Reg. No. | | | | | | | | | |

MANIPAL INSTITUTE OF TECHNOLOGY
MANIPAL
(A constituent unit of MAHE, Manipal)

SEVENTH SEMESTER B.TECH. (INSTRUMENTATION AND CONTROL ENGG.)

END SEMESTER DEGREE EXAMINATIONS, JANUARY - 2021

SUBJECT: ANALYTICAL AND OPTICAL INSTRUMENTATION [ICE 4101]

TIME: 3 HOURS | MAX. MARKS: 50

Instructions to candidates :*Answer ALL questions and missing data may be suitably assumed.*

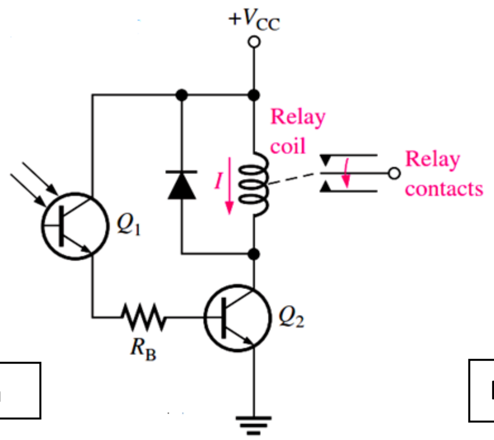
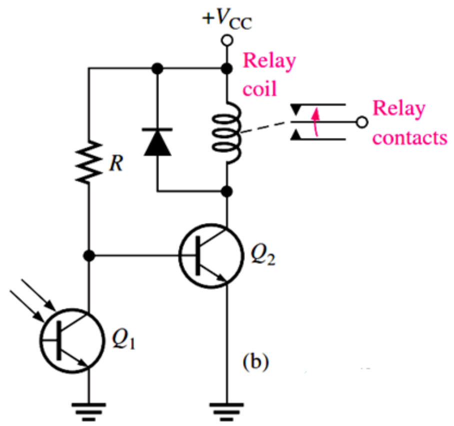
1A.	What is the likely range of bandgap (in eV) for a LED to emit red light (680 nm-740 nm). If a ruled grating GR25-1203 is placed perpendicular to this light's path, what is the angle of occurrence of first order maxima? (Refer Annex. 1)
1B.	 Fig.Q.1B.a  Fig.Q.1B.b Study the circuits Fig.Q.1B.a and Fig.Q.1B.b, and infer their mode of operation. Propose a use for each of the circuits.
1C.	The groove period of a ruled grating is 400 nm. What is the maximum wavelength that this grating may diffract? When 5000 grooves of this grating are illuminated with a monochromatic light of 530 nm, calculate the resolvable wavelength difference. (assume diffraction order as 1 and Refer Annex 1) A setting of 50 scans to average and integration time of 100 ms is used to acquire a first order binding event of time constant 1 second at a wavelength of 530 nm. Draw the absorbance response likely to be observed and comment on the settings used. If the absorbance value at t=0 is 1 and at t=10s is 2, determine the ratio of initial intensity (at t=0) to final intensity (at t=10).
	(2+4+4)
2A	The ^{1}H NMR spectrum of compound X ($C_4H_8O_2$) is shown in Fig Q2A. It also shows a strong IR absorption band near 1720 cm^{-1}. Propose a structure for X.

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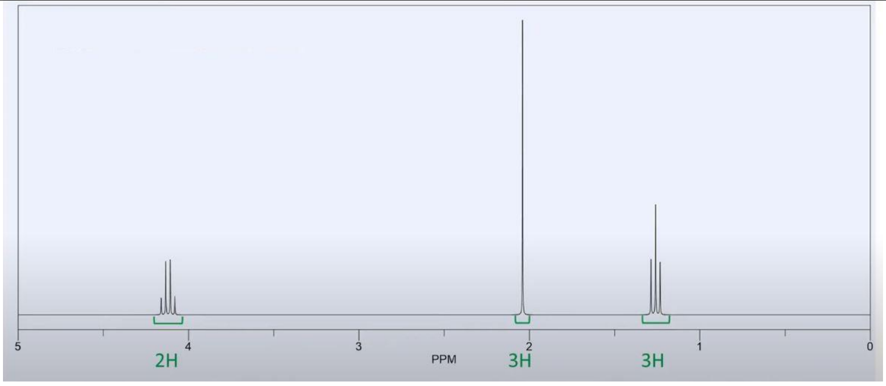
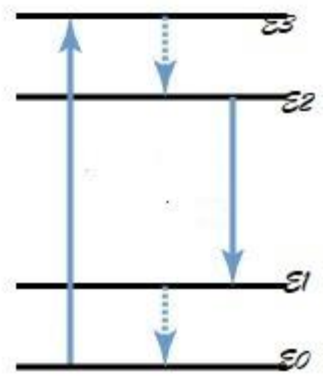
	Fig.Q.2A 
2B	With neat diagrams, explain the process of data transfer in a CMOS and CCD photodetectors. Compare the role of blooming and rolling shutter effects in the two detectors.
2C	With neat schematic explain the components of a gas chromatography system. Compare them with those of High Pressure Liquid Chromatography.
	(2+3+5)
3A	Fig.Q.3A  Fig.Q.3A shows the Energy level diagrams of a four level laser system. Discuss the lasing action and brief the significance of population inversion in lasing action.
3B	Explain the theory, principle and working of NMR spectroscopes. What is the significance of T1 and T2 relaxations while observing the NMR signal?
3C	With neat schematics explain the working of time of flight and quadrupole types of mass spectrometers. Discuss the different detectors used in mass spectroscopy.
	(2+4+4)
4A	Explain with a neat diagram, the use of a moving mirror interferometry in IR spectroscopy.
4B	Compare transmission mode and reflection mode of Holographic recordings. Which is the preferable mode to be chosen for a holographic display design?
4C	With neat diagrams explain the principles of surface plasmon resonance and localised surface plasmon resonance. Comment on the sensitivity and range of the two systems. How would you tweak the sensitivity of a LSPR system.
	(2+3+5)
5A	Why Oxygen in environment is easily measured using paramagnetic analysers? Can CO_2 be detected

	using paramagnetic analysers?
5B	With the help of schematics compare the working of Magnetic wind type gas analysers and Infrared gas analysers.
5C	Explain the different methods for the measurement of SO_2 and hydrocarbons in the environment.
	(2+3+5)

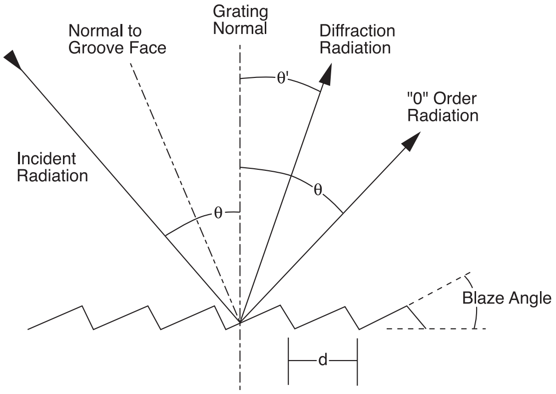
Annex-1

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

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.

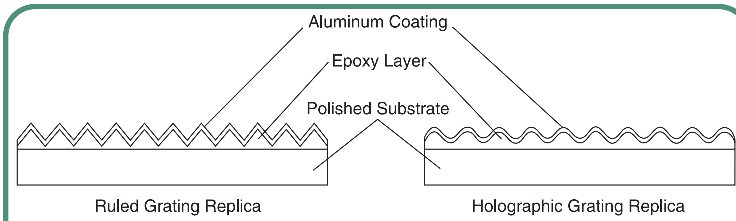
The Replication Process

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.

See Page 800

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.

See Page 802

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.

See Page 804

Transmission

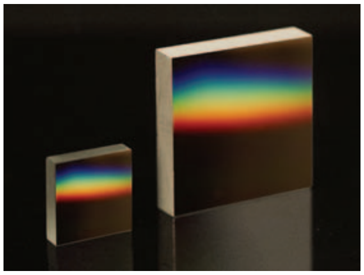
Transmission gratings allow for simple linear (source -> grating -> detector) optical designs that can bebeneficial in making compact fixed grating applications such as spectrographs. In addition, the performance of transmission gratings is insensitive to some types of grating alignment errors. Transmission 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.

See Page 805

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.

Ruled Diffraction Gratings



Highlights

- Higher Efficiencies Than Holographic Gratings
- Offered in 3 Sizes:
  12.7 x 12.7 x 6mm
  25 x 25 x 6mm
  50 x 50 x 9.5mm

Specifications

- **Efficiencies:** 60-80% at Blaze λ (in Littrow)
- **Dimensional Tolerances:** ±0.5mm
- **Ghost Intensities:** <0.5% of Parent Line
- **Damage Threshold:** 350mJ/cm^2 at 200ns (Pulsed); 40W/cm^2 (CW)

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.

ITEM#	GROOVES (lines/mm)	BLAZE λ (nm)	BLAZE ANGLE	DISPERSION (nm/mrad)	SIZE	$	£	€	RMB
GR13-0303	300	300	2° 34'	3.33	12.7 x 12.7 x 6mm	$ 60.00	£ 37.80	€ 55,80	¥ 573.00
GR13-0305	300	500	4° 18'	3.32	12.7 x 12.7 x 6mm	$ 60.00	£ 37.80	€ 55,80	¥ 573.00
GR13-0310	300	1000	8° 36'	3.30	12.7 x 12.7 x 6mm	$ 60.00	£ 37.80	€ 55,80	¥ 573.00
GR13-0603	600	300	5° 9'	1.66	12.7 x 12.7 x 6mm	$ 60.00	£ 37.80	€ 55,80	¥ 573.00
GR13-0605	600	500	8° 37'	1.65	12.7 x 12.7 x 6mm	$ 60.00	£ 37.80	€ 55,80	¥ 573.00
GR13-0608	600	750	13° 0'	1.62	12.7 x 12.7 x 6mm	$ 60.00	£ 37.80	€ 55,80	¥ 573.00
GR13-0610	600	1000	17° 27'	1.59	12.7 x 12.7 x 6mm	$ 60.00	£ 37.80	€ 55,80	¥ 573.00
GR13-0613	600	1250	22° 1'	1.55	12.7 x 12.7 x 6mm	$ 60.00	£ 37.80	€ 55,80	¥ 573.00
GR13-0616	600	1600	28° 41'	1.46	12.7 x 12.7 x 6mm	$ 60.00	£ 37.80	€ 55,80	¥ 573.00
GR13-1203	1200	300	10° 22'	0.82	12.7 x 12.7 x 6mm	$ 60.00	£ 37.80	€ 55,80	¥ 573.00
GR13-1204	1200	400	13° 53'	0.81	12.7 x 12.7 x 6mm	$ 60.00	£ 37.80	€ 55,80	¥ 573.00
GR13-1205	1200	500	17° 27'	0.80	12.7 x 12.7 x 6mm	$ 60.00	£ 37.80	€ 55,80	¥ 573.00
GR13-1208	1200	750	26° 44'	0.74	12.7 x 12.7 x 6mm	$ 60.00	£ 37.80	€ 55,80	¥ 573.00
GR13-1210	1200	1000	36° 52'	0.67	12.7 x 12.7 x 6mm	$ 60.00	£ 37.80	€ 55,80	¥ 573.00
GR13-1850	1800	500	26° 44'	0.50	12.7 x 12.7 x 6mm	$ 60.00	£ 37.80	€ 55,80	¥ 573.00
GR25-0303	300	300	2° 34'	3.33	25 x 25 x 6mm	$ 100.00	£ 63.00	€ 93,00	¥ 955.00
GR25-0305	300	500	4° 18'	3.32	25 x 25 x 6mm	$ 100.00	£ 63.00	€ 93,00	¥ 955.00
GR25-0310	300	1000	8° 36'	3.30	25 x 25 x 6mm	$ 100.00	£ 63.00	€ 93,00	¥ 955.00
GR25-0603	600	300	5° 9'	1.66	25 x 25 x 6mm	$ 100.00	£ 63.00	€ 93,00	¥ 955.00
GR25-0605	600	500	8° 37'	1.65	25 x 25 x 6mm	$ 100.00	£ 63.00	€ 93,00	¥ 955.00
GR25-0608	600	750	13° 0'	1.62	25 x 25 x 6mm	$ 100.00	£ 63.00	€ 93,00	¥ 955.00
GR25-0610	600	1000	17° 27'	1.59	25 x 25 x 6mm	$ 100.00	£ 63.00	€ 93,00	¥ 955.00
GR25-0613	600	1250	22° 1'	1.55	25 x 25 x 6mm	$ 100.00	£ 63.00	€ 93,00	¥ 955.00
GR25-0616	600	1600	28° 41'	1.46	25 x 25 x 6mm	$ 100.00	£ 63.00	€ 93,00	¥ 955.00
GR25-1203	1200	300	10° 22'	0.82	25 x 25 x 6mm	$ 100.00	£ 63.00	€ 93,00	¥ 955.00
GR25-1204	1200	400	13° 53'	0.81	25 x 25 x 6mm	$ 100.00	£ 63.00	€ 93,00	¥ 955.00
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GR25-1208	1200	750	26° 44'	0.74	25 x 25 x 6mm	$ 100.00	£ 63.00	€ 93,00	¥ 955.00
GR25-1210	1200	1000	36° 52'	0.67	25 x 25 x 6mm	$ 100.00	£ 63.00	€ 93,00	¥ 955.00
GR25-1850	1800	500	26° 44'	0.50	25 x 25 x 6mm	$ 100.00	£ 63.00	€ 93,00	¥ 955.00
GR50-0303	300	300	2° 34'	3.33	50 x 50 x 9.5mm	$ 176.00	£ 110.90	€ 163,70	¥ 1,680.80
GR50-0305	300	500	4° 18'	3.32	50 x 50 x 9.5mm	$ 176.00	£ 110.90	€ 163,70	¥ 1,680.80
GR50-0310	300	1000	8° 36'	3.30	50 x 50 x 9.5mm	$ 176.00	£ 110.90	€ 163,70	¥ 1,680.80
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GR50-0608	600	750	13° 0'	1.62	50 x 50 x 9.5mm	$ 176.00	£ 110.90	€ 163,70	¥ 1,680.80
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GR50-1850	1800	500	26° 44'	0.50	50 x 50 x 9.5mm	$ 176.00	£ 110.90	€ 163,70	¥ 1,680.80

Handling of Gratings

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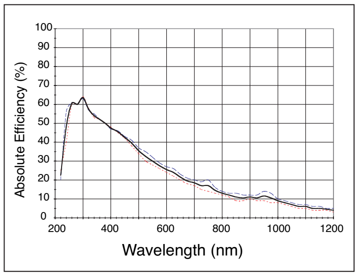
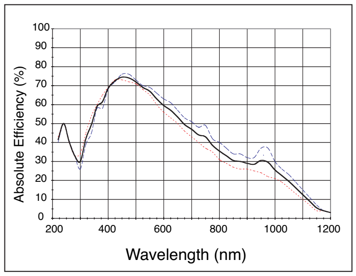
Ruled Diffraction Gratings

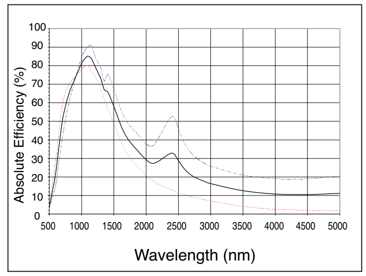
See our web site for large format plots.



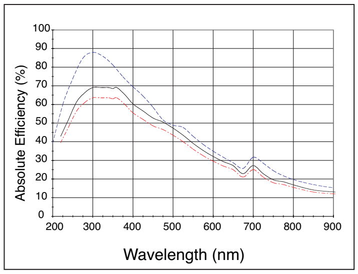
300 grooves/mm Blazed at 300 nm



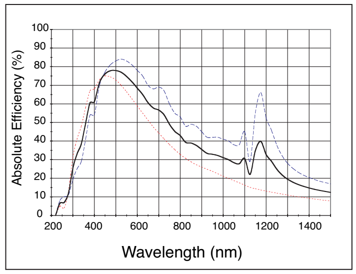
300 grooves/mm Blazed at 500 nm



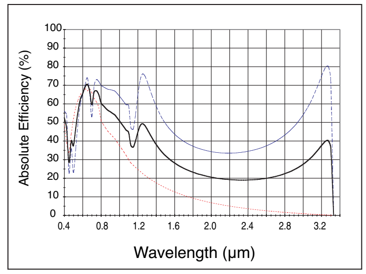
300 grooves/mm Blazed at1.0 μm



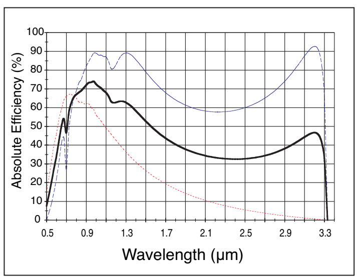
600 grooves/mm Blazed at 300 nm



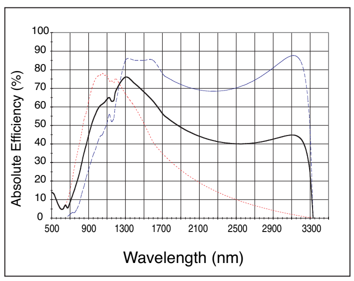
600 grooves/mm Blazed at 500 nm



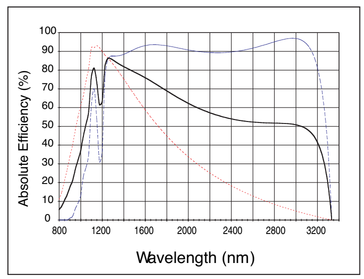
600 grooves/mm Blazed at 750 nm



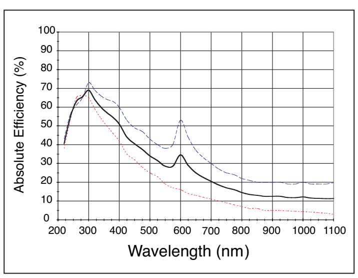
600 grooves/mm Blazed at 1.0μm



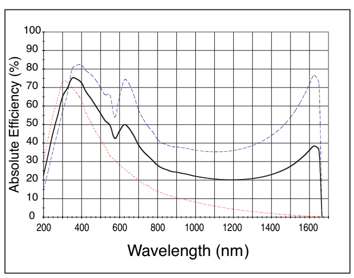
600 grooves/mm Blazed at 1.25 μm



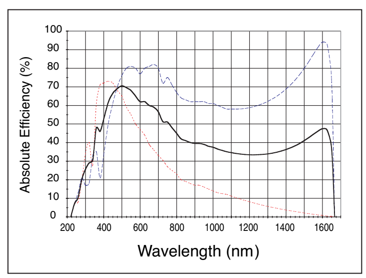
600 grooves/mm Blazed at 1.6 μm



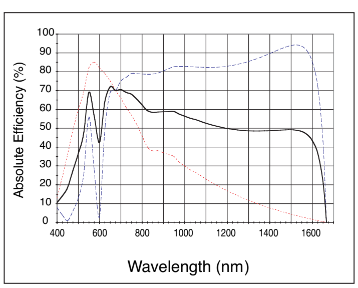
1200 grooves/mm Blazed at 300 nm



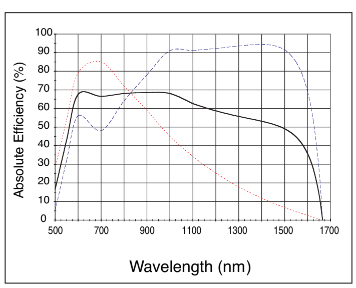
1200 grooves/mm Blazed at 400 nm



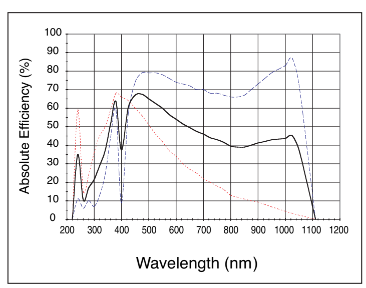
1200 grooves/mm Blazed at 500 nm



1200 grooves/mm Blazed at 750 nm



1200 grooves/mm Blazed at 1.0 μm



1800 grooves/mm Blazed at 500 nm

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

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

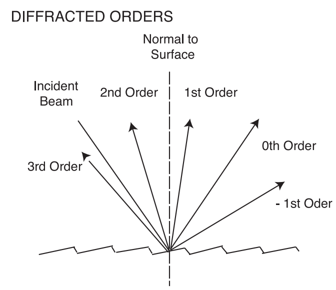
The resolution of an optical system, usually determined by examination of closely spaced absorption or emission lines for adherence to the Rayleigh criteria ($R = \lambda/\Delta\lambda$), depends not only on the grating resolving power but also on focal length, slit size, f number, the optical quality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

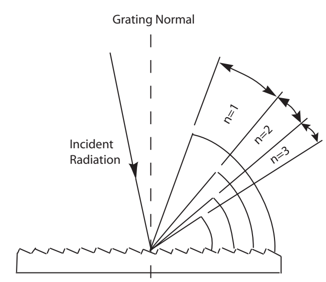
For a given set of angles (θ, θ') and groove spacing, the grating equation is valid at more than one wavelength, giving rise to several "orders" of diffracted radiation.

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.