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. Diffraction limited echelle spectrometers, 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.

Approach and Results

Our approach is to combine 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 KOH etching of custom-oriented silicon will provide the precise blaze angle and atomically flat facets to achieve high efficiency. 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). UT has fabricated silicon immersion gratings up to 6 inches in diameter, and JPL can e-beam pattern up to 9-inch substrates, so gratings of sufficient size for PRV instruments should be realizable. To effectively demonstrate our echelle grating fabrication techniques, we plan to fabricate gratings for the PARVI and iLocater spectrographs and optically test their performance (wavefront error, efficiency, and scatter) in MDL's grating characterization laboratory, UT's grating laboratory, and if possible by the PARVI and iLocater teams. Our recent results are shown in the figures below.

Significance/Benefits to JPL and NASA

If our JPL-UT collaboration can develop an improved fabrication technique for high-performance echelle gratings, we will be in a strong position to win future PRV instrument opportunities and make breakthrough science discoveries.

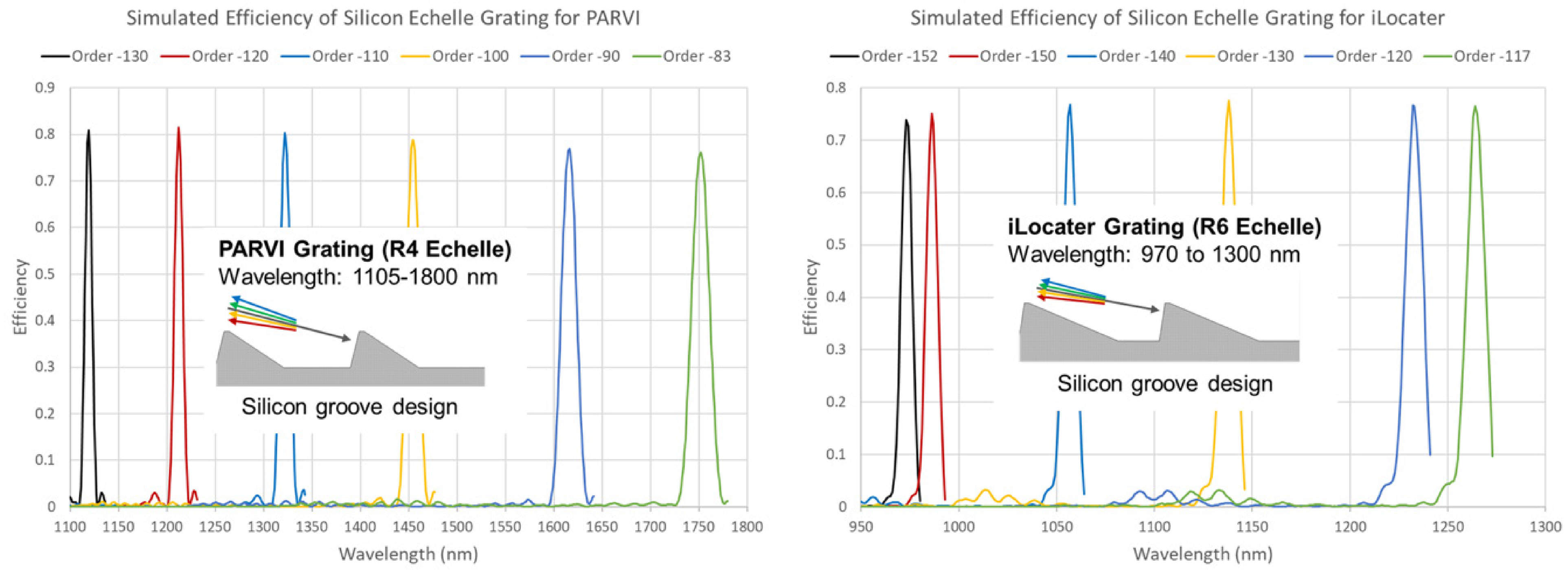

Figure 1. Echelle grating designs and efficiency simulations for PRV spectrographs PARVI and iLocater.

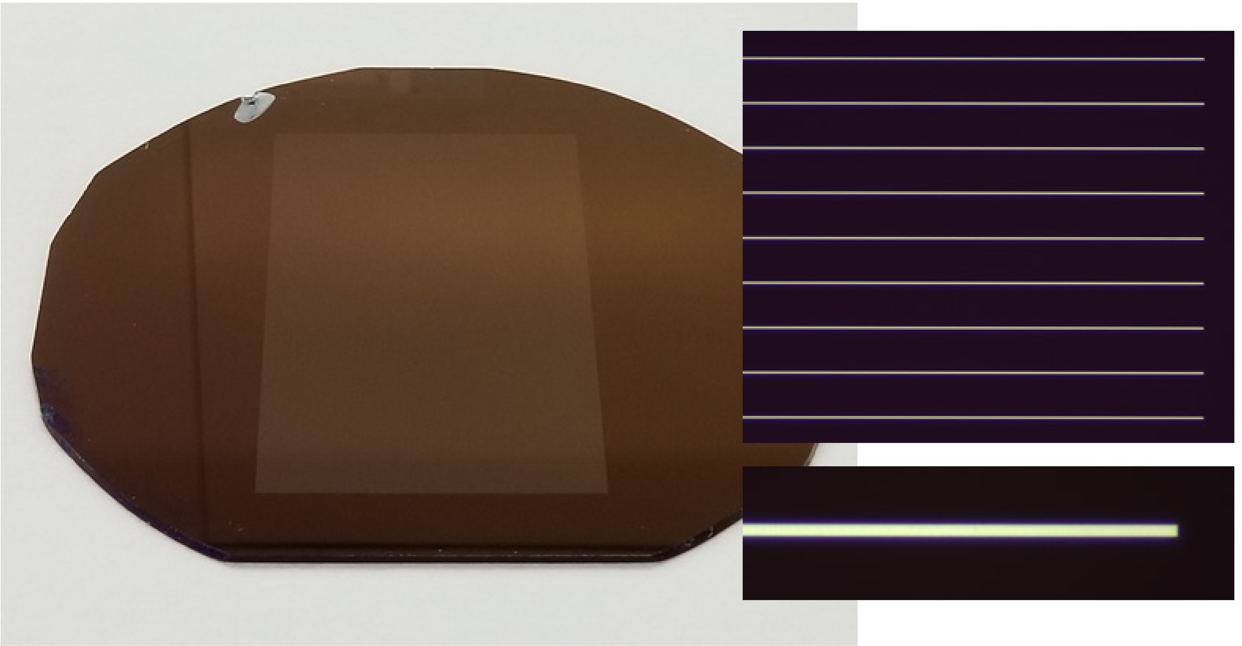

Figure 3. E-beam patterned grating of chromium lines on custom crystallographically oriented silicon wafer (6-inch dia.) to test PARVI grating fabrication process.

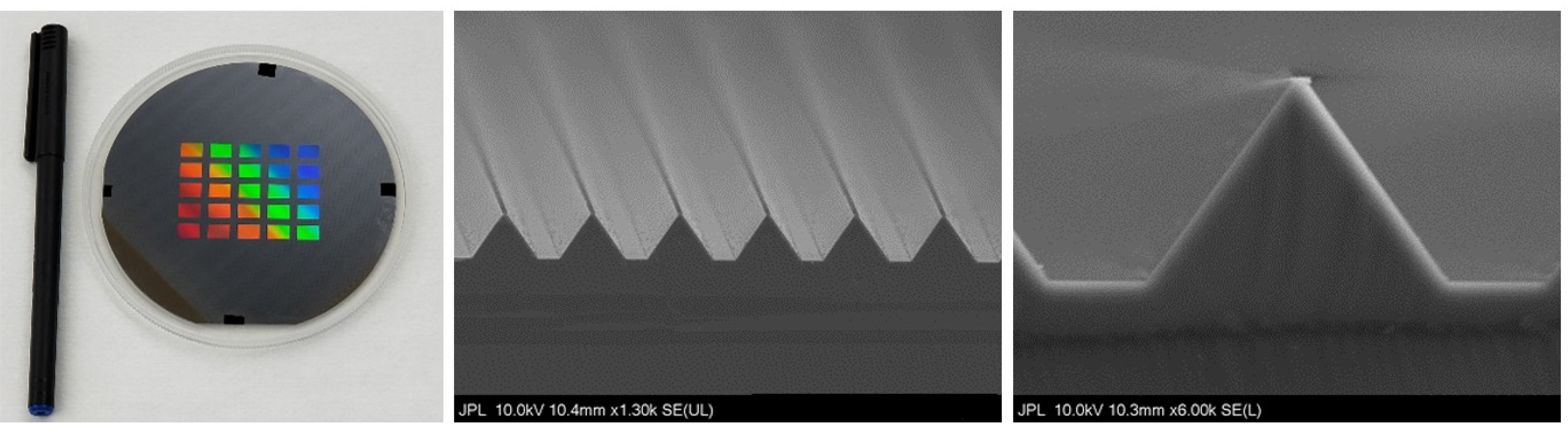

Figure 2. Test gratings in <100> silicon fabricated by JPL electron-beam lithography and Univ. of Texas KOH etching.

Figure 4. Grating substrates cut from custom crystallographically oriented silicon. Left to right: PARVI echelle, iLocater echelle, iLocater cross-disperser.

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