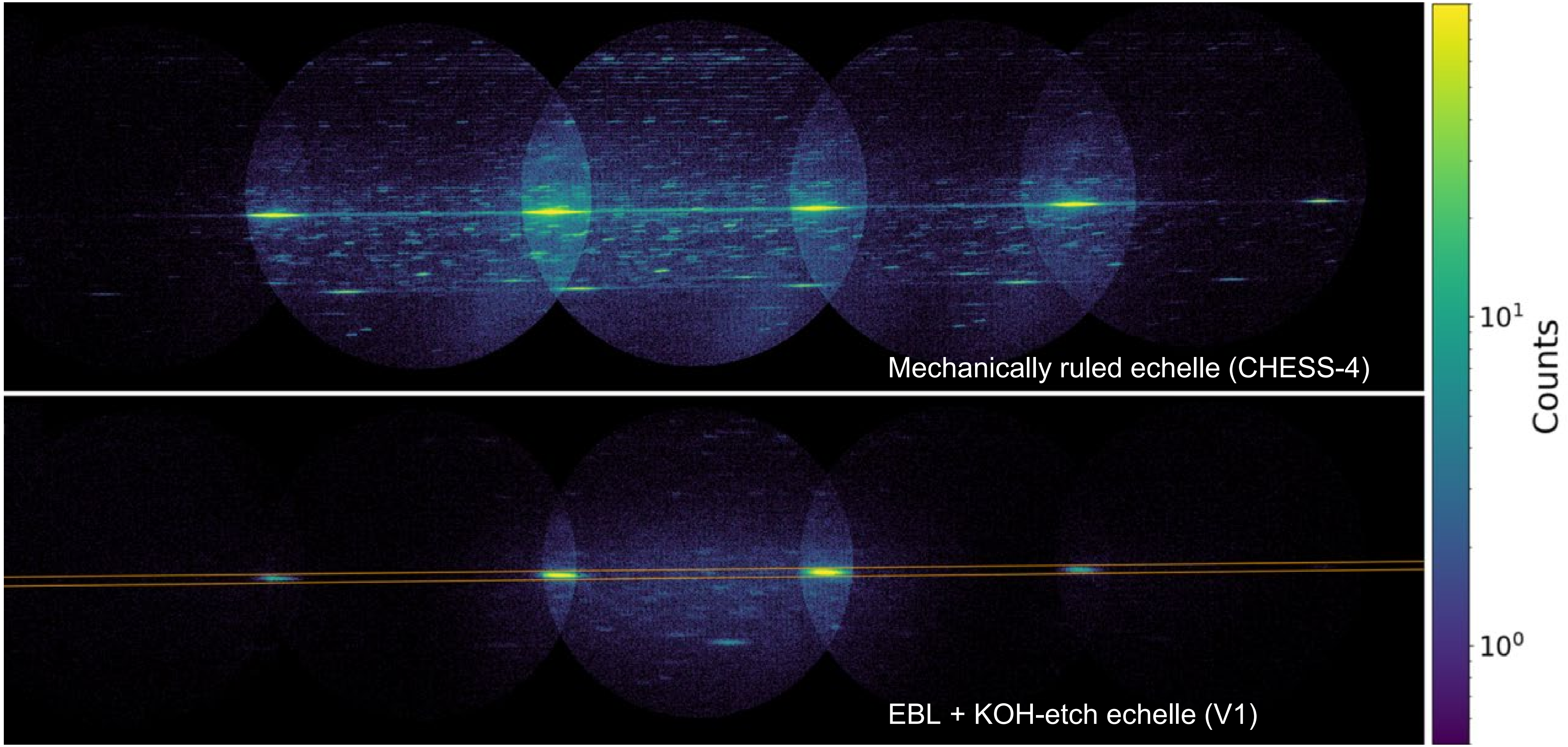
Performance of EBL/KOH gratings

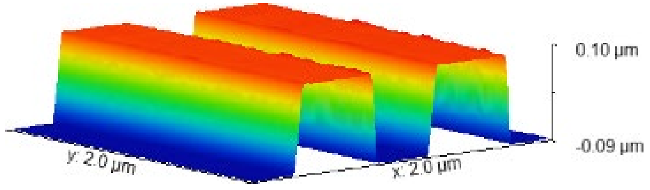
- Improved stray light control in an integrated spectograph system



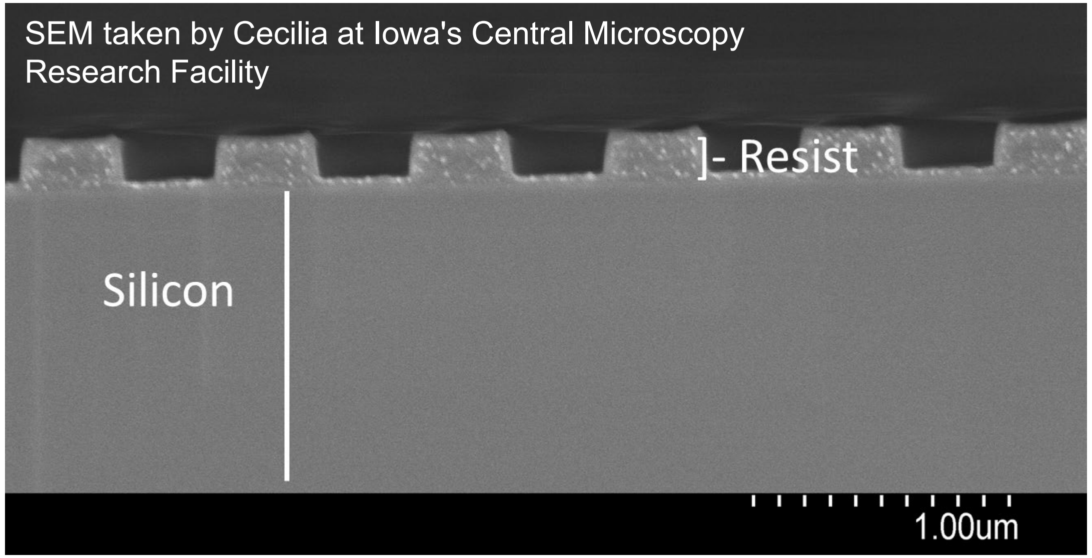
Kruczek+ 2022

Limitations & Challenges

- Large write areas possible, but time consuming
- Paths forward: Nano-imprinting, grating arrays



AFM of imprinted grating by Mateo Batkis, GSFC



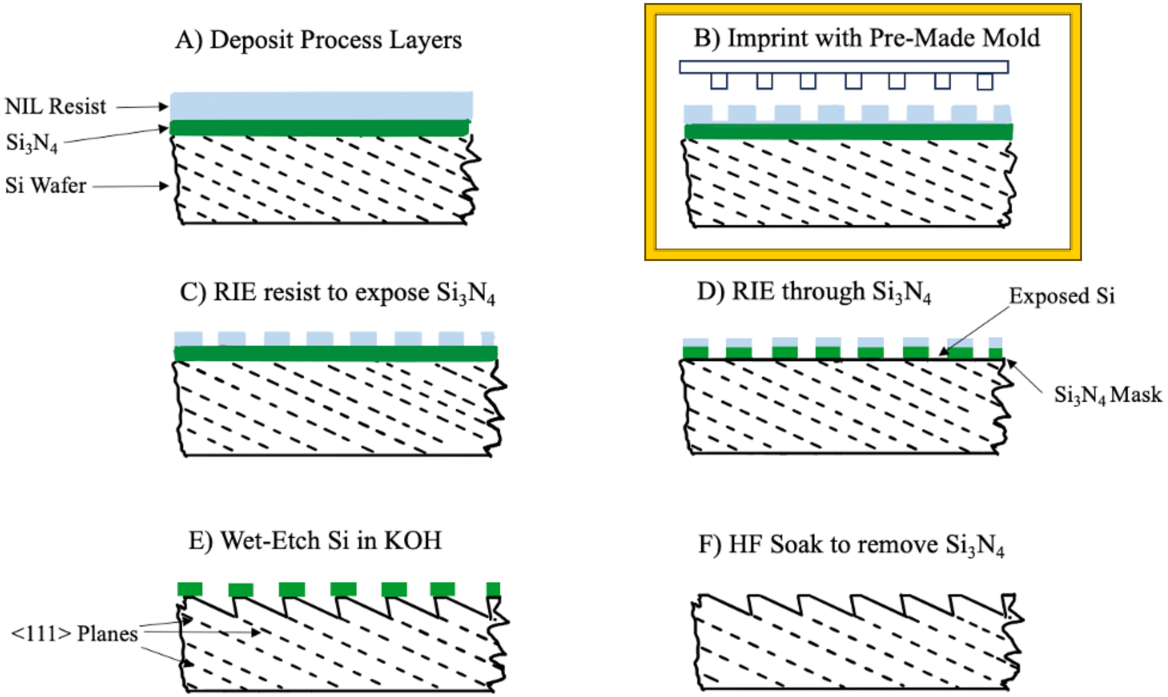
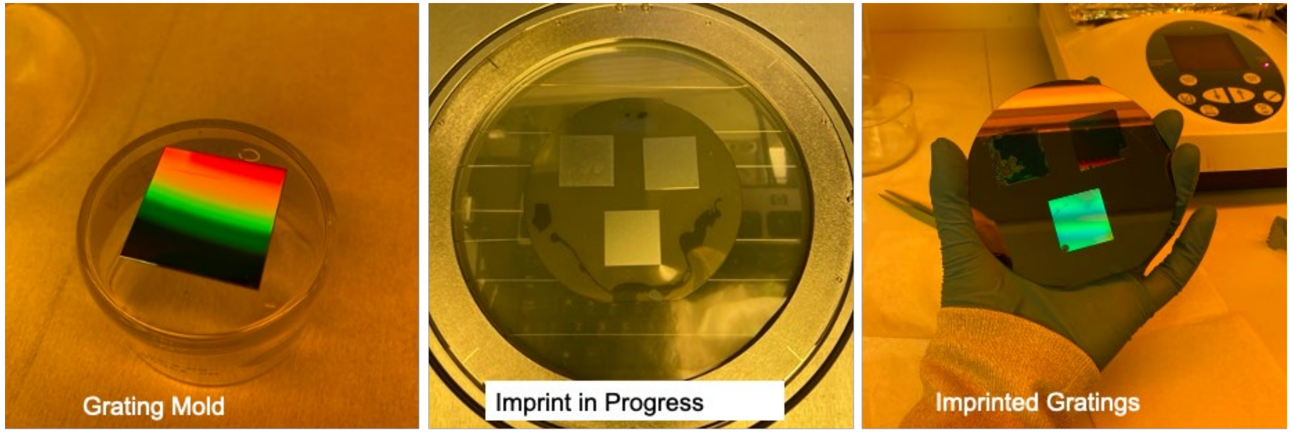
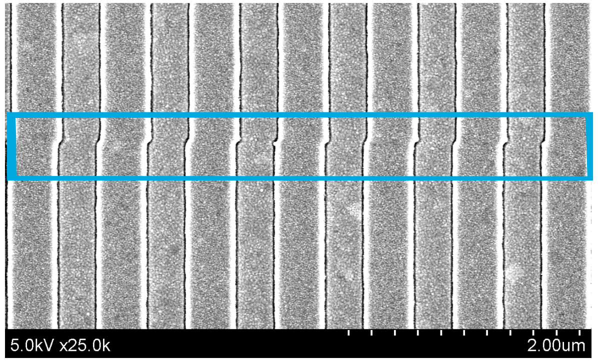


Figure inspired by Chang et al. 2003

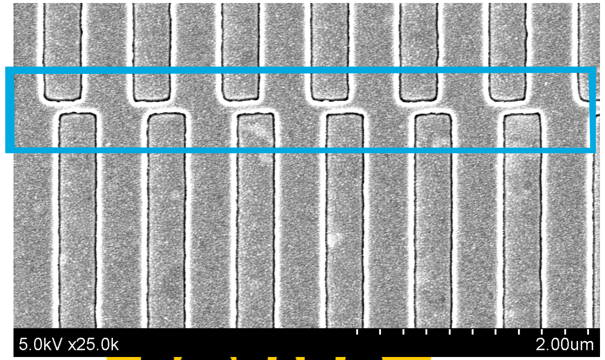


Limitations & Challenges

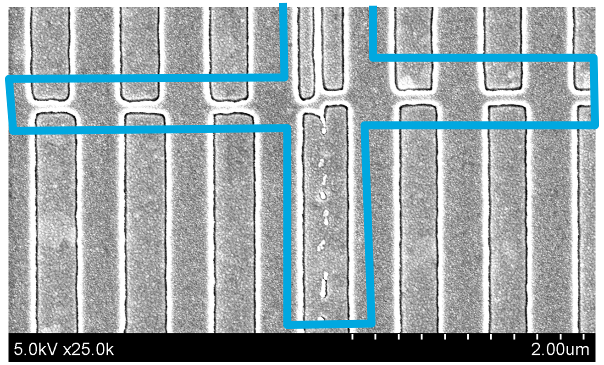
- Spectral "ghosts": Errors in write field pattern placement & correction



Can see field boundaries interferometrically

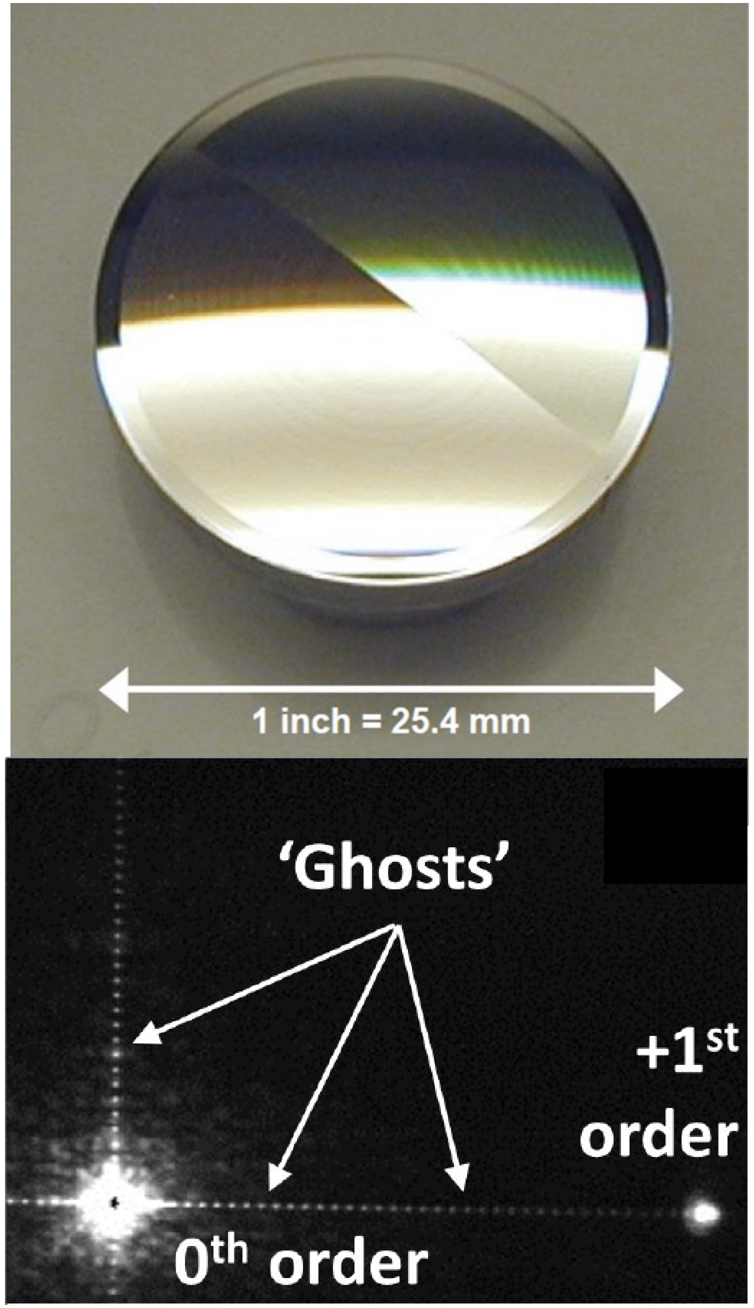


SEM images of stitch error



Different stitch error across the same substrate

Spherical CRISM Grating: significant “ghosting”



Limitations & Challenges

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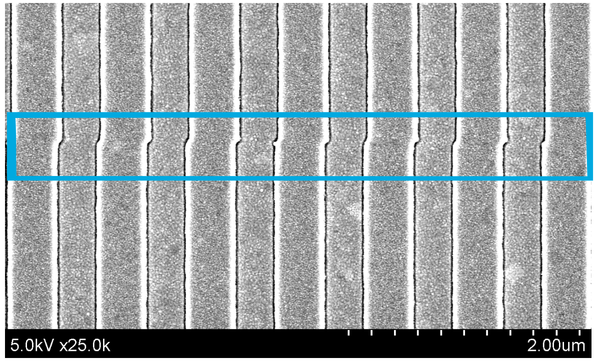

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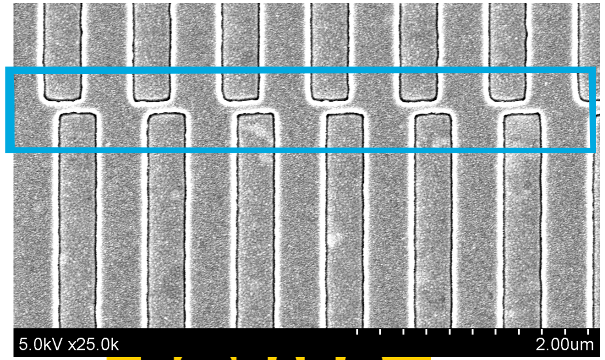

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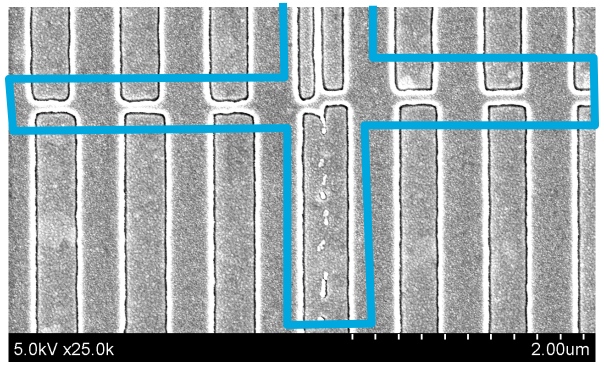
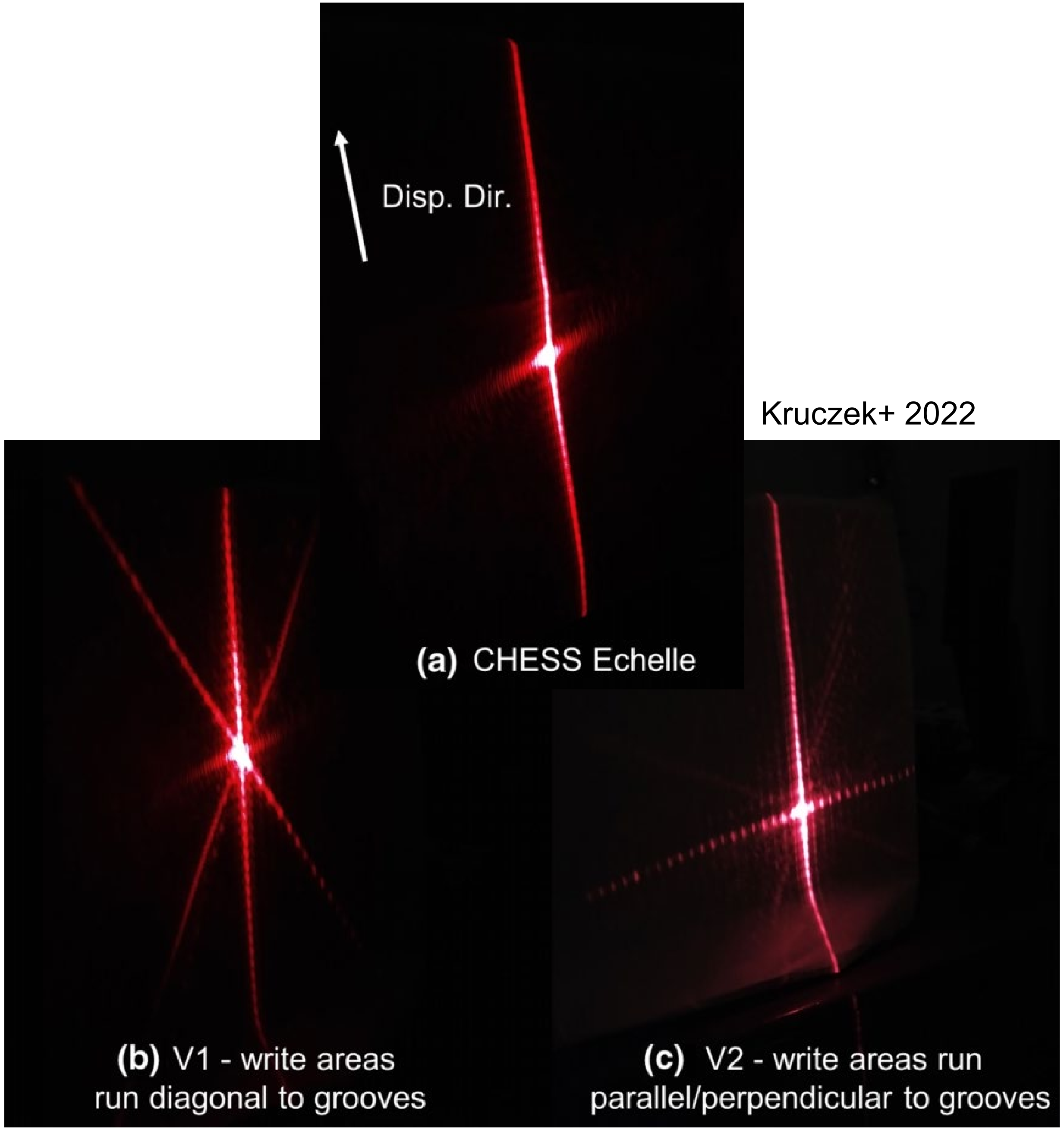


Different stitch error across the same substrate

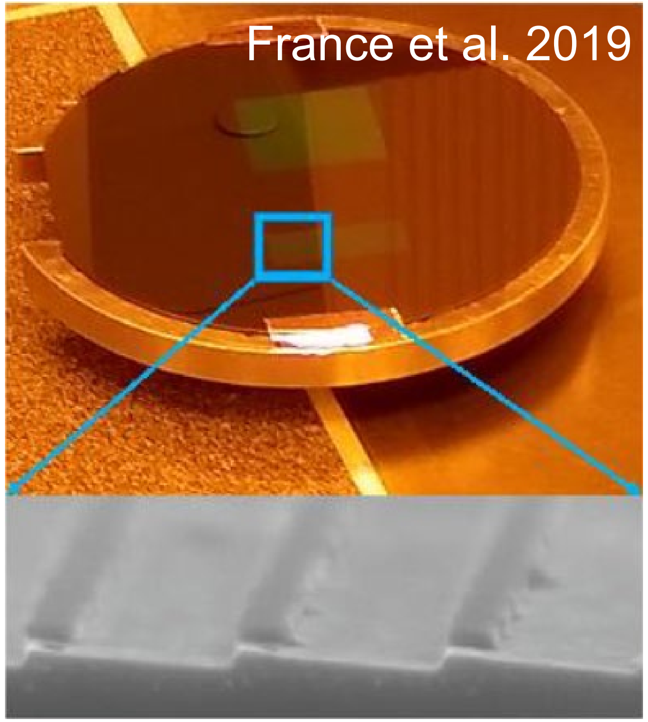
Kruczek+ 2022

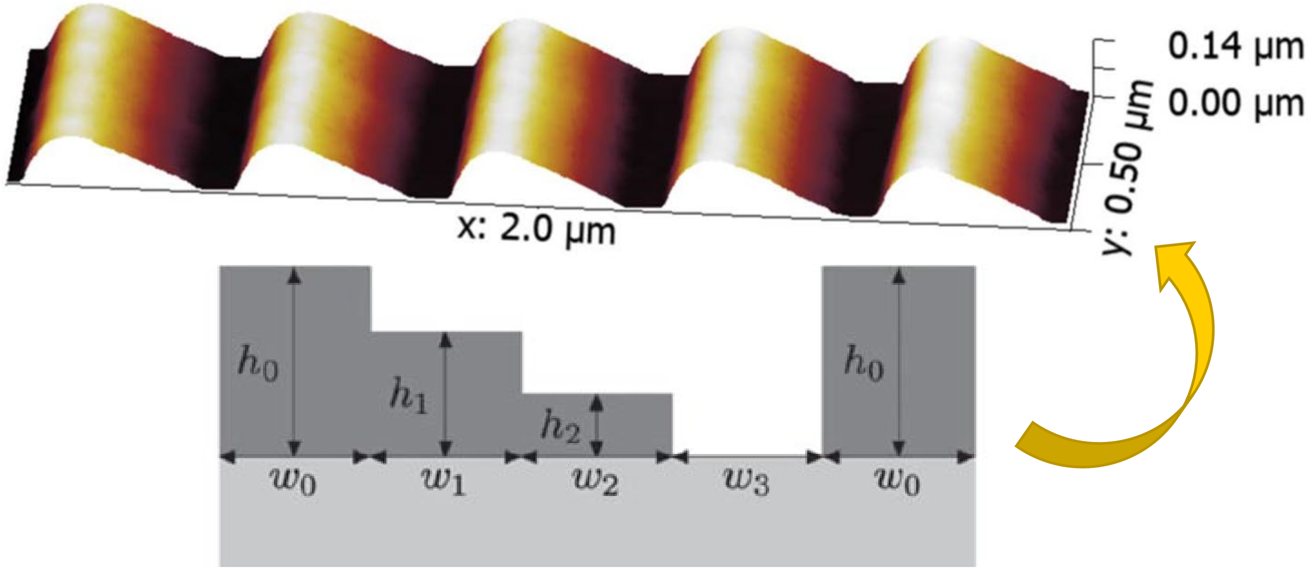


Customizable Gratings for Space UV Spectroscopy

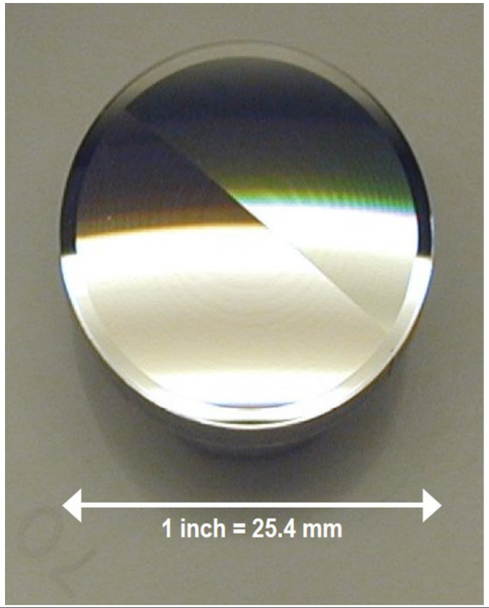
- "Customizable" = control over groove period, pattern, blaze angle, substrate curvature, size…
- Leads to innovative instrument concepts

ESCAPE grating: radially-ruled grooves with a "curve" (Grisé: 11821-28, Kruczek: 11821-12)





Direct Write Blazing via TASTE (McCoy et al. 2020, McCurdy et al. 2020)

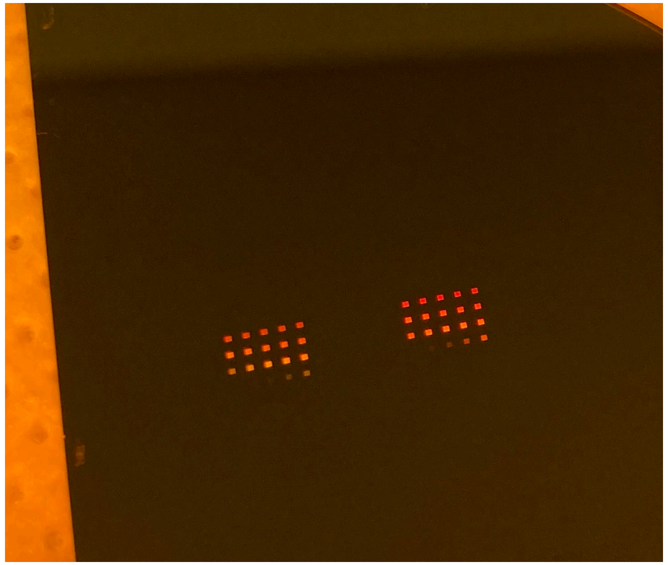


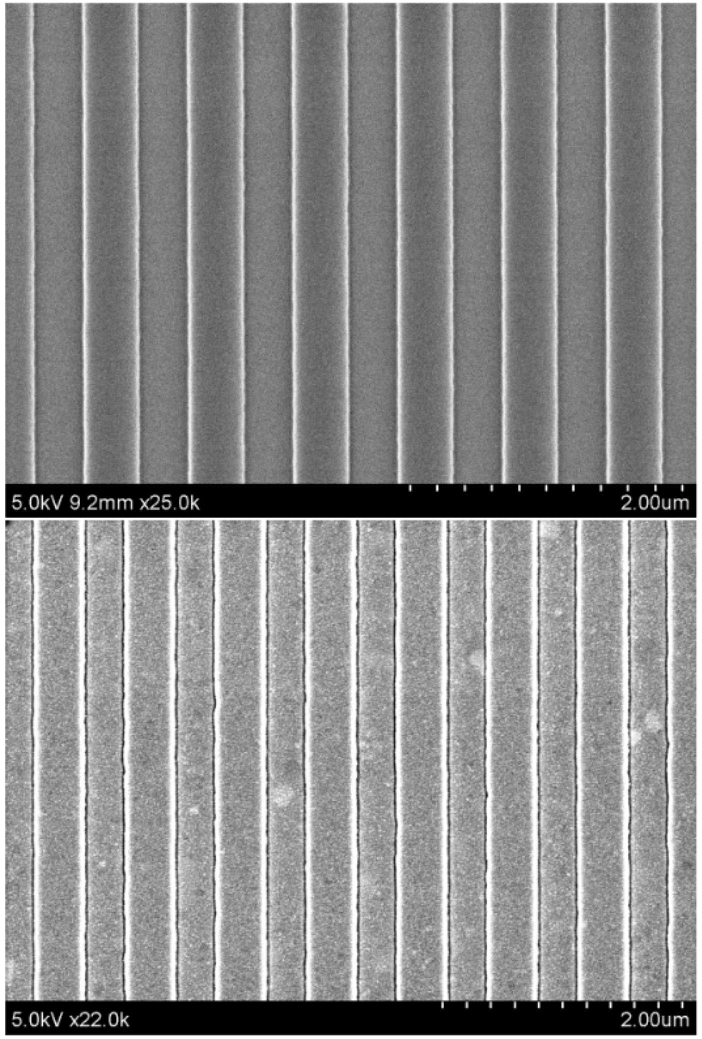
CRISM Spherical Grating with two blaze angles, (Wilson et al. 2003)

Summary

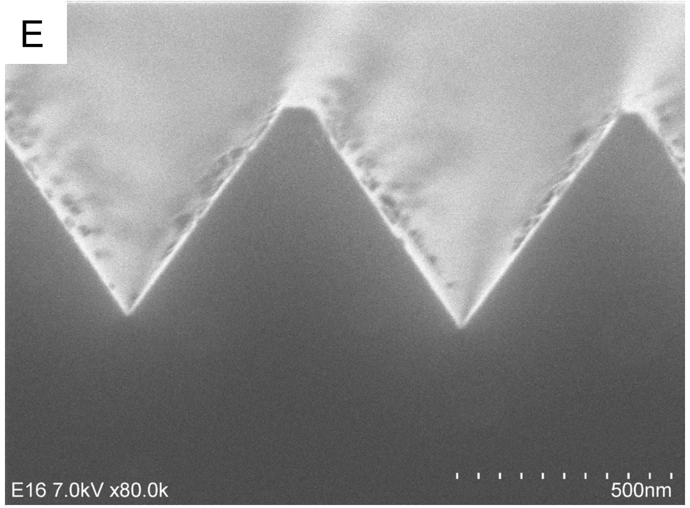
- UV Gratings for future UV spectrograph missions must be improved to achieve necessary gains in SNR, sensitivity
- EBL+KOH offers a promising path forward
- Promising results: High peak groove efficiencies demonstrated, low stray light backgrounds in spectrographs, large format ruling on the way
- Challenges ahead: Continuing to increase grating size, "ghosting" patterns
- Looking ahead: Improving EBL writing for customization of patterning (VLS, curved substrates, aberration correction, …), TASTE, grating arrays, ...

500 micron write fields dose test.





Top shows 3-nm layer of Iridium coating for SEM imaging, while the bottom shows 30-nm Au layer for UV testing.



SEM of KOH-etch blaze profile (~54 degree blaze angle)