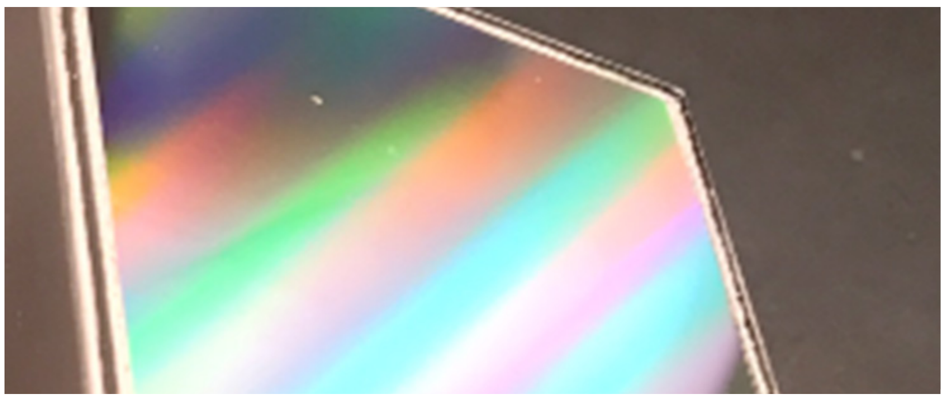
Application Note

Materials testing and research

Rapid, Automated, Quality Control Measurements of Diffraction Grating Efficiency

The Agilent Cary 7000 UMS reduces measurement time and manual handling



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This application note was part of an SPIE publication (details on page 5)

Introduction

Diffraction gratings are designed to separate specific wavelengths of light from broadband illumination sources such as incandescent lights or sunlight. When illuminated, diffraction gratings display the familiar color spectrum of a rainbow, acting like a prism to separate light into parts based on wavelength. Separating the incident light into specific wavelengths allows the subsequent selection of the wavelength(s) required for the application. Every modern spectrophotometer includes a diffraction grating and yet, despite being used commercially for over 60 years, practical and efficient characterization of diffraction gratings has been challenging.

Part of the challenge can be attributed to the unique angular-dependent geometry or off-axis dispersion of gratings. Shorter wavelengths are diffracted at smaller angles while longer wavelengths have larger diffraction angles (Figure 1).

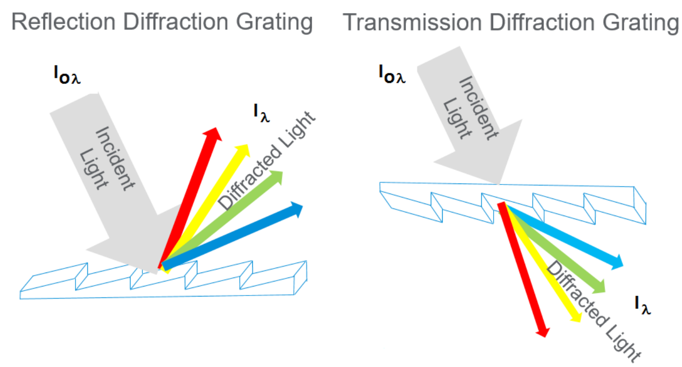


Figure 1. Schematic presentation of the beam pathways for a reflective and a transmissive diffraction grating. Incident light intensity as a function of wavelength, Ioλ(λ) and diffraction light as a function of wavelength I(λ).

Diffraction gratings contribute to the performance of a spectrophotometer, particularly for parameters such as the spectral resolution and dynamic range, via stray light control. Well-controlled consistency in the quality and performance of gratings is of paramount importance for the spectrophotometer manufacturing industry.

An important performance characteristic of a grating is its diffraction efficiency, often used as a quality metric for gratings. Absolute efficiency, as shown in the equation below, is defined as the ratio of the intensity of the desired wavelength of diffracted light compared to the intensity of the incident light.

% Absolute Efficiency, AE(λ) = $I_{\lambda}/I_{o\lambda}$ x100%

Relative efficiency is measured relative to a reference mirror. The diffraction efficiency is determined by the grating constant (number of grooves per millimeter), the shape of the grooves, and by their regularity (constant spacing and parallelism). For a given grating, the diffraction efficiency is wavelength-dependent and changes with the angle of incidence (AOI) [1].

Grating diffraction efficiency curves are usually measured using customized in-house systems which are often inflexible (e.g. allowing only one AOI or diffraction angle) or require frequent user intervention [2]. These systems often consume significant operator time, take a long time to complete measurements and require significant post-collect data processing. It would not be unusual for an operator to take an entire working day to characterize a single diffraction grating sample.

Efficiency curves are usually collected for all new master gratings but manufacturers often struggle when it comes to the routine characterization and QC/QA of manufactured gratings. Prior to the introduction of the Agilent Cary 7000 Universal Measurement Spectrophotometer (UMS), commercial instrumentation that allowed fast, efficient and accurate characterization of diffraction gratings was not available.

The Cary 7000 UMS is a high-performance UV-Vis/NIR spectrophotometer that automates absolute reflection and transmission measurements at almost any angle over a wavelength range of 250 nm to 2500 nm. The detector position and sample angle are automated and independently controlled. This allows transmission and reflection data to be collected in a single sequence at a pre-set series of measurement geometries, without repositioning the sample. An automated polarizer ensures accurate measurements at S, P, or any user-specified polarization angle.

This study examines the use of the Cary 7000 UMS for the routine characterization of diffraction gratings in a production environment.

Experimental

The dispersion spectra of four reflection gratings (300, 1200, 1800 and 3600 grooves per mm) were measured with the Cary 7000 UMS. As the efficiency of a grating can be dependent on the polarization of the incoming light beam, spectra were collected for both s- and p-polarized light.

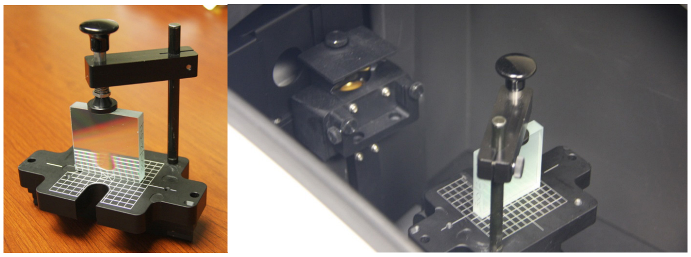


Figure 2. Left: A grating with 300 lines per mm was mounted on a Cube Beam Splitter Sample Holder. Right: The sample holder, placed onto the sample stage in the Cary 7000 UMS. Detector held at 10°.

As can be seen in Figure 2, the grating samples were mounted on an Agilent Cube Beam Splitter Holder and placed into the sample compartment of the Cary 7000 UMS to be measured. The reflection characteristics of the gratings were analyzed for a fixed reflection angle. To achieve this the detector angle was fixed at 10°. The angle at which light is reflected from a grating is dependent on the wavelength of the incident light. To ensure that the reflected light hit the detector at 10° for every wavelength, the angle of incidence was automatically changed for each wavelength. The automation was achieved by using a custom software program. The program was written in Agilent's proprietary Applications Development Language (ADL) program (refer to the More Information section). The program moved the grating to keep the angle of incidence consistent for each analytic wavelength and also set the polarization angle.

Each spectrum was collected first with a data interval of 1 nm and then again with a data interval of 10 nm. This was done to study the impact of data collection speed on the accuracy of the results.

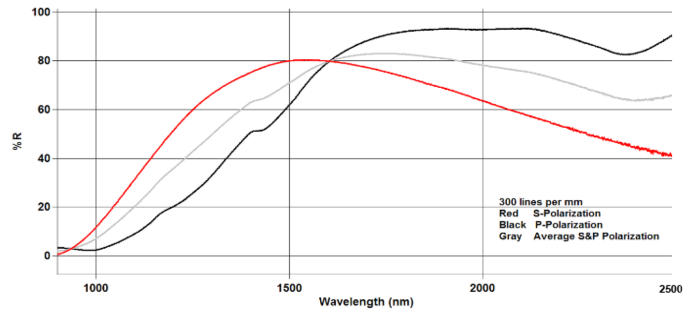
The parameters given in Table 1 were used for the analysis.

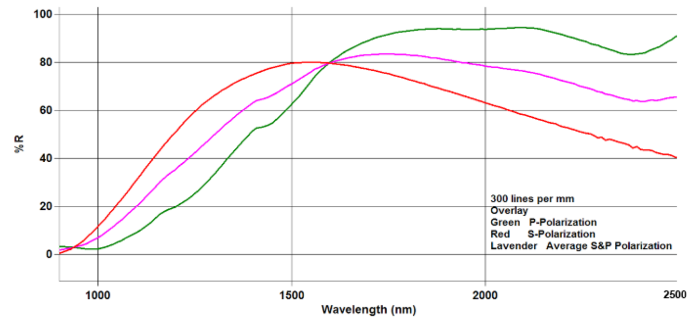
Table 1. Agilent Cary 7000 UMS parameters used to acquire the %R spectra of the four different gratings.

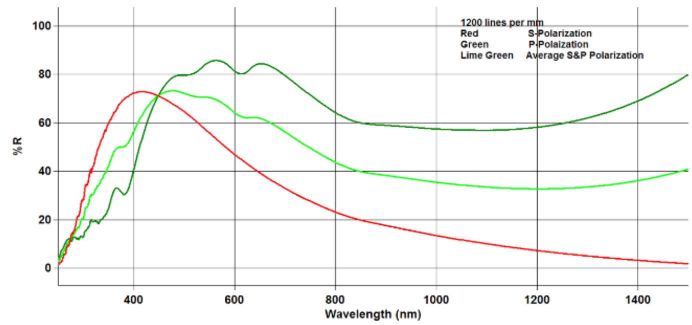
Parameter	Value
Angle of incidence	Typically 15 deg to 45 deg
Detector angle	10°
Wavelength range	250 – 2500 nm
Data interval	10 nm and 1 nm
Spectral bandwidth	2 nm
Signal averaging time	0.5 sec
Polarization	s-and p-polarization
Incident beam aperture	3°x1° (vertical x horizontal)
Baseline correction	On

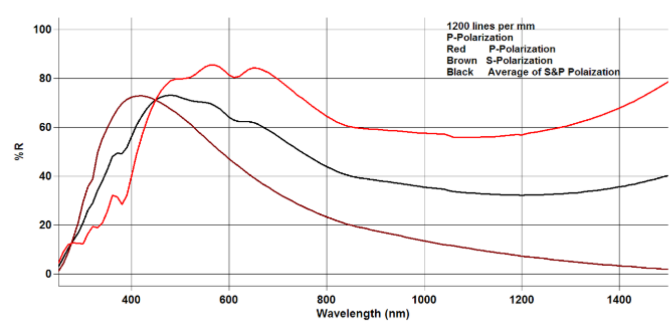
Results and Discussion

In Figure 3 the reflection spectra of the four different diffraction gratings are shown. The spectra were collected first with a data interval of 1 nm and then again with a data interval of 10 nm. The use of the larger data interval reduced the number of collected data points and the overall time needed to acquire the spectrum (Table 2). Comparing the short and long data collection intervals, the reflection spectra collected with 10 nm interval show the same level of absolute grating efficiency as the spectra collected at a 1 nm interval. The 7000 UMS data fidelity clearly indicates that the faster data collection parameters can be used without the loss of any analytical integrity.









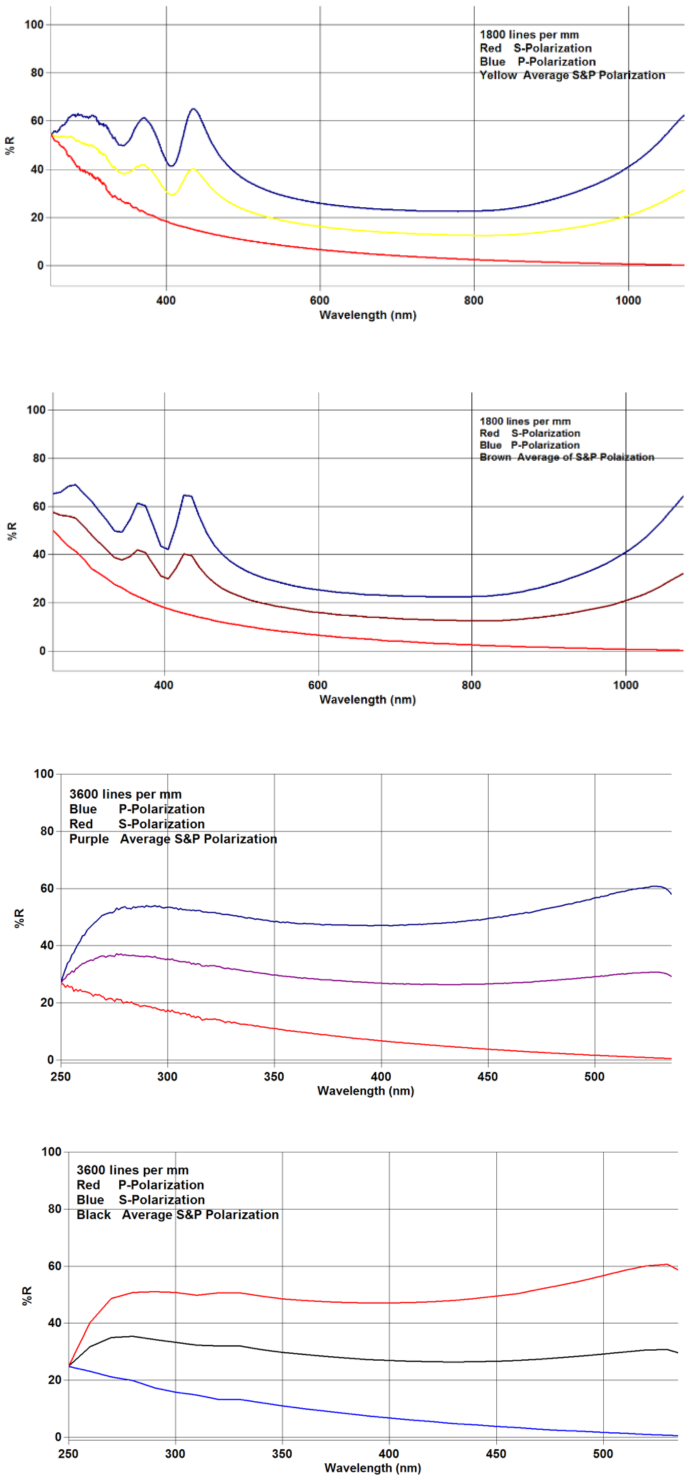


Figure 3. % reflectance of each grating at a 10° detector angle. Four pairs of graphs represent the four grating types; 300 l/mm, 1200 l/mm, 1800 l/mm and 3600 l/mm respectively. For each pair of graphs the first graph is collected at 1.0 nm data interval and 2 nm SBW, and the second graph is collected at 10 nm data interval and 2 nm SBW. Spectra collected at 10 nm intervals show the same level of accuracy as the spectra collected at 1 nm interval.

The tabulated results (Table 2) demonstrate that grating characterization and quality across a broad wavelength range can be determined in a matter of minutes without any user intervention. Longer scans can also be performed, when a greater depth of spectral detail is needed across a wide spectral range using a narrow spectral resolution and small data intervals. These more detailed scans could be performed unattended overnight.

Extremely rapid peak efficiency scans across a short wavelength range at only the grating blaze wavelength could also be performed - providing almost instantaneous feedback on grating quality.

Table 2. Agilent Cary 7000 UMS parameters used to acquire the %R spectra of the four different gratings.

Sample	Grating Lines per mm	Data interval = 1 nm		Data interval = 10 nm	
		Total Elapsed Time	Number of Data Points	Total Elapsed Time	Number of Data Points
1	300	5 hrs 29 min 15 sec	1601	34 min 38 sec	161
2	1200	4 hrs 21 min 30 sec	1251	28 min 57 sec	126
3	1800	2 hrs 52 min 50 sec	826	18 min 34 sec	83
4	3600	1 hr 41 sec	290	7 min 57 sec	29

Conclusions

The Agilent Cary 7000 UMS proved to be a fast and practical analytical tool for the characterization of diffraction gratings. The instrumentation easily performed multi-angle photometric spectroscopy measurements while providing the flexibility to characterize gratings at a chosen angle of incidence. The data collection process was fully automatic, with programmatic rotation of the grating and of the polarization of the incident light allowing control over the sample measurement process. Most measurements could be completed in under 30 minutes. Longer measurements could be performed overnight as user intervention is not required.

Note: Cary 4000, 5000 and 6000i instruments can be upgraded to have the same capabilities as the Cary 7000 UMS with the addition of the Cary Universal Measurement Accessory (UMA).

References

1. Optical Grating Evaluator: A Device for Detailed Measurement of Diffraction Grating Efficiencies in the Vacuum Ultraviolet, D. J. Michels, T. L. Mikes, and W. R. Hunter *Applied Optics*, Vol. 13, Issue 5, pp. 1223-1229, **1974** doi: 10.1364/AO.13.001223.

2. Hutley, M. Ch.: Spectroscopic Properties. In Diffraction Gratings, 1st Edn. Academic Press, (1982).

More Information

This application note was part of an earlier SPIE publication; Mark R. Fisher, Travis C. Burt, "Rapid, automated, quality control of diffraction grating efficiency", Proc. SPIE 10373, Applied Optical Metrology II, 103730O (23 August 2017); doi: 10.1117/12.2275526;

The Diffraction Grating Efficiency Program used to control the sample is available for download.