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Diffraction gratings, either transmissive or reflective, can separate different wavelengths of light using a repetitive structure embedded within the grating. The structure affects the amplitude and/or phase of the incident wave, causing interference in the output wave. In the transmissive case, the repetitive structure can be thought of as many tightly spaced, thin slits. Solving for the irradiance as a function wavelength and position of this multi-slit situation, we get a general expression that can be applied to all diffractive gratings when $\theta_i = 0°$,

$$a \sin(\theta_m) = m\lambda \quad (1)$$

known as the *grating equation*. The equation states that a diffraction grating with spacing a will deflect light at discrete angles (θ_m), dependent upon the value $m\lambda$, where m is the order of principal maxima. The diffracted angle, θ_m, is the output angle as measured from the surface normal of the diffraction grating. It is easily observed from Eq. 1 that for a given order m, different wavelengths of light will exit the grating at different angles. For white light sources, this corresponds to a continuous, angle-dependent spectrum.

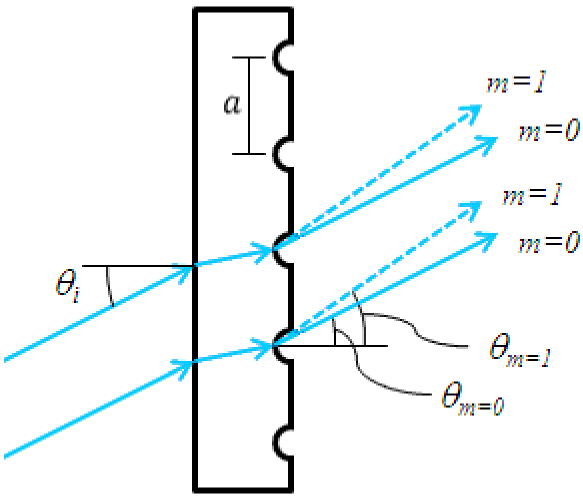


Figure 1. Transmission Grating

Transmission Gratings

One popular style of grating is the transmission grating. The sample diffraction grating with surfaces grooves shown in Figure 1 is created by scratching or etching a transparent substrate with a repetitive series of narrow-width grooves separated by distance a. This creates areas where light can scatter.

The incident light impinges on the grating at an angle θ_i, as measured from the surface normal. The light of order m exiting the grating leaves at an angle of θ_m, relative to the surface normal. Utilizing some geometric conversions and the general grating expression (Eq. 1) an expression for the transmissive diffraction grating can be found:

$$a\,[\sin(\theta_m) - \sin(\theta_i)] = m\lambda \quad (2)$$

where both θ_i and θ_m are positive if the incident and diffracted beams are on opposite sides of the grating surface normal, as illustrated in the example in Figure 1. If they are on the same side of the grating normal, θ_m must then be considered negative.

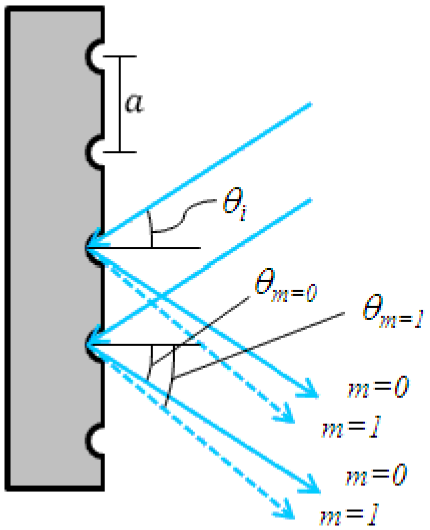


Figure 2. Reflective Grating

Reflective Gratings

Another very common diffractive optic is the reflective grating. A reflective grating is traditionally made by depositing a metallic coating on an optic and ruling parallel grooves in the surface. Reflective gratings can also be made of epoxy and/or plastic imprints from a master copy. In all cases, light is reflected off of the ruled surface at different angles corresponding to different orders and wavelengths. An example of a reflective grating is shown in Figure 2. Using a similar geometric setup as above, the grating equation for reflective gratings can be found:

$$a\,[\sin(\theta_m) + \sin(\theta_i)] = m\lambda \quad (3)$$

where θ_i is positive and θ_m is negative if the incident and diffracted beams are on opposite sides of the grating surface normal, as illustrated in the example in Figure 2. If the beams are on the same side of the grating normal, then both angles are considered positive.

Both the reflective and transmission gratings suffer from the fact that the zeroth order mode contains no diffraction pattern and appears as a surface reflection or transmission, respectively. Solving Eq. 2 for this condition, $\theta_i = \theta_m$, we find the only solution to be m=0, independent of wavelength or diffraction grating spacing. At this condition, no wavelength-dependent information can be obtained, and all the light is lost to surface reflection or transmission.

This issue can be resolved by creating a repeating surface pattern, which produces a different surface reflection geometry. Diffraction gratings of this type are commonly referred to as blazed (or ruled) gratings. More information about this can be found in the section below.

Blazed (Ruled) Gratings

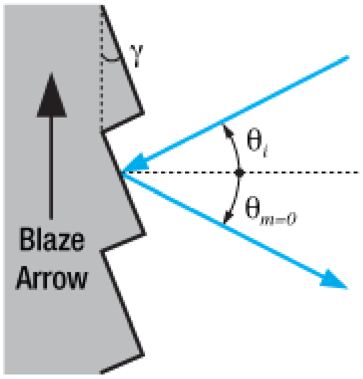


Figure 4. Blazed Grating, 0th Order Reflection

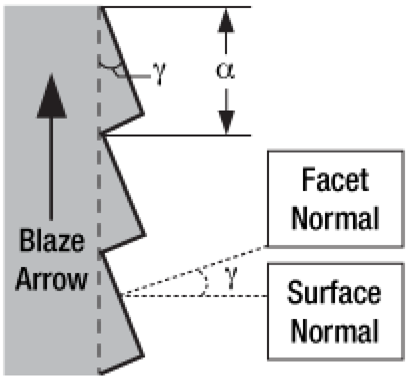


Figure 3. Blazed Grating Geometry

The blazed grating, also known as the echelette grating, is a specific form of reflective or transmission diffraction grating designed to produce the maximum grating

efficiency in a specific diffraction order. This means that the majority of the optical power will be in the designed diffraction order while minimizing power lost to other orders (particularly the zeroth). Due to this design, a blazed grating operates at a specific wavelength, known as the blaze wavelength.

The blaze wavelength is one of the three main characteristics of the blazed grating. The other two, shown in Figure 3, are a, the groove or facet spacing, and γ, the blaze angle. The blaze angle γ is the angle between the surface structure and the surface parallel. It is also the angle between the surface normal and the facet normal.

The blazed grating features geometries similar to the transmission and reflection gratings discussed thus far; the incident angle (θ_i) and m^{th} order reflection angles (θ_m) are determined from the surface normal of the grating. However, the significant difference is the specular reflection geometry is dependent on the blaze angle, γ, and NOT the grating surface normal. This results in the ability to change the diffraction efficiency by only changing the blaze angle of the diffraction grating.

The 0^{th} order reflection from a blazed grating is shown in Figure 4. The incident light at angle θ_i is reflected at θ_m for m = 0. From Eq. 3, the only solution is $\theta_i = -\theta_m$. This is analogous to specular reflection from a flat surface.

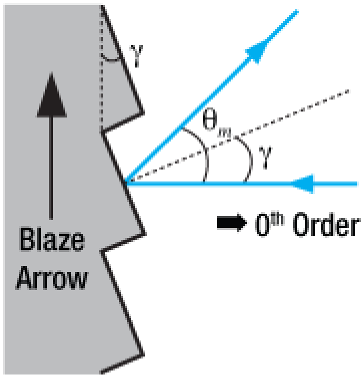


Figure 6. Blazed Grating, Incident Light Normal to Grating Surface

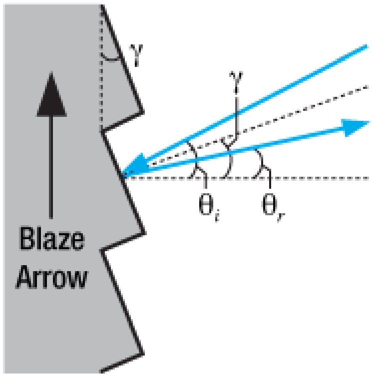


Figure 5. Blazed Grating, Specular Reflection from Facet

The specular reflection from the blazed grating is different from the flat surface due to the surface structure, as shown in Figure 5. The specular reflection, θ_r, from a blazed grating occurs at the blaze angle geometry. This angle is defined as being negative if it is on the same side of the grating surface normal as θ_i. Performing some simple geometric conversions, one finds that

$$\theta_i - \theta_r = 2\gamma \quad (4)$$

Figure 6 illustrates the specific case where $\theta_i = 0°$, hence the incident light beam is perpendicular to the grating surface. In this case, the 0th order reflection also lies at 0°. Utilizing Eqs. 3 and 4, we can find the grating equation at twice the blaze angle:

$$a \sin(-2\gamma) = m\lambda \quad (5)$$

Littrow Configuration for Reflective Gratings

The Littrow configuration refers to a specific geometry for blazed gratings and plays an important role in monochromators and spectrometers. It is the angle θ_i at which the grating efficiency is the highest. In this configuration, the angle of incidence of the incoming and diffracted light are the same, $\theta_i = \theta_m$, and $m > 0$ so

$$2a \sin(\theta_L) = m\lambda_D \quad (6)$$

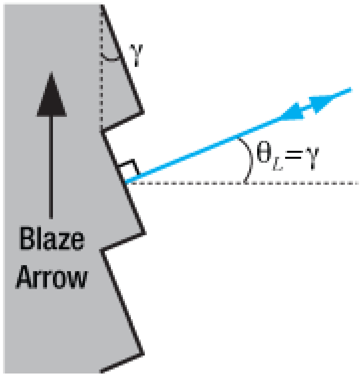


Figure 7. Littrow Configuration

The Littrow configuration angle, θ_L, is dependent on the most intense order (m = 1), the design wavelength, λ_D, and the grating spacing a. It is easily shown that the Littrow configuration angle, θ_L, is equal to the blaze angle, γ, at the design wavelength. The Littrow / blaze angles for all Thorlabs' Blazed Gratings can be found in the grating specs tables.

$$\theta_L = \gamma \quad (7)$$

It is easily observed that the wavelength dependent angular separation increases as the diffracted order increases for light of normal incidence (for θ_i = 0°, θ_m increases as m increases). There are two main drawbacks for using a higher order diffraction pattern over a low order one: (1) a decrease in efficiency at higher orders and (2) a decrease in the free spectral range, $(\Delta\lambda)_{FSR}$, defined as:

$$(\Delta\lambda)_{FSR} = \frac{\lambda}{m} \quad (8)$$

where λ is the central wavelength, and m is the order.

The first issue with using higher order diffraction patterns is solved by using an Echelle grating, which is a special type of ruled diffraction grating with an extremely high blaze angle and relatively low groove density. The high blaze angle is well suited for concentrating the energy in the higher order diffraction modes. The second issue is solved by using another optical element: grating, dispersive prism, or other dispersive optic, to sort the wavelengths/orders after the Echelle grating.

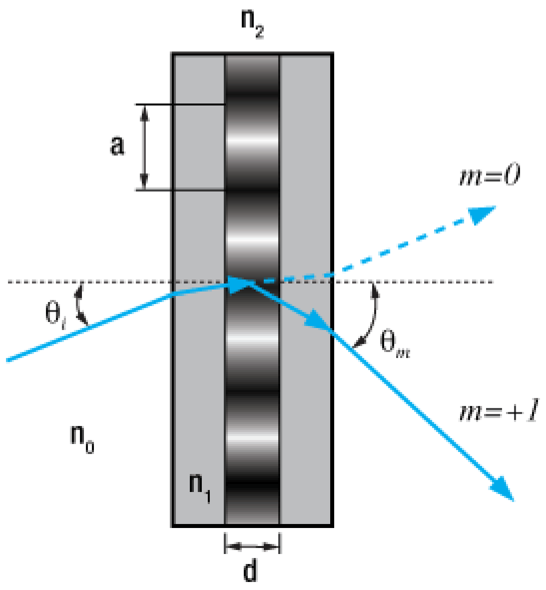


Figure 8. Volume Phase Holographic Grating

Volume Phase Holographic Transmission Gratings

Unlike traditional gratings, volume phase holographic (VPH) gratings do not have surface grooves. Instead, VPH gratings consist of a dichromated gelatin (DCG) film between two glass substrates. These VPH gratings are designed to reduce the periodic errors that can occur in blazed gratings. Surface gratings with high groove density also have an issue with polarization dependent loss. These unique transmission gratings deliver high first-order diffraction peak efficiency, low polarization dependence, and uniform performance over broad bandwidths.

The desired grating pattern is comprised of a repetitive series of lines separated by distance a. The fringe planes for transmission gratings are perpendicular to the plane of the plate as seen in Figure 8, allowing any frequency of light to pass through the plate. Diffraction occurs as incoming light crosses through the DCG film. Therefore, the three major factors that determine performance are film thickness, bulk index (the average index of refraction between Bragg planes), and index modulation (the difference of index of refraction between the Bragg planes). The incident light enters the grating at an angle of θ_i, as measured from the surface normal. The light of order m exiting the grating leaves at an angle of θ_m, relative to the surface normal. The grating expression mentioned above can be used to calculate diffraction angles for volume phase holographic gratings since dispersion is based on the line density. The quality of the grating is determined by the fringe contrast, with a poor fringe contrast resulting in low efficiency or no grating at all.

The DCG film is taken through multiple quality control steps to ensure it performs up to standard and then cut into the desired size. The film is sealed between two glass covers to prevent degradation of the material. Since the DCG film is contained between two glass substrates, VPH gratings have high durability and long lifetimes, as well as easy maintenance compared to other gratings that can be easily damaged.

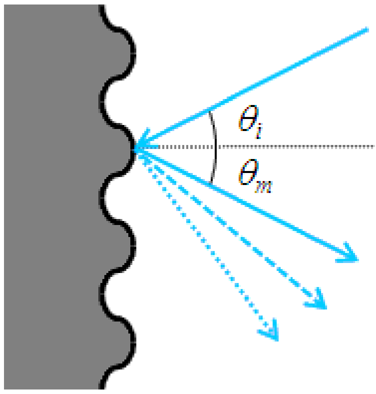


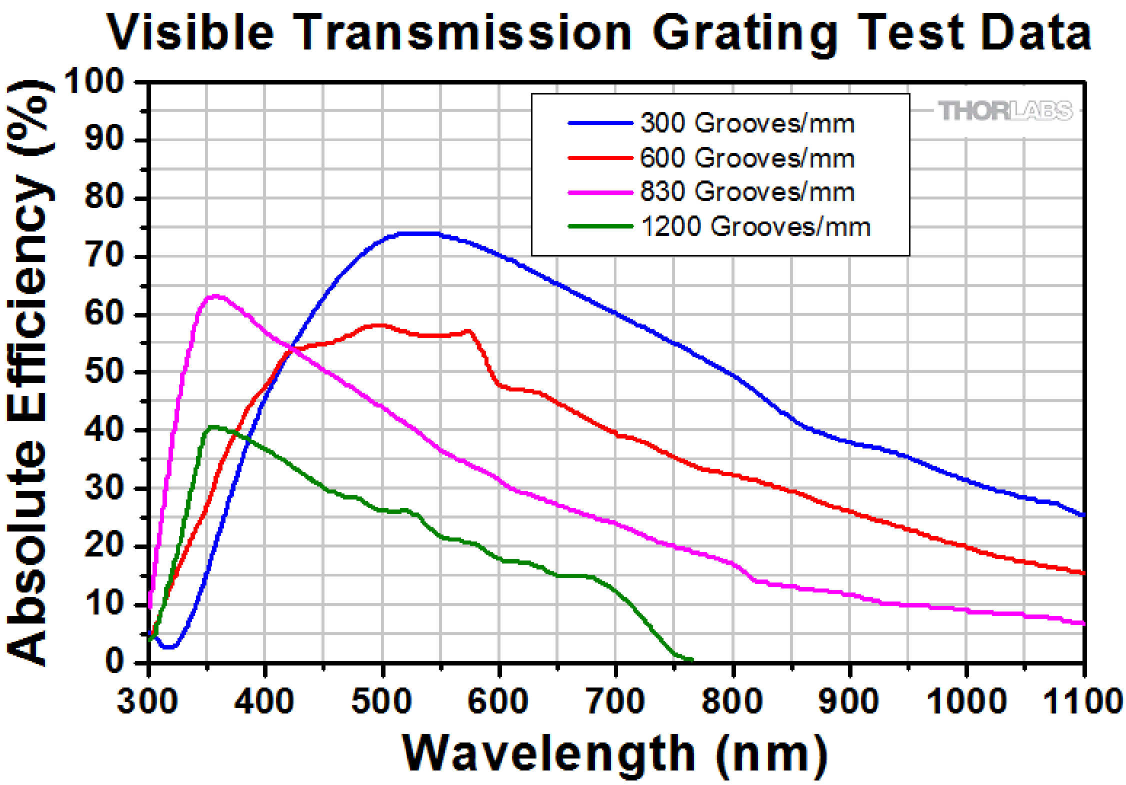
Figure 9. Holographic Grating

Holographic Surface Reflective Gratings

While blazed gratings offer extremely high efficiencies at the design wavelength, they suffer from periodic errors, such as ghosting, and relatively high amounts of scattered light, which could negatively affect sensitive measurements. Holographic gratings are designed specially to reduce or eliminate these errors. The drawback of holographic gratings compared to blazed gratings is reduced efficiency.

Holographic gratings are made from master gratings by similar processes to the ruled grating. The master holographic gratings are typically made by exposing photosensitive material to two interfering laser beams. The interference pattern is exposed in a periodic pattern on the surface, which can then be physically or chemically treated to expose a sinusoidal surface pattern. An example of a holographic grating is shown in Figure 9.

Please note that dispersion is based solely on the number of grooves per mm and not the shape of the grooves. Hence, the same grating equation can be used to calculate angles for holographic as well as ruled blazed gratings.



Transmission gratings require relatively low groove densities to maintain high efficiency. As the diffraction angles increase with higher groove densities, the refractive properties of the substrate material limits the transmission at the higher wavelengths and performance drops off. The grating dispersion characteristics, however, lend themselves to compact systems utilizing small detector arrays. These gratings are also relatively polarization insensitive. Our visible transmission gratings are offered with four different groove densities in three different sizes. Please see the *Gratings Guide* tab to choose the right grating type for your application.

Optical gratings can be easily damaged by moisture, fingerprints, aerosols, 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 oil from fingers from reaching the grating surface. No attempt should be made to clean a grating other than blowing off dust with clean, dry air or nitrogen. Solvents will likely damage the grating's surface.

Selecting a grating requires consideration of a number of factors, some of which are listed below:

Efficiency:

Ruled gratings generally have a higher efficiency than holographic gratings. Holographic grating tend to have a lower efficiency but a broader effective wavelength range. The efficiency of ruled gratings may be desirable in applications such as fluorescence excitation and other radiation-induced reactions.

Blaze Wavelength:

Ruled gratings have a sawtooth groove profile created by sequentially etching the surface of the grating substrate. As a result, they have a sharp peak efficiency around their blaze wavelength. Holographic gratings are harder to blaze, and tend to have a sinusoidal groove profile resulting in a less intense peak around the design wavelength. Applications centered around a narrow wavelength range could benefit from a ruled grating blazed at that wavelength.

Stray Light:

Due to a difference in how the grooves are made, holographic gratings have less stray light than ruled gratings. The grooves on a ruled grating are machined one at a time which results in a higher frequency of errors. Holographic gratings are made through a lithographic process, which generally creates smoother grating masters free of tool marks. Replicants made from these masters exhibit less stray light. Applications such as Raman spectroscopy, where signal-to-noise is critical, can benefit from the limited stray light of the holographic grating.

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 $R = \lambda/\Delta\lambda = n*N$, where $\Delta\lambda$ is the resolvable wavelength difference, n is the diffraction order, and N is the number of grooves illuminated. Due to their low groove density, Echelle gratings provide high resolving power.

Polarization Dependence:

Surface gratings that have high groove densities also have an issue with polarization dependent loss, often with significantly lower efficiency when exposed to parallel- versus perpendicularly-polarized light. Volume phase holographic gratings are designed for applications that require low polarization dependent loss at higher spatial frequencies.

For further information about gratings and selecting the grating right for your application, please visit our Gratings Tutorial.

Caution for Gratings with Surface Grooves:

The surface of a diffraction grating with surface grooves 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 oil from fingers from reaching the grating surface. Solvents will likely damage the grating's surface. 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. Conversely, volume phase holographic gratings can be cleaned using standard optics cleaning procedures and have high durability.