



**HAL**  
open science

# Cylindrical Screen and Applications: Transmission Grating and Reflective Grating Experiments

Hui Peng

► **To cite this version:**

Hui Peng. Cylindrical Screen and Applications: Transmission Grating and Reflective Grating Experiments. 2022. hal-03873615

**HAL Id: hal-03873615**

**<https://hal.science/hal-03873615>**

Preprint submitted on 27 Nov 2022

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

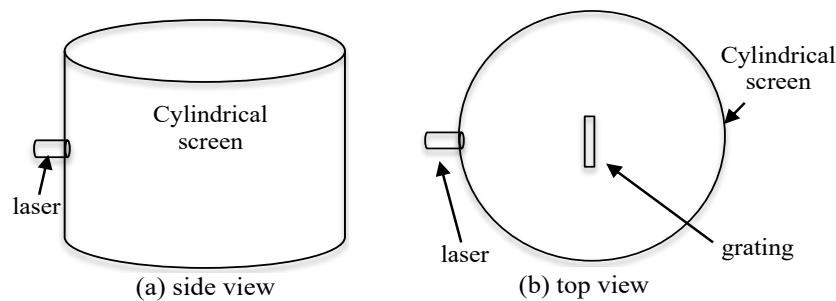
# Cylindrical Screen and Applications: Transmission Grating and Reflective Grating Experiments

Hui Peng

Email: davidpeng1749@gmail.com

## Abstract

The standard detecting screens utilized in the wave experiments, such as the transmission grating and reflective grating experiments, are planar screen. To study the orientation-dependence of the curved, expanded and inclined diffraction patterns of the grating, we proposed the cylindrical screen.



The cylindrical screen shows the location of each diffraction order of the diffraction patterns. Then the CCD can be placed at the precise location of each diffraction order to collect data. By using the cylindrical screen, two coordinates are needed to describe the curved, expanded and inclined diffraction patterns of the rotating grating. The cylindrical screen may be used to test the theories of the grating rotating around 3 axes.

**Keywords:** grating, transmission grating, reflective grating, grating experiments, diffraction pattern, oblique incident light beam, orientation-dependence, non-uniform diffraction pattern, curved diffraction pattern, expanded diffraction pattern, inclined diffraction pattern

## Content

1. Introduction
2. Cylindrical Screen: Experiment Setup and Coordinate System
3. Application (1): Cylindrical Screen Studying Transmission Grating Rotating CW and CCW
  - 3.1. Experiments: transmission grating producing both expanded horizontal transmission patterns and expanded horizontal reflective patterns simultaneously
  - 3.2. Experiments: transmission grating producing both curved vertical transmission patterns and curved vertical reflective patterns simultaneously

3.3. Experiments: transmission grating producing both expanded, curved and inclined transmission patterns and expanded, curved and inclined reflective patterns simultaneously

3.4. Discussion

4. Application (2): Cylindrical Screen Studying Reflective Grating Rotating CW and CCW

4.1. Experiments: reflective grating producing expanded horizontal patterns

4.2. Experiments: reflective grating producing curved vertical patterns

4.3. Experiments: tilt reflective grating producing expanded, curved and inclined patterns (1)

4.4. Experiments: tilt reflective grating producing expanded, curved and inclined patterns (2)

5. Summary

## 1. Introduction

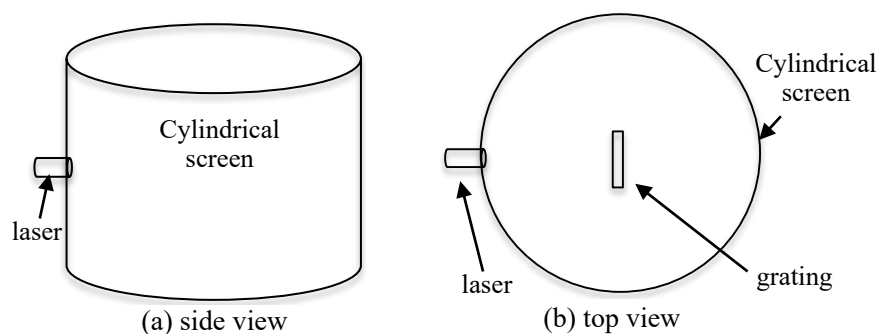
The orientation-dependence of the diffraction patterns of the 1D-transmission grating and 2D-transmission grating experiments have been studied [1-7]. The non-uniform spacing, curved, expanded and inclined diffraction patterns (denoted as “pattern”) simultaneously emerged in the same grating experiment. Indeed, the new phenomena show that the characteristics of the patterns depend on the orientations of the grating.

The textbook-screen in the grating experiments is normally a planar screen [8]. To study the orientation-dependence of the diffraction patterns of the grating, the novel cylindrical screen is proposed [9-11], which shows visually the location of each diffraction order. Thus, the CCD can be placed at the precise location to collect data without missing orders, especially those 2-dimension orders of the curved, expanded and inclined patterns. The cylindrical screen can be utilized in the transmission grating experiments and reflective grating experiments.

The cylindrical screen may be used to test the theories of the grating rotating around 3 axes [12-15].

## 2. Cylindrical Screen and Experiment Setup

We propose the cylindrical screen (Figure 1) and apply to the transmission grating experiments and the blazed reflective grating experiments.



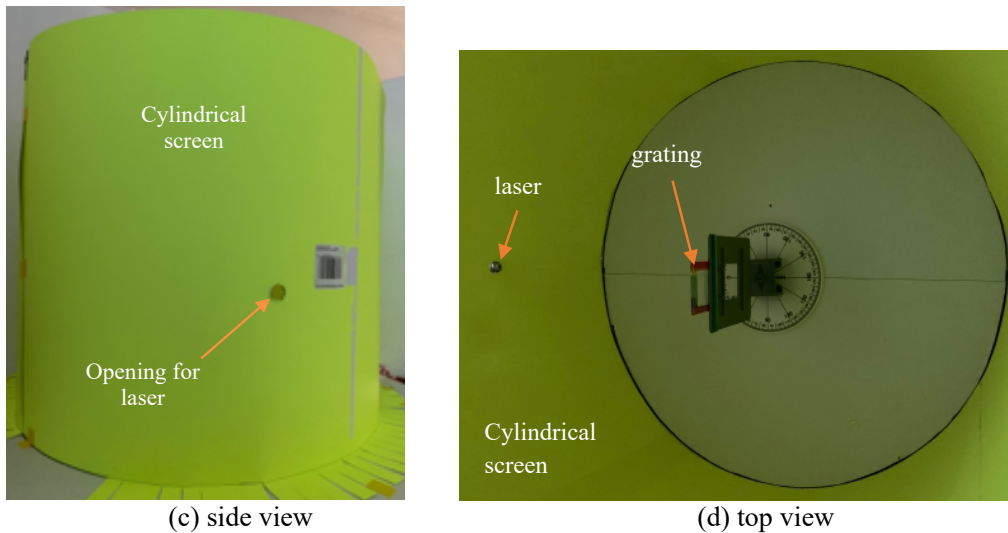


Figure 1. Experiment setup: cylindrical screen + grating + laser

Figure 1a/1c are the side view, Figure 1b/1d are the top view. There is an opening on the side-wall of the cylindrical screen for a laser source. The grating is placed at the center of the bottom of the cylindrical screen. The grating can be either the transmission grating or the reflective grating.

For the transmission grating (dual-grating) [16-18], the experiment setup is shown in Figure 2: Figure 2a is the side view, Figure 2b is the top view, Figure 2c and 2d are the top view with the CW and CCW rotating grating respectively. In Figure 2, the orange-arrows represent the laser beam.

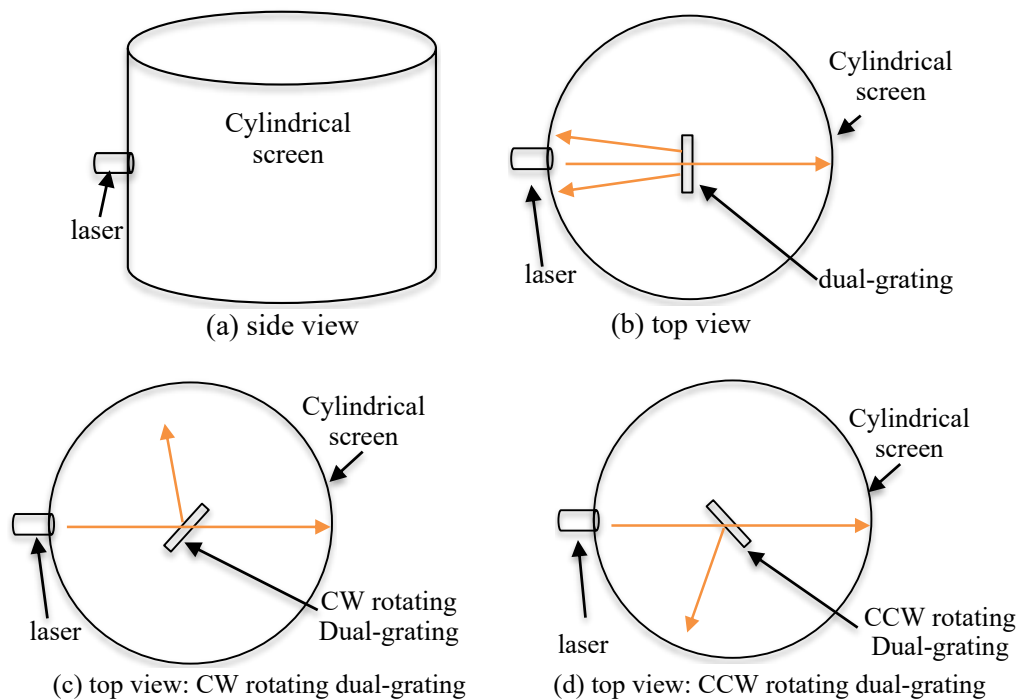


Figure 2 Schematic of cylindrical screen and dual-grating experiment setup

For a reflective grating [19,20], Figure 3 shows the schematics of experiment setup.

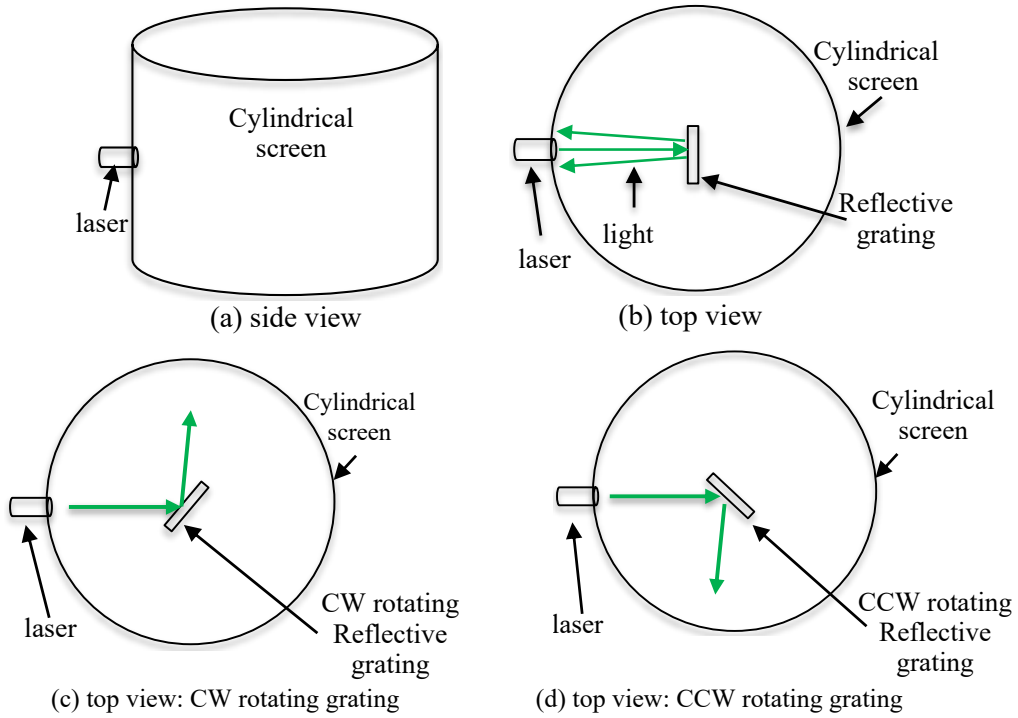


Figure 3. Schematic of experiment setup: cylindrical screen + reflective grating

In the Figure 3, the green-arrows represent the light beam.

The cylindrical coordinate system  $(r, \varphi, z)$  (Figure 4) can be used to determine the position of each diffraction order of transmission pattern and of reflective pattern. For convenience, we can rewrite the height  $z = r \tan \gamma$ . For the cylindrical screen, the radial distance  $r$  is a constant, thus the position of a diffraction order is a function of two angles, the angular coordinate  $\varphi$  and the angle  $\gamma$ ,  $(r, \varphi, r \tan \gamma)$ .

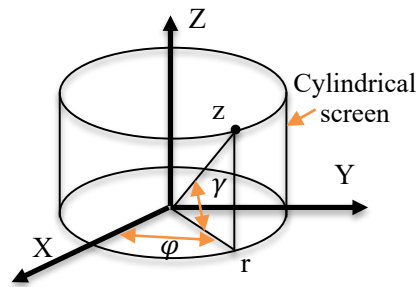


Figure 4. Cylindrical coordinate system and cylindrical screen

### 3. Application (1): Cylindrical Screen Studying Curved, Expanded and inclined Diffraction Patterns of Transmission Grating (Dual-grating) Rotating CW and CCW

Recently, it shown that a transmission grating produces not only a transmission diffraction pattern but also a reflective diffraction pattern [16-18]. In the experiment, the transmission grating reflects partial incident light and produces the diffraction patterns (referred as “reflective pattern”), while the

partial light passing through the grating and produces the diffraction pattern (referred as “transmission pattern”). Namely, the transmission grating plays not only a role of a transmission grating but also a role of a reflective grating simultaneously in the same experiment (hereafter referred it as *dual-grating*). The characteristics of the patterns are dependent on both the orientations of the slits of the dual-grating and of the orientations of the dual-grating.

Next we apply the cylindrical screen on several examples of the dual-grating experiments. We use the cylindrical screen (Figure 2) first then, for comparison, use the planar screen (Figure 5).

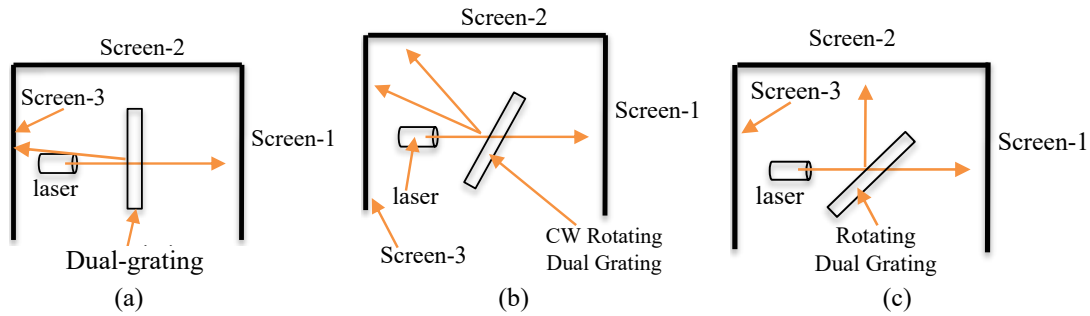


Figure 5 Schematics of experiment setup with planar screen

At special rotating angles of the dual grating, the reflective pattern is  $90^0$  bended and formed on screen-2 and screen-3 simultaneously (Figure 5b).

In the experiments, we use the dual-gratings with different orientated slits formed in the Y-Z plane (Figure 6).

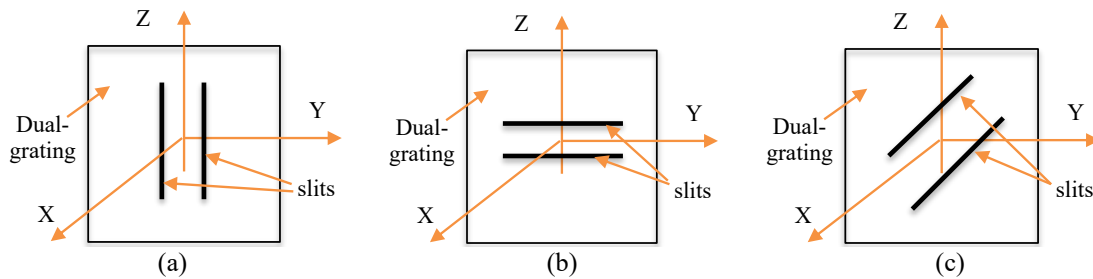


Figure 6. Orientations of slits of dual-grating

Figure 6a shows the dual-gratings of vertical slits, which produces the horizontal pattern. Figure 6b shows the dual-gratings of horizontal slits, which produces the vertical pattern. Figure 6c shows the dual-gratings of tilt slits, which produces the tilt pattern. Note that when the dual grating rotates, the dual grating of Figure 6a produces the expanded horizontal pattern, the dual grating of Figure 6b produces the curved vertical pattern, the dual grating of Figure 6c produces the expanded, curved and inclined pattern [16-18].

### 3.1. Experiments: dual-grating producing both expanded horizontal transmission patterns and expanded horizontal reflective patterns simultaneously

Let us start with the dual-grating with vertical slits (Figure 6a)

**Experiment-1 (Figure 7): non-rotating dual-grating: cylindrical screen**

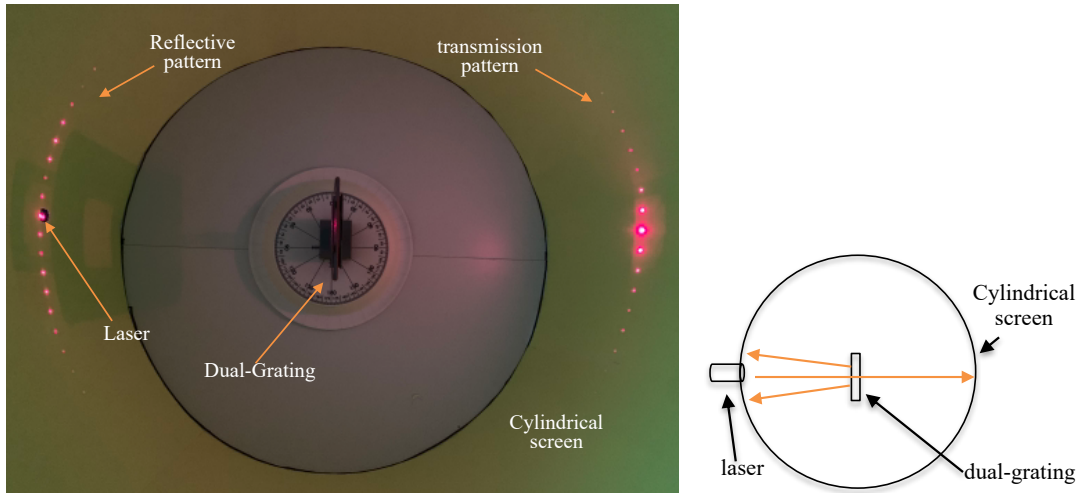


Figure 7 Top view: Dual-grating produces horizontal transmission pattern and reflective pattern

**Observation (Figure 7):** Dual-grating produces the horizontal transmission pattern and the horizontal reflective pattern on the cylindrical screen simultaneously.

**Experiment-2 (Figure 8): non-rotating dual-grating: planar screen**

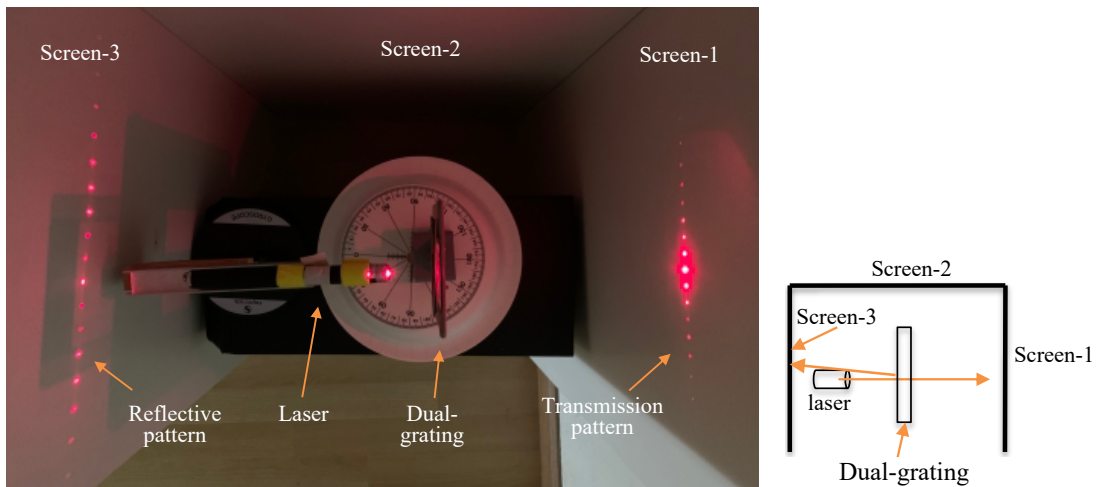


Figure 8 Top view: Dual-grating produces a transmission pattern and a reflective pattern:  
planar screen

**Observation (Figure 8):** Dual-grating produces the horizontal transmission pattern and the horizontal reflective pattern on the screen-1 and screen-3 respectively and simultaneously. No pattern on screen-2.

**Comparing Experiment-1 and experiment-2:**

(A) with a cylindrical screen, (1) the radial distance is the constant, i.e., each diffraction order has the same distance to the center of the dual grating; (2) each order has the same angle  $\gamma$ . Thus, only need one parameter, the angular coordinate  $\varphi$ , to determine the location of a diffraction order.

(B) with a planar screen, (1) each order has the same angle  $\gamma$ ; (2) the distance between each diffraction order to the center of the dual grating is different; (3) the angular coordinate  $\varphi$  of each order is different. Thus, one needs two parameters to determine the location of a diffraction order.

**Experiment-3** (Figure 9): CW rotating dual-grating at  $30^\circ$ : cylindrical screen

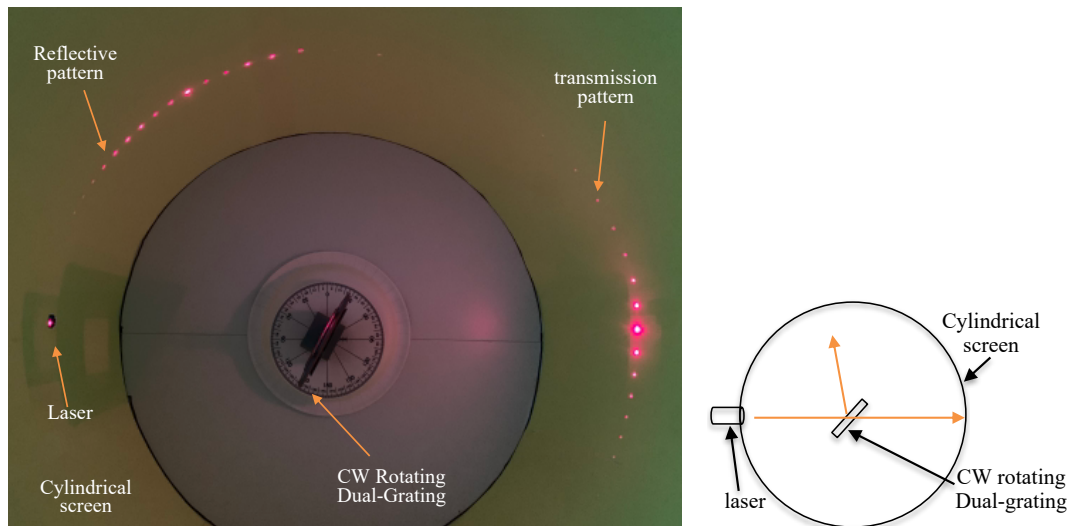


Figure 9. Top view: Expanded horizontal transmission pattern and Expanded horizontal reflective pattern of dual-grating: CW rotating  $30^\circ$

**Observation** (Figure 9): the dual-grating produces both expanded horizontal transmission pattern and expanded horizontal reflective pattern simultaneously in the same experiment.

**Experiment-4** (Figure 10): CCW rotating dual-grating at  $30^\circ$ : cylindrical screen

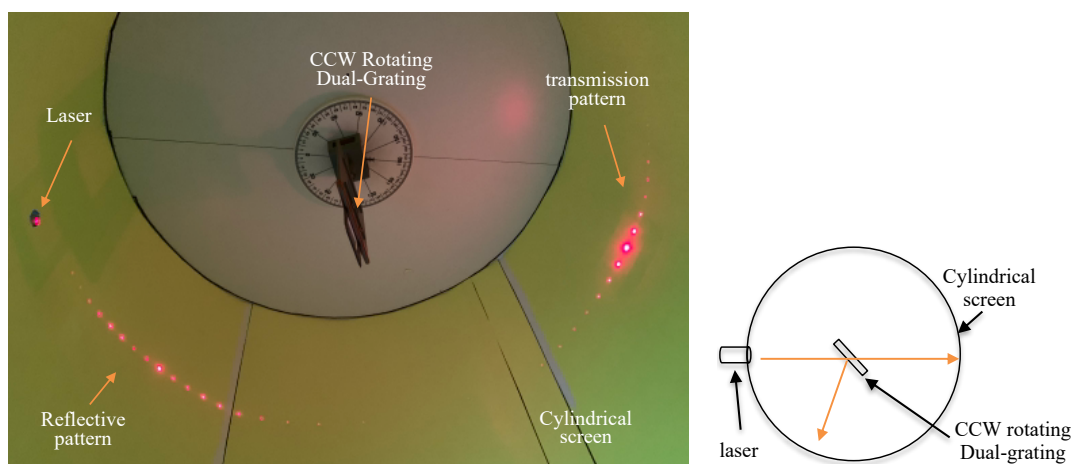


Figure 10. Top view: Expanded transmission pattern and expanded reflective pattern of dual-grating: CCW rotating  $30^\circ$

**Observation** (Figure 9 and 10): Dual-grating produces the expanded transmission pattern and the expanded reflective pattern on the cylindrical screen simultaneously, when it CW and CCW rotates.



**Experiment-5** (Figure 11): CW rotating dual-grating at  $30^\circ$ : planar screen

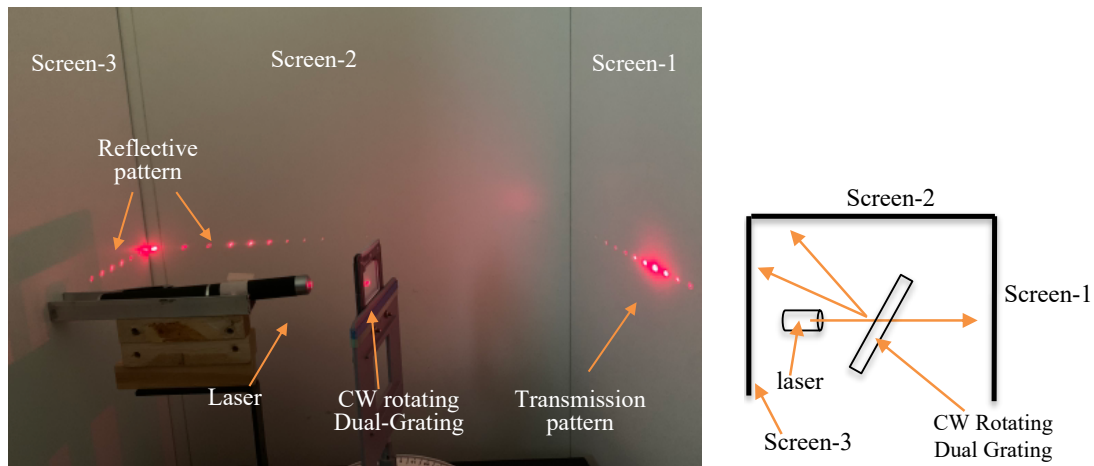


Figure 11 Transmission pattern and reflective pattern of dual-grating: CCW rotating  $30^\circ$

**Observation** (Figure 11): for CW rotating the dual grating the angle  $30^\circ$ , the transmission pattern expands, while the expanded reflective pattern  $90^\circ$  distributes on both screen-2 and screen-3 respectively and simultaneously.

**Comparing Experiment-3 and 4 with experiment-5:**

(A) with a cylindrical screen, (1) the radial distance is the constant; (2) each order has the same angle  $\gamma$ . Only need the angular coordinate  $\varphi$ , to determine the location of each diffraction order.

(B) however, with a planar screen, (1) the reflective pattern shows on screen-2 and screen-3 respectively; (2) the distance between each diffraction order to the center of the dual grating is different; (3) the angular coordinate  $\varphi$  of each order is different; (4) each order has the same angle  $\gamma$ . Thus, it is more complex to determine the location of each diffraction order.

The angle of the dual-grating rotated, at which the reflective pattern shows on screen-2 and screen-3 simultaneously, is determined by the distance between the grating and screen-2 and screen-3.

**Experiment-6** (Figure 12): CW rotating dual-grating at  $45^\circ$ : cylindrical screen

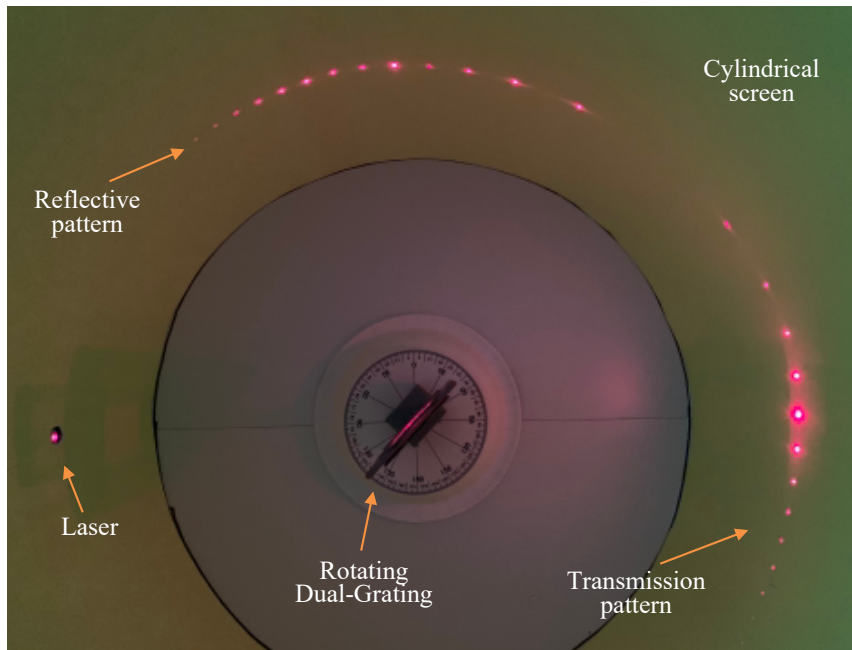


Figure 12. Top view: Transmission pattern and reflective pattern of dual-grating CW rotating at  $45^\circ$   
**Observation** (Figure 12): Dual-grating produces the expanded transmission pattern and the expanded reflective pattern on the cylindrical screen simultaneously.

**Experiment-7** (Figure 13): CW rotating dual-grating at  $45^\circ$ : planar screen

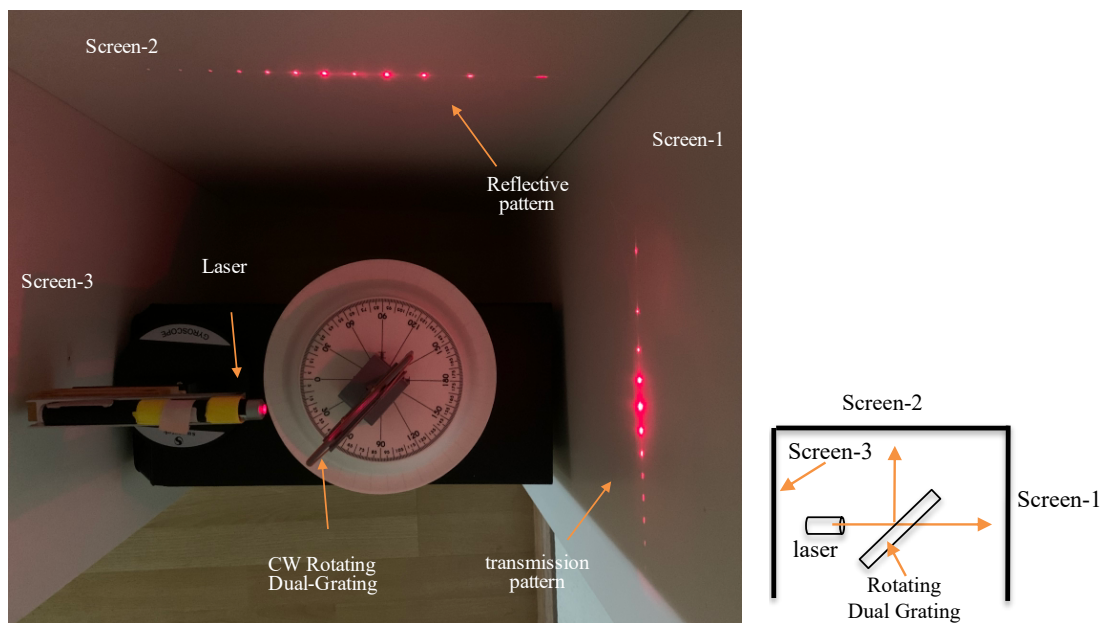


Figure 13. Top view: Transmission pattern and reflective pattern of dual-grating CW rotating at  $45^\circ$   
**Observation** (Figure 13): for CW rotating the dual grating, say  $45^\circ$ , the expanded transmission pattern and the expanded reflective pattern show on both screen-1 and screen-2 respectively and simultaneously.

The larger the rotation angle, the larger the expansions of both patterns.

### 3.2. Experiments: transmission grating producing both curved vertical transmission patterns and curved vertical reflective patterns simultaneously

Let us start with the dual-grating with horizontal slits (Figure 6b)

#### Experiment-8 (Figure 14, 15): non-rotating dual-grating: cylindrical screen

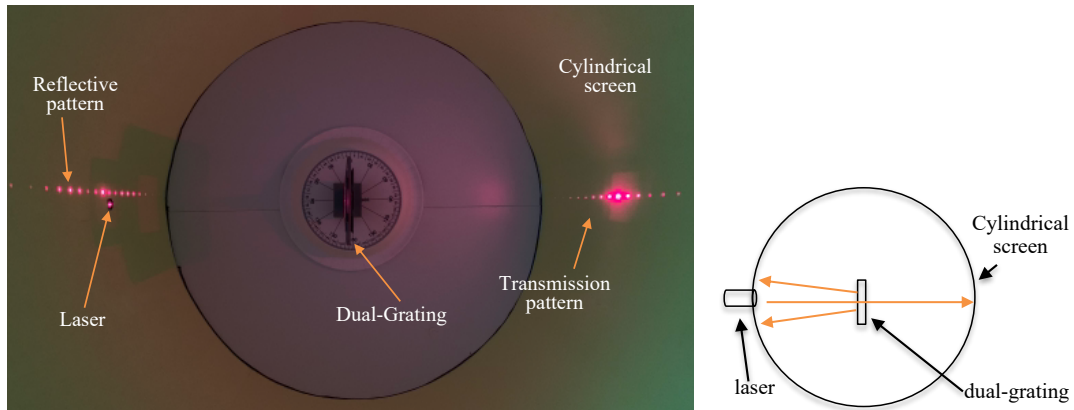


Figure 14 Top view: Dual-grating of horizontal slits produces the vertical transmission Pattern and the vertical reflective patten simultaneously: cylindrical screen

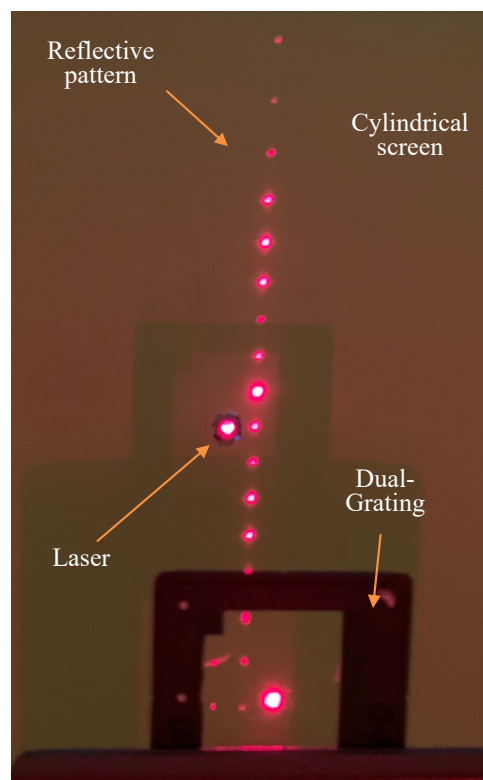


Figure 15. Zoomed vertical reflective pattern of dual grating of horizontal slits

**Observation** (Figure 14 and 15): Dual-grating with horizontal slits produces the vertical transmission pattern and the vertical reflective patten simultaneously on cylindrical screen (Figure 14).

#### Experiment-9 (Figure 16): non-rotating dual-grating: planar screen

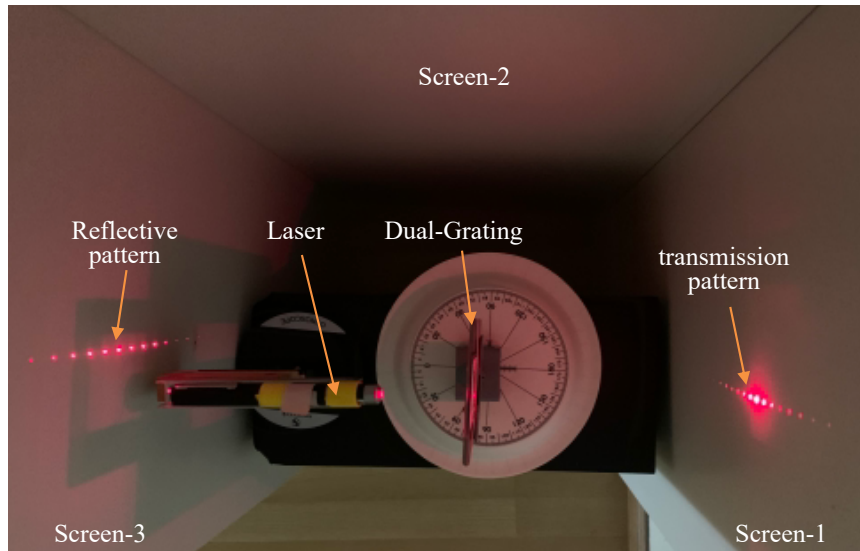


Figure 16. Top view: Vertical transmission pattern and vertical reflective pattern of dual-grating:  
**Observation** (Figure 16): A dual-grating of horizontal slits produces the vertical transmission pattern and the vertical reflective pattern simultaneously on planar screen-1 and screen-3 respectively.

**Experiment-10 (Figure 17-19): rotating dual-grating: cylindrical screen**

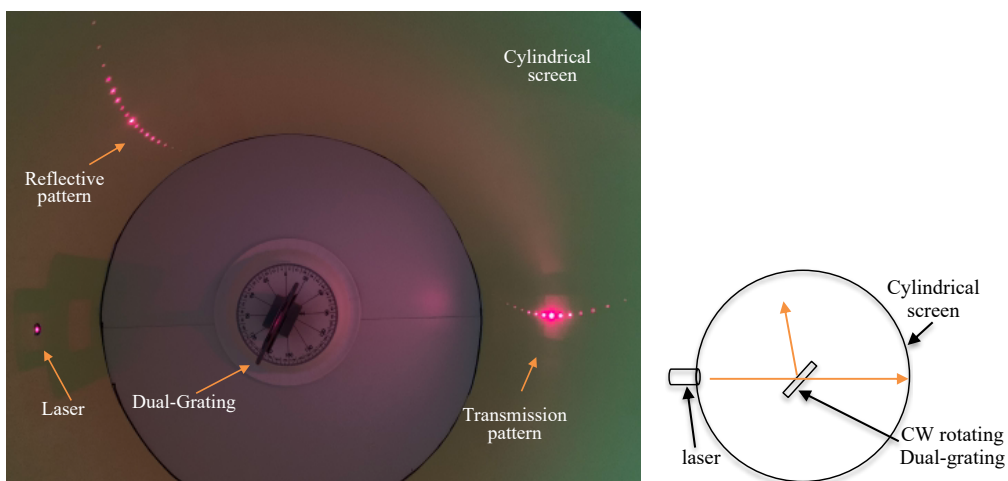


Figure 17. Top view: Transmission pattern and reflective pattern of grating CW rotating  $30^\circ$

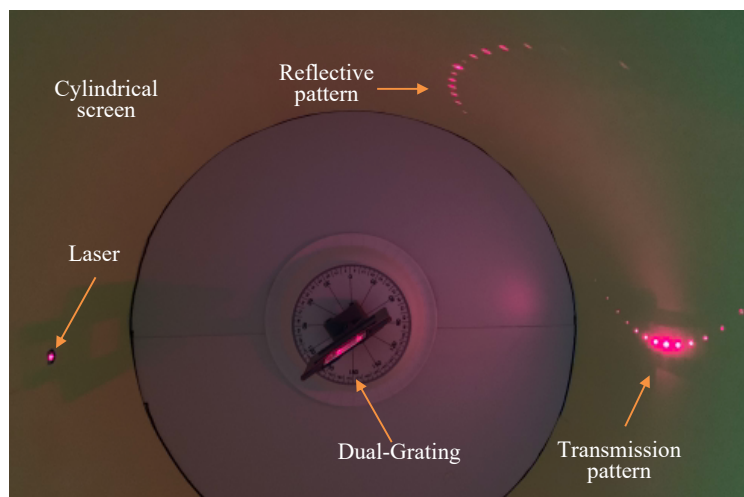


Figure 18. Top view: Transmission pattern and reflective pattern of grating CW rotating  $60^{\circ}$

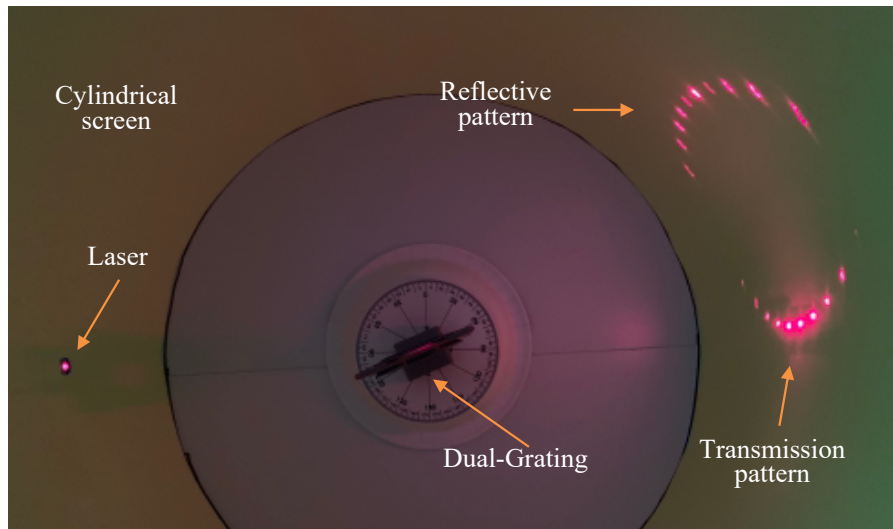


Figure 19. Top view: Transmission pattern and reflective pattern of grating CW rotating  $70^{\circ}$

**Observation** (Figure 17-19): Dual-grating of horizontal slits produces the curved vertical transmission pattern and the curved vertical reflective pattern simultaneously on cylindrical screen. The larger the rotation angle, the larger the curvatures of the patterns. Both patterns have the same characteristics.

**Experiment-11 (Figure 20): Rotating dual-grating: planar screen**

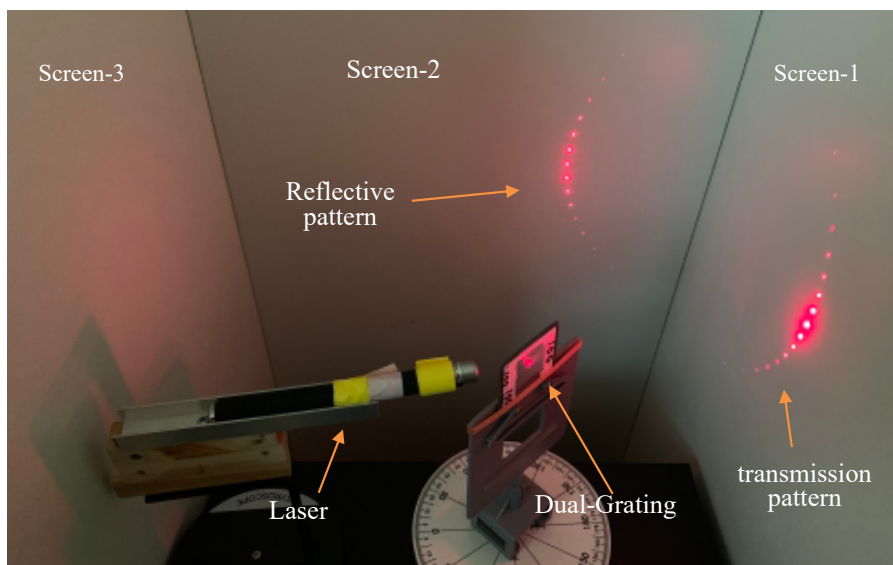


Figure 20. Curved transmission and reflective patterns of dual-grating CW rotating at  $60^{\circ}$

**Observation** (Figure 20): The vertical transmission pattern and the vertical reflective pattern produced by rotating dual-grating are curved.

The larger the rotation angle, the larger the curvature of the transmission and reflective patterns.

**2.3. Experiments: tilt transmission grating producing both expanded/curved/inclined**

**Transmission pattern and expanded/curved/inclined reflective pattern**

**Experiment-12 (Figure 21, 22): non-rotating dual-grating of tilt slits: cylindrical screen**

Let us start with the dual-grating with tilt slits (Figure 6c)

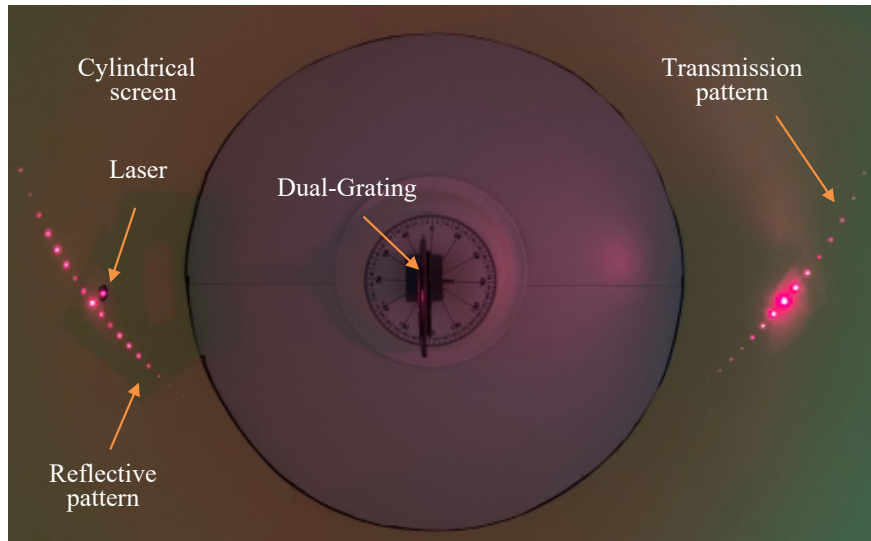


Figure 21 Top view: Both tilt transmission and tilt reflective patterns

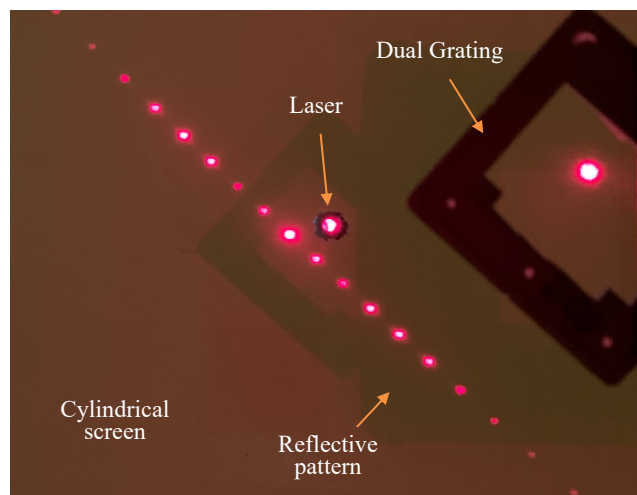


Figure 22. Zoomed tilt reflective patter

**Observation** (Figure 21 and 22): The dual-grating with tilt slits produces tilt transmission pattern and tilt reflective pattern in the same experiment.

**Experiment-13 (Figure 23): non-rotating dual-grating of tilt slits: planar screen**

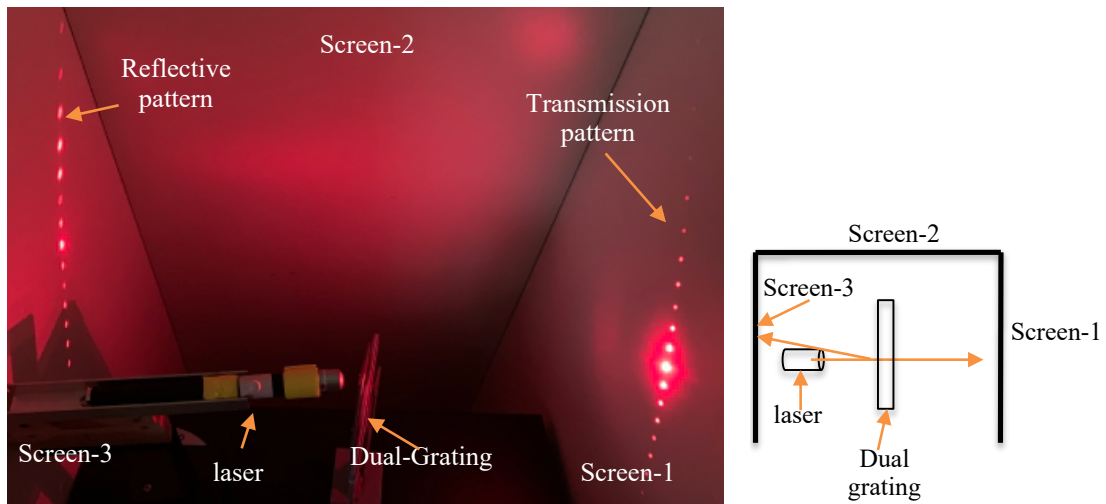


Figure 23 Top view: Both tilt transmission and tilt reflective patterns

**Observation** (Figure 23): The dual-grating of tilt slits produces the tilt transmission pattern on screen-1 and the tilt reflective pattern on screen-3 respectively.

**Experiment-14** (Figure 24, 25): **rotating dual-grating of tilt slits: cylindrical screen**

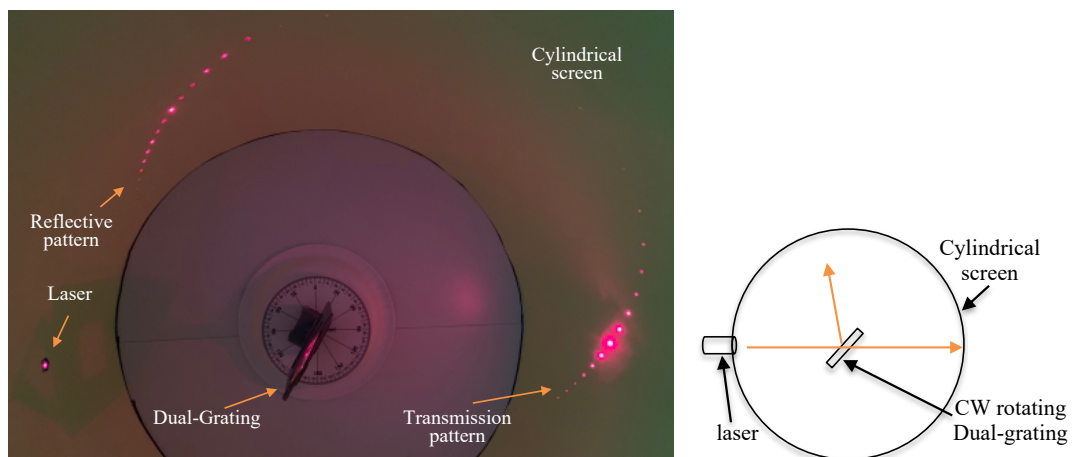


Figure 24. Transmission pattern and reflective pattern of dual-grating CW rotating  $30^\circ$

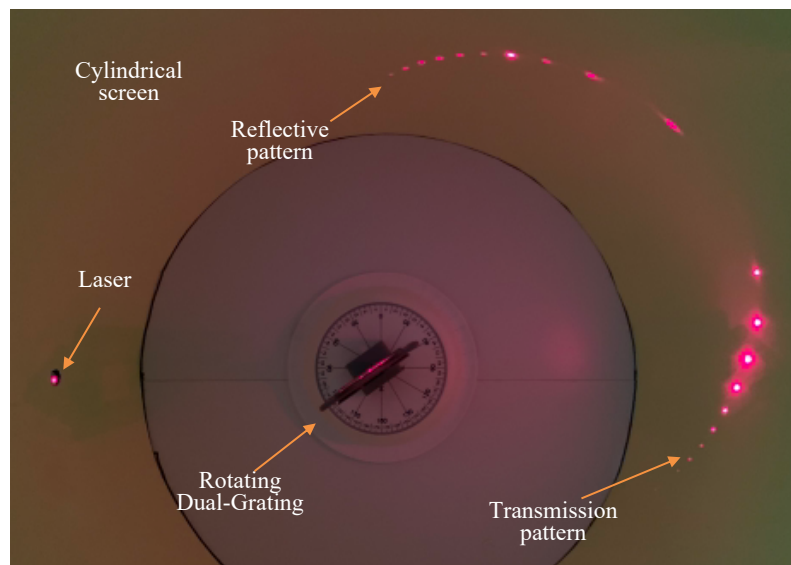


Figure 25. Transmission pattern and reflective pattern of dual-grating rotating  $60^\circ$

**Observation** (Figure 24, 25): The dual-grating produces transmission pattern and reflective pattern simultaneously. Both patterns are curved, expanded and inclined towards horizontal direction. The larger the rotation angle of the dual grating, both patterns expand more, curve more and incline more.

**Experiment-15 (Figure 26): rotating dual-grating of tilt slits: planar screen**

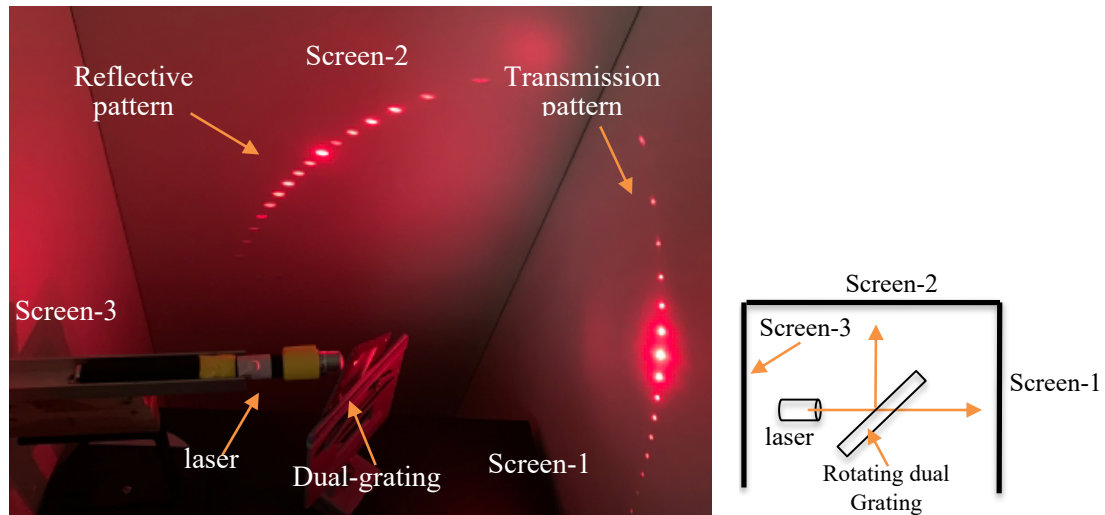


Figure 26 Transmission pattern and reflective pattern of CW rotating dual-grating of tilt slits at  $60^\circ$ :  
Curved, expanded and inclined

**Observation** (Figure 26): When the dual grating of tilt slits rotates, it produces the curved, expanded and inclined reflective pattern and the curved, expanded and inclined transmission pattern.

**3.4. Discussion**

The cylindrical screen can be conveniently utilized to describe the diffraction patterns, especially for: (1) the patterns produced by rotating the 1D-grating around one axis and/or more axes; and (2) the dual-grating (transmission grating) produces the transmission pattern and reflective pattern simultaneously [16-18].

One of the benefits is that, by using the cylindrical screen, only two coordinates are needed to describe the curved, expanded and inclined transmission and reflection patterns.

Another benefit is that the cylindrical screen shows the location of each diffraction order visually and thus, one can place precisely a CCD at the location of each diffraction order.

**4. Application (2): Cylindrical Screen for Studying Reflective Grating Rotating CW and CCW**

The cylindrical screen is convenient to be used in the grating experiments to study the orientation-dependence of the patterns in experiments. Now, we apply the cylindrical screen in several experiments of the blazed reflective grating [19,20] (Figure 27).



Figure 27a shows the reflective gratings that produces either the horizontal pattern or the vertical patterns (by rotating the grating  $90^{\circ}$  around its normal). Figure 27b shows the tilt reflective gratings, i.e., the grating (Figure 27a) is rotated CW or CCW around its normal an angle between  $0^{\circ}$  and  $90^{\circ}$ , for example,  $45^{\circ}$ , in Figure 27b.

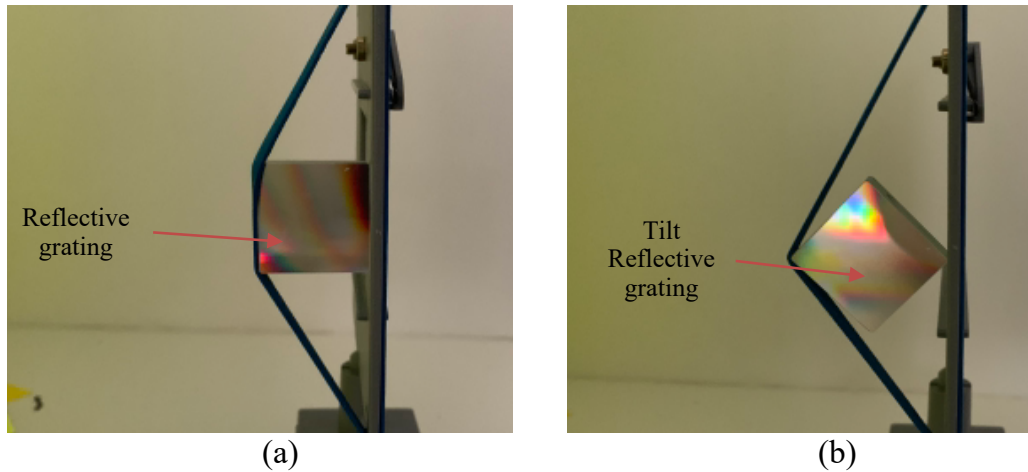


Figure 27. Orientations of blazed grating

#### 4.1. Experiments: reflective grating producing expanded horizontal pattern

Choice an orientation of the reflective grating, such that it produces the horizontal pattern.

##### 4.1.1. Non-rotating reflective grating

##### Experiment-16 (Figure 28)

The light beam incidents normally to the reflective grating.

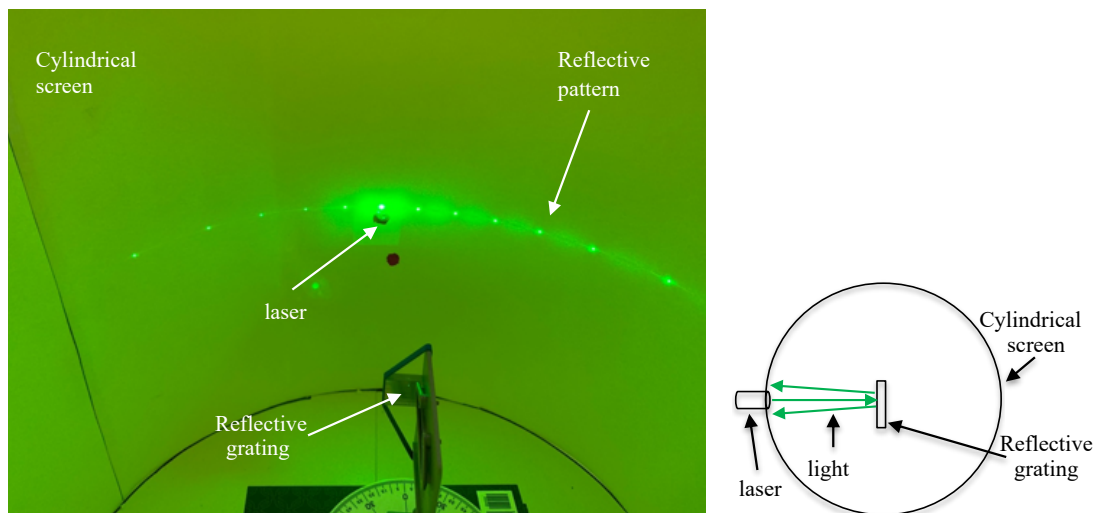


Figure 28. Light beam incidents normally to the reflective grating

**Observation** (Figure 28): the reflective grating reflects the light beam back to the laser source and produces the horizontal pattern on the cylindrical screen.

#### 4.1.2. CW rotating reflective grating

Figure 29 shows how we rotate CW the reflective grating around the Z axis.

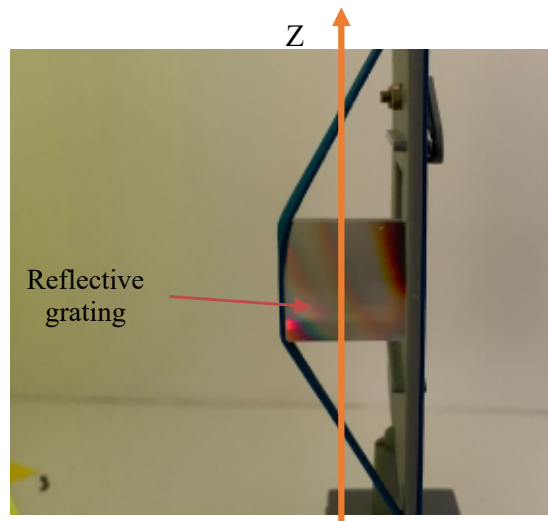


Figure 29. Reflective grating rotating around Z axis CW and CCW

#### Experiment-17 (Figure 30,31)

The reflective grating CW rotates around the Z axis at  $30^\circ$  (Figure 30) and  $60^\circ$  (Figure 31) respectively. The light beam incidents obliquely to the reflective grating.

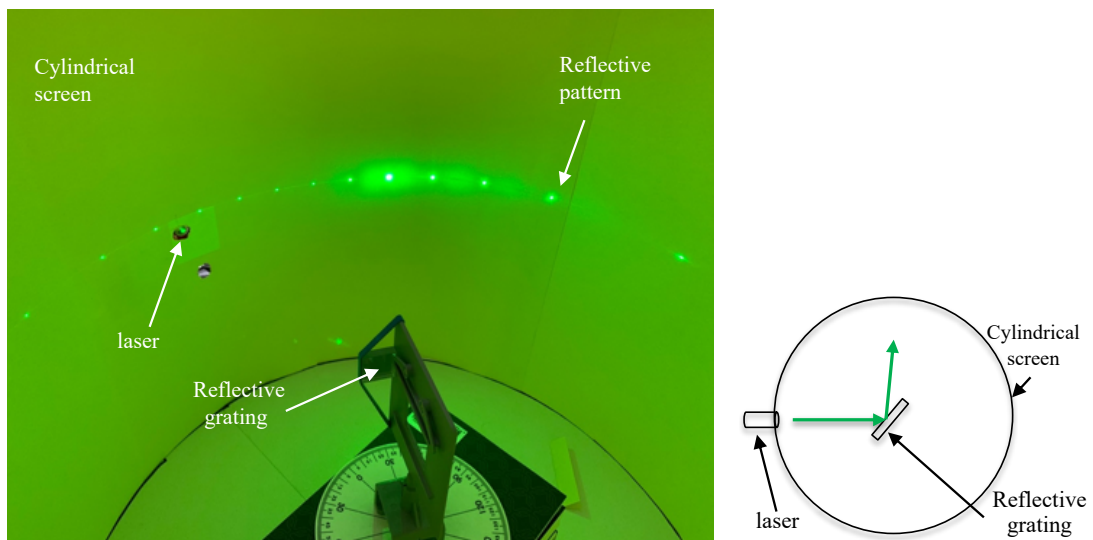


Figure 30. Reflective grating rotates CW at  $30^\circ$ .

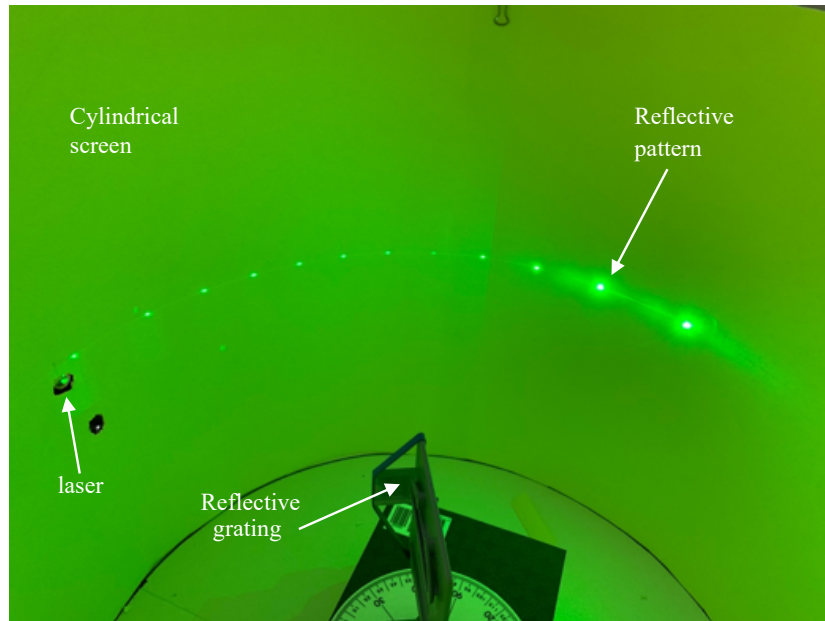


Figure 31. Reflective grating rotates CW at  $60^\circ$ .

**Observation** (Figure 30,31): the horizontal diffraction patterns are expanded due to the rotate the grating. The larger the rotation angle, the larger the expansion.

Note that on the one side of the  $m = 0$  order, there are more  $m \neq 0$  orders, however on the other side of the  $m = 0$  order, there are less  $m \neq 0$  orders.

#### 4.1.3. CCW rotating reflective grating

##### Experiment-18 (Figure 32,33)

Starting from Figure 28. Then we rotate the reflective grating CCW (Figure 32,33). The reflective grating CCW rotates at  $30^\circ$  (Figure 32) and  $60^\circ$  (Figure 33) respectively. The light beam incidents obliquely to the reflective grating.

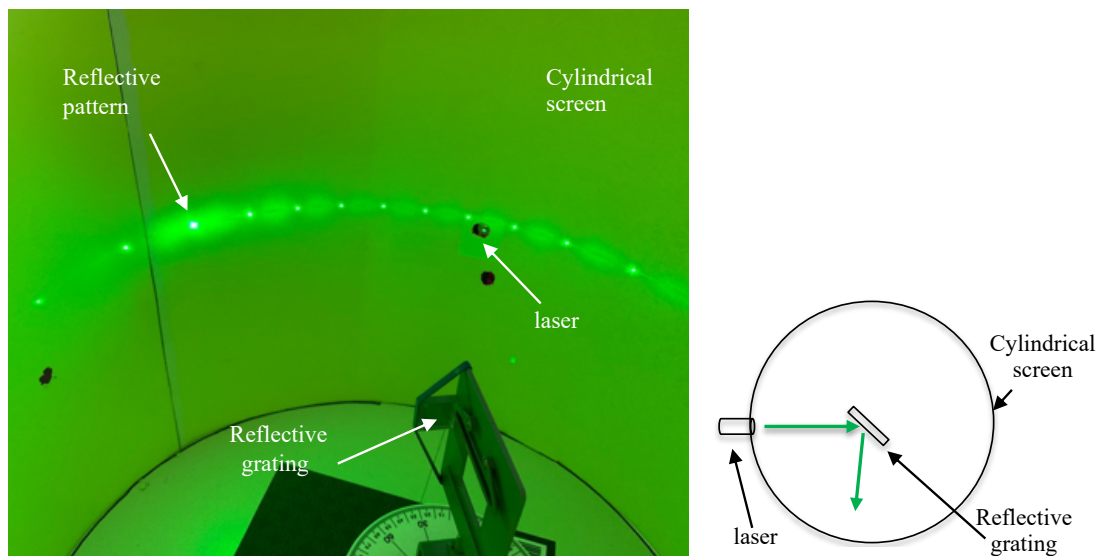


Figure 32. Reflective grating CCW rotates at  $30^\circ$

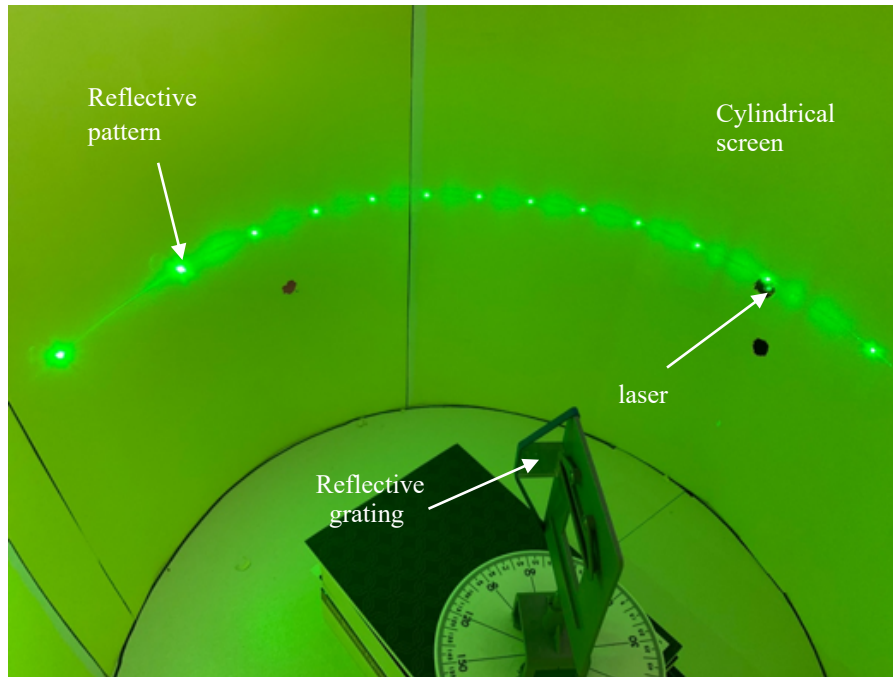


Figure 33. Reflective grating CCW rotates at  $60^\circ$ .

**Observation** (Figure 32,33): like the observation of Experiment-2, the horizontal diffraction patterns are expanded due to the rotate the grating. The larger the rotation angle, the larger the expansion.

Note that on the one side of the  $m = 0$  order, there are more  $m \neq 0$  orders, however on the other side of the  $m = 0$  order, there are less  $m \neq 0$  orders after rotation of the grating.

#### 4.2. Experiments: reflective grating producing curved vertical pattern

Rotating the reflective grating around its normal at the angle  $90^\circ$  from its orientation, such that it produces the vertical pattern (Figure 34), when the light beam incidents normally to the reflective grating.

##### 4.2.1. Non-rotating reflective grating

**Experiment-19** (Figure 34)

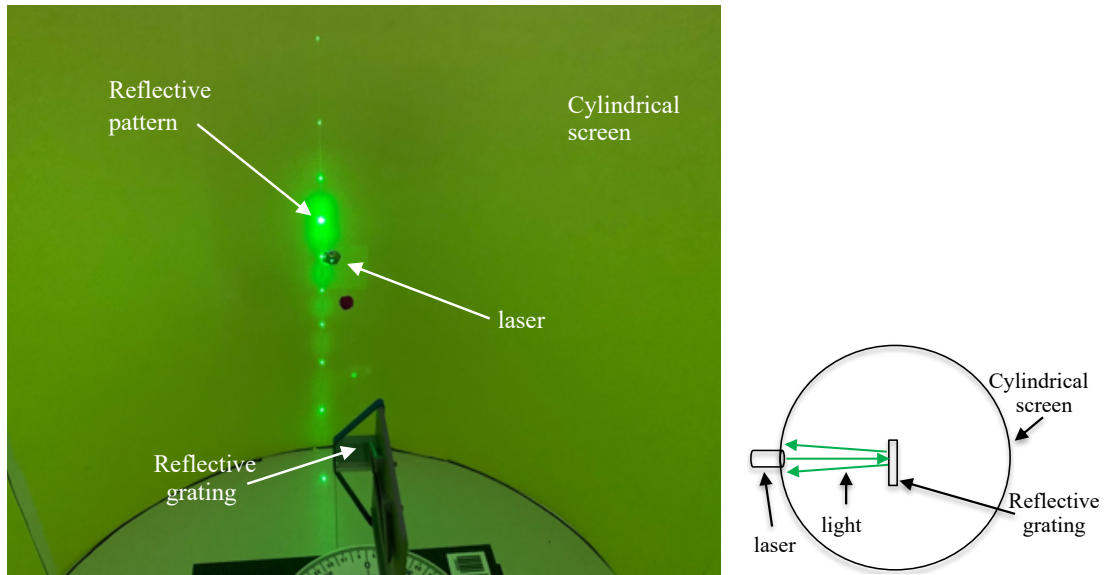


Figure 34. Light beam incidents normally to the reflective grating

**Observation** (Figure 34): the reflective grating reflects the light beam back to the laser source and produces the vertical pattern on the cylindrical screen. There are  $m \neq 0$  orders on each side of the  $m = 0$  order. Note that we rotate the grating a little, so that the laser light and the vertical pattern do not overlap.

#### 4.2.2. CW rotating reflective grating

##### Experiment-20 (Figure 35,36)

Rotating the reflective grating CW at  $30^\circ$  (Figure 35) and  $60^\circ$  (Figure 36) respectively. The light beam incidents obliquely to the reflective grating.

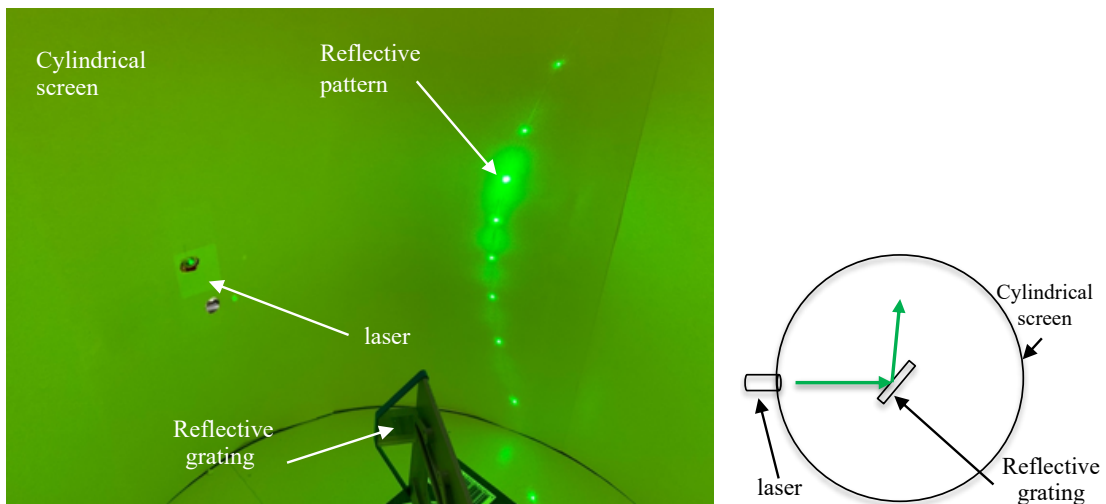


Figure 35. Reflective grating CW rotates at  $30^\circ$

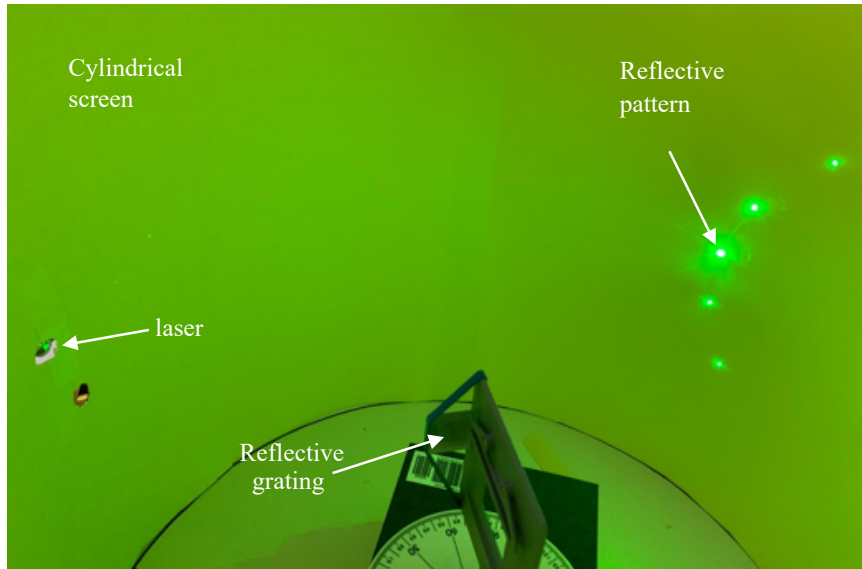


Figure 36. Reflective grating CW rotates at  $60^\circ$

**Observation** (Figure 35,36): the diffraction patterns are curved due to the rotation of the grating. The larger the rotation angle, the larger the curvatures.

The CW rotation of the transmission grating obeys the right-hand rule [23] and thus, the pattern should curve toward to the left. However, the reflection by the reflective grating makes the patterns curve towards the right.

#### 4.2.3. CCW rotating reflective grating

We start from Figure 34.

#### Experiment-21 (Figure 37,38)

Next let us rotating CCW the grating at  $30^\circ$  (Figure 37) and  $60^\circ$  (Figure 38), respectively. The light beam incidents obliquely to the reflective grating.

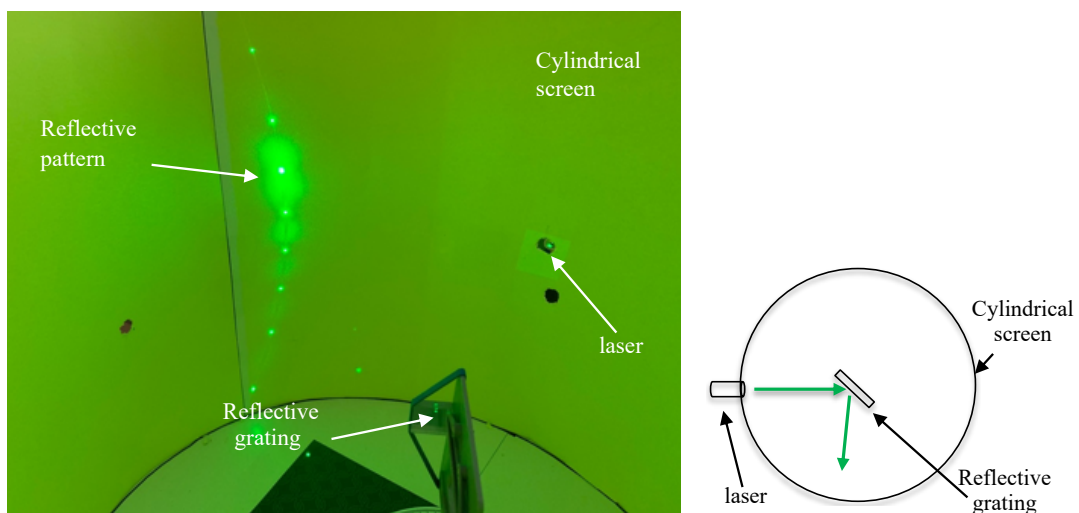


Figure 37. Reflective grating CCW rotates at  $30^\circ$

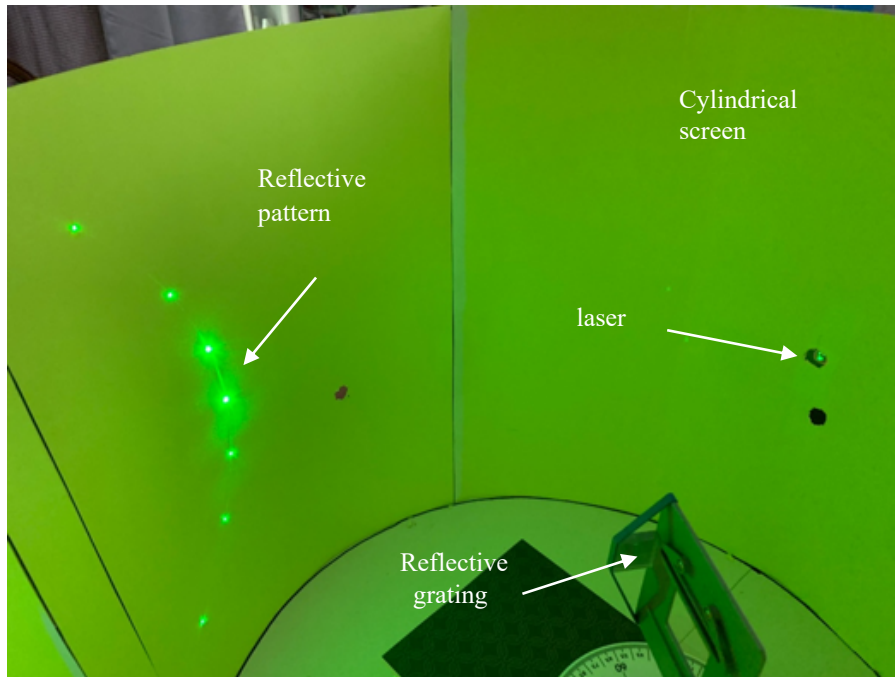


Figure 38. Reflective grating CCW rotates at  $60^\circ$

**Observation** (Figure 37,38): the diffraction patterns are curved due to the rotate the grating. The larger the rotation angle, the larger the curvatures.

The CCW rotation of the transmission grating obeys the left-hand rule [23] and thus, the pattern curves toward to the right. However, the reflection by the reflective grating makes the patterns curve towards the left.

#### 4.3.Experiments: tilt reflective grating producing expanded, curved, inclined patterns (1)

The tilt reflective grating is shown in Figure 39b.

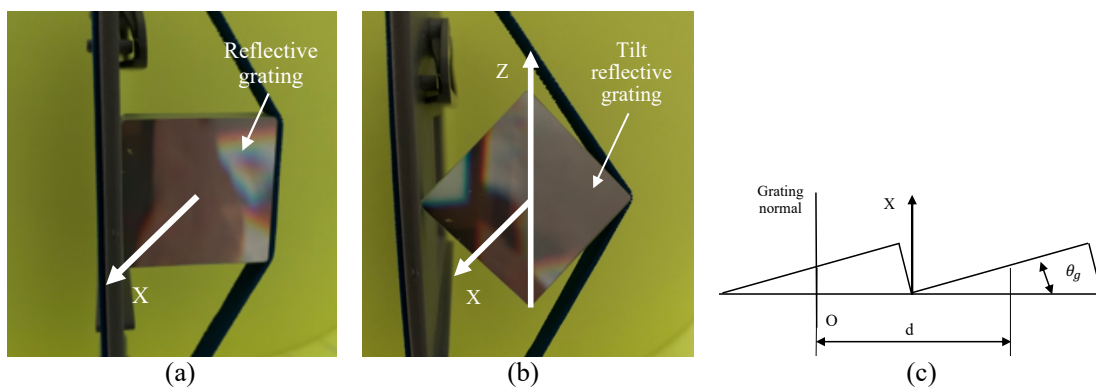


Figure 39. Tilt reflective grating rotating around Z axis CW and CCW

We rotate the blazed grating CW and CCW around the X-axis (Figure 39a), say  $45^\circ$ , respectively, and get tilt reflective grating (Figure 39b). Then CW and CCW rotate the tilt grating around the Z-axis respectively.

### 4.3.1. Non-rotating tilt reflective grating: original pattern-A

#### Experiment-22 (Figure 40)

The tilt reflective grating (Figure 39b) produces the tilt pattern (referred as orientation-A) (Figure 40), when the light beam incidents normally to the grating.

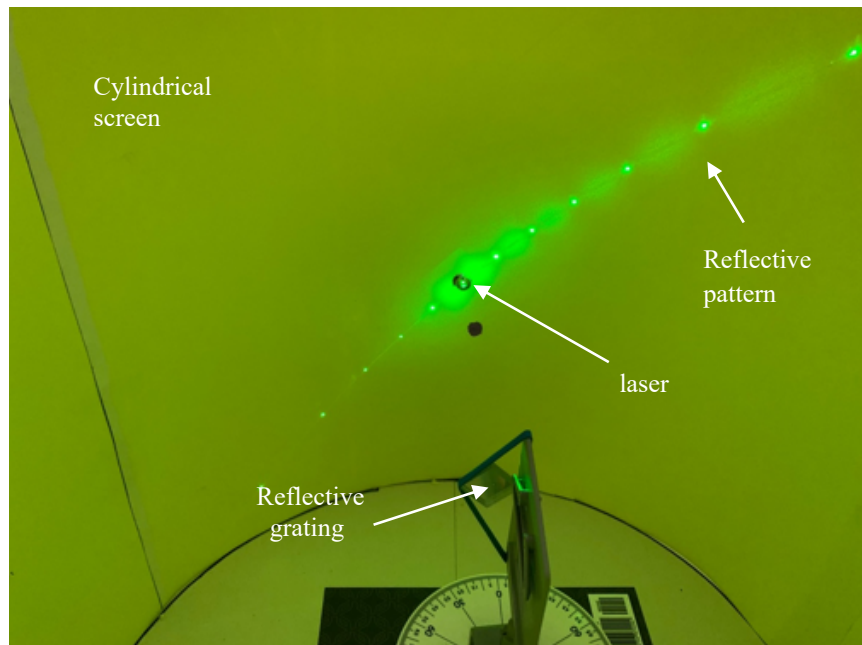


Figure 40. Light beam incidents normally to tilt reflective grating

**Observation** (Figure 40): the tilt grating produces the tilt pattern. Namely one end of the pattern is closer to the bottom of the cylindrical screen than the other end. In Figure 40, the left end of the pattern is closer to the bottom than the right end.

### 4.3.2. CW rotating tilt reflective grating

Next let us rotate the tilt reflective grating around Z axis CW (Figure 39b).

#### Experiment-23 (Figure 41,42)



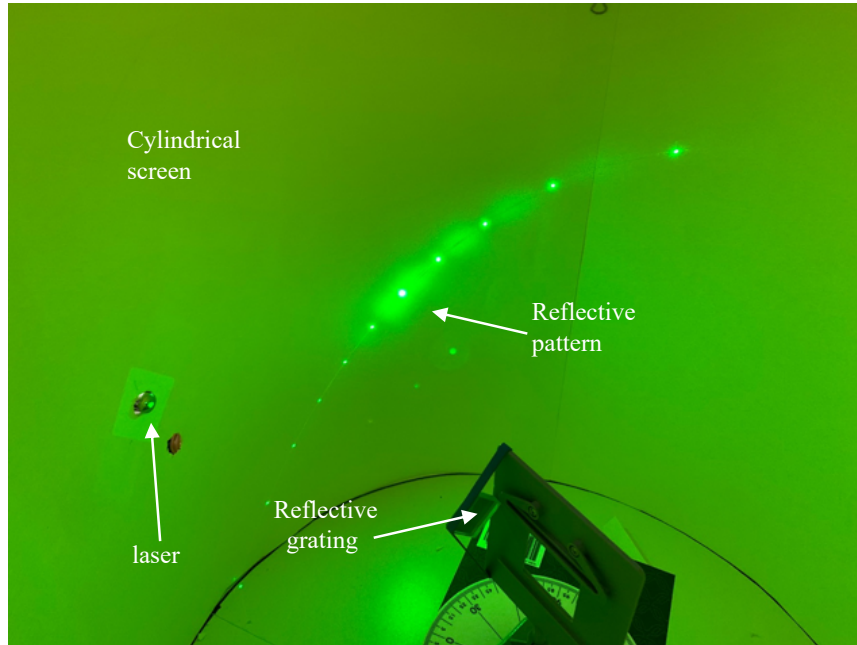


Figure 41. Tilt reflective grating CW rotates around Z axis at  $30^{\circ}$

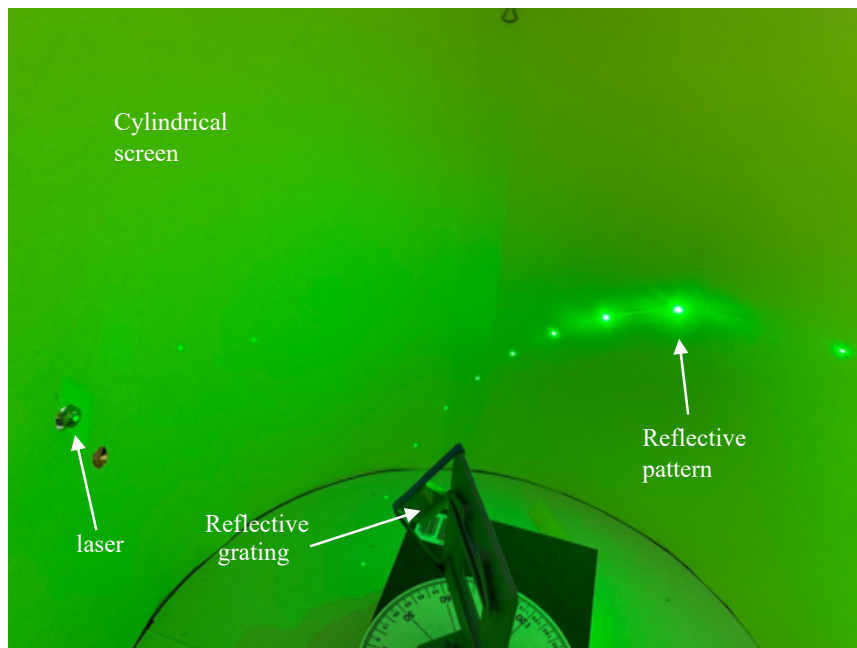


Figure 42. Tilt reflective grating CW rotates around Z axis at  $60^{\circ}$

**Observation** (Figure 41,42): the rotating tilt reflective grating produces the non-uniform, expanded, curved (curved towards the right) and inclined (towards to the horizontal) pattern.

### 4.3.3. CCW rotating reflective grating

#### Experiment-24 (Figure 43,44)

Let us start from Figure 40. Then CCW rotating the tilt reflection grating around the Z axis (Figure 39b).

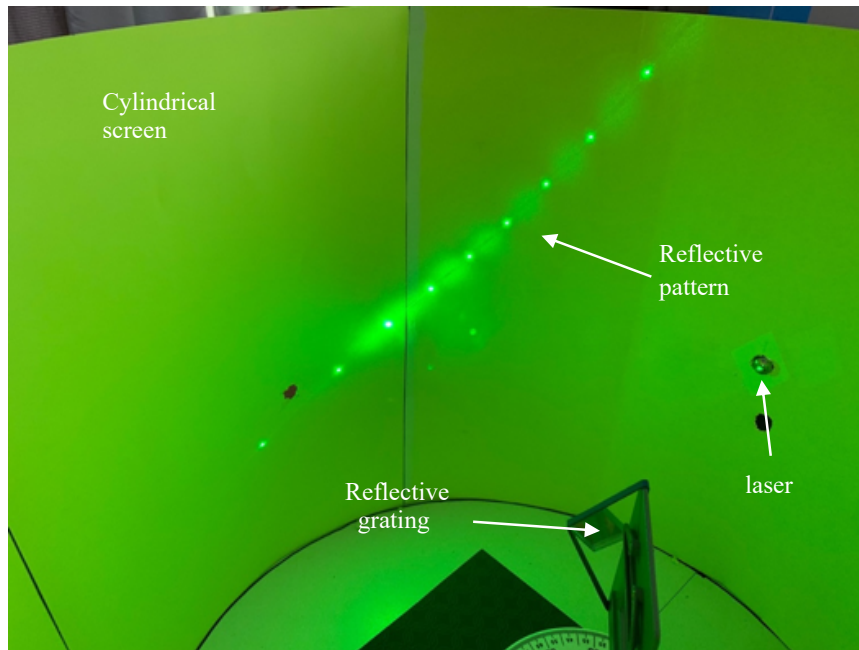


Figure 43. Tilt reflective grating CCW rotates around Z axis at  $30^\circ$

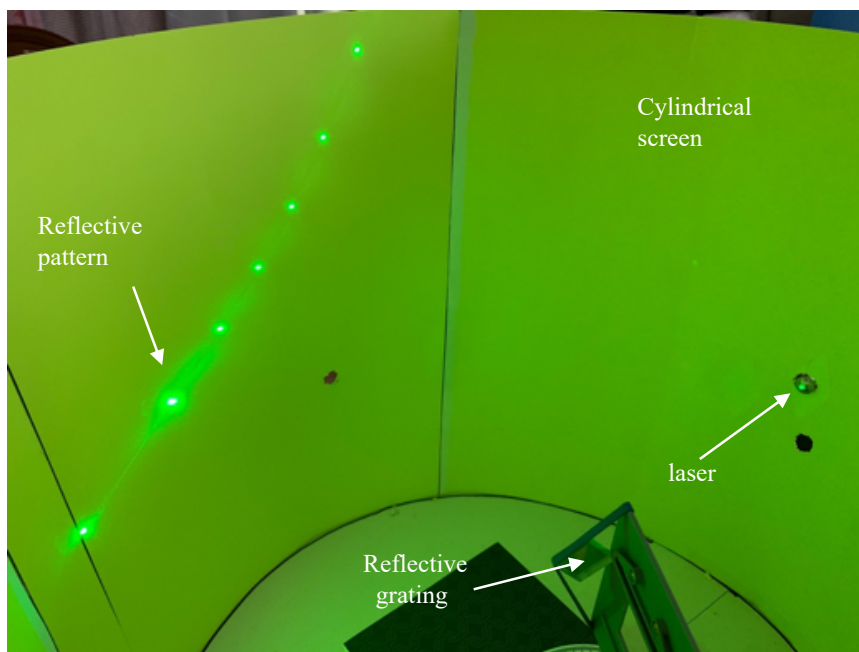


Figure 44. Tilt reflective grating CCW rotates around Z axis at  $60^\circ$

**Observation** (Figure 43, 44): the CCW rotating tilt reflective grating produces the expanded, curved (towards left side) and inclined (towards upward) patterns.

#### 4.4. Experiments: tilt reflective grating producing expanded, curved, inclined patterns (2)

##### 4.4.1. Non-rotating tilt reflective grating: original pattern-B

First let us start with the orientation of the tilt grating, which produces tilt pattern (Figure 45).

**Experiment-25** (Figure 45)

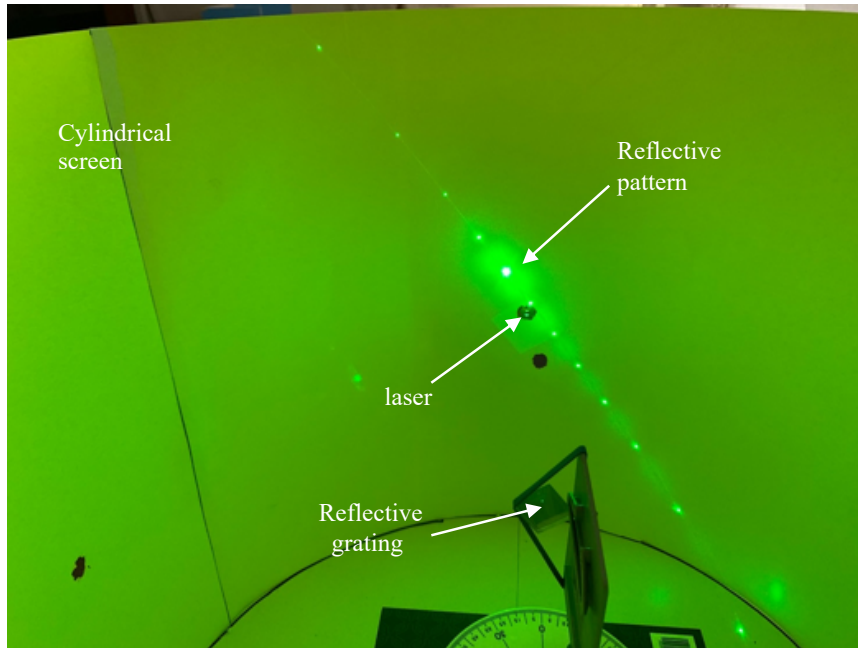


Figure 45. Light beam incidents normally to tilt reflective grating

The tilt reflective grating produces the tilt pattern (referred as original pattern-B) (Figure 45), when the light beam incidents normally to the grating.

**Observation** (Figure 45): the tilt grating produces the tilt pattern. Namely one end of the pattern is closer to the bottom of the cylindrical screen than the other end. In Figure 45, the right-side end of the pattern is closer to the bottom than the left-side end.

#### 4.4.2. CW rotating tilt reflective grating

Next let us CW rotate the tilt reflective grating around Z axis (Figure 39b).

**Experiment-26** (Figure 46,47)

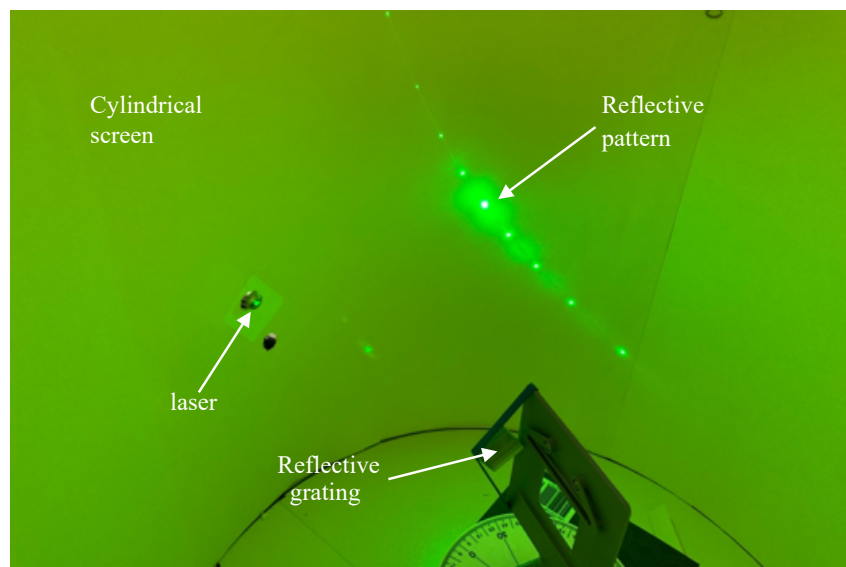


Figure 46. Tilt reflective grating CW rotates around Z axis at  $30^\circ$

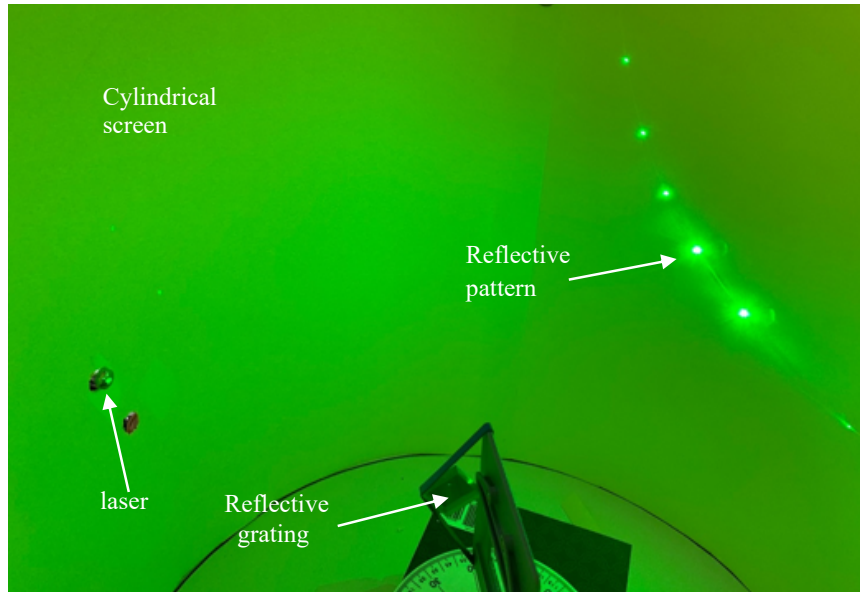


Figure 47. Tilt reflective grating CW rotates around Z axis at  $60^\circ$

**Observation** (Figure 46,47): the CW rotating tilt reflective grating produces the non-uniform, expanded, curved (upwards) and inclined (towards the vertical axis) patterns

#### 4.4.3. CCW rotating tilt reflective grating

First let us start with the orientation of the tilt grating, which produces tilt pattern (Figure 45), when the light beam incidents normally to the grating. Then CCW rotating the tilt reflective grating around Z axis (Figure 39b).

Finally comparing the diffraction patterns of the orientation-A and orientation-B of the reflective gratings (Table).

#### Experiment-27 (Figure 48,49)

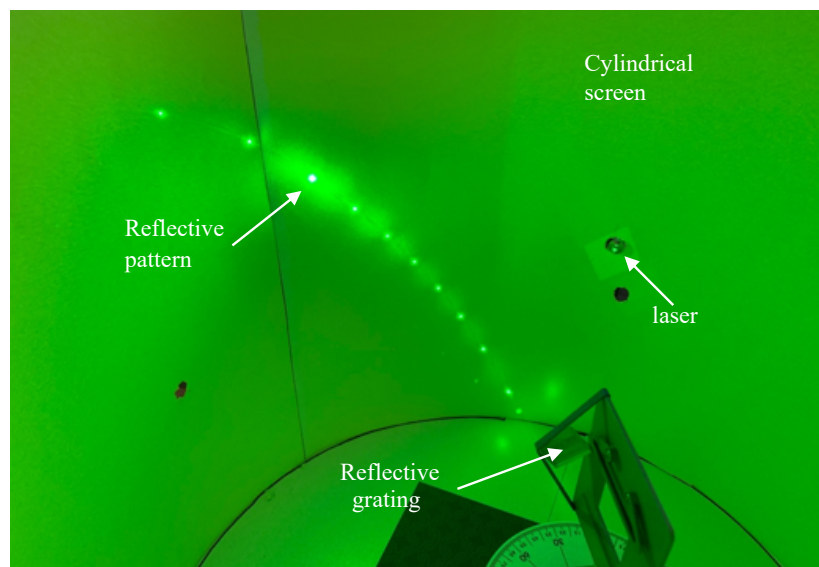


Figure 48. Tilt reflective grating CCW rotates around Z axis at  $30^\circ$

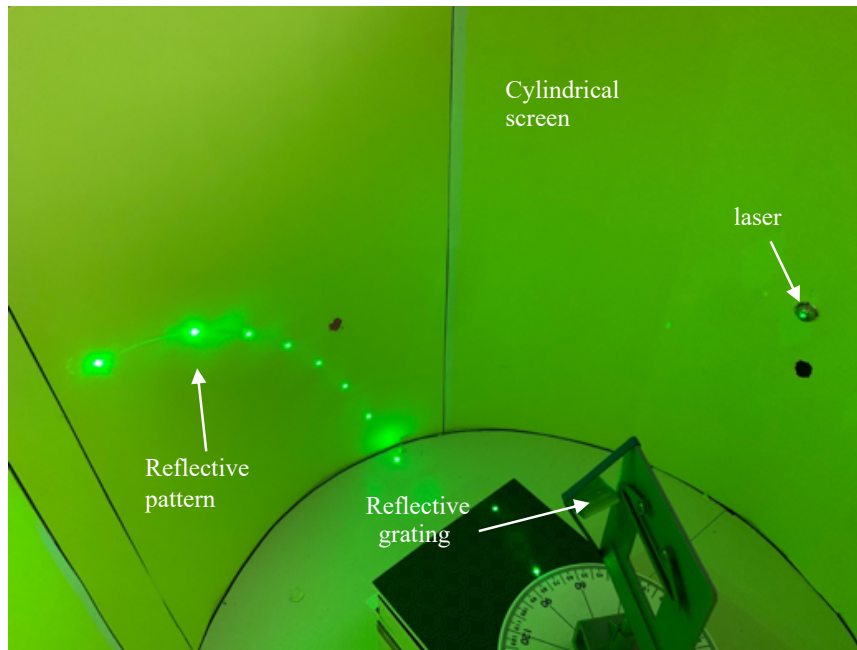


Figure 49. Tilt reflective grating CCW rotates around Z axis at  $60^\circ$

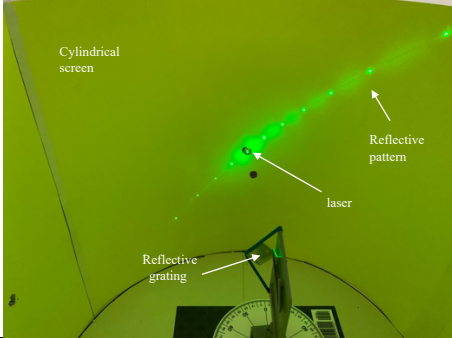
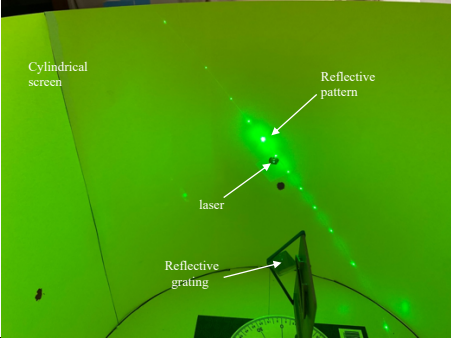
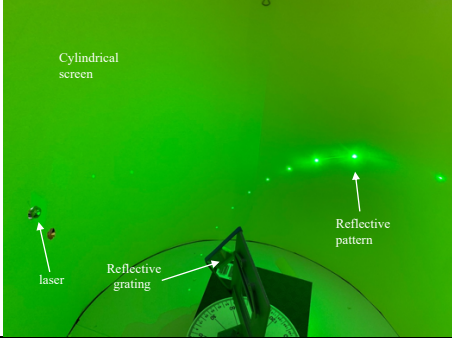
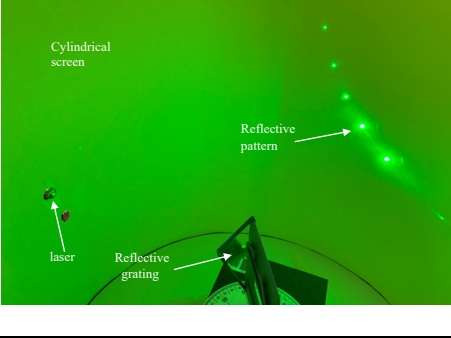
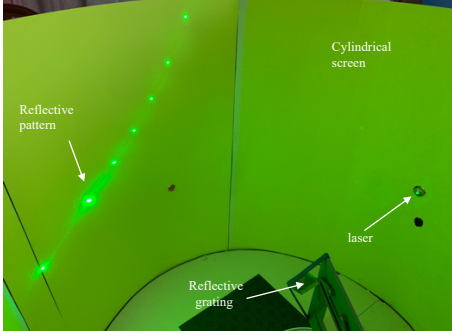
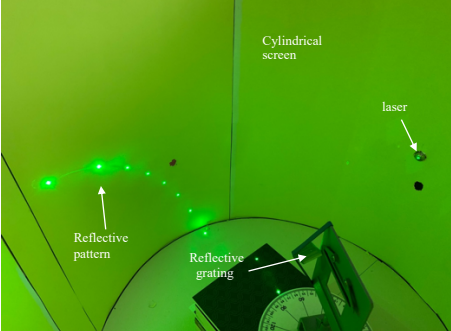
**Observation** (Figure 48,49): the CCW rotating tilt reflective grating produces the non-uniform, expanded, curved (downwards) and inclined (towards the horizontal axis) patterns.

## 5. Summary

The textbook-screens for studying the interference patterns and diffraction patterns are the planar-screen. Based on the standard diffraction equation, the diffraction orders are determined by the incident angle and the diffraction angle. To describe the angular-dependent diffraction orders, we proposed the cylindrical screen. The cylindrical screen shows the location of each diffraction order visually and thus, one can place precisely a CCD at the location of each diffraction order to collect data without missing diffraction orders. By using the cylindrical screen, two coordinates are needed to describe the curved, expanded and inclined diffraction patterns.

We show that (1) the transmission gratings play the role of the dual-grating, namely, the transmission gratings produce both the transmission diffraction patterns and the reflective diffraction patterns, both patterns are determined by the orientation of the gratings; (2) the reflective blazed grating produces the expanded, curved and inclined attribute to CW and CCW rotation of the reflective grating. Indeed, the tilt reflective gratings with either the original orientation-A or the original orientation-B produce the diffraction patterns of different characteristics (see Table).

Table: Comparison of diffraction patterns of orientation-A and orientation-B.

	original orientation-A (Figure 40-44)	original orientation-B (Figure 45-49)
Normal incident		
CW rotating grating		
CCW rotating grating		

We suggest that the cylindrical screen provides a tool for analyzing the diffraction/interference patterns, and may be used to test/develop the theories of the grating rotating around 3 axes [12-15].

## References

- [1] Hui Peng, “Double Slit Experiment Still Has Much to Offer (7): Particle Nature of Photons, Normal Diffraction Pattern and Curved Diffraction Pattern Emerging in Same Grating Experiment”, hal-03362721, Oct. 2021.
- [2] Hui Peng, “Double Slit Experiment Still Has Much to Offer (9): —Continuously Curved Diffraction Patterns of 2D-Cross-Grating Experiments”, hal-03425563, Nov. 2021.
- [3] Hui Peng, “Non-Uniform, Curved, Expanded and Inclined Diffraction Pattern of 1D-Grating Experiments —Rotating Grating Around Three Axes”. hal-03560970, Feb. 2022.
- [4] Hui Peng, “Non-Uniform Diffraction Pattern of 2D-Cross-Grating —Rotating Grating Around Three Axes”. hal-03574213, Feb. 2022.

- [5] Hui Peng, “Curved, Expanded, Inclined and Mirror-Symmetric Diffraction Patterns of 2D-Cross-Grating--- Rotating Grating Around Three Axes (2)”, Research Square, preprint, DOI: <https://doi.org/10.21203/rs.3.rs-1244947/v1>, Jan. 2022.
- [6] Hui Peng, “Non-Uniform, Curved, Expanded and Inclined Diffraction Pattern of 1D-Grating Experiments ---Rotating Grating Around Three Axes”. TechRxiv. Preprint. <https://doi.org/10.36227/techrxiv.19134743.v1> DOI: [10.36227/techrxiv.19134743.v1](https://doi.org/10.36227/techrxiv.19134743.v1), Feb. 2022.
- [7] Hui Peng, “Non-Uniform Diffraction Pattern of 2D-Cross-Grating ---Rotating Grating Around Three Axes”. TechRxiv. Preprint. <https://doi.org/10.36227/techrxiv.19172846.v1>. DOI: [10.36227/techrxiv.19172846.v1](https://doi.org/10.36227/techrxiv.19172846.v1), Feb. 2022.
- [8] “Interference and Diffraction”, <https://web.mit.edu>.
- [9] Hui Peng, “Novel Cylindrical Screen Studying Grating Experiments”, TechRxiv. Preprint. <https://doi.org/10.36227/techrxiv.19817506.v1>, May 2022.
- [10] Hui Peng, “Cylindrical Screen--- Rotating Grating Around Three Axes (6)”, Research Square, preprint, DOI: <https://doi.org/10.21203/rs.3.rs-1636397/v1>, May 2022.
- [11] Hui Peng, “Reflective Grating Producing Curved, Expanded and Inclined Patterns --- Observed by Cylindrical Screen”, Research Square, preprint, DOI: <https://doi.org/10.21203/rs.3.rs-1721580/v1>, June, 2022.
- [12] James E. Harvey and Cynthia L. Vernold, “Description of Diffraction Cross-grating Behavior in Direction Cosine Space”, *Applied Optics* 37(34):8158-8160. DOI: [10.1364/AO.37.008158](https://doi.org/10.1364/AO.37.008158), Dec. 1998.
- [13] C. Braig, et al., “An EUV beam-splitter based on conical grazing incidence diffraction”, *Optics Express*, Vol. 20, No. 2 / 1825, January 2012.
- [14] Ninad R. Jetty, Akash Suman and Rajesh B. Khaparde, “Novel cases of diffraction of light from a cross-grating: Theory and experiment”, *American Journal of Physics* 80(684):972. DOI: [10.1119/1.4737854](https://doi.org/10.1119/1.4737854), 2012.
- [15] Georg Heuberger, et al., “Light diffraction from a phase cross-grating at oblique incidence in the intermediate diffraction regime”, *Applied Physics B* 127:72, <https://doi.org/10.1007/s00340-021-07620-x>, April 2021.
- [16] Hui Peng, “Transmission Grating Producing Both Transmission Diffraction Pattern and Reflective Diffraction Pattern Simultaneously. TechRxiv. Preprint. <https://doi.org/10.36227/techrxiv.19769410.v1>, May 2022.
- [17] Hui Peng, “Transmission Grating Functioning as both Transmission Grating and Reflective Grating Simultaneously in Same Experiment--- Rotating Grating Around Three Axes (5)”,

- Research square, Preprint, DOI: <https://doi.org/10.21203/rs.3.rs-1615025/v1>, May 2022.
- [18] Hui Peng, “A Transmission Grating Producing Dual-Pattern: Transmission Patterns and Reflective Patterns Simultaneously”, hal-03677848, May 2022.
- [19] Hui Peng “Cylindrical Screen Studying Reflective Grating --- Curved, Expanded and inclined Diffraction Patterns”. TechRxiv. Preprint. <https://doi.org/10.36227/techrxiv.19945106.v1>, May 2022.
- [20] Hui Peng, “Reflective Grating Producing Curved, Expanded and Inclined Patterns --- Observed by Cylindrical Screen”, Research Square, preprint, DOI: <https://doi.org/10.21203/rs.3.rs-1721580/v1>, June 2022.
- [21] Hui Peng, “Novel Double Slit and Cross-Double Slit Experiments--- Interference Patterns Depending on Orientation of Diaphragm”, Research Square, preprint, DOI: <https://doi.org/10.21203/rs.3.rs-653201/v1>, June 2021.
- [22] Hui Peng, “Double Slit Experiment Still Has Much to Offer (7): Particle Nature of Photons, Normal Diffraction Pattern and Curved Diffraction Pattern Emerging in Same Grating Experiment”. hal-03362721, 2021.
- [23] Hui Peng, “Novel Double Slit Experiments: Right-hand Rule and Left-hand Rule ---Interference Patterns Curved, Expanded and Inclined Simultaneously”, Research Square, preprint, DOI: <https://doi.org/10.21203/rs.3.rs-737506/v1>, July 2021.