TRANSMISSION ENHANCEMENT THROUGH SINGLE SLIT EMBEDDED IN PLASMONIC MULTILAYER STRUCTURE

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Abstract: We investigate the extraordinary transmission through single slit embedded in the plasmonic multilayer structure which consists of a relief metallic grating, a cavity layer, a metallic film. The spectrum presents a Fano-liked shape and a transmission maximum at wavelength of 600nm with a cross section maximum of 5.5. The enhanced transmission performs a loose angular tolerance of 10° and 20° respectively for 1dB and 3dB loss.

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1. Introduction

Extraordinary transmission by subwavelength hole arrays [1] as well as a single hole surrounded by surface corrugations [2-5] has attracted a great amount of interest and offers promising applications. The transmission processes of this kind of grating-surrounded metallic aperture can be separated into three independent steps: coupling in, transmission through and coupling out from the aperture [6, 7]. The “coupling in” can be optimized by tailoring the geometric parameters for a higher transmission [2-4, 8]. However, in current research, the input beam was considered as a plane wave with a single wave-vector and an infinite beam width. Nevertheless, in practical, this kind device for visible light has only a size around 10µm x 10µm. The input beam should be focused for a higher optical efficiency. A focused beam has multiple wave-vectors meaning that the device should be with a loose angular tolerance. However, current grating-surrounded structures are highly angular-dependent owing to the nature of grating-coupled surface plasmon (SP).

In this paper, we investigate the extraordinary transmission through single slit embedded in the plasmonic multilayer structure which consists of a relief metallic grating, a cavity layer, a metallic film. The dispersion as well as the angle-resolved spectral response of the plasmonic multilayer structure is analyzed by using rigorous-coupled wave analysis (RCWA) method. A resonant dip with a high immunity for the angular deviation is designed through the use of the localized SP (LSP). Finally, the transmission properties and the angular tolerance of single slit embedded in the plasmonic multilayer structure is analyzed by using the finite differential time domain (FDTD) method. The spectrum presents a Fano-liked shape and a transmission maximum at a wavelength of 600nm with a cross section maximum of 5.5. The enhanced transmission performs a loose angular tolerance of 10° and 20° respectively for 1dB and 3dB loss.

2. Designation

The propose structure presented in Figure 1. It is a single slit embedded in the plasmonic multilayer structure comprised of a relief metallic grating, a cavity layer, a metallic film (from up to bottom). The metallic grating periodicity is denoted by Λ, the filling factor is f, the depth is denoted by tg, and its complex dielectric constant is denoted by εm where εm=εmr+iεmi. According to classical waveguide theory [9], narrow slits are able to support TM waveguide modes that have no cutoff in frequency. Between and above the grating grooves the dielectric constant is denoted by εd. The thickness of the SiO2 cavity layer is assumed to be tw and its dielectric constant is denoted by εw. The material, aluminum, of the metallic film with a thickness of tf is identical to the grating. The slit with a width of ws is arranged in the metallic film. The structure is illuminated with an incident plane wave at an angle of θ. The input light is TM-polarized in which the magnetic vector is parallel to the grating grooves. The wavelength-dependent optical constants of the investigated materials are referred from ref. [10].

Fig. 1. Basic geometry of the investigated structure. It is a single slit embedded in the plasmonic multilayer structure which consists of a relief metallic grating, a cavity layer, a metallic film.
3. Analysis results

Figure 2 shows the simulated angle-dependent reflectance spectra by using RCWA. The dark shading represents a lower reflectivity. The geometric parameters of the plasmonic multilayer structure (without a slit) were denoted as follows: \( A=400\text{nm} \), \( fA=330\text{nm} \), \( t_g=30\text{nm} \) and \( w_s=30\text{nm} \). For normal incidence, the spectrum shows a clear resonant dip occurring at 2.2eV. The resonant peak at 3.1eV is corresponding to the grating-coupled SPs which obeys the conservation of momentum for SPs: \( k_{sp}=k_0+G \), where \( k_{sp} \) is the wave vector of SPs; \( G=2\pi n/A \) denotes the reciprocal lattice vectors of the grating; \( m \) is an integer. As the incident angle increases, the resonant dip at 3.1eV splits into two peaks respectively referred to \( m=1 \) and \( m=-1 \). At the same time, the resonant wavelength of the dip at 2.2eV is almost the same for \( 0^\circ < \theta < 10^\circ \). In the other word, the plasmonic multilayer structure can confine the incident energy with an angular tolerance of \( 10^\circ \).

![Fig. 2. The band structure of plasmonic multilayer with \( A=400\text{nm} \), \( fA=330\text{nm} \), \( t_g=30\text{nm} \) and \( w_s=30\text{nm} \).](image)

Figure 3 shows the wavelength dependent transmission cross section of a single slit embedded in the plasmonic multilayer structure for the normally incident case. The cross section is the transmission power normalized to the width of the slit. The spectrum presents a Fano-like shape and a transmission maxima at wavelength of 600nm corresponding to the resonant dip (2.2eV) shown in Figure 2. The maxima of the cross section is 5.5.

![Fig. 3. The transmit peak at wavelength 0.6\mu m and shows a FWHM about 0.1\mu m. The parameters are: \( A=400\text{nm} \), \( fA=330\text{nm} \), \( t_g=30\text{nm} \), \( t_w=30\text{nm} \) and \( w_s=50\text{nm} \).](image)

The angular tolerance of this device is also analyzed. The 1dB and 3dB angular tolerance is 10° and 20° respectively. The \( H_2^z \) distributions of the fields respectively for \( \theta=0^\circ \) and \( \theta=10^\circ \) were also simulated by the FDTD method at wavelength of 580nm and shown in Figure 4(a) and 4(b). The geometric parameter was: \( A=400\text{nm} \), \( fA=330\text{nm} \), \( t_g=30\text{nm} \), \( t_w=30\text{nm} \), \( t_f=110\text{nm} \) and \( w_s=50\text{nm} \). It can be seen that the fields were resonant along lateral direction under the Al ridge.

![Fig. 4. \( H_2^z \) density field distribution for \( \theta=0^\circ \) and \( \theta=10^\circ \), respectively.](image)

4. Conclusions

In this paper, we investigate the extraordinary transmission through single slit embedded in the plasmonic multilayer structure which consists of a relief metallic grating, a cavity layer, a metallic film. The enhanced transmission performs a loose angular tolerance of 10° and 20° respectively for 1dB and 3dB loss. This kind of device with a loose angular tolerance is suited for enhancing the transmission of a focused beam through a single aperture.

5. References