National Aeronautics and Space Administration

Curved UV Spectrometer Gratings

Principal Investigator: Richard J. Terrile (725)

Daniel W. Wilson (389), James P. McGuire (383)

Program: Spontaneous R&TD

Project Objective:

Our objective is to demonstrate that UV dispersive gratings can be fabricated on curved optical substrates that meet the performance requirements for current proposed UV instruments. Specifically, the demonstration of an echelle grating operating at order 16 with a nearly flat free-form optical surface and a cross disperser on an aspherical optic. These would demonstrate utility for use in the UV-SCOPE spectrometer, under consideration for the current SMEX call and demonstrate the feasibility of future high-efficiency spectrometer designs, both in the UV and optical.

Benefits to NASA and JPL (or significance of results):

Spectroscopy in the ultraviolet is challenging because mirror efficiencies are only about 85% at best and light beam collimation, dispersion and cross dispersion can require many reflections. The ability to build UV spectrometers with dispersive gratings on curved substrates with optical power can save at least three reflections or add about 40% in efficiency. This translates into the equivalent of moving from a 40 cm aperture telescope to a 31 cm aperture. This is an enormous competitive leverage in mass and cost for UV instruments. Currently, JPL is proposing several UV instruments that could directly benefit from this innovation. UV-SCOPE has specifically identified a factor of 40% efficiency increase that can be achieved if non-flat UV gratings can be fabricated with the required optical performance. This immediately translates into a potential proposed mission cost reduction of several million dollars.

There are two distinct advantages to demonstrating advanced UV grating using e-beam lithography. First, this technique allows writing grating on curved substrates. This feature will allow optical designs that combine collimation and dispersion in the same optical elements, saving several reflections, and thereby providing significant improvements in throughput. The second advantage of e-beam lithography is the ability to write complex grating geometries that are dependent on available software resources and not physical limitations. For optical designs of compact UV spectrometers, it is often required that grating provide additional aberration correction in the shape of their rulings. This can require complex geometries that have been unavailable using traditional grating fabrication techniques. However, e-beam lithographic techniques have the advantage that their geometries are digitally specified and can be arbitrarily complex and limited by the available computational resources. Typically, the availability of these resources scale with Moore's Law increases and can become economical very rapidly.

FY18/19 Results:

To investigate whether grayscale e-beam lithography can be used to fabricate gratings needed for UV-SCOPE and similar instruments, we fabricated several test gratings in the JPL Microdevices Laboratory. We fabricated candidate designs for the UV-SCOPE echelle and the cross-disperser gratings on flat substrates, and characterized them by atomic force microscopy (AFM) and scanning electron microscopy (SEM). Fabrication on curved substrates has been demonstrated for other applications using similar e-beam fabrication techniques.

Echelle grating

The echelle grating had the following design: period = 3243 nm, angle-of-incidence (AOI) = 15 deg, orders 12-16, wavelength range 120 – 170 nm. Figure 1 shows the geometry of the grating incidence and diffracted orders. Figure 2 shows the simulated efficiency (PCGrate-X v6.1 software) of an idealized triangular grating coated with aluminum (80 nm) and MgF_2 (25 nm). This shows the efficiency that could be achieved if a perfectly sharp triangular grating groove could be fabricated. Figure 3 shows the echelle grating that we fabricated by grayscale e-beam lithography. The grating was fabricated in e-beam resist on a flat silicon wafer, but we have fabricated many gratings on convex and concave substrates using the same technique. The fabricated echelle grating has accurate blaze angle (~17.4 deg compared to the 17.5 deg triangular grating blaze), but exhibits some rounding at the bottom of the groove that will decrease its efficiency. The measured AFM profile (~150 points/groove) was input into the PC-Grate software, and the resulting simulated efficiency is shown in Figure 4. The peak efficiency of the orders is just less than 50%. We believe that further optimization of the grayscale e-beam fabrication parameters can decrease the groove rounding and hence increase the efficiency.

Cross-disperser grating

The cross-disperser grating had the following design: period = 750 nm, AOI = 3 deg, wavelength range 120 – 170 nm. Figure 5 shows the simulated efficiency of an idealized triangular grating (bare aluminum) and confirms that very high 1st order efficiency is possible, if an ideal groove with high reflectivity can be fabricated. Figure 6 shows our first attempt at fabricating the cross-disperser grating by grayscale e-beam lithography. The grating is quite rough and slightly shallow compared to design since it was fabricated on the same wafer as the echelle grating. Future fabrication runs that are optimized for this groove profile will produce more representative gratings, and we will fully characterize and simulate their performance.

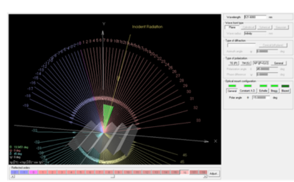

Figure 1. UV-SCOPE echelle grating geometry

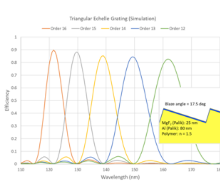

Figure 2. Simulated efficiency of ideal triangular echelle grating

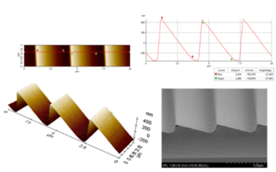

Figure 3. Grayscale e-beam fabricated echelle grating

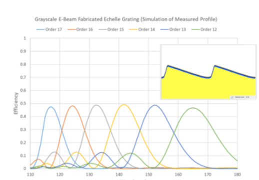

Figure 4. Efficiency simulated from AFM profile of grayscale e-beam fabricated echelle grating

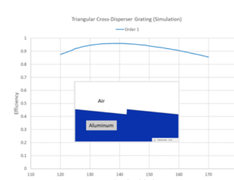

Figure 5. Simulated efficiency of triangular cross-disperser grating

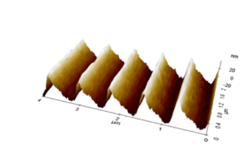

Figure 6. AFM profile of initial attempt at fabricating the cross-disperser grating

Publications:

PI/Task Mgr. Contact Information:

818 354-6158 rich.terrile@jpl.nasa.gov

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

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