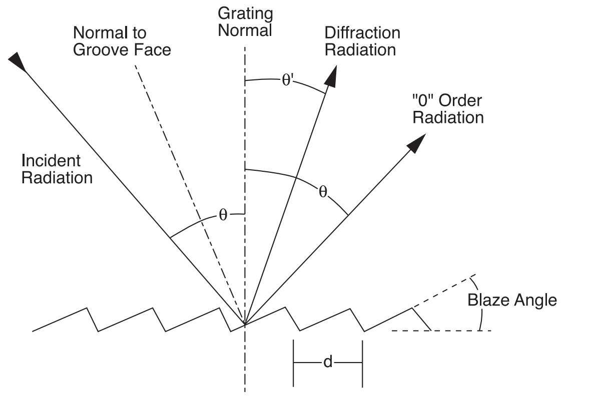
Introduction to Diffraction Grating

Diffraction Gratings (Ruled and Holographic)

Diffraction gratings can be divided into two basic categories: holographic and ruled. A ruled grating is produced by physically forming grooves on a reflective surface by using a diamond tool mounted on a ruling engine. The distance between adjacent grooves and the angle they form with the substrate affect both the dispersion and efficiency of the grating.



GRATING ANGLES & TERMS

A holographic grating, by contrast, is produced using a photolithographic process where an interference pattern is generated to expose preferentially portions of a photoresist coating.

The general grating equation may be written as

$$n\lambda = d(\sin\theta + \sin\theta')$$

where n is the order of diffraction, λ is the diffracted wavelength, d is the grating constant (the distance between grooves), θ is the angle of incidence measured from the grating normal, and θ′ is the angle of diffraction measured from the grating normal.

The overall efficiency of the gratings depends on several application-specific parameters such as wavelength, polarization, and angle of incidence of the incoming light. The efficiency is also affected by the grating design parameters such as blaze angle for the ruled gratings and profile depth for the holographic gratings.

The Ruling Process

Ruling an original or master grating requires an appropriate substrate (usually glass or copper), polishing the substrate to a tenth wave (λ/10), and coating it with a thin layer of aluminum by vacuum deposition. Parallel, equally spaced grooves are ruled in a groove profile. The ruling engine must be able to retrace the exact path of the diamond forming tool on each stroke and to index (advance) the substrate a predetermined amount after each cut. Numerous test gratings are created and measured. After testing, a new original grating is ruled on a large substrate. The original grating is very expensive, and as a result, ruled gratings were raerly used until after the development of the replication process.

The Holographic Process

The substrate for a holographic grating is coated with a photosensitive (photoresist) material rather than the reflective coating used in ruled gratings. The photoresist is exposed by positioning the coated blank between the intersecting, monochromatic, coherent beams of light from a laser (e.g. an argon laser at 488nm). The intersecting laser beams generate a sinusoidal intensity pattern of parallel, equally spaced interference fringes in the photoresist material. Since the solubility of the resist is dependent on its exposure to light, the intensity pattern becomes a surface pattern after being immersed in solvent. The substrate surface is then coated with a reflective material and can be replicated by the same process used for ruled originals. Since holographic gratings are produced optically, groove form and spacing are extremely uniform, which is why holographic gratings do not exhibit the ghosting effects seen in ruled gratings. The result is that holographic gratings generate significantly less stray light than ruled gratings.

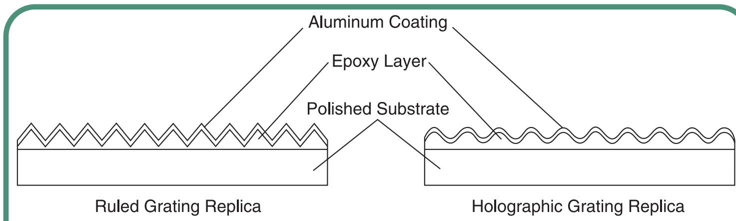
The Replication Process

In the late 1940's, White and Frazer developed the process for precision replication, allowing a large number of gratings to be produced from a single master, either ruled or holographic. This procedure results in the transfer of the three dimensional topography of a master grating onto another substrate. Hence, the master grating is reproduced in full relief to extremely close tolerances. This process led to the commercialization of gratings and has resulted in the current widespread use of gratings in spectrometers.

Transmission Grating

Transmission gratings simplify optical designs and can be beneficial in fixed grating applications such as spectrographs.

Thorlabs' offering of blazed transmission gratings is designed for optimum performance in the visible, UV, or near IR spectrum, with varying dispersiveness. In most cases, the efficiency is comparable to that of reflection gratings typically used in the same region of the spectrum. By necessity, transmission gratings require relatively coarse groove spacings to maintain high efficiency. As the diffraction angles increase with the finer spacings, the refractive properties of the materials used limit the transmission at the higher wavelengths and performance drops off. The grating dispersion characteristics, however, lend themselves to compact systems utilizing small detector arrays. In addition, the transmission gratings are relatively insensitive to the polarization of the incident light and are very forgiving of some types of grating alignment errors.



REPLICATED GRATINGS

Choosing a Diffraction Grating

Factors in Selecting a Thorlabs Grating
Selection of a grating requires consideration of a number of factors, some of which are listed below.

Efficiency: In general, ruled gratings have a higher efficiency than holographic gratings. Applications such as fluorescence excitation and other radiation-induced reactions may require a ruled grating.

Blaze Wavelength: Ruled gratings with a "sawtooth" groove profile have a relatively sharp efficiency peak around their blaze wavelength, while some holographic gratings have a flatter spectral response. Applications centered around a narrow wavelength range could benefit from a ruled grating blazed at that wavelength.

Wavelength Range: The spectral range covered by a grating is dependent on groove spacing and is the same for ruled and holographic gratings having the same grating constant. As a rule of thumb, the first order efficiency of a grating decreases by 50% at $0.66\lambda_B$ and $1.5\lambda_B$, where λ_B is the blaze wavelength. Note: No grating can diffract a wavelength that is greater than 2 times the groove period.

Stray Light: For applications such as Raman spectroscopy, where signal-to-noise is critical, the inherent low stray light of a holographic grating is an advantage.

Resolving Power: The resolving power of a grating is a measure of its ability to spatially separate two wavelengths. It is determined by applying the Rayleigh criteria to the diffraction maxima; two wavelengths are resolvable when the maxima of one wavelength coincides with the minima of the second wavelength. The chromatic resolving power (R) is defined by $R = \lambda/\Delta\lambda = nN$, where $\Delta\lambda$ is the resolvable wavelength difference, n is the diffraction order, and N is the number of grooves illuminated.

Diffraction Grating Quick Reference

Custom Grating Sizes Available

Ruled

These replicated, ruled diffraction gratings are offered in a variety of sizes and blaze angles. Ruled gratings typically can achieve higher efficiencies than holographic gratings due to their blaze angles. Efficiency curves for all of these gratings are shown on the following pages to aid in selection of the appropriate grating.

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Holographic

These gratings do not suffer from the periodic errors that can occur in ruled gratings, and hence, ghosted images are nonexistent. Particularly in applications like Raman spectroscopy, where signal to noise is critical, the inherent low stray light of holographic gratings is an advantage. Thorlabs offers these gratings with spacings up to 3600 lines/mm.

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Echelle

These gratings are special low period gratings designed for use in the high orders. They are generally used with a second grating or prism to separate overlapping diffracted orders. The resolution of an Echelle grating built on a precision glass substrate is typically 80-90% of the maximum theoretical resolution, which makes them ideal for high resolution spectroscopy.

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Transmission

Transmission gratings allow for simple linear (source -> grating -> detector) optical designs that can bebeneficial in making compact fixed grating applications such as spectrographs. In addition, the performance of transmission gratings is insensitive to some types of grating alignment errors. Transmission and reflection gratings have comparable efficiencies, which can be optimized for a specific spectral region by selecting the appropriate groove spacing and blaze angle. Transmission gratings are relatively insensitive to the polarization of the incident light. Thorlabs offers gratings optimized for UV, near IR, and visible applications.

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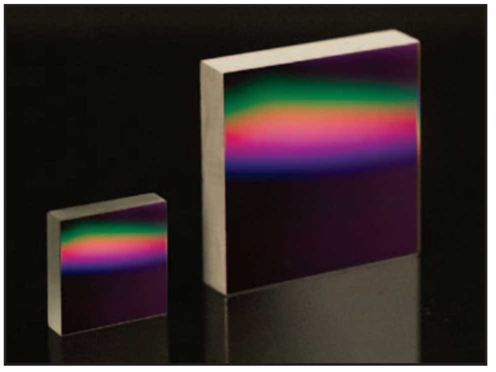
HANDLING OF GRATINGS
The surface of a diffraction grating can be easily damaged by fingerprints, aerosols, moisture, or the slightest contact with any abrasive material. Gratings should only be handled when necessary and always held by the sides. Latex gloves or a similar protective covering should be worn to prevent transfer of oil from fingers to the grating surface.

Any attempt to clean a grating with a solvent voids the warranty. No attempt should be made to clean a grating other than blowing off dust with clean, dry air or nitrogen. Scratches or other minor cosmetic imperfections on the surface of a grating do not usually affect performance and are not considered defects.

Holographic Diffraction Gratings



Holographic gratings do not suffer from the periodic errors that can occur in ruled gratings, and thus, ghosted images are nonexistent. Particularly in applications like Raman spectroscopy, where signal to noise is critical, the inherent low stray light of holographic gratings is an advantage. Thorlabs offers these gratings with spacings from 600-3600 lines/mm.

Highlights

- Free From Random Spacing Errors (Virtually Eliminates Ghosting)
- Versions Optimized for the UV or Visible Spectrum
- Reflection Efficiency is Relatively Independent of Angle of Incidence Compared to Ruled Gratings.

Specifications

- **Efficiencies:** 45-65% at peak λ (in Littrow)
- **Dimensional Tolerances:** ±0.5mm
- **Damage Threshold:** 350mJ/cm² at 200ns (Pulsed); 40W/cm² (CW)

ITEM#	GROOVES (lines/mm)	DISPERSION (nm/mrad)	OPTIMUM EFFICIENCY	SIZE	$	£	€	RMB
GH13-06U	600	1.67@250nm	UV Optimized	12.7 x 12.7 x 6mm	$ 78.00	£ 49.10	€ 72,50	¥ 744.90
GH13-10U	1000	0.99@250nm	UV Optimized	12.7 x 12.7 x 6mm	$ 78.00	£ 49.10	€ 72,50	¥ 744.90
GH13-12U	1200	0.82@250nm	UV Optimized	12.7 x 12.7 x 6mm	$ 78.00	£ 49.10	€ 72,50	¥ 744.90
GH13-12V	1200	0.79@500nm	VIS Optimized	12.7 x 12.7 x 6mm	$ 78.00	£ 49.10	€ 72,50	¥ 744.90
GH13-18U	1800	0.54@250nm	UV Optimized	12.7 x 12.7 x 6mm	$ 78.00	£ 49.10	€ 72,50	¥ 744.90
GH13-18V	1800	0.50@500nm	VIS Optimized	12.7 x 12.7 x 6mm	$ 78.00	£ 49.10	€ 72,50	¥ 744.90
GH13-24U	2400	0.40@250nm	UV Optimized	12.7 x 12.7 x 6mm	$ 78.00	£ 49.10	€ 72,50	¥ 744.90
GH13-24V	2400	0.33@500nm	VIS Optimized	12.7 x 12.7 x 6mm	$ 78.00	£ 49.10	€ 72,50	¥ 744.90
GH13-36U	3600	0.25@250nm	UV Optimized	12.7 x 12.7 x 6mm	$ 78.00	£ 49.10	€ 72,50	¥ 744.90
GH25-06U	600	1.67@250nm	UV Optimized	25 x 25 x 6mm	$ 124.80	£ 78.60	€ 116,10	¥ 1,191.80
GH25-10U	1000	0.99@250nm	UV Optimized	25 x 25 x 6mm	$ 124.80	£ 78.60	€ 116,10	¥ 1,191.80
GH25-12U	1200	0.82@250nm	UV Optimized	25 x 25 x 6mm	$ 124.80	£ 78.60	€ 116,10	¥ 1,191.80
GH25-12V	1200	0.79@500nm	VIS Optimized	25 x 25 x 6mm	$ 124.80	£ 78.60	€ 116,10	¥ 1,191.80
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GH25-24U	2400	0.40@250nm	UV Optimized	25 x 25 x 6mm	$ 124.80	£ 78.60	€ 116,10	¥ 1,191.80
GH25-24V	2400	0.33@500nm	VIS Optimized	25 x 25 x 6mm	$ 124.80	£ 78.60	€ 116,10	¥ 1,191.80
GH25-36U	3600	0.25@250nm	UV Optimized	25 x 25 x 6mm	$ 124.80	£ 78.60	€ 116,10	¥ 1,191.80
GH50-06U	600	1.67@250nm	UV Optimized	50 x 50 x 9.5mm	$ 286.00	£ 180.20	€ 266,00	¥ 2,731.30
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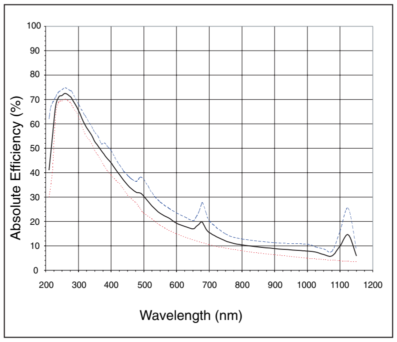
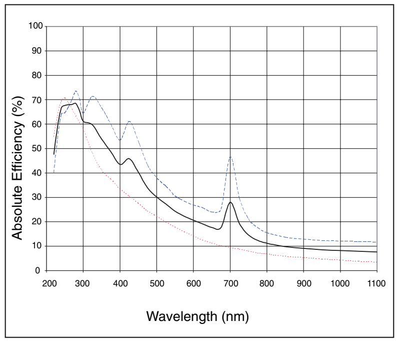
Holographic Diffraction Gratings

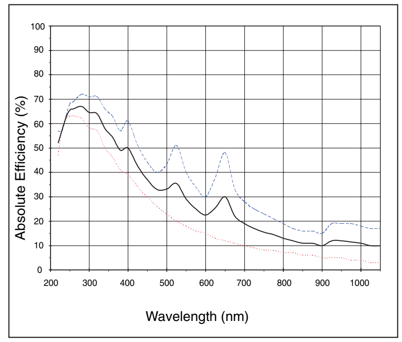
See our web site for large format plots.



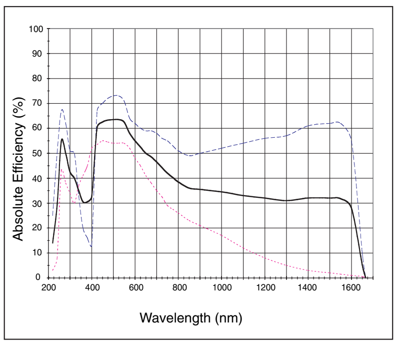
600 grooves/mm Optimized for the UV



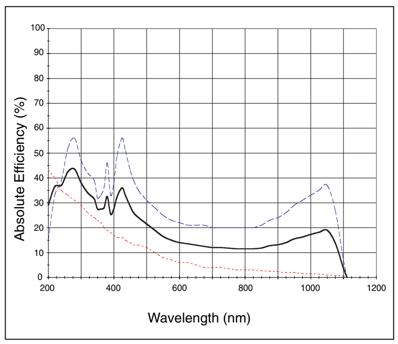
1000 grooves/mm Optimized for the UV



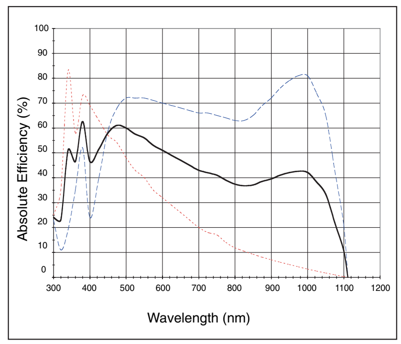
1200 grooves/mm Optimized for the UV



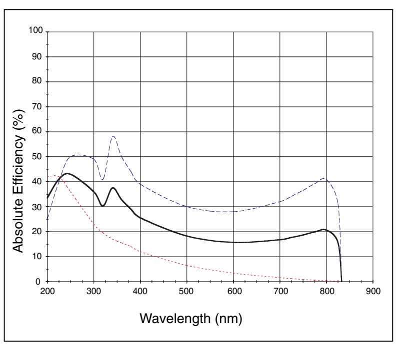
1200 grooves/mm Optimized for the Visible



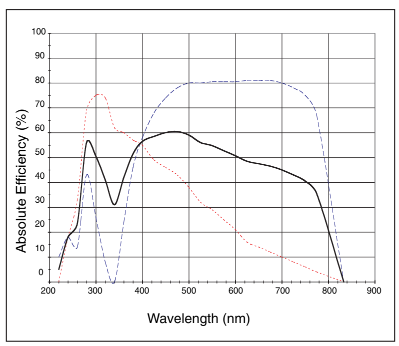
1800 grooves/mm Optimized for the UV



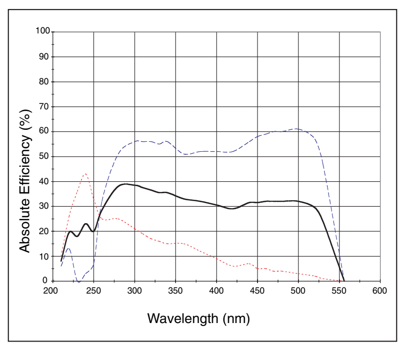
1800 grooves/mm Optimized for the Visible



2400 grooves/mm Optimized for the UV



2400 grooves/mm Optimized for the Visible



3600 grooves/mm Optimized for the UV

- - - - Perpendicular Polarization
.... Parallel Polarization
—— Average

Efficiency Curve Key

* All gratings are measured in the Littrow mounting configuration

* All gratings utilize an aluminum (Al) reflective coat

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Optical Systems
Free Space Isolators
E-O Devices
Spherical Singlets
Multi-Element Lenses
Cylindrical Lenses
Aspheric Lenses
Mirrors
Diffusers & Lens Arrays
Windows
Prisms
Gratings
Polarization Optics
Beamsplitters
Filters & Attenuators
Gas Cells

Parameters of Diffraction Gratings

Efficiency

Grating efficiency can be expressed as either absolute efficiency or relative efficiency. The absolute efficiency of a grating is the percentage of incident monochromatic radiation on a grating that is diffracted into the desired order. This efficiency is determined by both the groove profile (blaze) and the reflectivity of the grating's coating. In contrast, relative (or groove) efficiency compares the energy diffracted into the desired order with the energy reflected by a plane mirror coated with the same material as the grating. All efficiency curves in this catalog are expressed as absolute.

Blaze Angle and Wavelength

The grooves of a ruled grating have a sawtooth profile with one side longer than the other. The angle made by a groove's longer side and the plane of the grating is the "blaze angle". Changing the blaze angle concentrates the diffracted radiation of a specific region of the spectrum, increasing the efficiency of the grating in that spectral region. The wavelength at which maximum efficiency occurs is the blaze wavelength. Holographic gratings are generally less efficient than ruled gratings because they cannot be blazed in the classical sense. There are also special cases (e.g. when the spacing to wavelength ratio is near one) where a sinusoidal grating has virtually the same efficiency as a ruled grating. A holographic grating with 1800 lines/mm can have the same efficiency at 500nm as a blazed, ruled grating.

Resolving Power:

The resolving power of a grating is the product of the diffracted order in which it is used and the number of grooves illuminated by the incident radiation. It can also be expressed in terms of grating width, groove spacing, and diffracted angles. Resolving power is a property of the grating, and therefore, unlike resolution, it is not dependent on the optical and mechanical characteristics of the system in which it is used.

System Resolution

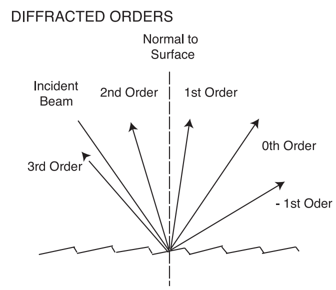
The resolution of an optical system, usually determined by examination of closely spaced absorption or emission lines for adherence to the Rayleigh criteria ($R = \lambda/\Delta\lambda$), depends not only on the grating resolving power but also on focal length, slit size, f number, the optical quality of all components, and system alignment. The resolution of an optical system is usually much less than the resolving power of the grating.

Dispersion

Angular dispersion of a grating is a function of the angles of incidence and diffraction, the latter of which is dependent upon groove spacing. Angular dispersion can be increased by increasing the angle of incidence or by decreasing the distance between successive grooves. A grating with a large angular dispersion can produce good resolution in a compact optical system. Angular dispersion is the slope of the curve given by $\lambda = f(\theta)$. In auto collimation, the equation for dispersion is given by

$$\frac{d\lambda}{d\theta} = \frac{\lambda}{2 \tan \theta}.$$

This formula may be used to determine the angular separation of two spectral lines or the bandwidth that will be passed by a slit subtending a given angle at the grating.



Diffracted Orders

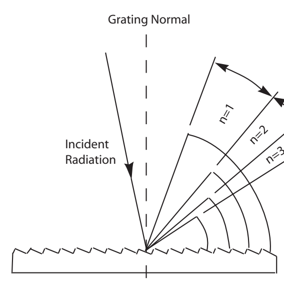
For a given set of angles (θ, θ') and groove spacing, the grating equation is valid at more than one wavelength, giving rise to several "orders" of diffracted radiation.

Constructive interference of diffracted radiation from adjacent grooves occurs when a ray is in phase but retarded by a whole integer number of wavelengths. The number of orders produced is limited by the groove spacing and the angle of incidence, which naturally cannot exceed 90°. At higher orders, efficiency and free spectral range decrease while angular dispersion increases. Order overlap can be compensated for by the judicious use of sources, detectors, and filters and is not a major problem in gratings used in low orders.

Free Spectral Range

Free spectral range is the maximum spectral bandwidth that can be obtained in a specified order without spectral interference (overlap) from adjacent orders. As grating spacing decreases, the free spectral range increases. It decreases with higher orders. If λ_1 and λ_2 are the lower and upper limits, respectively, of the band of interest, then

$$\text{Free Spectral Range} = \lambda_2 - \lambda_1 = \lambda_1/n.$$



Ghosts and Stray Light

Ghosts are defined as spurious spectral lines arising from periodic errors in groove spacing. Interferometrically controlled ruling engines minimize ghosts, while the holographic process eliminates them.

On ruled gratings, stray light originates from random errors and irregularities of the reflecting surfaces. Holographic gratings generate less stray light because the optical process, which transfers the interference pattern to the photoresist, is not subject to mechanical irregularities or inconsistencies.

Sizes

Gratings are available in several standard square and rectangular sizes ranging from 12.5mm square up to 50mm square. Non-standard sizes are available upon request. Unless otherwise specified, rectangular gratings are cut with grooves parallel to the short dimension.