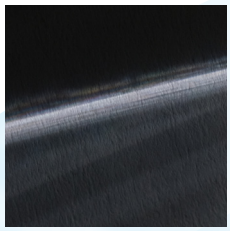
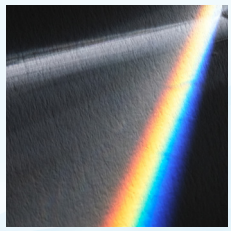
HORIBA

OSD

On-axis Diffraction Grating Rotation in HORIBA iHR Spectrometers





Technical Note OSD250101

Introduction

The HORIBA iHR series of high-resolution imaging spectrometers and spectrographs is unique among research instruments for its patented on-axis diffraction grating drive.

This design offers three benefits

1. Gratings can be used over a larger wavelength range
2. Spectra recorded over that range have higher resolution
3. Spectra recorded over that range have higher signal-to-noise ratio

On- and Off-axis Designs

Numerous manufacturers offer spectrometers with multiple-grating turrets which add flexibility and extend the useful range of the instrument. In a typical configuration, three plane gratings are mounted on a motorized turret. A software command rotates the turret to an orientation such that one of the gratings diffracts a particular wavelength at an angle determined by the grating equation

(1) $$\sin \alpha + \sin \beta = k \bullet n \bullet \lambda$$

where *k* is the diffraction order and n is the grating groove density. In this model, the angle of incidence ***α*** is fixed, and the diffracted angle ***β*** increases with wavelength. For high resolution instruments using high groove density gratings large values of ***β*** are commonplace.

Foreshortening and Beam Walkoff

Figure 1 shows that rotating the grating to a steeper angle of incidence will reduce the system throughput as foreshortening decreases the projected area of the collimated beam on the grating. Oversized gratings mitigate this effect. A more serious problem arises in instruments with off-axis grating drives. Figure 2a shows an off-axis design where the *turret* rotates around its axis. As the grating rotates to steeper angles its surface is not only foreshortened, but tends to walk off the path of the collimated beam. This walkoff not only reduces system throughput but also increases the stray light level.

The design used in HORIBA's on-axis grating drive uses a single motor combined with stop arms that allow each of the (up to) three gratings mounted on a turret to rotate about *their own optical axes*. This design eliminates grating walkoff and permits each grating to be used at steep angles not attainable in off-axis designs. The long-wavelength usable limit for a grating is determined by its maximum rotation angle, and HORIBA's design provides the longest limits available:

Mechanical wavelength limit = 1,800,000/*n* where *n* is the groove density in mm^{-1}.

This works out to an upper limit of 1000 nm with an 1800 groove/mm grating and 1500 nm with 1200 grooves/mm.

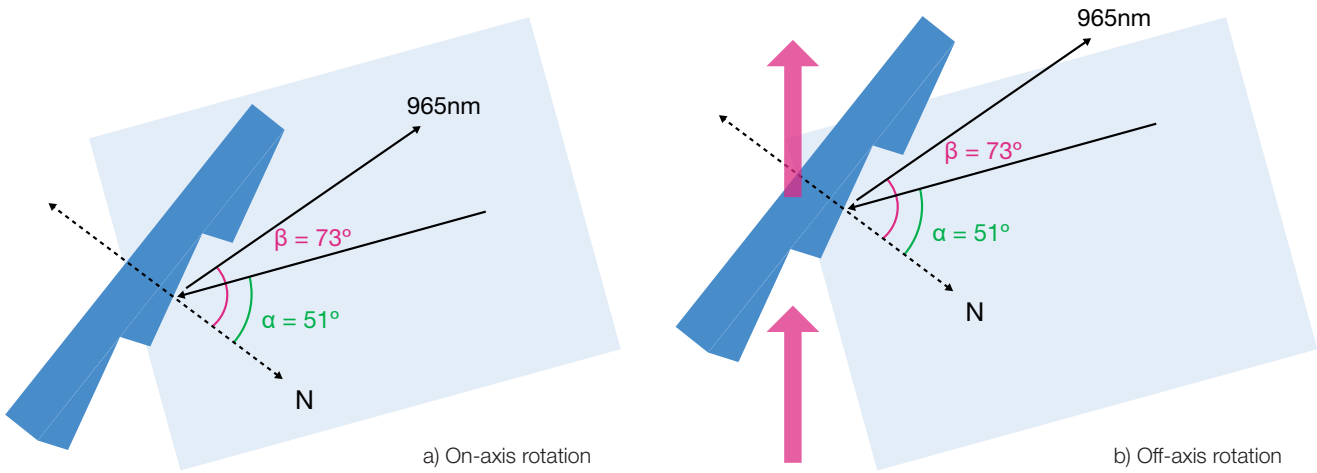


Figure 1. The on-axis design (a) ensures that more of the grating surface is illuminated at high angles than in the off-axis design (b)

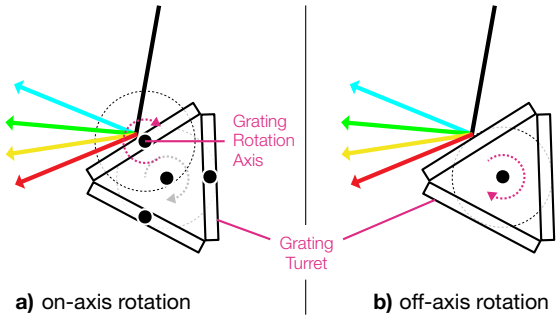


Figure 2. In the off-axis design (b) each grating rotates around the axis of the turret

How large is the walkoff effect? Clearly, different instruments will vary in their efficiency at steep angles of incidence. HORIBA measured the effect using a stable emission source in two 320 mm focal length iHR instruments equipped with an 1800 groove/mm holographic grating and an open electrode CCD camera. The spectrometers used identical components apart from the grating drive. The ratio of the signal recorded by the two instruments is plotted vs. wavelength in Figure 3.

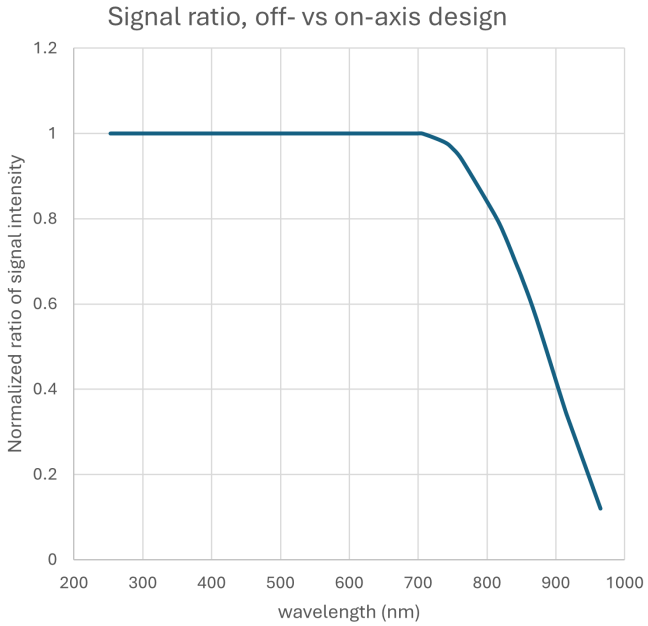


Figure 3. Off-axis vs. on-axis signal plotted vs. wavelength.

The foreshortening effect is identical for both instruments and does not affect the comparison. The walkoff effect first becomes noticeable at 700 nm, corresponding to a diffraction angle of 50°. The relative throughput of the off-axis instrument has decreased by nearly 20% at 800 nm and by 60% at 900 nm. While the instrument is still technically usable, the performance is seriously compromised. By contrast, the on-axis instrument can be used out to the design limit of 1000 nm with good efficiency, high resolution and narrow linewidth, a consequence of the asymmetric Czerny-Turner design of the iHR.

High Spectral Resolution and High Throughput

The extended wavelength range provided by a single grating in an on-axis drive spectrometer improves the user experience. For example, with an iHR 320 or 550 one can acquire a complete photoluminescence spectrum of InGaAs to 1000 nm using a single 1800 groove/mm grating. With an off-axis grating drive it would be necessary to change to a lower density grating, interrupting and complicating the acquisition.

The linear dispersion is related to groove density and diffraction angle by equation 2.

(2) $$\frac{d\lambda}{dx} = \frac{10^6 \cos\beta}{knL_B} \; nm/mm$$

The achievable spectral resolution of the system is inversely proportional to the linear dispersion, and so it increases at longer wavelengths due to the cosine term. Hence, extending the long-wavelength limit of a grating improves both the signal-to-noise ratio (by diffracting more photons) and the performance (by preserving high spectral resolution).

Off-axis Spectrometers

An off-axis grating drive is mechanically simpler and can more quickly rotate the turret to change from one grating to the next. HORIBA manufactures an off-axis OEM spectrometer for industrial use that has been tested over 1.3 million grating rotation cycles. While the off-axis design may be preferred for some industrial applications, researchers in search of the highest optical performance should use a spectrometer with an on-axis grating drive.

Conclusion

HORIBA's iHR spectrometers allow gratings to be used at steeper angles than is possible with off-axis grating drive instruments. This extends the useful range of every grating while enhancing the throughput, resolution and SNR.

References

[1] US 5767965: Apparatus and Method for Driving Diffraction Gratings

info.sci@horiba.com www.horiba.com/scientific

USA: +1 732 494 8660
UK: +44 (0)1604 542 500
China: +86 (0)21 6289 6060
Taiwan: +886 3 5600606
France: +33 (0)1 69 74 72 00
Italy: +39 06 51 59 22 1
India: +91 80 41273637
Brazil: +55 (0)11 2923 5400
Germany: +49 (0) 6172 1396 0
Japan: +81(75)313-8121
Singapore: +65 (0)6 745 8300
Other: +33 (0)1 69 74 72 00