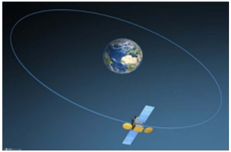


Design and Modelization of a convex grating for the hyperspectral imager Chandrayaan 2: spectral optimization based on free form profile

Bernard SABUSHIMIKE

First International Conference on Optics, Photonics and Materials

26-28 October 2016

Outline

1. Introduction
   - Goal
   - Chandrayaan 2 hyperspectral instrument
2. Design and modelization of a convex grating for Chandrayaan 2
   - Choice and optimization of the hyperspectral imager configuration
   - Design and modeling of a convex grating for Chandrayaan 2 in the range of 0.7-5 μm
   - Realistic profile impact on the diffraction efficiency and the polarization sensitivity
   - Diffraction efficiency and Polarization sensitivity depending on incidence angle
   - Characterization of the grating
3. Conclusions and Perspectives

Goal

The aim of our work is to distribute the grating diffraction efficiency over a spectral range that goes from 0.7 to 5 μm using free-form grating based on the multi-level profile to meet the diffraction efficiency requirements.

FIGURE 1: *Multi-level grating*

After manufacturing by diamond turning of the grating by Advanced Mechanical and Optical Systems (AMOS), HOLOLAB proceeds to its characterization to check performances.

Chandrayaan 2 hyperspectral instrument

Chandrayaan 2 is an hyperspectral instrument for observing the moon in the infrared. It includes a telescope and a grating spectrometer. AMOS is the project leader and HOLOLAB deals with the design, modeling and optical characterization of the grating (profiles).

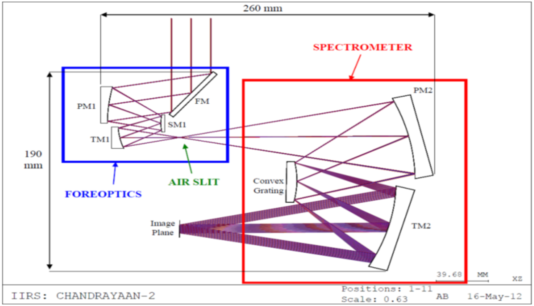


FIGURE 2: *chandrayaan 2 hyperspectral Instrument (AMOS)*

Outline

Choice and optimization of the hyperspectral imager configuration

The choice was focused on the Offner configuration. The optimization is done using Zemax software (AMOS). This configuration offers many advantages including :

- It comprises an entrance slit placed at the focal plane of a telescope and only needs three optical elements namely two concave mirrors and a convex grating in between.

Choice and optimization of the hyperspectral imager configuration

The choice was focused on the Offner configuration. The optimization is done using Zemax software (AMOS). This configuration offers many advantages including :

- It comprises an entrance slit placed at the focal plane of a telescope and only needs three optical elements namely two concave mirrors and a convex grating in between.
- This type of spectrometer has a much more compact form.

Choice and optimization of the hyperspectral imager configuration

The choice was focused on the Offner configuration. The optimization is done using Zemax software (AMOS). This configuration offers many advantages including :

- It comprises an entrance slit placed at the focal plane of a telescope and only needs three optical elements namely two concave mirrors and a convex grating in between.
- This type of spectrometer has a much more compact form.
- It operates at a relatively low F-number($\leq$ f/2) and accept a long slit while maintaining a compact size and low distorsion

Choice and optimization of the hyperspectral imager configuration

The choice was focused on the Offner configuration. The optimization is done using Zemax software (AMOS). This configuration offers many advantages including :

- It comprises an entrance slit placed at the focal plane of a telescope and only needs three optical elements namely two concave mirrors and a convex grating in between.
- This type of spectrometer has a much more compact form.
- It operates at a relatively low F-number($\leq$ f/2) and accept a long slit while maintaining a compact size and low distorsion
- It offers a wide field of view

Choice and optimization of the hyperspectral imager configuration

The choice was focused on the Offner configuration. The optimization is done using Zemax software (AMOS). This configuration offers many advantages including :

- It comprises an entrance slit placed at the focal plane of a telescope and only needs three optical elements namely two concave mirrors and a convex grating in between.
- This type of spectrometer has a much more compact form.
- It operates at a relatively low F-number($\leq$ f/2) and accept a long slit while maintaining a compact size and low distorsion
- It offers a wide field of view

Design and modeling of a convex grating for Chandrayaan 2

Main characteristics of the grating

- spectral range : 0.7 μm to 5 μm

Main characteristics of the grating

- spectral range : 0.7 μm to 5 μm
- Coating : gold

Main characteristics of the grating

- spectral range : 0.7 μm to 5 μm
- Coating : gold
- Optimization order : +1

Main characteristics of the grating

- spectral range : 0.7 μm to 5 μm
- Coating : gold
- Optimization order : +1
- Period : 50 μm

Main characteristics of the grating

- spectral range : 0.7 μm to 5 μm
- Coating : gold
- Optimization order : +1
- Period : 50 μm
- Incidence angle : 27.12 degrees

Main characteristics of the grating

- spectral range : 0.7 μm to 5 μm
- Coating : gold
- Optimization order : +1
- Period : 50 μm
- Incidence angle : 27.12 degrees
- Diffraction efficiency requirements

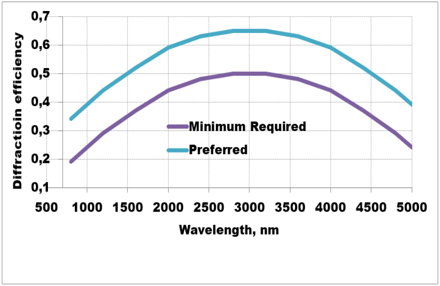


FIGURE 3: *Reference curves of the diffraction efficiency*

Simulation tools

1. Scalar theory

Simulation tools

1. Scalar theory
2. Rigorous theory

Simulation tools

1. Scalar theory
2. Rigorous theory

Scalar theory

The diffraction efficiency of a grating in reflection is given by the following formula according to this theory

$$\eta_{dif} = sinc^2\left(\frac{2h}{\lambda} - k\right) \quad (1)$$

Simulation tools

1. Scalar theory
2. Rigorous theory

Scalar theory

The diffraction efficiency of a grating in reflection is given by the following formula according to this theory

$$\eta_{dif} = sinc^2\left(\frac{2h}{\lambda} - k\right) \tag{1}$$

k : diffraction order and h is the depth of the grooves directly related to the blaze wavelength :

$$\lambda_b = \frac{2h}{k} \tag{2}$$

By combining the two equations for +1 order, we obtain :

$$\eta_{dif} = sinc^2\left(\frac{\lambda_b}{\lambda} - 1\right) \quad (3)$$

By combining the two equations for +1 order, we obtain :

$$\eta_{dif} = sinc^2\left(\frac{\lambda_b}{\lambda} - 1\right) \tag{3}$$

Validity of this theory

Scalar theory is valid in the following case :

$$\frac{\Lambda}{\lambda} \geq 10 \tag{4}$$

Where Λ is the grating period

Rigorous theory : PCgrate software

This theory uses the integral method for solving Maxwell equations. It gives information about polarization sensitivity.

Rigorous theory : PCgrate software

This theory uses the integral method for solving Maxwell equations. It gives information about polarization sensitivity.

profile construction

The following profile is for a blaze wavelength of 3000 nm.Note that the axes are not at the same scale.

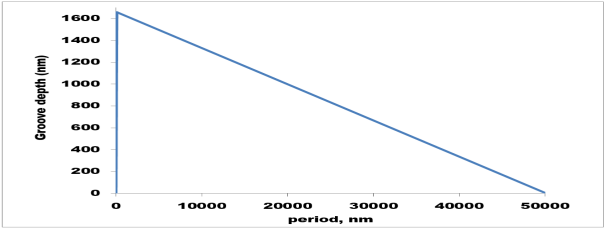


FIGURE 4: *ideal Profile for a central wavelength of 3000 nm*

The diffraction efficiency calculated at blaze wavelength of 3000 nm
By scalar theory

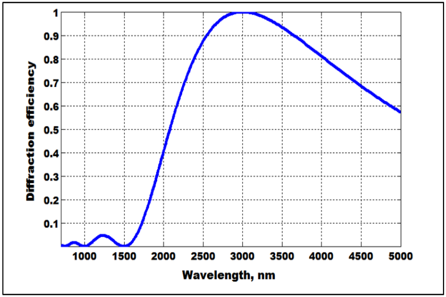


FIGURE 5: *Diffraction efficiency of a grating at a blaze wavelength of 3000 nm given by the scalar theory*

The diffraction efficiency calculated at blaze wavelength of 3000 nm

By scalar theory

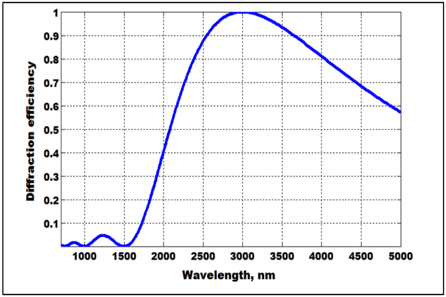


FIGURE 5: *Diffraction efficiency of a grating at a blaze wavelength of 3000 nm given by the scalar theory*

By rigorous theory

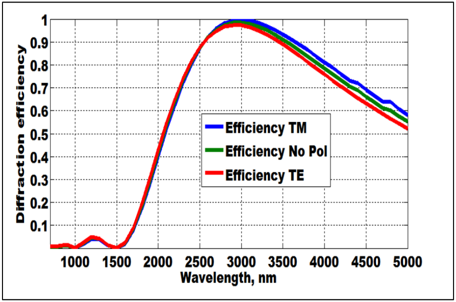


FIGURE 6: *Diffraction efficiency of a perfect grating at a blaze wavelength of 3000 nm given by the rigorous theory*

Conclusions

- The results of the rigorous theory for a perfect grating confirm those of the scalar theory.

Conclusions

- The results of the rigorous theory for a perfect grating confirm those of the scalar theory.
- A grating optimized with a single blaze wavelength can not cover the entire spectral band with the required diffraction efficiency.

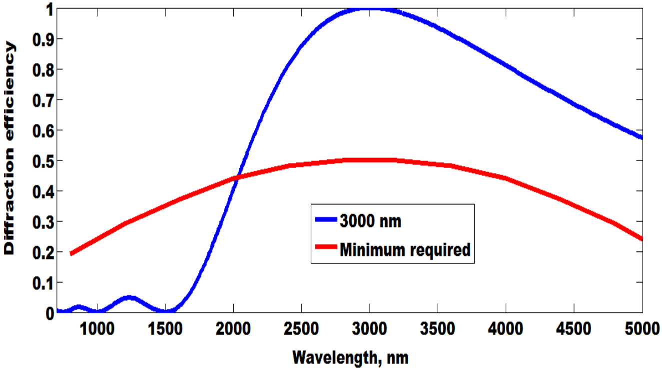
Conclusions

- The results of the rigorous theory for a perfect grating confirm those of the scalar theory.
- A grating optimized with a single blaze wavelength can not cover the entire spectral band with the required diffraction efficiency.

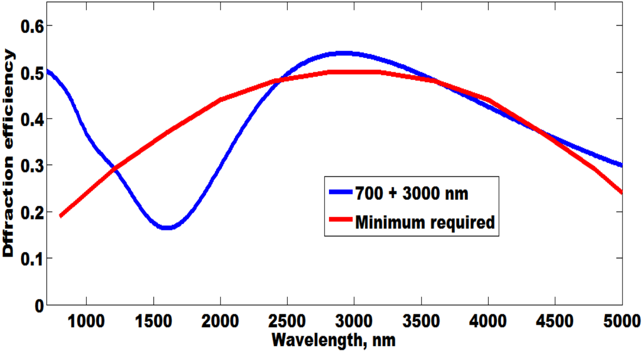
Solution

The multi-blaze method seems most appropriate to solve this problem : I propose a multi-blaze grating with 9 blaze wavelengths which give to the grating a multi-level character. The 9 blaze wavelengths are : 700, 1000, 1400, 1800, 2200, 2500, 3000, 3300 and 4400 nm.

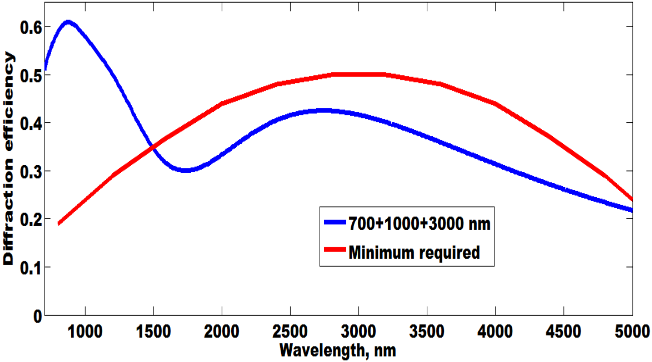
Methodology



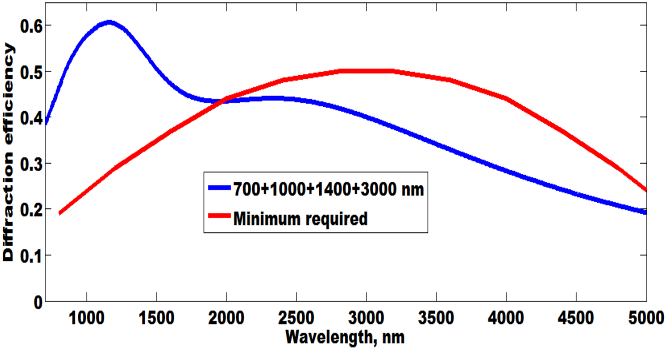
Methodology



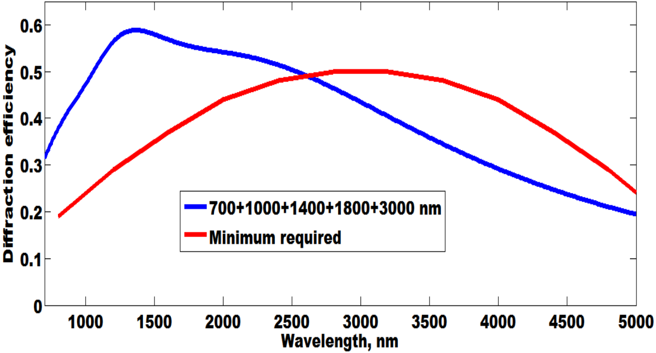
Methodology



Methodology

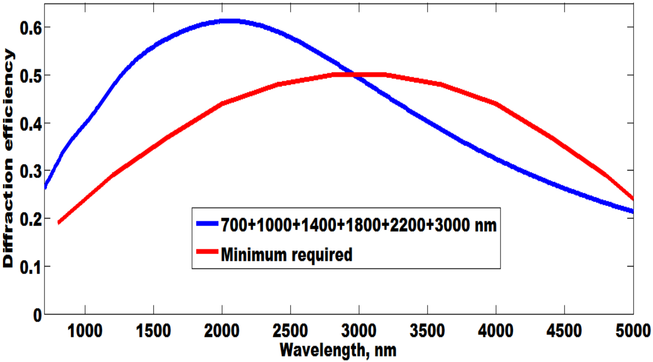


Methodology



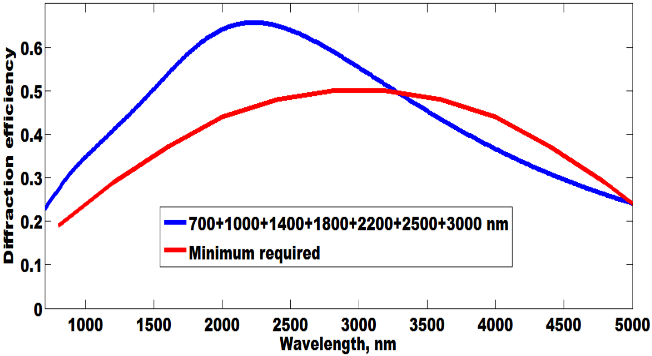
Design and modeling of a convex grating for Chandrayaan 2

Methodology

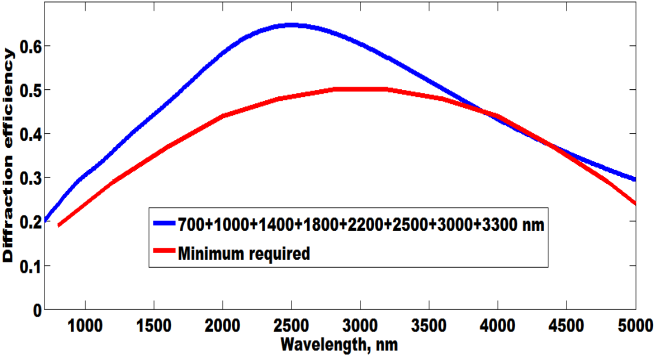


Design and modeling of a convex grating for Chandrayaan 2

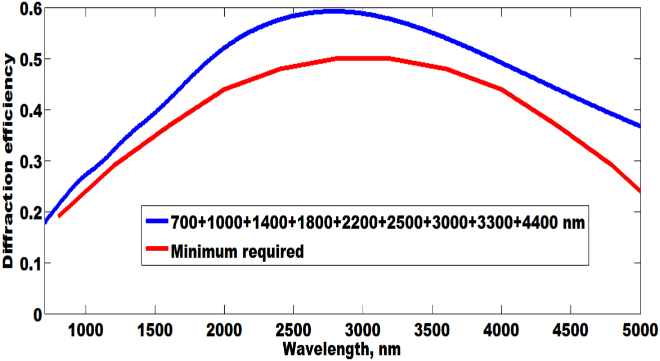
Methodology



Methodology



Methodology



Calculation of the diffraction efficiency of the multi-blaze grating
By scalar theory

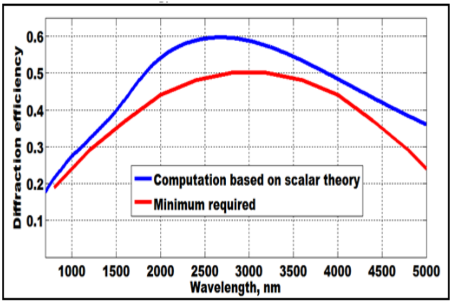


FIGURE 7: *Diffraction efficiency of multi-blaze grating by scalar theory*

Calculation of the diffraction efficiency of the multi-blaze grating

By scalar theory

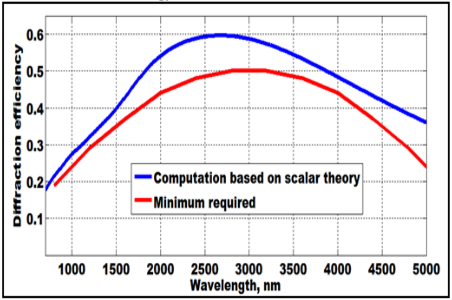


FIGURE 7: *Diffraction efficiency of multi-blaze grating by scalar theory*

By rigorous theory

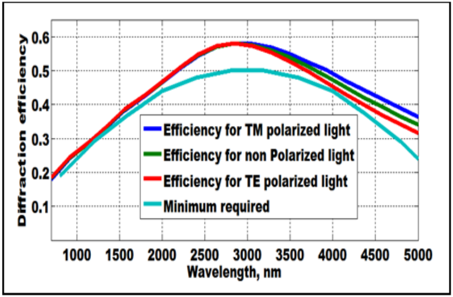


FIGURE 8: *Diffraction efficiency of multi-blaze grating by rigorous theory*

Conclusions

- The diffraction efficiency curve of the multi-blaze grating given by the scalar theory is similar to those given by the rigorous theory.

Conclusions

- The diffraction efficiency curve of the multi-blaze grating given by the scalar theory is similar to those given by the rigorous theory.
- Scalar theory does not take into account polarization effects.

Realistic profile impact on the diffraction efficiency and the polarization sensitivity

Realistic profile model

According to the diamond tool, the realistic profile that we consider is a profile flattened at the top on 5 μm, rounded down to the last 3 μm with a radius of curvature of 5 μm (less rounded) and another with a radius of curvature of 10 μm (more rounded) to the last 5 μm . The corresponding blaze wavelength is 3000 nm

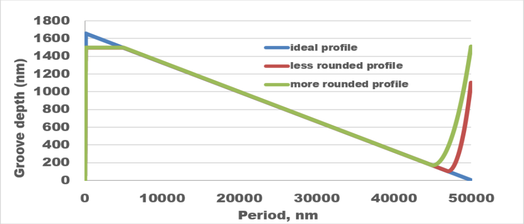


FIGURE 9: *ideal, less and more rounded profiles*

Realistic profile impact on the diffraction efficiency and the polarization sensitivity

Comparison of the diffraction efficiency of the multi-blaze grating with rounded and ideal profiles

ideal profile

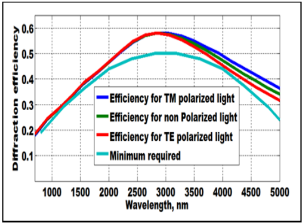


FIGURE 10: *Diffraction efficiency of multi-blaze with ideal profile*

Realistic profile impact on the diffraction efficiency and the polarization sensitivity

Comparison of the diffraction efficiency of the multi-blaze grating with rounded and ideal profiles

ideal profile

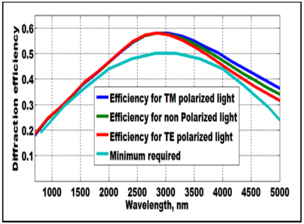


FIGURE 10: *Diffraction efficiency of multi-blaze with ideal profile*

Less rounded profile

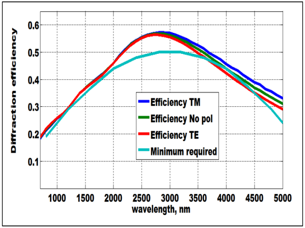


FIGURE 11: *Diffraction efficiency of multi-blaze with less rounded profile*

Realistic profile impact on the diffraction efficiency and the polarization sensitivity

Comparison of the diffraction efficiency of the multi-blaze grating with rounded and ideal profiles

ideal profile

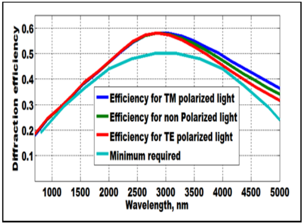


FIGURE 10: *Diffraction efficiency of multi-blaze with ideal profile*

Less rounded profile

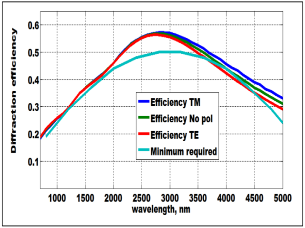


FIGURE 11: *Diffraction efficiency of multi-blaze with less rounded profile*

More rounded profile

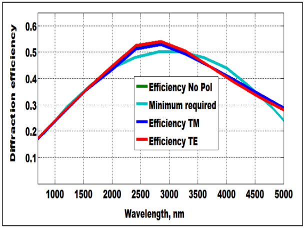


FIGURE 12: *Diffraction efficiency of multi-blaze with more rounded profile*

Realistic profile impact on the diffraction efficiency and the polarization sensitivity

Conclusion

The diffraction efficiency decreases with the rounded profile. The efficiency decreased by 5 % (absolute) from the ideal profile to the more rounded profile.

Comparison of no polarized efficiencies of the three profiles

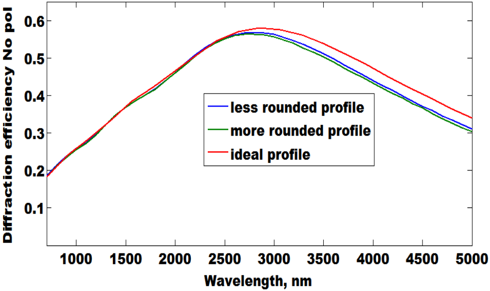


FIGURE 13: *No polarized efficiencies of ideal, less and more rounded profile*

Polarization sensitivity of the multi-blaze grating

The polarization degree of multi-blaze grating is calculated by the following formula :

$$\frac{\eta_{TE} - \eta_{TM}}{\eta_{TE} + \eta_{TM}} \quad (5)$$

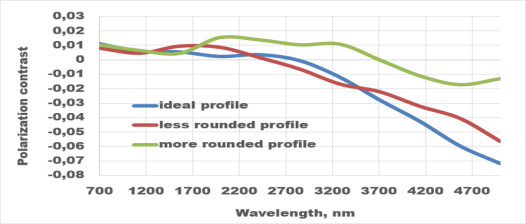


FIGURE 14: *Polarization sensitivity of multi-blaze with ideal and rounded profiles*

Realistic profile impact on the diffraction efficiency and the polarization sensitivity

Conclusion

The polarization sensitivity decreases with the rounded profile in the middle infrared where the sensitivity is too high. It decreased by 6 % from the ideal profile to the more rounded profile especially at the end of the band.

Diffraction efficiency and Polarization sensitivity depending on incidence angle

The simulation is done for a wavelength of 3000 nm

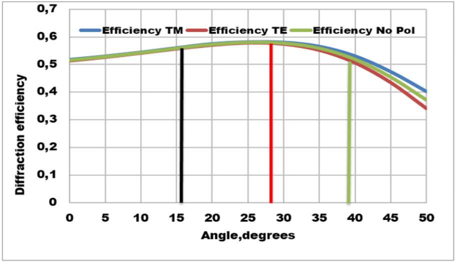


FIGURE 15: *Diffraction efficiency as function of incidence angle*

Diffraction efficiency and Polarization sensitivity depending on incidence angle

The simulation is done for a wavelength of 3000 nm

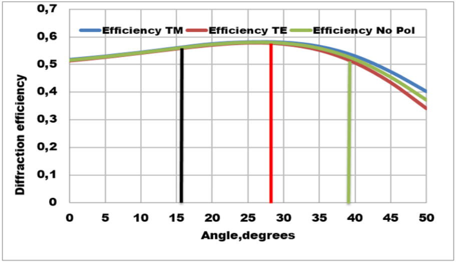


FIGURE 15: *Diffraction efficiency as function of incidence angle*

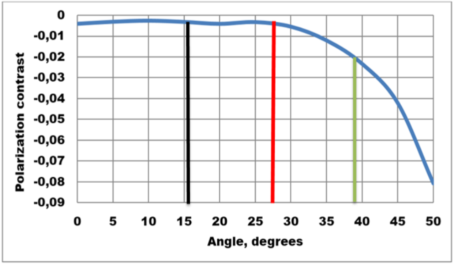


FIGURE 16: *Polarization sensitivity as function of incidence angle*

Diffraction efficiency and Polarization sensitivity depending on incidence angle

The simulation is done for a wavelength of 3000 nm

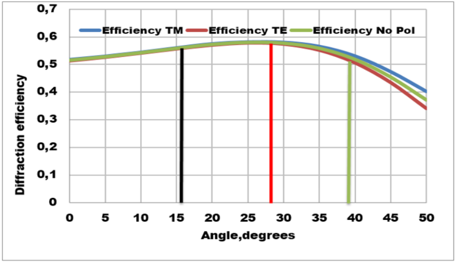


FIGURE 15: *Diffraction efficiency as function of incidence angle*

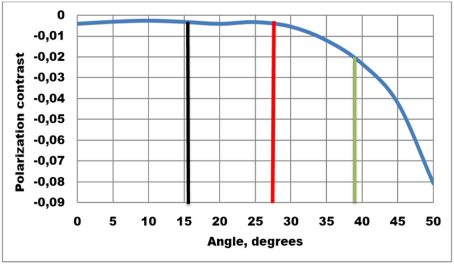


FIGURE 16: *Polarization sensitivity as function of incidence angle*

Conclusion

The diffraction efficiency varies very little and the polarization sensitivity is low between the 2 working limits.

Characterization of the grating

The characterization will be done using :

Characterization of the grating

The characterization will be done using :

- SuperContinuum IR Source in the spectral range 0.7 to 4 μm

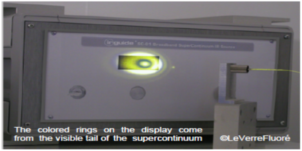


FIGURE 17: *IRguide® SC-01*

Characterization of the grating

The characterization will be done using :

- SuperContinuum IR Source in the spectral range 0.7 to 4 μm

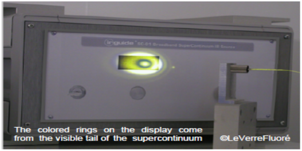


FIGURE 17: *IRguide® SC-01*

- A6700sc Camera FLIR

FIGURE 18: *A6700SC Camera*

Characterization of the grating

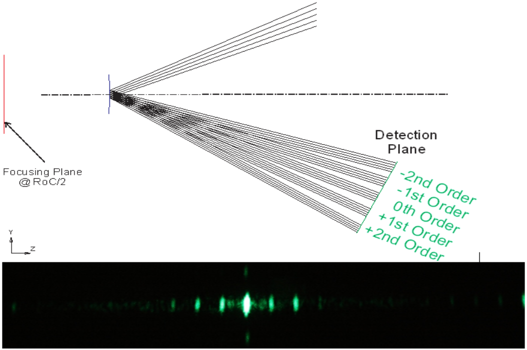


FIGURE 19: *Experimental setup(ESA ITT AO/1-7022)*

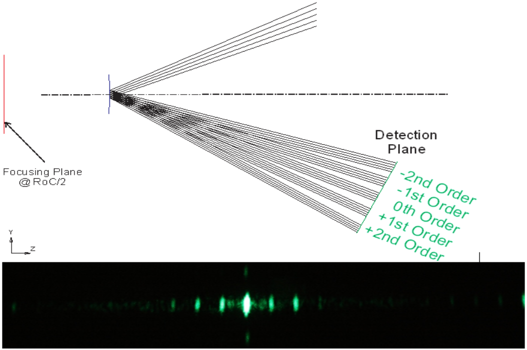


FIGURE 19: *Experimental setup(ESA ITT AO/1-7022)*

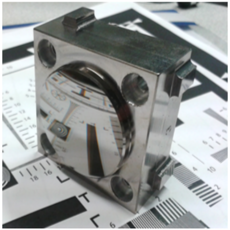


FIGURE 20: *Free Form Grating*

Outline

Conclusions et Perspectives

The multi-blaze method is a method used when the simple blaze is unable to meet the spectral requirements as is the case in this project.

Conclusions et Perspectives

The multi-blaze method is a method used when the simple blaze is unable to meet the spectral requirements as is the case in this project.

- The number of blaze depends on the spectral band and the expected performance of the grating.

Conclusions et Perspectives

The multi-blaze method is a method used when the simple blaze is unable to meet the spectral requirements as is the case in this project.

- The number of blaze depends on the spectral band and the expected performance of the grating.
- 9 blaze wavelengths were necessary to meet grating requirements : 700, 1000, 1400, 1800, 2200, 2500,3000, 3300 and 4400 nm.

Conclusions et Perspectives

The multi-blaze method is a method used when the simple blaze is unable to meet the spectral requirements as is the case in this project.

- The number of blaze depends on the spectral band and the expected performance of the grating.
- 9 blaze wavelengths were necessary to meet grating requirements : 700, 1000, 1400, 1800, 2200, 2500,3000, 3300 and 4400 nm.
- I have shown the impact of the realistic profile on diffraction efficiency and polarization sensitivity.

Conclusions et Perspectives

The multi-blaze method is a method used when the simple blaze is unable to meet the spectral requirements as is the case in this project.

- The number of blaze depends on the spectral band and the expected performance of the grating.
- 9 blaze wavelengths were necessary to meet grating requirements : 700, 1000, 1400, 1800, 2200, 2500,3000, 3300 and 4400 nm.
- I have shown the impact of the realistic profile on diffraction efficiency and polarization sensitivity.
- This profile helps mitigate the polarization sensitivity in the middle infrared.

Conclusions et Perspectives

The multi-blaze method is a method used when the simple blaze is unable to meet the spectral requirements as is the case in this project.

- The number of blaze depends on the spectral band and the expected performance of the grating.
- 9 blaze wavelengths were necessary to meet grating requirements : 700, 1000, 1400, 1800, 2200, 2500,3000, 3300 and 4400 nm.
- I have shown the impact of the realistic profile on diffraction efficiency and polarization sensitivity.
- This profile helps mitigate the polarization sensitivity in the middle infrared.

In perspective, I am working on a dual angle profile which can be used to optimize a grating in two diffraction orders.

Conclusion et perspectives

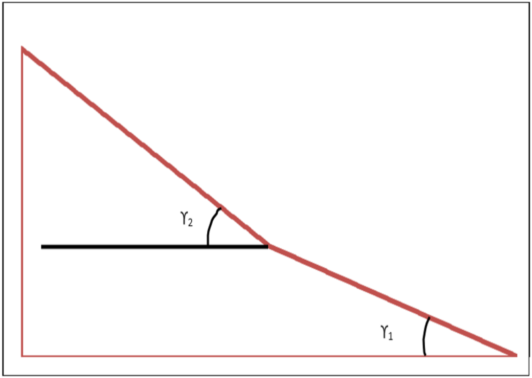


FIGURE 21: *Model of dual angle profile*

Thank you for your attention

bsabushimike@doct.ulg.ac.be