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Extraordinary Transmission through Metallic Grating with Subwavelength Slits for S-Polarization Illumination *

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Based on the rigorous coupled-wave analysis algorithm, we have systematically analysed the effect of the geometrical parameters of a dielectric film coated metallic grating with subwavelength slits on extraordinary optical transmission for s-polarization illumination. Results show that the dielectric film which sustains a waveguide electromagnetic mode on the top of the metallic lamellar grating can strongly enhance the transmittance, the positions of the transmission peaks are mainly determined by the period of the metallic grating, the thickness and refractive index of the dielectric film. This structure shows potential applications in excellent polarizers or polarization-isotropic devices at infrared spectral range by appropriately choosing the geometrical parameters.

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Since the extraordinary optical transmission (EOT) through two-dimensional (2D) hole arrays perforated on an optically thick metallic film was reported in 1998,[1] many works have been performed to investigate the underlying physical mechanism theoretically and experimentally.[2-6] Generally surface plasmons (SPs) are involved in the extraordinary transmission process for 2D hole arrays; the holes behave like subwavelength cavities for the evanescent waves coupling the surface plasmons on either side of the film. In recent years, much attention has also been paid to analysing of the transmission properties of 1D arrays of subwavelength slits[7-10] in which s- and p-polarizations are decoupled. SPs play a key role in the EOT process for p-polarization in real metals. Since SPs are excluded for s-polarization, it seems that EOT is restricted to p-polarization. However, in Ref. [11], the authors have proposed that the addition of a thin dielectric film on the lamellar metallic grating interface creates a surface wave that allows for EOT for s-polarization. Here the dependence of transmittance spectra and transmission mechanism with geometrical parameters, such as the thickness and refractive index of the dielectric film, the period of the metallic grating, the thickness of the metal film and slit width, are systematically demonstrated by numerical simulation. We find that effective optical transmission is always incorporated with strong absorption at the resonant peaks for s-polarization. This structure shows potential applications in excellent polarizers or polarization-isotropic devices in infrared spectral range, we can conveniently improve their performance by appropriately chosen the geometrical parameters of the coated dielectric film.

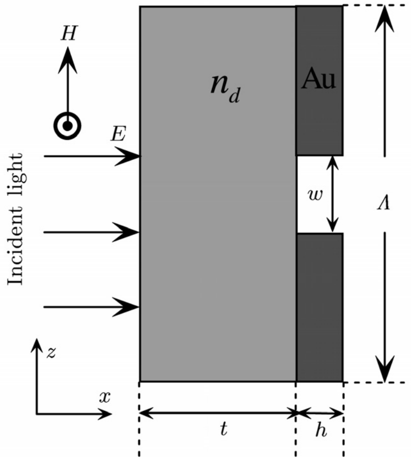

Fig. 1. Schematic diagram of metallic lamellar grating for an s-polarized plane wave at normal incidence.

The system considered consists of a metallic lamellar grating coated by a dielectric layer (Fig. 1). Unless otherwise explicitly mentioned, the grating periodicity is $\Lambda = 3.5\,\mu$m, the slit width is $w = 1.0\,\mu$m and its thickness is $h = 0.1\,\mu$m, the refractive index of the dielectric film is $n_d = 2$, its thickness is $t = 1.0\,\mu$m. The grating is illuminated by a normally incident s-polarized plane wave from the left. We consider real metals with finite conductivity, the frequency-dependent permittivity of gold by use of a third-order polynomial fit in the infrared region of the spectrum between $4\,\mu$m and $6\,\mu$m is taken from the values tabulated in Ref. [12]. Our results are supported by numerical simulations performed with the rigorous coupled-wave analysis (RCWA) method. Convergence in RCWA can be achieved by including a

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sufficient number of space harmonics. We use 50 harmonics in the simulation, the grid size is 5 nm along the x and z axis.

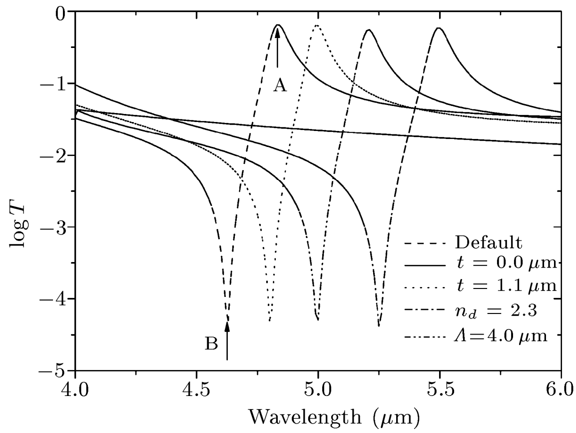

Fig. 2. Transmittance T versus incident wavelength for different geometrical parameters t, n_d and Λ. The vertical transmittance is in logarithm scale. The default values are described in the text.

Figure 2 represents the transmittance versus the incident wavelength for different t, Λ and n_d, while keeping the other parameters unchanged. Here the normalized transmittance is defined as the ratio of the transmitted light intensity to the incident light intensity. Without the dielectric film, the transmittance decreases exponentially with increasing incident wavelength and the spectrum is absolutely featureless in the considered range, but EOT is observed as soon as a sufficiently thick film is added (maximal transmittance approaches 65%). The transmittance curves with dielectric film display a resonant feature including a maximum and a minimum. It can be inferred from this figure that the position of the resonant peaks and dips are strongly dependent on the period of the metallic grating, the thickness and the refractive index of the surrounding medium. When increasing any one of t, Λ and n_d, both the resonant peaks and dips shift to longer wavelength. Figures 3(a) and 3(b) display the electric field distribution at the transmission peak 4.83 μm and dip 4.63 μm (labelled by A and B in Fig. 2, respectively) in the default case. At the transmission peak, the signature of a surface wave can be clearly recognized. The transmitted light propagates to far field along the original direction. The dielectric layer here can be considered as a dielectric waveguide, the incident plane waves are coupled into the dielectric waveguide electromagnetic mode due to the existence of slit in the metallic grating. The wave vector in vacuum is compensated for by the periodicity of the metallic grating and the high refractive index of the dielectric film, this is similar to the momentum-compensation by grating or high refractive index prism in the p-polarization case when SPs are effectively excited. Once the dielectric waveguide electromagnetic mode is produced, the reflectance at the metal/dielectric film interface is greatly reduced. Meanwhile, the transmittance peak is incorporated with strong absorption in real metals for s-polarization. This can be verified by the similarity between the transmission spectrum and absorption spectrum, the absorption efficiency is about 35% at the transmission peak. At the dip position, most of the incident energy flux are reflected back into the air. It is also interesting to mention that the transmittance at the resonant peak can be boosted for symmetrical structures, i.e. the metallic grating is coated by dielectric film on both sides with the same geometrical parameters, due to the match of the two dielectric waveguide electromagnetic modes.

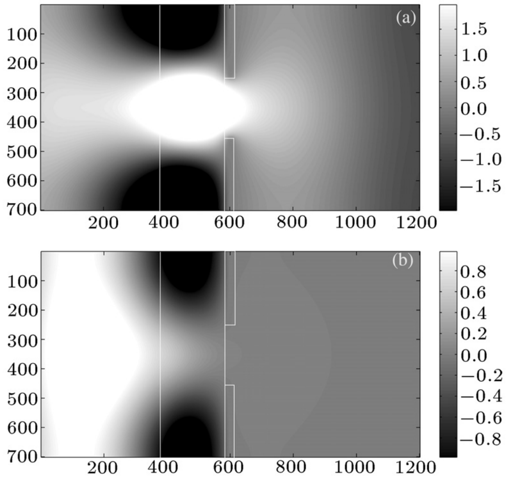

Fig. 3. The near-field distribution of E_y at resonant wavelengths labelled by A and B in Fig. 2. The white lines depict the position of the dielectric film and metallic grating.

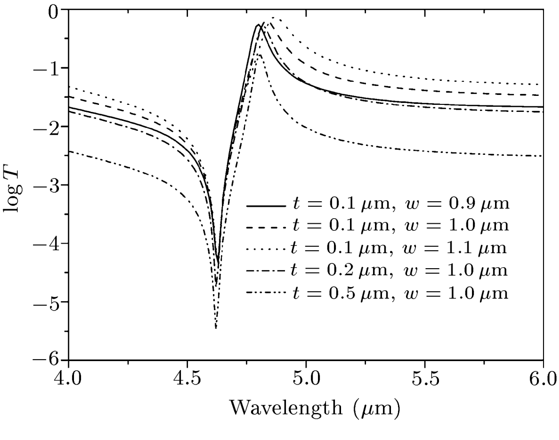

Fig. 4. Transmittance T versus incident wavelength for different geometrical parameters of the metallic grating. The parameters are described in the text.

Since the dispersion relation of the waveguide electromagnetic mode is mainly determined by the three parameters t, Λ and n_d, the position of the resonant peaks and dips are strongly dependent on them as mentioned above. On the contrary, the parameters of the metallic grating, such as thickness h and slit width w, should not significantly shift the position of the resonant peaks. This thought is verified in Fig. 4, the calculated results indicate that with a large change of h and w, the maximal transmittance spectrum only shows a very small shift in position, while the position of the minimal transmittance is nearly unchanged. The absolute transmittance decreases rapidly as the metal thickness grows or the slit width reduces. This is due to the weaker evanescent coupling. Moreover, for noble metals Au and Ag, they have quite similar dielectric constants in the considered spectral range, so they represent the same transmission and absorption properties. Surface defects in metal, such as grooves and protrusions, does not significantly affect the transmission spectra as well.

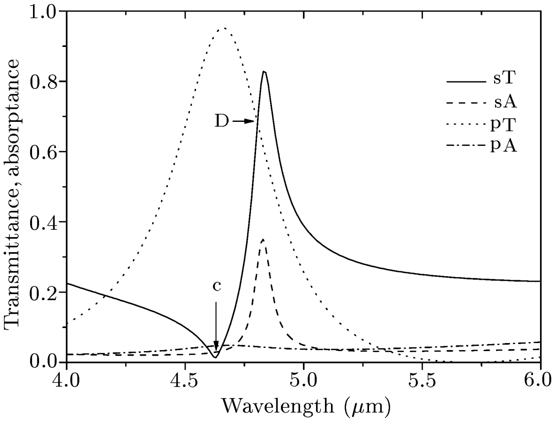

Fig. 5. Transmittance and absorbance versus incident wavelength for different polarization illumination. Here sT, sA, pT, pA represent the transmission and absorption spectrum for s-polarized and p-polarized waves, respectively. The parameters are described in the text.

We also consider the transmittance versus incident wavelength for s- and p-polarization with the same geometrical parameters, as shown in Fig. 5, both the polarizations display a resonant feature. At 4.63 μm (labelled by C in Fig. 5), p-polarized waves possess a high transmission (93.7%) for a dielectric film coated metallic grating, while s-polarized waves have an extremely low transmission (1.3%). The degree of polarization, defined by $P = \dfrac{T_p - T_s}{T_p + T_s}$, is as high as 0.97, where T_p and T_s are the transmittance of p- and s-polarized waves, respectively. In the infrared regime, the conventionally used metallic wire-type polarizers are costly and their performance is less satisfactory with respect to those in the visible range. Our results indicate that the coated metallic grating could act as an excellent polarizer at infrared wavelengths. For bare metallic grating, there are no resonant peaks at the considered spectrum range, the degree of polarization at 4.63 μm is only about 0.71. At 4.81 μm (labelled by D in Fig. 5), both p- and s-polarized waves have similar transmittances, so this highly polarization-anisotropic structure represents a very polarization-isotropic response at this incident wavelength. This feature shows potential applications in subwavelength optical polarization-isotropic elements. Thus we can obtain satisfactory performance of functional photonic elements for a dielectric film coated metallic grating provided that the geometrical parameters are properly tailored.

In summary, we have systematically analysed the effect of the geometrical parameters of the dielectric film and metallic grating on EOT for s-polarization based on RCWA algorithm. A dielectric film which sustains a waveguide electromagnetic mode on the top of the metallic structure can strongly enhance the transmittance. The position of the resonant peaks are mainly determined by the period of the metallic grating, the thickness and refractive index of the dielectric film. This structure can be used as functional photonic elements such as polarizers or polarization-isotropic devices at infrared spectral range by appropriately choosing the geometrical parameters.

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