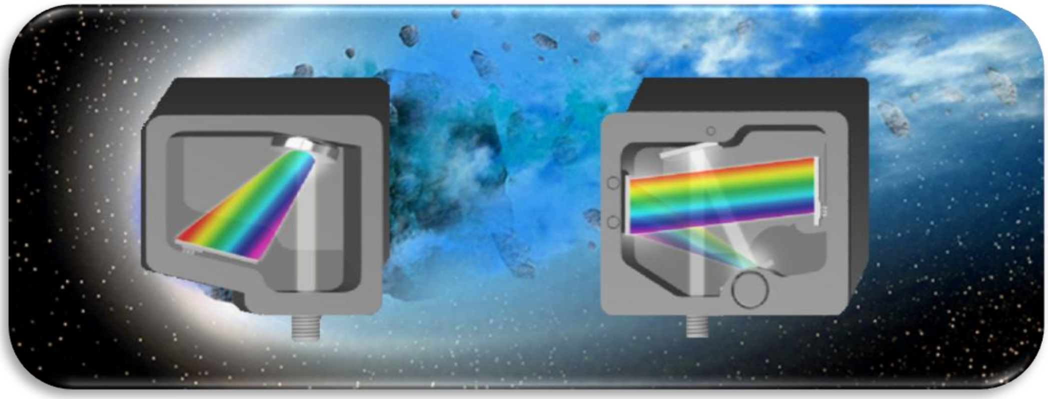

Performance Advantages of Concave Grating Optics in Compact Fiber Optic Spectrometers

Department of Technical Sales, StellarNet Inc. Fl 33626 Tampa ,USA.

Spectroscopy, like most sciences, never stops evolving. Revolutionary techniques, solutions, and instruments are devised every year. With improvements to grating design and optical components, spectroscopy has become an even more powerful tool used to analyze the world around us.

The use of plane gratings in spectroscopy is still popular due to their efficiency and ease of production. However, instruments utilizing plane gratings also require the use of mirrors and other optics, which can introduce aberrations and produce weaker sensitivity at ultraviolet and near-infrared wavelengths.

Most plane grating optics utilize several mirrors in order to properly image the spectrum on the detector. With applications that require the use of UV light, especially UV-Vis absorbance, fluorescence, and solar radiometry, multiple mirrors can be detrimental to the performance of an instrument. In some plane grating designs, UV sensitivity can be weak. The use of a holographic concave grating can eliminate the sensitivity issues and provide other benefits including: stray light reduction, aberration correction, thermal stability, and improved ruggedness.

Stray Light Reduction

One of the biggest benefits of concave grating optics is their ability to reduce stray light in a spectrometer. Stray light is light in any optical system, which was not intended to be detected in the design. This light will be interpreted as a false signal and typically limits the detection ability of the system. Using a single concave grating (in place of a plane grating and two mirrors) reduces the amount of light reflections. This reduces the amount of light scatter in the system as a whole.

Additionally, the surface of the holographic concave gratings is smoother compared to traditional ruled gratings. The smoother surface allows these instruments to have very minimal stray light. At 435nm, concave holographic grating designs were recorded having stray light levels of .02%, where traditional plane grating designs had .1% [1].

Because of the reduction in stray light, system detection limits are improved, and using concave holographic gratings for chemistry and absorbance spectroscopy is ideal.

Increased UV & NIR Sensitivity

Another standout benefit for compact spectrometers with concave grating optics is their increased sensitivity to UV & NIR light. With silicon detectors, every light refraction in the instrument causes a loss in intensity below 400nm and above 900nm [2]. Including a holographic concave grating reduces the number of refractions, and improves the signal at the ends of the UV-VIS-NIR spectrum. Figure 1 shows the response of different systems to a Deuterium- halogen light source.

Uniform Resolution + Aberration Correction

Several aberrations can be found in certain plane grating optics designs including coma, spherical aberration, astigmatism, and field curvature. The concave grating produces a “flat field” wavefront on the detector array. This allows each point to be in focus, providing uniform resolution across the entire detector.

Coma is a variation in magnification over an image. This occurs from imperfections within the optics and exists in many ruled grating systems. Chromatic aberrations can be caused by comas if it is dependent on wavelength. The image produced becomes distorted and has a comet-like tail, shown in figure 2.

Spherical aberration is an aberration when reflected rays do not share the same focal point on the same axis (figure 3). This defect can cause an imperfect image to be formed on the detector of a spectrometer, altering the resolution.

Superb Spectral Shape

Astigmatism, shown in figure 4, is caused when horizontal and vertical focal points of an optical system do not line up. This will lead to sharp images appearing elongated, or ovular.

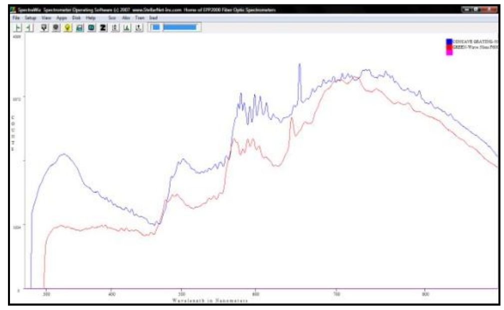

Figure 1: Sensitivity in the UV is enhanced for concave holographic spectrometers. Comparison of BLACK-Comet sensitivity (blue line) compared to plane grating spectrometer (red line).

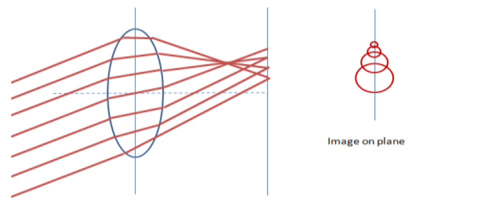

Figure 2: Diagram of coma caused by a lens. Graphic on the right shows the characteristic “comet tail” that is seen in coma aberrations.

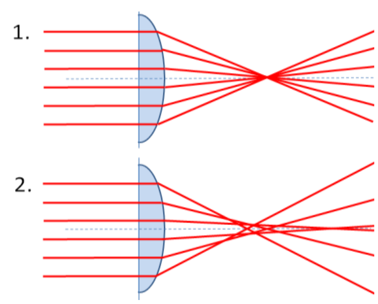

Figure 3: Diagram 1 shows the focal point of a perfect lens, while diagram 2 shows an imperfect lens displaying spherical aberration.

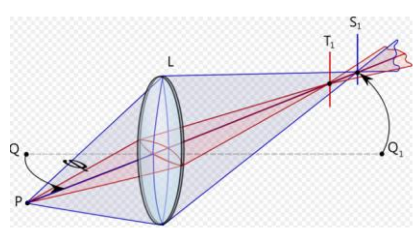

Figure 4: With astigmatism, the focal point of the horizontal plane (T_1) does not align with the focal point of the vertical plane (S_1), causing the final image to be obscured.

With some optics, it is not possible to focus a flat image on a flat imaging plane. With spectroscopy in particular, the detector is a flat linear array, and can lead to unfocused imaging on parts of the detector array (figure 4). Because of this, the best resolution is usually found in the center, with resolution becoming worse toward the ends of the array. All of these aberration corrections lead to improved spectral shape in the spectrometer.

By including a holographic concave grating into an optical bench of a spectrometer, aberrations can be severely reduced or eliminated. Eliminating many of the common abnormalities and incorporating high quality components allows the instrument to become more viable as a tool for research.

	BLACK Comet Spectrometer	**Standard Plane Grating Design**
Optical Bench Design	Research grade concave grating	Plane Grating
Use of Mirrors	No	Yes (2)
Stray Light Value	0.02% @ 435nm; 0.2% @ 200nm	<0.1% @ 435nm;<0.05% @ 600nm
Grating Type	Holographic & aberration corrected	Holographic & ruled

Figure 6: Comparison of StellarNet's BLACK- Comet Spectrometer against a standard plane grating design [4].

Simplicity

The simplicity of instruments using a concave holographic grating design can provide significant advantages. Holographic concave grating designs do not require multiple mirrors and spectrometers are able to be more compact. A single optic is able to diffract light and focus individual wavelengths onto the detector. Having a small footprint provides benefits to the lab as a whole, providing space on a lab bench to be optimized.

Thermal Stability

Using several optics also introduces errors that can occur with a change in temperature. Because all material will swell or contract to some degree with a change in temperature, multi-optic spectrometer systems are susceptible to this temperature induced error. As the temperature rises, all components could be adjusted slightly. With one optic the resulting error is minimal. With multiple optics, the individual error is multiplied. This also makes Czerny Turner optical benches less viable for solutions in environments with drastic temperature changes [4].

Ruggedness & Shock Proof

Using holographic concave gratings that doesn't require any adjustments or mounting turrets provides a stable platform for a rugged spectrometer. Typically the concave grating is milbonded to one side of the metal optical housing and the detector is bold-mounted to the other. Applications that benefit the most from the durability are those that include field work, process line applications, and laboratories where space is limited.

BLACK-Comet UV-VIS Spectrometer

The BLACK-Comet spectrometer uses a concave holographic grating, has reduced stray light, aberration correction, improved thermal stability, and is resilient in harsh environments.

In addition to the research quality of the instrument, the rugged nature of the BLACK-Comet design makes it ideal for use in the field and other harsh conditions. The instrument excels in situations where plane grating spectrometers with adjustable optics could shift or incur damage

The instruments size is always a key factor in purchasing. The small profile of the BLACK-Comet spectrometer (70 x 100 x 150 mm) and the rugged nature of the instrument encourages use in most laboratories where bench space is minimal. BLACK-Comet spectrometer systems can easily be set up for experiments and stored when not in use. Valuable space on a lab bench or in a facility doesn't have to be dedicated to one instrument.

Because of the simplicity of the instrument, incorporating it into existing products does not require excessive customization.

Conclusions

Holographic concave grating spectrometers address aberrations that can hinder the performance of typical plane grating spectrometers. The benefits of simplicity and aberration correction help holographic concave grating spectrometers to stand out against other plane grating instruments. Specific features in the BLACK-Comet spectrometer make a more viable option for use in almost any application that requires durability and performance. Its ease of use promotes utilization in the field, educational laboratory, or incorporation in other products.

Works cited

1. Slutter, Steve, Wu Jung, and Olivier Nicolle. *Introduction to Reflective Aberration Corrected Holographic Diffraction Gratings*. Tech. N.p., n.d. Web.

2. Flaherty, Ryan M. "Comparing Spectrometers: StellarNet vs. The Competition." *Photonics Online*. Photonics Online, 14 July 2014. Web. 20 Jan. 2016.

3. Kroch, Sebastian. "Astigmatism." *Wikipedia*. Wikimedia Foundation, 17 June 2010. Web. 20 Jan. 2016

4. StellarNet Inc. *Concave Grating Spectrometer Features*. N.p.: StellarNet, n.d.*BLACK-Comet UV-VIS Spectrometer*. Web.