National Aeronautics and Space Administration

Echelle Grating Fabrication for Precision Radial Velocity Spectrographs

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Objectives

Our objective is to develop improved techniques for fabricating high-performance echelle gratings for precision radial velocity (PRV) spectrographs. The gratings required for PRV spectrographs are challenging in 3 aspects: 1) low wavefront error (< 1/10 wave RMS desired), 2) high diffraction efficiency (> 70% desired) in very high diffraction orders (> 100th order), and 3) large size (100 mm to 300 mm long for candidate spectrographs). The combination of these specifications makes it difficult for the traditional echelle grating fabrication technique, diamond ruling, to meet them routinely. 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.

Background

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). Prior knowledge of where these Earths are will greatly benefit various aspects of these missions such as design, science strategy and planet yield. PRV measurements use echelle spectrographs with wide spectral grasp and high resolving power R~100,000 to measure Doppler shifts in the stellar spectrum. A limiting factor is the size/volume of these huge spectrographs and hence their internal stability. Co-I Vasisht has been working on diffraction limited echelle spectrometers (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).

Approach and Results

We believe that high-performance PRV echelle gratings can be fabricated by combining JPL electron-beam lithography with UT anisotropic silicon etching. Electron-beam lithography will provide ultra-precise line placement to achieve the required wavefront error and anisotropic silicon etching will provide the precise blaze angle and atomically flat facets to achieve high efficiency. The fabrication process is illustrated in Figure 1. It begins with a custom-ordered silicon substrate that is precisely cut from a boule at an angle such that the crystalline planes will form the desired blaze angle after etching in KOH (etch rate differs depending on crystal plane). To form grating grooves, the etch is masked by silicon nitride ribs that are patterned by electron-beam lithography and plasma etching. After KOH etching, the resulting grooves have extremely smooth and flat facets that produce high efficiency echelle gratings. The electromagnetic simulation in Fig. 2 predicts that such grooves can produce over 70% diffraction efficiency even at blaze angles as high as 80.7 degrees (R6.1 echelle). To effectively demonstrate our echelle grating fabrication techniques, we plan to fabricate gratings for the PARVI and iLocater (Notre Dame) spectrographs and optically test their performance.
Our recent results are as follows:

1. 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. The test gratings were returned to JPL, and the scanning electron microscopy images in Fig. 3 show that the facets are flat and smooth as desired to produce high efficiency.

2. University of Texas procured custom crystallographically oriented thin (2 mm) thick silicon substrates that were cut from 6" diameter boules, polished, and silicon nitride coated in the same manner that the thick substrates will be processed. At JPL, we e-beam patterned a full-area PARVI-design grating of chromium lines as shown in Fig. 4, to be followed by UT KOH etching and surface and optical metrology.

3. University of Texas procured custom crystallographically oriented thick silicon substrates to meet the specifications for the PARVI and iLocater gratings (the cut substrates are shown in Fig. 5). These substrates are now being sent for polishing and nitride coating in preparation for e-beam patterning at JPL and KOH etching at UT.

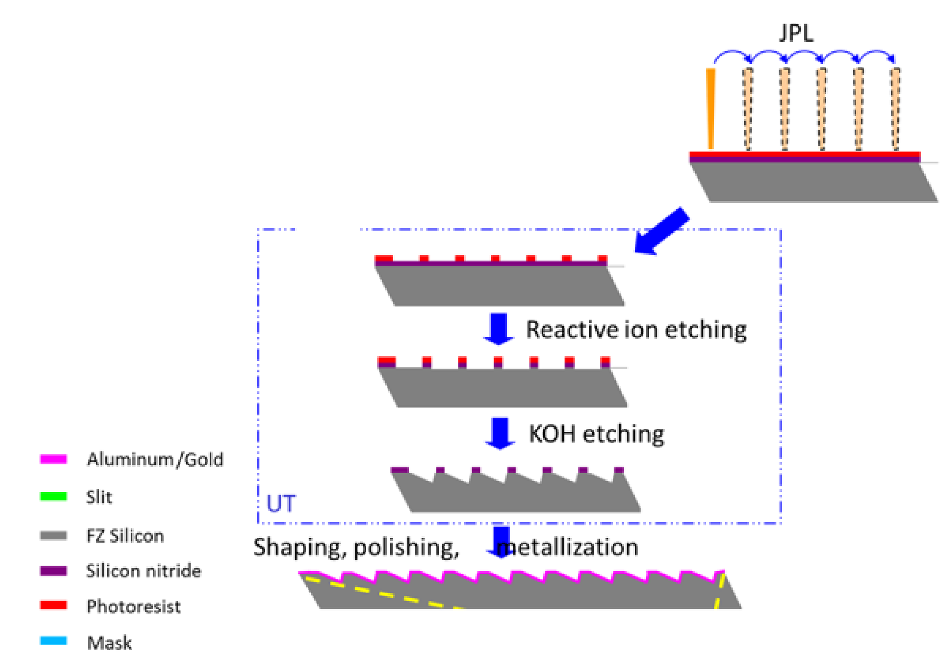

Figure 1. Process for fabricating blazed silicon gratings by binary electron-beam lithography (JPL) and KOH anisotropic silicon

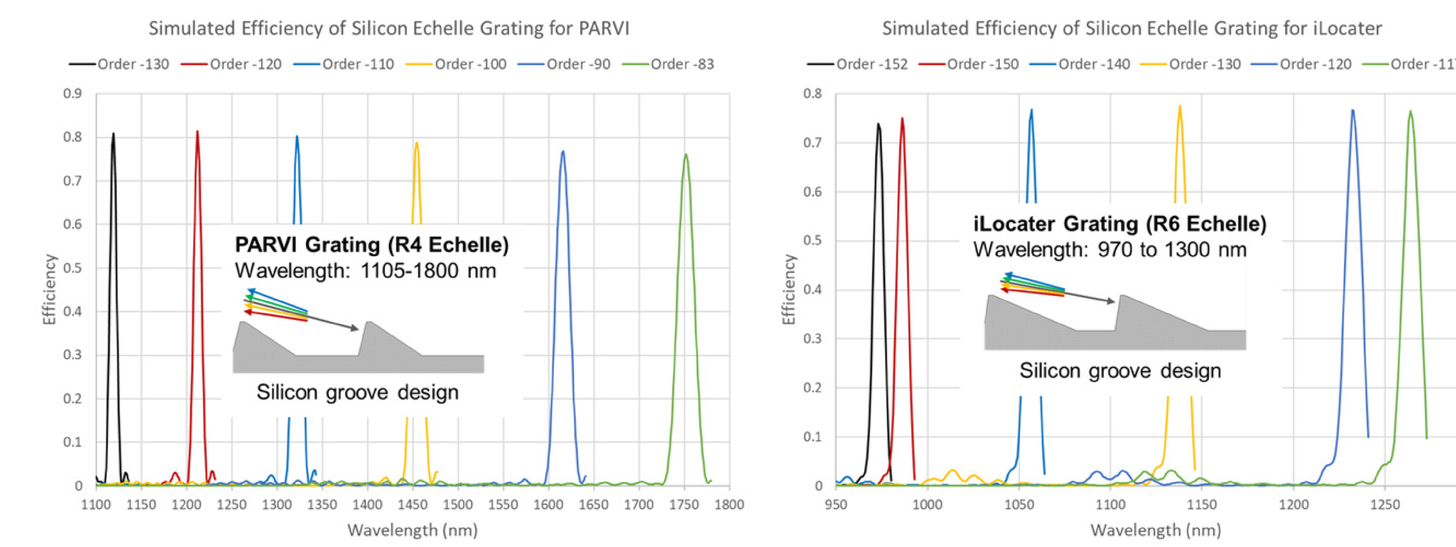

Figure 2. Echelle grating designs and efficiency simulations for RV spectrographs PARVI and iLocater.

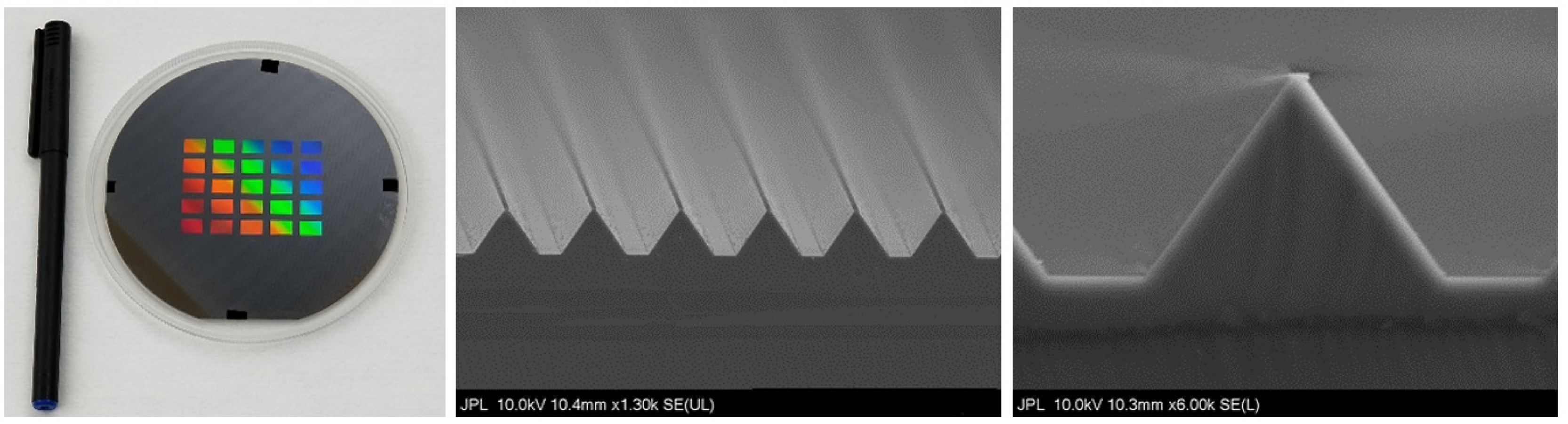

Figure 3. Test gratings in <100> silicon fabricated by JPL electron-beam lithography and Univ. of Texas KOH etching.

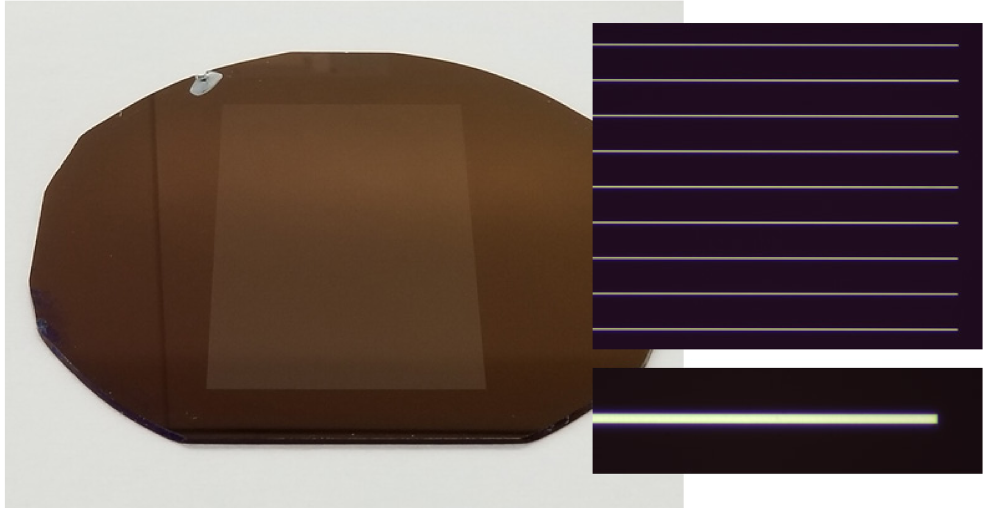

Figure 4. E-beam patterned grating of chromium lines on custom crystallographically oriented silicon wafer (6-inch dia.) to test PARVI grating fabrication process.

Figure 5. Grating substrates cut from custom crystallographically oriented silicon. Left to right: PARVI echelle, iLocater echelle, iLocater cross-disperser.

Significance/Benefits to JPL and NASA

If our JPL-UT collaboration can develop an improved fabrication technique for high-performance echelle gratings, then we will be in a strong position to win future PRV instrument opportunities and make breakthrough science discoveries. The results of our efforts thus far are promising and show that we are on track to fabricating echelle gratings with the desired groove characteristics and grating size. With the successful demonstration of full-size, high performance PRV echelle gratings made using this technique, new opportunities for future PRV spectrographs will be enabled.

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