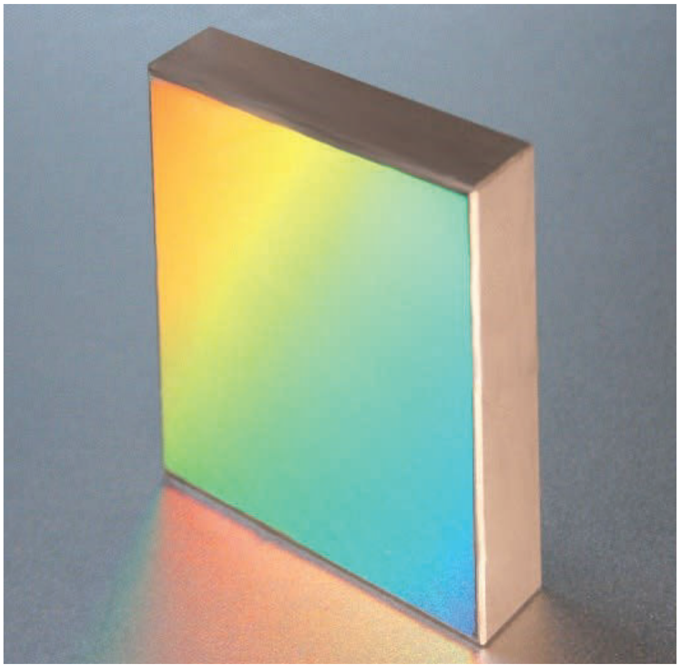
Optical replication offers significant advantages in Space instrumentation

Spectrum Scientific, Inc.

CASE STUDY The Ozone Mapping & Profiler Suites NASA Joint Polar Satellite System program

Optical replication allows the creation of high specification mirrors and gratings with highly repeatable performance, something which is critical for space instrumentation, and was a key criterion for the selection of Spectrum Scientific as a supplier for UV blazed gratings for NASA's Joint Polar Satellite System (JPSS) program.

The JPSS satellites are designed to provide sophisticated meteorological data and observations of atmosphere, ocean, and land for short-term, seasonal, and long-term monitoring and forecasting. These satellites carry instruments that gather global measurements of atmospheric, terrestrial and oceanic conditions, including sea and land surface temperatures, vegetation, clouds, rainfall, snow and ice cover, fire locations and smoke plumes, atmospheric temperature, water vapor and ozone.



Blazed Holographic Grating

The Ozone Mapping and Profiler Suites (OMPS) for JPSS-3 and JPSS-4 which are due to launch in 2028 and 2032 respectively, include next generation back-scattered Ultraviolet (BUV) radiation sensors consisting of three spectrometers: a downward-looking nadir mapper, a nadir profiler, and a limb profiler

The grating specification for OMPS required very high efficiency from 250nm to 310nm, minimal wavefront distortion and extremely low stray light.

Holographic gratings were selected as they produce the lowest stray light possible due to the inherent nature of the holographic process.

Unlike mechanically ruled and lithographic manufacturing methods, interference lithography (holographic) gratings produce perfectly equidistant groove periods with excellent groove shape, eliminating ghost images and other forms of optical scatter.

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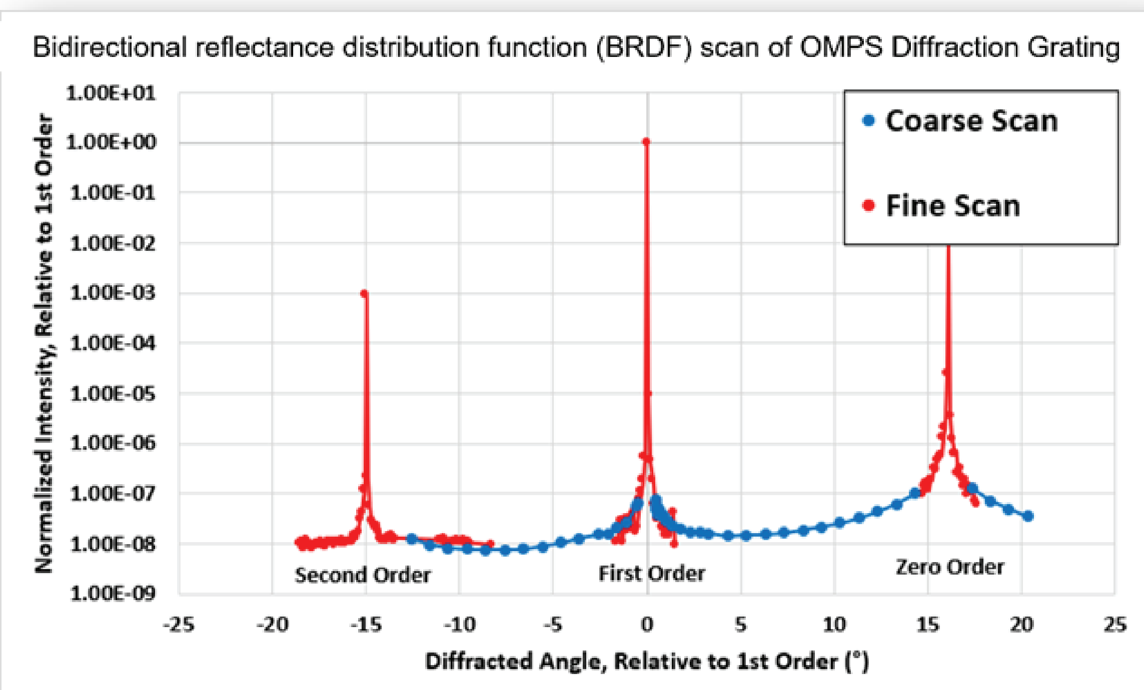
Optical blazing, to create a sawtooth profile giving high diffraction efficiency, requires many variables to be tightly controlled to obtain a precise groove profile with the blaze angle optimized for the specified wavelength. Exposure uniformity, angles of incidence, etching parameters and post processing activities need to be tightly controlled.

At the specified angle of incidence, the absolute diffraction efficiency at 250nm was 74% which is only a few percent lower than the theoretical limit. The combination of high diffraction efficiency and low stray light enabled excellent signal-to-noise ratios - critical for atmospheric sensing instruments.

Stray light was measured relative to the intensity of the first diffracted order using a Scatterworks® BRDF instrument. Measurements were made in the plane of diffraction and out-of-plane.

The performance was exceptional with energy levels falling off sharply and reducing to less than $1x10^{-6}$ a few nanometres away from the first order. Energy between orders fell below $1x10^{-8}$



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CASE STUDY JPL UV Mirrors

In a similar requirement for fast-focusing concave mirrors with a focal ratio of F/1 (NA = 0.45), NASA's Jet Propulsion Laboratory (JPL) required high-performance UV mirrors on aluminum substrates. Surface roughness and figure were critical requirements and the mirrors needed to provide excellent imaging quality with very low optical scatter with a surface roughness of less than 10Å (with best effort of 5Å) and surface figure error < 25nm RMS.

It is common for polished glass substrates to meet these requirements; however, aluminium mirrors cannot normally achieve this. It is possible to diamond turn concave mirrors onto aluminum that is plated with electroless nickel, however it would require post polishing each mirror one at a time to obtain the final figure and to remove the periodic structure left over from the diamond turning process.

Very few companies have the capability of achieving these requirements and the process would need to be repeated for each mirror, incurring a substantial unit cost.

JPL recognized that a replicated optic would meet the performance requirements and be very cost effective.

The strategy was to transfer the precision surface of a polished glass optic onto a machined aluminum substrate.

For this project, a precision glass optical tool was final polished using the magnetorheological finishing (MRF) method.

This technique uses a deterministic process to control the final figure and inherently results in very low surface roughness. The accuracy of the concave radius was held to ± 0.1% (± 100 microns). With precision glass master tools it would be possible to use the replication process to produce hundreds of virtually identical parts and meet the stringent specifications required.

The final set of concave mirrors had a surface figure of less than λ/80 RMS at 632.8nm and surface roughness on the order of 7Å. The final overcoat was aluminum with reflectivity at 200nm exceeding 90%.

Parameter	Measured Result
Substrate Material	6061-T6 Al
Surface Irregularity (RMS m)	6.9
Surface Irregularity (RMS waves @ 633nm)	λ/80
Surface Roughness (Å)	6.2
Scratch Dig	40/20

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Conclusion

These case studies demonstrate that optical replication is not only a solution for many commercial applications but can also be used for critical, high specification instruments and sensors such as those used in space flight, providing performance enhancements, cost advantages and repeatability.

About Spectrum Scientific

Spectrum Scientific, Inc (SSI) has been manufacturing high volume flat, aspheric and freeform reflective optics, hollow retroreflectors and holographic diffraction gratings since 2004.

We primarily use the optical replication process allowing us to supply high fidelity, high specification precision optics at a lower cost compared to traditional volume manufacturing.

One of our key capabilities is the manufacture of freeform optics, off-axis paraboloids and ellipsoid mirrors with surface figures down to λ/10 or better. We also manufacture plane, concave and convex holographic diffraction gratings, which can be supplied as blazed gratings using our proprietary blazing technique, which not only offers high efficiency in the UV, but lower stray light compared to conventional ion etched gratings.

Spectrum Scientific is ISO 9001:2015 certified and RoHS compliant and our production and test areas are space qualified offering a silicone free production environment where we can replicate reflective optics for space borne telescopes and optical interconnect systems.

We have supplied a number of ultra-low stray light gratings for a number of high profile projects, including the Orbiting Carbon Observatory (OCO) and Ozone Mapping Profiler Suite (OMPS).

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