Optical Simulation of Triangular Wired Grid Polarizer for Far Ultraviolet Applications

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Abstract. Polarimetric observations in the far ultraviolet (FUV) are very useful for us to understand the role played by the magnetic field of the coronal plasma in the energy transfer process from the inner parts of the sun to the outer space. To observe these processes there are various key spectral lines in the FUV, from which H I Lyman $\alpha$ (121.6 nm) is the strongest one. We designed and optimized a triangular wire grid polarizer (WGP) based on Al/MgF\textsubscript{2} multilayer coatings to obtain high polarization with a simultaneous high Rs. As a result, at incidence angle of 50° and 60° whereas Rp was minimized, this model have a 99.98% and 99.99% degree of polarization with a Rs of 0.32 and 0.69 respectively.

1. Introduction

Polarizers for FUV applications have been studying for many years [1-4]. FUV includes many important spectral lines for astrophysics, solar physics, and atmospheric physics, one of the key FUV spectral line is H I Lyman $\alpha$ at 121.6 nm. Al/MgF\textsubscript{2} multilayer thin films are commonly used for polarizers at this wavelength because of the high reflectance of the Al, lower absorption of MgF\textsubscript{2}. Therefore, many scholars have conducted research on it in FUV applications. Kim et al. [5] achieved 87.95% reflectance for Rs and 0.43% for Rp with a 99.03% degree of polarization by means of a MgF\textsubscript{2}/Al/MgF\textsubscript{2} three layer structure on an opaque thick film of Al as the substrate. Larruquert et al. [6] designed a polarizer based on Al/ MgF\textsubscript{2} multilayer coatings resulted in efficient polarizers at 121.6nm, with Rp=0.01-0.017 and Rs=0.69-0.725. Bridou et al. [7] based on Al/ MgF\textsubscript{2} multilayer coatings, obtained 69% reflectance for Rs at the incident angle of maximum polarization. However, all of their maximum polarization angles are closed to glancing angle. Therefore, an efficient nano-optical wire grid polarizer (WGP) could be useful to achieve high polarization below glancing angle because of large achievable element sizes (wafer size), compactness (wafer thickness), and large acceptance angles [8].

In this paper, we designed a triangular WGP based on a Al/MgF\textsubscript{2} multilayer thin films to shape light in its propagation behavior in FUV application. As is shown in Figure 1, where $h$, $w_1$ and $w$ is height, width
and period of the WGP. Such application needs to be evaluated by using the polarization degree parameter defined as

$$P = \frac{(R_s - R_p)}{(R_s + R_p)}$$

where $R_s$ and $R_p$ are the reflectances in S and P polarization respectively. This parameter has to be more than 99.6% and a $R_s$ more than 0.2. Through the simulation and analysis, revealed that this kind of polarizers are promising.

![Figure 1](image1.png)

**Figure 1.** (a) 3D theoretical model, (b) 2D theoretical model.

2. **Material and structure requirements**

In our model, 150 nm for the thickness of Al has been chosen, because this value is enough to reflect all the incoming radiation at the target wavelength 121.6 nm. In order to choose the optimal thickness for MgF$_2$, we set the thickness of MgF$_2$ as a variable parameter in the IMD simulations [9]. We selected the working angle of 45$^\circ$, which is a value useful for folding mirrors in optical systems. The results are reported in Figure 2, where the reflectance at the working angle has been plotted versus MgF$_2$ thickness. We selected the MgF$_2$ thickness of 65 nm because it produces a constructive interference and it guarantee a good protection for the Al oxidation.

![Figure 2](image2.png)

**Figure 2.** The reflectance versus MgF$_2$ thickness.
Moreover, on top of the Al\textsubscript{MgF\textsubscript{2}} bi-layer a TiO\textsubscript{2} layer was selected as absorber. This topmost layer is the starting point to be etched for the realization of absorbing nano-structures on-top of the high-reflective Al\textsubscript{MgF\textsubscript{2}} bi-layer. The thickness of this layer as well as all the parameters required to describe the triangular nano-structure (i.e. width, height and period) were carried out by using the wave optics module of COMSOL Multiphysics software [10]. Due to the symmetry of our structure, we use a 2-D modeling of the structure. The optical constants of TiO\textsubscript{2} was taken from literature [8] whereas for the all other materials were taken from IMD database (see Table 1).

| Material | n     | k     |
|----------|-------|-------|
| TiO\textsubscript{2} | 1.1222 | 0.9157 |
| Al       | 0.0423 | 1.1404 |
| MgF\textsubscript{2} | 1.7047 | 0.0180 |
| Air      | 1     | 0     |

The geometry of the model used in the simulations are presented in Figure 3. The top edge of the air domain was set up with incident port and the bottom edge of the Al domain was set up with exit port, the periodic Floquet’s boundary condition established on the corresponding left and right boundaries of the model.

![Figure 3. Geometry model.](image)

Futhermore, the incident angle is a variable, so four parameters sweep at the same time.

### 3. Results

After the optimization process, two different structures for WGP ensuring good performance have been found (see Table 2).

| Structure | Rs   | P       |
|-----------|------|---------|
| A         | 0.32 | 99.98%  |
| B         | 0.69 | 99.99%  |

The S and P reflectance versus incidence angle of each structure is reported in Figure 4. The best result is obtained for Structure B which shows the highest polarization selection (P=0.9999) as well as a highest reflectance at 121.6 nm.
For both optimized structures, the analysis of the sensitivity between the three free parameters and the final optical performance has been carried out. This sensitivity was evaluated by swiping one parameter at a time and leaving the others at the nominal values of Table 2. The dependence graphs are reported in Figure 5. From the analysis emerged that the structure reflectance is little affected by the optimization parameters whereas the polarization degree is highly conditioned by these parameters. For instance, a polarization degree greater than 99.6% is preserved for deviation of just several nanometers for both the height (h) and the triangle base width (w). On the other hand, the structure periodicity results to be very decisive on the polarization, requiring a tolerance that seems to be lower than 1 nm.

**Figure 4.** Reflectance versus different incident angles.

**Figure 5.** (a), (b) and (c) are P and Rs curve versus height, width and period of Structure A. (e), (f) and (g) is P and Rs curve versus heigh, width and period of Structure B.
4. Summary

We designed and simulated a WGP based on triangular nanostructure for FUV application. The reported results suggest a good performance in both Rs and P, especially when incident angle equal to 60°, the reflectance can be reached 0.69, and we also discuss the tolerance of key parameters. These can provide much information for our future manufacturing.

5. References

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