Enhanced Diffraction by a Completely Planar Adjacent Grating

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Abstract. A completely planar adjacent grating (AG) structure, which is composed of two identical planar dielectric gratings connected by thin metallic or dielectric film, is proposed in the paper. We carry out the numerical investigations of AG according to rigorous coupled-wave approach. The calculated results indicate that the completely planar grating structure is another highly efficient structure to enhance diffraction due to the interaction of surface waves excited by gratings at resonant conditions on both interfaces of the thin connection layer. The results also reveal that the modulation of refractive index is the same crucial role to excite or couple out surface wave as the roughness of the surface does.

1. Introduction
Over the past 30 years the rigorous coupled-wave analysis (RCWA) [1-5] has been used successfully and accurately to analyze periodic structures including holographic gratings [1-2] and arbitrary profiled dielectric or metallic surface-relief gratings [3,6-8]. The researches about optical diffractions attract so much and so everlasting interest owing to their many applications not only in traditional fields of photo-electronics, integrated optics, spectroscopy and holography but also in the leading fields of nano-photonics. At present, using sub-wavelength gratings to excite or couple out surface wave [9-10] is one of the most hot research areas since the experimental finding of extraordinary light transmission by T.W.Ebbesen [11]. However, most of these studies consider arbitrary profile sub-wavelength holes arrays [11-14] or arbitrary profile metallic surface-relief gratings [3, 6-10]. In this study, a completely planar grating structure, namely AG, is presented. The characteristics of AG is that it consists of two identical planar dielectric gratings whose relative permittivity is sinusoidal modulation, moreover, the two dielectric gratings can be connected by either thin metallic or dielectric film. For the proposed AG structure, we firstly conceive the field expression in each region and then formulate equations satisfying the electromagnetic boundary conditions according to the rigorous coupled-wave approach (RCWA) in Reference [15]. The numerical investigations for the diffraction spectra of AG show that the proposed AG structure is another highly effective structure to enhance transmission or reflection at resonant conditions due to the interaction of surface waves on both interfaces of the thin connection layer. The other more important aim of designing this completely planar grating is to demonstrate the fluctuation of refractive index is the same crucial role to excite or couple out surface resonance wave as the geometrical roughness of the surface does.

2. The adjacent-grating structure
A schematic diagram of the proposed adjacent-grating structure is shown in Fig. 1. The configuration consists of two identical planar sinusoidal dielectric gratings adjoined by continuous thin silver films.
or dielectric films of thickness $h$. The lossless planar dielectric grating [1-2] is characterized by a periodical medium. The relative permittivity can be depicted by

$$
\varepsilon_2(x,z) = \varepsilon_4(x,z) = \varepsilon_{\text{avg}} + \Delta \varepsilon \cos[K(x \sin \phi + z \cos \phi)]
$$

(1)

where $\varepsilon_{\text{avg}}$ is the average permittivity and $\Delta \varepsilon$ is the amplitude of the sinusoidal permittivity. The grating thickness, the grating period and the grating slant angle are represented respectively by symbols $d$, $A$ and $\phi$. And $K \approx \gamma / A$. The permittivity in the region I ($z < 0$) is $\varepsilon_1$ and the one in the region V ($z > 2d + h$) is $\varepsilon_5$. While the permittivity of Ag film in the region III is $\varepsilon_3$. The complex permittivity of metallic films is described by the Drude model

$$
\varepsilon_3(\omega) = 1 - \frac{\omega^2_p}{\omega^2 + j \gamma \omega}
$$

(2)

where $\omega_p = 1.37 \times 10^{16} \text{rad/s}$ is the plasma frequency for Ag and $\gamma = 7.29 \times 10^{13} \text{rad/s}$ is the collision frequency for Ag [16], $j = \sqrt{-1}$.

3. Numerical calculations and discussions

In the followings, we first calculate the diffractive efficiencies of an adjacent-grating structure connected by thin metallic film according to the rigorous coupled-wave approach (RCWA) in Reference [15]. Figure 2 shows the calculated reflection and transmission spectra at normal incidence in the visible light range. The unslant grating has 400nm grating period and 100nm thickness and its average permittivity is 2.25 and the modulation is 0.33. The thickness of the connection layer of thin Ag film is 40nm. Suppose the adjacent-grating structure in water, There are three diffractive orders no matter in reflective spectra or transmitted spectra. The 0th order diffraction holds mainly energies, and the +1st and -1st diffraction has the same energy owing to the symmetrical structure at normal incidence. Moreover the 0th order diffraction spectrum has two evident resonant peaks. One narrow short-wavelength peak is at the wavelength of 596 nm, whose transmission reaches 0.613364 and reflection is 0.07936 and corresponding absorption is 0.303276. The other wider long-wavelength peak is at 647nm, whose transmission is 0.337835 and absorption is 0.453405. The results indicate that the proposed AG structure excited evident enhanced transmission peaks.
Fig. 3 shows the diffraction spectra of only single grating coated with thin Ag film shown on Fig. 3 (a). Other parameters are the same with Fig. 2. Without the second layer grating, there are also two reflected peaks but no transmitted peaks. The differences of diffractive spectra between AG and single grating manifest that the highly transmitted enhancement is due to that the first layer grating indeed couples the incident light wave into resonant surface modes at resonant conditions and then the evanescent waves are outcoupled for radiation modes [17-18] by the second layer grating when the metallic film is thin enough. On the other hand, the evident resonant peaks indicate that the modulation of refractive index in the completely planar adjacent grating (AG) structure can also excite or couple out the surface wave at resonant conditions as the rough surface in arbitrary profile surface-relief gratings does.

In order to highlight the particular feature in AG connected by thin dielectric film ($\varepsilon_r = 2.25$), only the 0th order reflection spectra is depicted in Fig. 4. The other parameters are the same as those of Figure 3. Interestingly, there emerges a sharp enhanced peak (reaching 0.96561) at 557nm in reflection spectra shown with red solid line. When the second grating is substituted by the same depth dielectric film with relative permittivity 2.25, there is only one single grating and the relative reflection spectrum
exhibits that the enhanced reflection is only 0.2449 at the same wavelength 557 nm. If the first grating is also changed into identical thick dielectric film with relative permittivity 2.25, the five regions degenerate to three regions and there is no enhanced peak shown in Figure 4. The results indicate that strongly enhanced (reaching 96% is four times as that of single grating) and highly selective reflection is achieved by AG connected with thin dielectric film.

In this section, we calculate the diffractive spectra of the proposed structure. The diffractive spectra of AG show that the double-wavelength enhanced transmission can be acquired by AG connected with thin metallic film, while the strongly enhanced and highly selective reflection is achieved by AG connected with thin dielectric film.

4. Conclusion
From the above discussions, one conclusion can be drawn that the proposed completely planar AG structure is another highly efficient structure to enhance diffractions due to the interaction of surface waves excited by gratings at resonant conditions on both interfaces of the thin connection layer. The results also reveal that the modulation of refractive index is the same crucial role to excite or couple out surface resonant wave as the roughness of the surface does.

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