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Numerical Analysis of the Buried Parallelogramic Grating

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Abstract: The buried parallelogramic grating is to embed tilt dielectric film in the waveguide with sub-wavelength cycles. Based on rigorous coupled-wave analysis, the grating is modeled and numerically analyzed. The diffraction efficiency under different polarization states and incident angels is calculated. The result shows that with the TE-mode incidence, the 1st order diffraction efficiency varies between [0, 37%] with the film thickness and stays almost the same with the change of incident angles. The other non-zero orders′ efficiencies are below 2%. This feature could satisfy the increasing efficiency required in the head-up display. It could also reduce the energy loss and unwanted image rays. When the incident angle changes between [45 °, 70 °] in vertical and [−15 °, 15 °] in horizontal, the 1st order diffraction efficiency stays almost the same to maintain the uniform display in different view fields. The effect on the diffraction efficiency is also discussed with the change of polarization, inclination, cycle and materials. This article can provide theoretical guidance in the manufacture of the grating.

Key words: Grating; Diffraction efficiency; Rigorous Coupled -Wave Analysis(RCWA)

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0 Introduction

The waveguide holographic helmet mounted display (W-HMD) is a novel design of helmet mounted display (HMD) which could reduce the burden of the pilot by showing targets outside and instruments information inside at the same time[1]. The traditional HMD applies the off-axis method to display the image which needs complex lenses, heavy and occupying too much space[2]. To solve the problem several patents from BAE Systems in UK reveal the idea of W-HMD by folding the optical paths inside the waveguide to make the structure lighter and more integrated[3]. The collimated beam of different view fields is coupled into the waveguide and diffracted by the grating buried inside to generate the 1st order diffraction with different directions. At the same position of the grating, the efficiency could stay the same with incident angles to get the uniform display from different view fields[4].

The grating plays an important part in the W-HMD but there are few documents analyzing its diffraction features in detail. The article models the grating and analyzes its detailed diffraction features based on Rigorous Coupled-wave Analysis (RCWA). The result shows that the structure could diffract the 1st order diffraction perpendicular to the grating, change the 1st order diffraction efficiency (DE) with the thickness of the film and suppress other non-zero orders′ DE. By changing the incident angle the 1st order DE stays almost the same. These features could meet the requirements of the increased DE in W-HMD and maintain uniform display of different view fields. At the end of the article the effects of several parameters on the DE are discussed such as polarization, inclination, cycle and materials.

1 Calculation of RCWA

To suppress the DE of higher orders, the cycle of the grating is set around the sub-wavelength range. The article chooses the RCWA to get the rigorous results from any incident angles and polarizations[5-6]. The rectangular relief grating is calculated by the programming of RCWA and the relation between DE and groove depth is shown in Fig. 1. The parameters of the grating is the same with previous works[7] and the result is identical, which could prove the correctness of the program.

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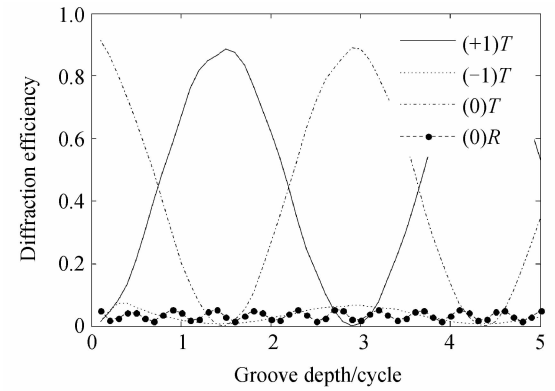


Fig. 1　Diffraction efficiency for square-wave surface-relief grating

2　Diffraction features of the buried parallelogramic grating

2.1　Structure

The structure is shown in Fig. 2(a), combined of two parts. The first part is the base, similar to the blazed grating made of Plexiglass (PMMA) with $n=1.495$; the second part is the dielectric film, coated on the inclined plane made of Titanium dioxide (TiO_2) with $n=2.5$[8]. They are bonded together with the matching refraction index glue. The beam propagates in the waveguide in the ways of forward and backward as shown in Fig. 2 (a). The thickness is named x, cycle is named T and the groove depth is named d.

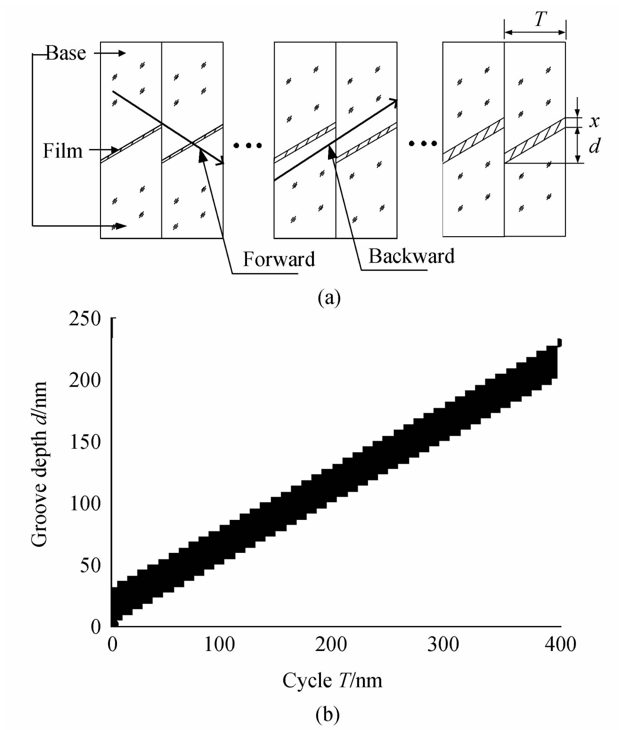


Fig. 2　(a) Structure of the buried parallelogramic grating; (b) Simulation of one cycle

Fig. 2(b) shows the one cycle in the RCWA program with the stratified number set to 50[9]. The white area stands for the base and the black stands for the film.

2.2　Curves of the DE

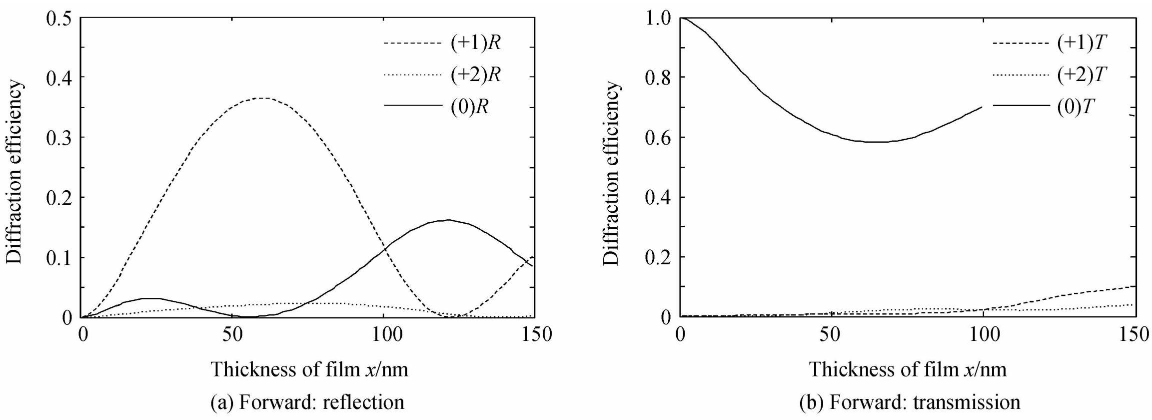
The incident beam is TE mode with angle set to 60° and lambda set to 532 nm. To make the direction of 1^{st} order perpendicular to the grating, the cycle T is set to 410 nm with $n=1.495$. The groove depth d is set to 220 nm and the relation between DE and thickness of the film is shown in the Fig. 3.

When the thickness of the film changes between [0 nm, 60 nm], the DE of the 1^{st} order increases gradually with the peak of 37%. The peak of the 2^{nd} order is 2% and the other non-zero orders are approaching zero.

As the beam makes total internal reflection (TIR) in the waveguide, the energy deceases gradually with the diffraction[10-11]. To achieve the uniform display, the DE should make corresponding increments. The rising efficiency of the 1^{st} order could meet this requirement and the suppression of the non-zero orders could reduce the energy loss and scattered imaging beams.

2.3　1^{st} order DE changing with the incident angle

The view field of W-HMD is generally set to 20°×30°. To achieve this the horizontal angle a is set in [−15°,15°] and the vertical angel b is set in [45°,70°].



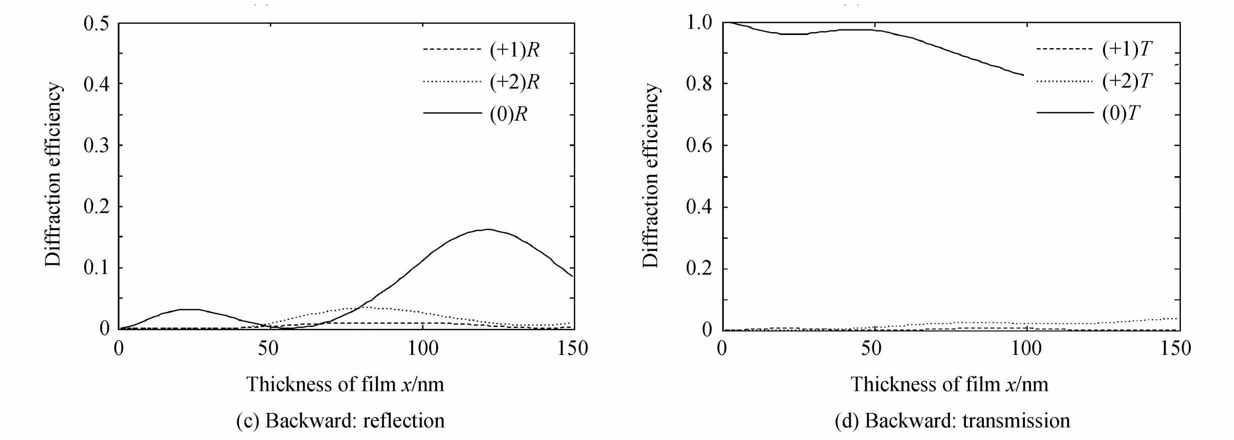


Fig. 3 Diffraction efficiency changing with x

First b is set to 0° and a changes in [−15°, 15°], the relationship between a and the 1st order's DE is shown in Fig. 4(a). At different thickness x, the DE stays almost the same with the changing of a.

Second a is set to 0° and b changes in [45°, 70°], the relationship between b and the 1st order's DE is shown in Fig. 4(b). It has some slight fluctuations with the changing of b, but the overall trend keeps stable.

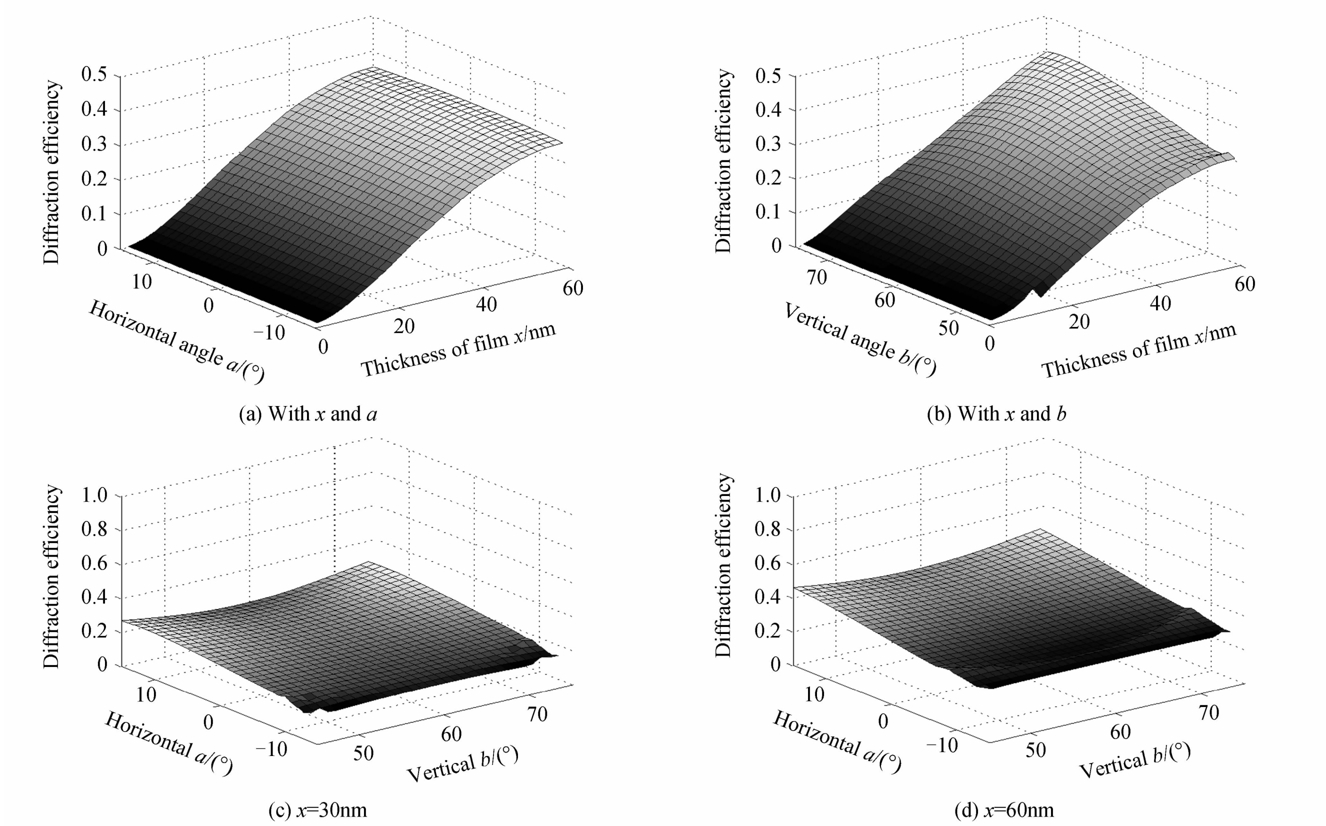
Then certain x is chosen and the 1st order's DE changing with a and b is shown in Fig. 4(c) and (d). The x is set to 30 nm and 60 nm respectively. From the figures the 1st order's DE can keep stable with the incident angles. Its insensitivity to the angles could be conductive to the uniform display of the whole view field.

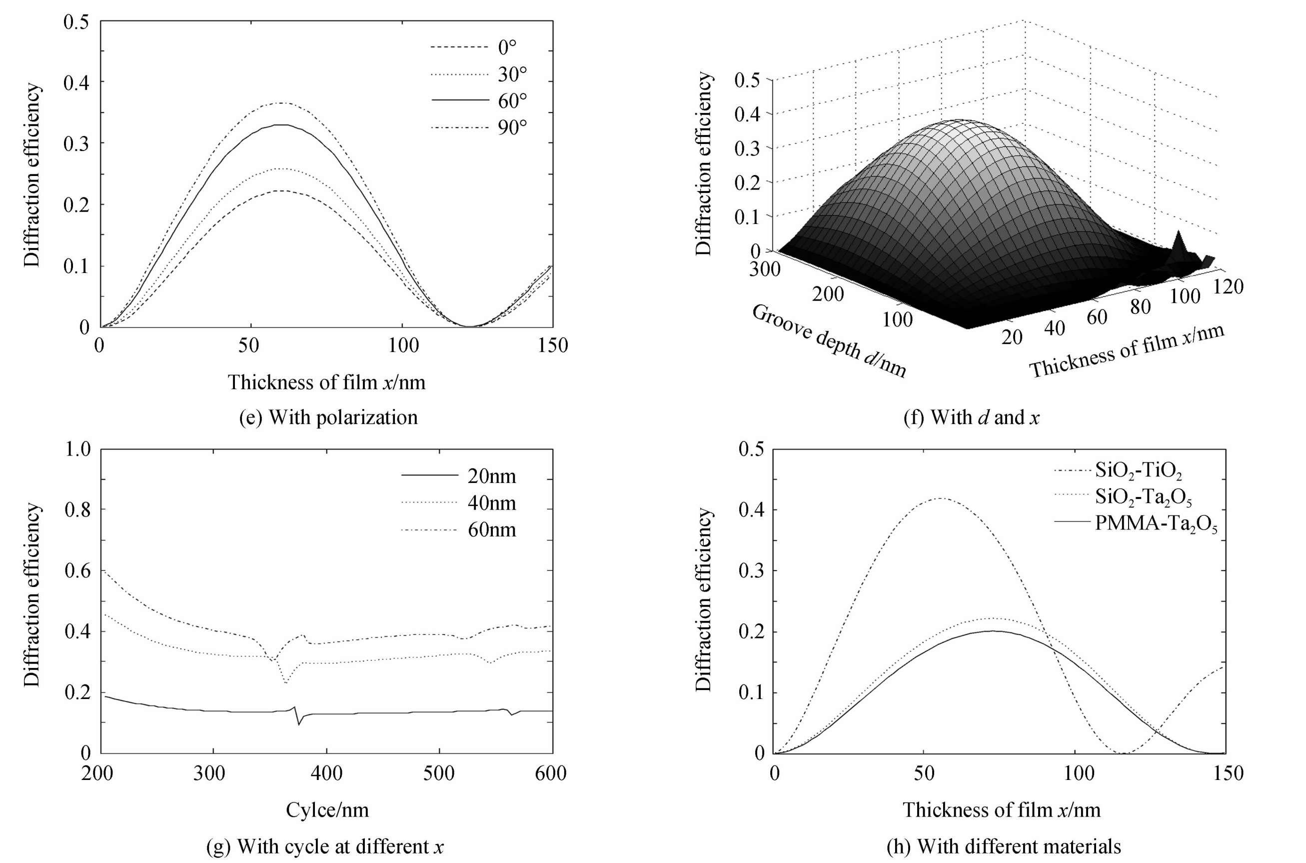
3 Analyses of the changing parameters

In the manufacture or assembly, there are some restrictions from the technology and fabrication, which could change the parameters from the calculated values. This section focuses on the effects of changing polarization, inclination, cycle and materials.

3.1 Polarization

The angle of electric field decides the polarization, for example 0° stands for TM mode and 90° for TE mode. The angle is set to 0°, 30°, 60° and 90° respectively. The relationship between





(e) With polarization (f) With d and x

(g) With cycle at different x (h) With different materials

Fig. 4 Diffraction efficiency changing with parameters

the 1st order's DE and the thickness x is shown in Fig. 4 (e). The curve shows that with the polarization changing from TE to TM, the peak of 1st order's DE deceases gradually, but the trend of the curve keeps the same.

3.2 Inclination

Changing the inclination of the film means changing the groove depth d. Fig. 4(f) shows the 1st order's DE could reach 37% when d is between [220 nm, 230 nm] and x is between [55 nm, 65 nm]. The inclination angle is 26°. When the d is outside the range, the peak efficiency decreases gradually with the thickness x.

3.3 Cycle

With thickness x chosen as 20 nm, 40 nm and 60 nm, the relation between the cycle and the 1st order's DE is shown in Fig. 4(g). It has guided mode resonance[12] at the cycle around 380 nm and 560 nm. In the range of 390 nm to 500 nm it changes smoothly.

3.4 Combination of different materials

Several other materials are chosen to replace PMMA and TiO_2. For example the base can choose Silica (SiO_2) with $n=1.46$ and the film can choose the Tantalum oxide (Ta_2O_5) with $n=2.25$. Fig. 4(h) shows that, when the difference between two indices is larger, the efficiency would be higher. Such as the combination of SiO_2 and TiO_2, the peak efficiency could reach 41.8%. And when the difference is smaller, x would be larger at the peak efficiency. Such as the combination of PMMA and Ta_2O_5, the thickness x is 75 nm at the peak efficiency of 17%.

4 Conclusion

Based on the RCWA, the article models the grating in the W-HMD and makes numerical study on the diffraction efficiencies with the change of incident polarizations and angles. The result shows that in the TE mode, the 1st order's DE changes between [0, 37%] and the other non-zero orders are below 2%. While the incident angle changes between [45°, 75°] in vertical and [−15°, 15°] in horizontal, the 1st order DE keeps stable. These features could meet the requirements of the uniform display at different view fields of the W-HMD. Other parameters are analyzed at the end of the article which could provide theoretical guidance in the manufacture of the grating.

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嵌入式镀膜光栅的数值模拟研究

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摘　要:嵌入式镀膜光栅是将平行四边形的介质膜层,以亚波长量级的周期嵌入波导中.针对该光栅在不同偏振态、不同角度入射下的各级衍射效率问题,本文基于严格耦合波分析理论,对该光栅进行建模与数值分析.结果表明,在TE模入射时,该光栅的一级衍射效率可随膜厚在[0, 37%]内变化,其余非零级次的衍射效率低于2%.衍射特性可以满足平视器成像的效率递增要求,同时可以减少能量的损失与杂散成像光线.当入射光束的角度在纵向[45°,70°]、横向[−15°,15°]内变化时,一级衍射效率的变化平稳,可以保持平视器不同视场的成像能量均匀.针对入射光偏振态、光栅材料、嵌入膜层倾角、光栅周期对衍射特性的影响,给出了相应的数值分析,可为波导全息平视器中衍射元件的制作提供理论指导.

关键词:光栅;衍射效率;严格耦合波理论