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SHA Modeling of Gold Gratings for Oblique Light Incidence

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Abstract: We use spatial harmonic analysis (SHA) to model gold double-strip gratings under obliquely incident light. The simulation results are compared to experimentally measured values and excellent matches are achieved.

OCIS codes: (160.3918) Metamaterials; (050.6624) Subwavelength structures

1. Introduction

Metamaterials have drawn great research interests recently due to their unique properties such as negative refractive index, and potential applications such as a superlens [1]. Several metamaterial designs have been realized and characterized [2-4]. However the effective properties of these matematerials were only studied for normally incident light, whereas for a number of applications, such as a superlens, their characteristics under oblique incidence are also important.

To study matematerials under oblique incidence we use spatial harmonic analysis (SHA), also known as Fourier modal method (FMM) or rigorous coupled-wave analysis (RCWA). SHA is a method to rigorously solve Maxwell's equations for periodic gratings [5-6]. It was used to calculate diffraction efficiencies of gratings, and is naturally suited for modeling periodic structures under obliquely incident plane waves. In this report we use a fast converging SHA algorithm [5-6], and show that a two-dimensional periodic structure can be accurately modeled by SHA.

2. Sample characterization and modeling

A side view of the studied structure is illustrated in Fig. 1 (a). In each unit cell two closely spaced gold strips were fabricated on a glass substrate with a thin indium tin oxide (ITO) layer. A thin titanium layer was deposited under the gold strips as an adhesion layer. A scanning electron microscopy (SEM) image of the fabricated device in Fig. 1 (b) shows the top view. The device was then characterized using optical transmittance spectroscopy with the incident angle varying from 0 to 30 degrees. The transmittance spectra for both transverse electric (TE) and transverse magnetic (TM) polarizations were taken in the wavelength range of 550 nm to 850 nm (Fig. 2).

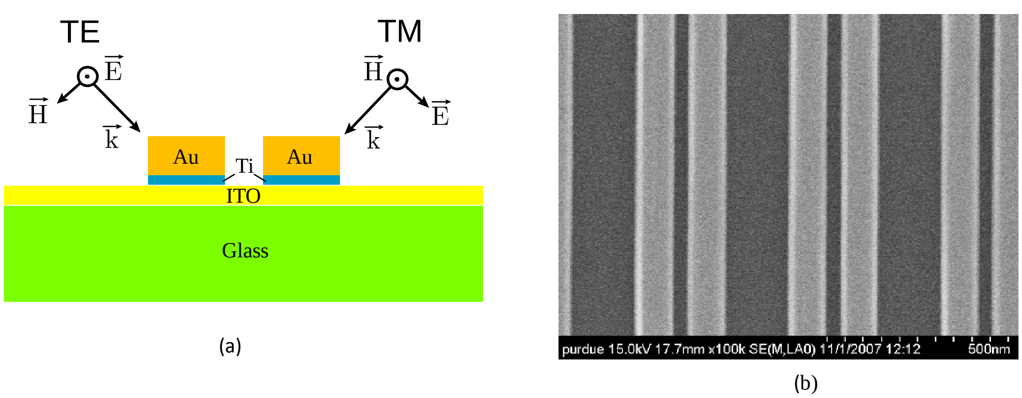

Fig. 1 (a) The schematic of the structure under study; (b) SEM image of the fabricated device.

The transmittance of the device was then modeled using SHA with 20 Fourier modes for both TE and TM polarizations. The refractive indices of the glass substrate and the ITO film were obtained using spectroscopic ellipsometry. The refractive index of gold was taken from [7], and the refractive index of titanium was taken from [8]. The period was fixed at 400 nm. The width and thickness of the gold strips, the gap between gold strips, and the thickness of the titanium strips were adjusted to match the experimental spectra. It has been observed that the loss in gold in nanostructures may be higher than in bulk gold, and the higher loss can be described by a loss factor [9], therefore in our simulations a loss factor for gold was introduced as a fitting parameter. The fitted parameters are: width of gold strips 82 nm, gap 55 nm, thickness of gold strips 13 nm, thickness of titanium 2 nm, loss factor for gold 2.7. The simulated transmittance spectra are compared to experimental spectra in Fig. 2.

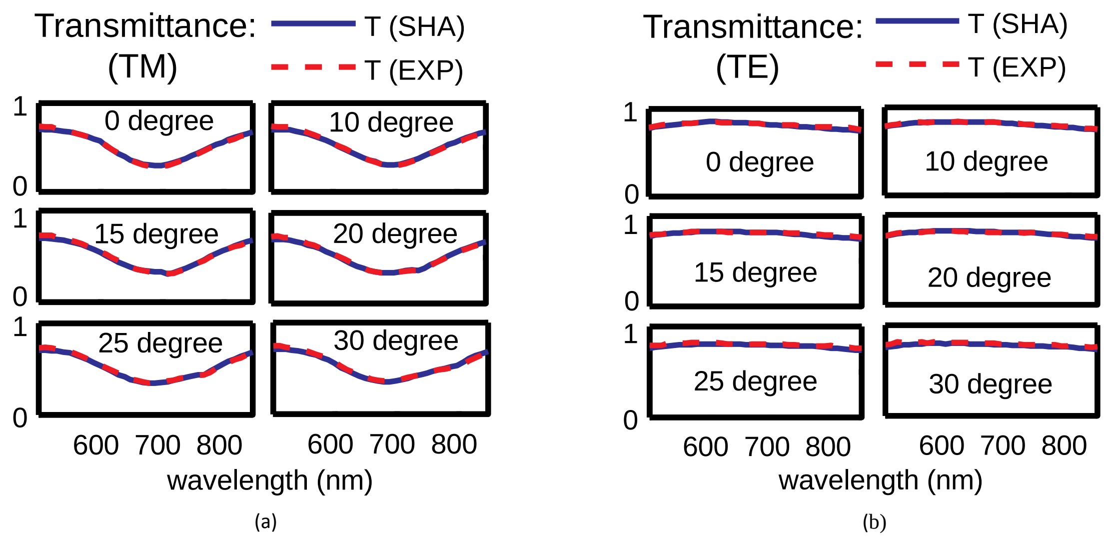

Fig. 2 The experimentally measured (EXP) and simulated (SHA) transmittance for (a) TM polarization and (b) TE polarization. The incident angles are shown in each plot.

Fig. 2 (a) shows the simulated (SHA) and experimental (EXP) spectra for TM polarization. A resonance can be seen for all incident angles. The wavelength at which the first diffraction order starts can be calculated using: $\lambda = p(n_2 + \sin\theta_i)$, where p is the period, n_2 is the refractive index of the substrate, and θ_i is the incident angle [10]. For incident angles of 0, 10, 15, 20, 25, and 30 degrees, the diffraction wavelengths are 608, 677, 711, 745, 777, and 808 nm respectively, which agree very well with the experimental spectra. For TE polarization, Fig. 2 (b), no resonances were observed, and the device acts like a uniform layer of diluted metal. For both polarizations and all incident angles, the SHA simulations reproduced the experimental spectra with high fidelity.

3. Conclusion

We have demonstrated that SHA is a useful tool for modeling periodic nanostructures under obliquely incident light. The two-dimensional SHA tool is now available online [11].

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