Virtual Research Presentation Conference

Echelle Grating Fabrication for Precision Radial Velocity Spectrographs

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Program: Strategic Initiative

Assigned Presentation #RPC-027

Jet Propulsion Laboratory
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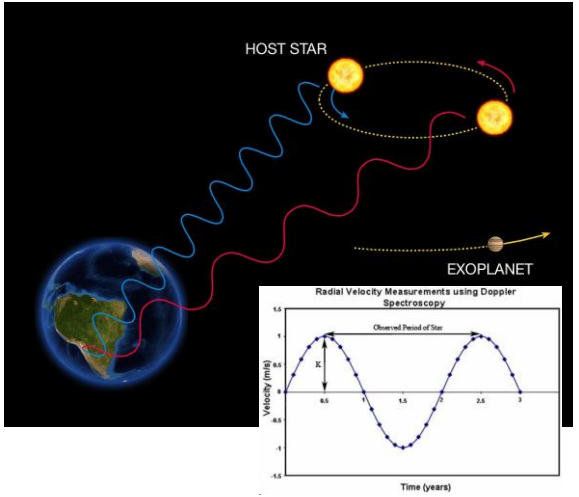
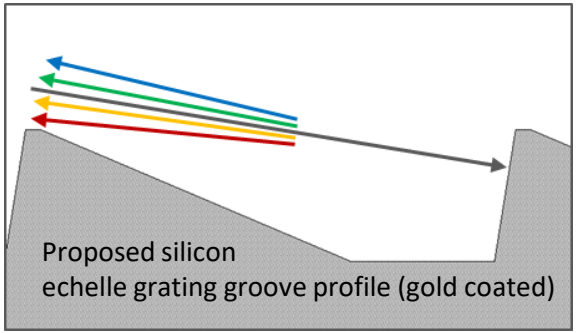
Tutorial Introduction

Abstract

Our objective is to develop improved techniques for fabricating high-performance echelle gratings for precision radial velocity (PRV) spectrographs.

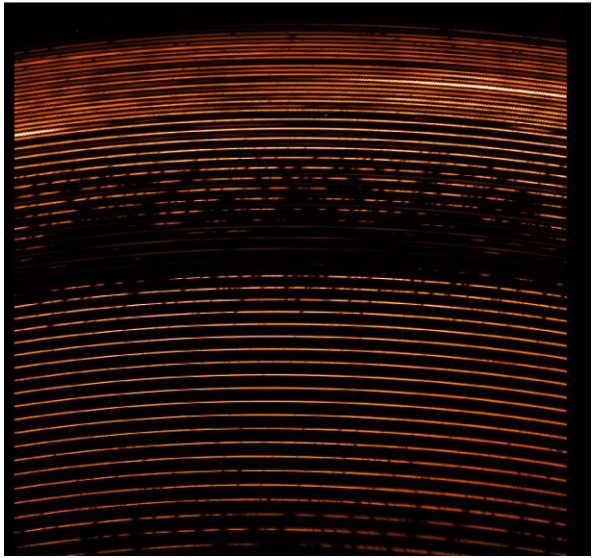
- PRV spectrographs are used to detect and quantify the mass of exoplanets orbiting distant stars through Doppler spectroscopy measurements and analysis
- Echelle gratings required for next generation PRV spectrographs are challenging in 3 specifications:
    1. Low wavefront error (< 1/10 wave RMS desired)
    2. High diffraction efficiency (> 70% desired) in very high diffraction orders (> 100th order) and high angle of incidence (> 70 deg)
    3. Large size (100 mm to 300 mm long for candidate spectrographs)
- Diamond ruling has been used to make echelle gratings for decades, but the extremely high performance required for PRV has proven difficult.
- We believe a combined technique of electron-beam lithography (JPL) with wet anisotropic etching of silicon (University of Texas at Austin) can produce gratings with the desired performance characteristics.





Problem Description

- Precision radial velocity (PRV) measurement is the only technique for finding nearby Earth-mass planets in the next ~20 years prior to the launch of an imaging flagship mission (HabEx or LUVOIR)
- PRV measurements use echelle spectrographs with wide spectral range and high resolving power R~100,000 to measure Doppler shifts in the stellar spectrum.
- Next generation PRV spectrographs aim to improve stability by reducing size/volume. Co-I Vasisht has been working on diffraction limited echelles (PARVI: Palomar Radial Velocity Instrument), fed by single mode fiber, that are 10x (1000x) smaller than conventional spectrographs in size (volume), and are also well suited for implementation in space missions (e.g. NASA's EarthFinder Probe).
- However, these diffraction-limited PRV spectrographs require echelle gratings with very low wavefront error and high efficiency--difficult for diamond ruling
- If our JPL-UT collaboration results in high performance gratings, we will be in a strong position to win future PRV instrument opportunities and make breakthrough science discoveries.

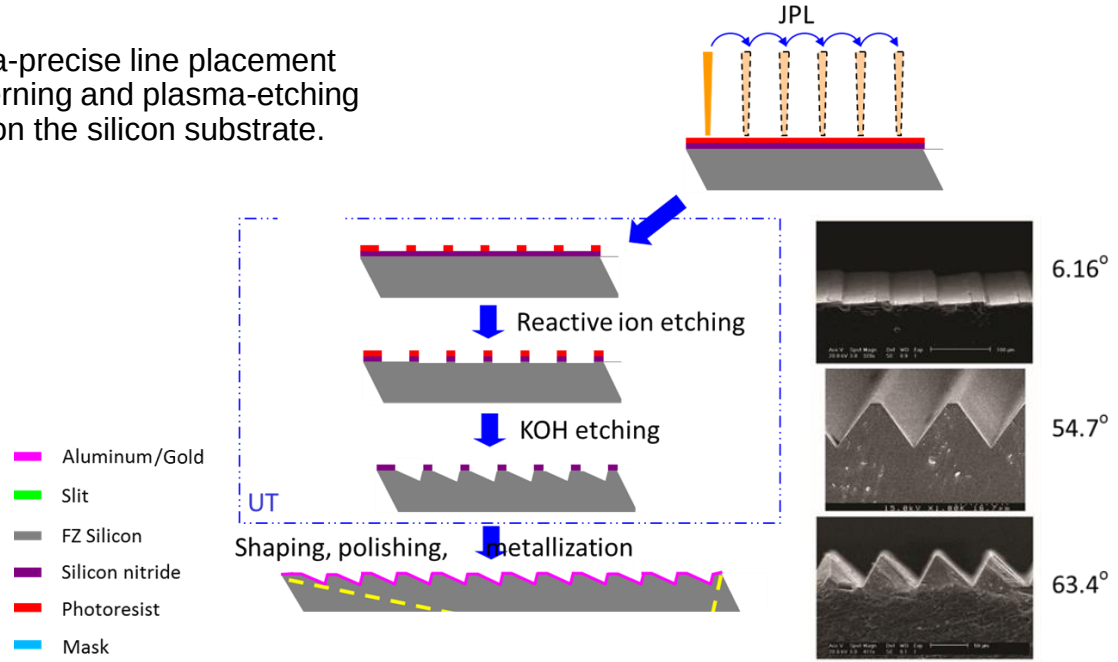


First light image from PARVI – Palomar Radial Velocity Instrument (recorded 6/14/19, Gautam Vasisht, JPL/Caltech)

- Grating used was diamond-ruled engineering model with 15% diffraction efficiency

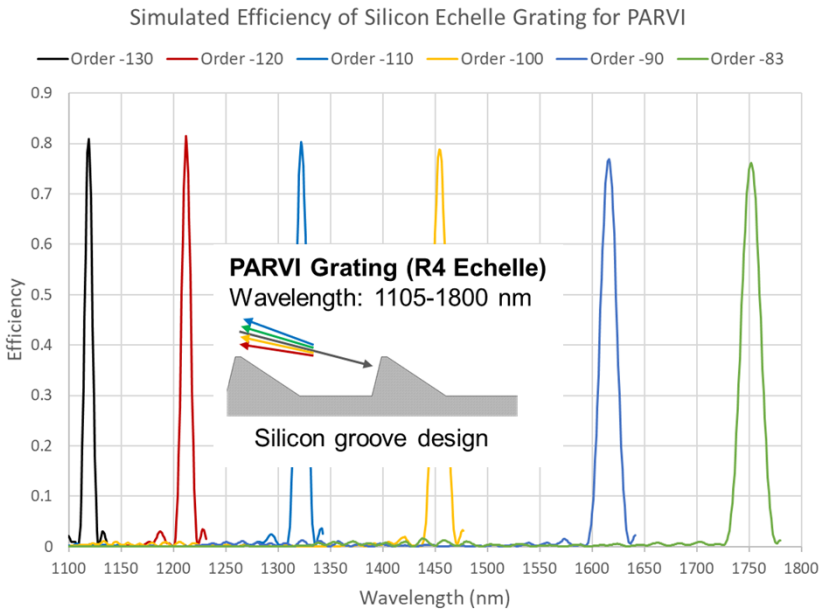
Methodology

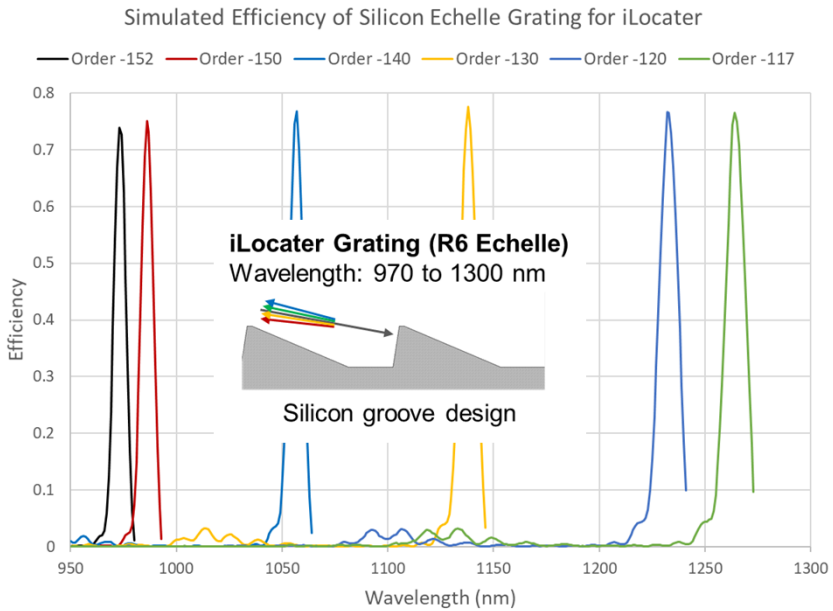
- Combine JPL precision electron-beam grating patterning with Univ. of Texas at Austin anisotropic silicon etching to create world-best echelle gratings for PRV spectrographs
- JPL electron-beam lithography will provide ultra-precise line placement to achieve the required wavefront error. A patterning and plasma-etching process is used to fabricate silicon nitride ribs on the silicon substrate.
- Anisotropic silicon etching will provide the precise blaze angle and high efficiency. The silicon substrate is custom oriented such that the crystalline planes will form the desired blaze angle after etching in KOH (etch rate differs depending on crystal plane). The e-beam patterned silicon nitride ribs mask the etching to form the grating grooves, and the resulting facets are flat and smooth, producing very high efficiency echelle gratings.



Results

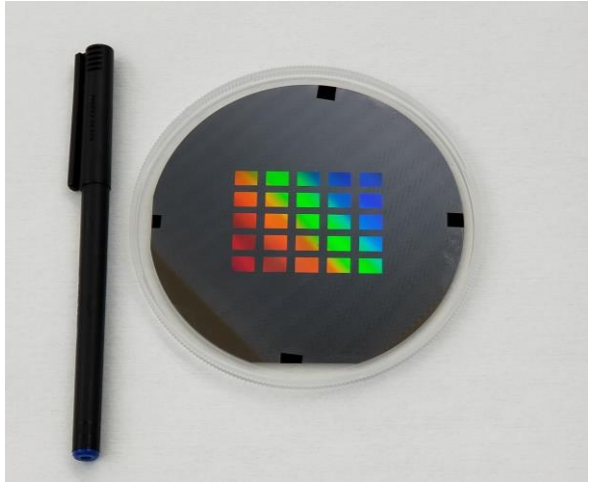
1. We designed silicon echelle gratings for PARVI and iLocater (Notre Dame), determining the predicted efficiency as a function of wavelength and operating diffraction order for expected groove shapes after KOH etching.

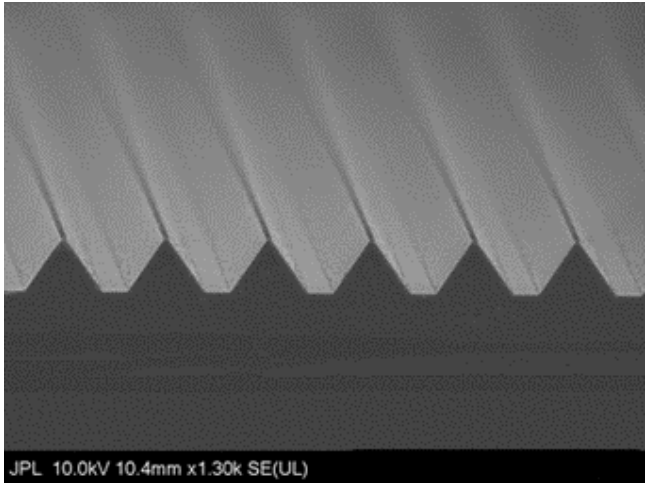


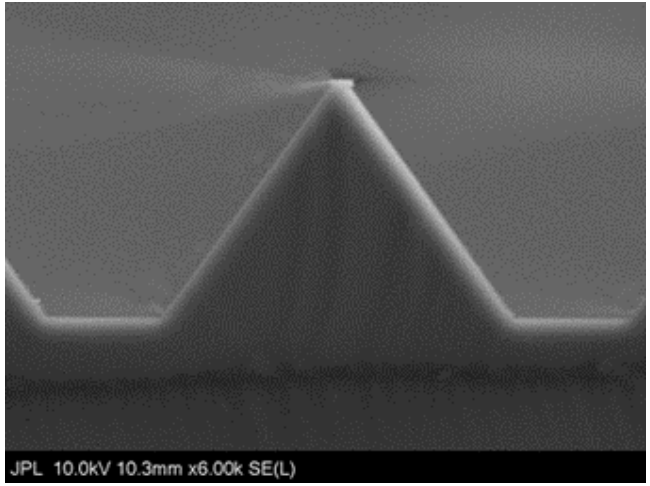


Results

2. We fabricated small-area silicon test gratings using the combined JPL-UT technique: JPL e-beam fabricated chrome grating lines on nitride-coated <100>-oriented silicon wafers, and then UT plasma-etched the nitride and KOH-etched the silicon into echelle gratings.

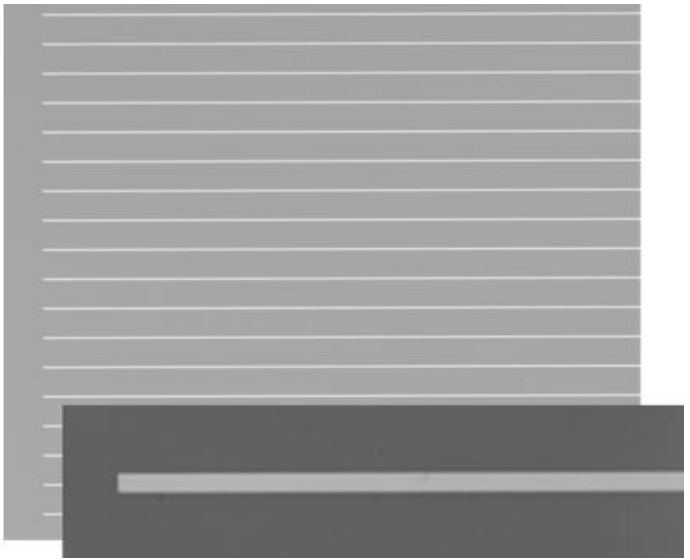






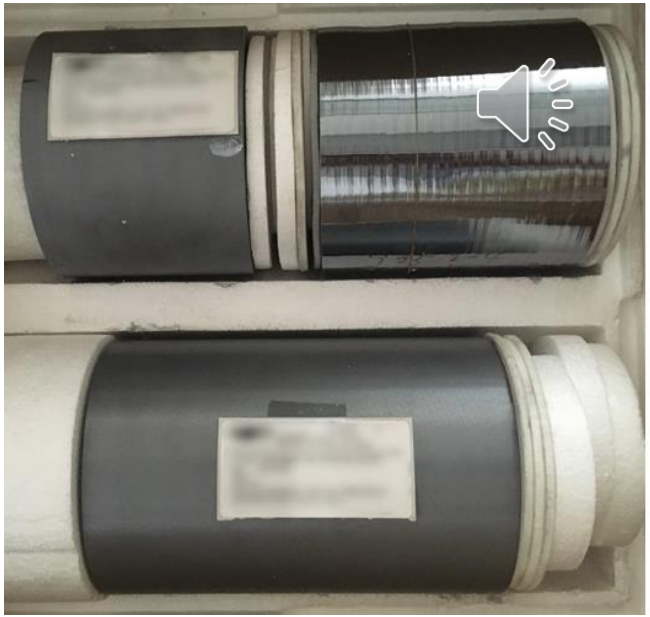
Results

3. We electron-beam fabricated large-area test gratings. A grating of size 60 x 120 mm (larger than required for PARVI) was patterned to form metal and then silicon nitride lines on a 6-inch diameter <100> silicon wafer (Fig. 4). The nitride grating lines will mask the KOH etch that will be performed at Univ. of Texas.



Results

4. University of Texas procured custom crystallographically oriented silicon appropriate for the PARVI and iLocater gratings (the boules are shown in Fig. 5). In parallel, UT has improved their optical lithography and KOH etching techniques, allowing fabrication of gratings on thick silicon substrates up to 6 inches in diameter.



Next Steps

JPL: Fabricate full size gratings on thick silicon substrates, have them etched by UT, measure performance characteristics as possible (efficiency, scatter, wavefront).

University of Texas: Send silicon boules for cutting, polishing, and nitride coating. Etch patterned silicon from JPL.

Publications and References

Michael A. Gully-Santiago, Daniel T. Jaffe, Cynthia B. Brooks, Daniel W. Wilson, and Richard E. Muller "High performance Si immersion gratings patterned with electron beam lithography", Proc. SPIE 9151, Advances in Optical and Mechanical Technologies for Telescopes and Instrumentation, 91515K (28 July 2014); https://doi.org/10.1117/12.2056912

Cynthia B. Brooks, Benjamin Kidder, Michelle Grigas, Ulf Griesmann, Daniel W. Wilson, Richard E. Muller, and Daniel T. Jaffe "Process improvements in the production of silicon immersion gratings", Proc. SPIE 9912, Advances in Optical and Mechanical Technologies for Telescopes and Instrumentation II, 99123Z (22 July 2016); https://doi.org/10.1117/12.2233388