Optik - International Journal for Light and Electron Optics 171 (2018) 130–138

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.com/locate/ijleo

Original research article

Electromagnetic dipole resonant characteristics of all-dielectric one dimensional grating in terahertz region

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ARTICLE INFO

Keywords:
Grating
Terahertz
All-dielectric

ABSTRACT

Mie-type magnetic and electric resonances in an all-dielectric one-dimensional grating are theoretically demonstrated in terahertz region. It is found that strong polarization-sensitivity and frequency-selection behaviors of resonances can be excited in all dielectric subwavelength grating structure. This all dielectric grating with less absorption loss can be carefully designed as broadband reflectors and polarization beam splitters. The coupling effects of the array silicon pillar and the electromagnetic field distribution were numerically calculated by use of finite element method. The effective constitutive parameters of subwavelength grating, including in the effective refractive index, effective permittivity, effective permeability, and effective impedance, can be extracted by using the standard retrieval method of inversion algorithm. Magnetic and electric Mie resonances can be revealed by enhanced effective parameters at resonant frequencies.

1. Introduction

Recently, with the development of terahertz time domain spectroscopy (THz-TDS) technology [1], terahertz imaging, terahertz liquid crystal devices, and terahertz polarizers [2] became interesting research fields. Particularly, the extraordinary optical transmission or reflection of the metallic one dimensional grating based on the excitation of surface plasmons is attractive at terahertz region [3], which can be applied in high extinction ratio polarizer and high contrast cut-off filters. However, metallic subwavelength gratings often suffer from a high level of intrinsic ohmic losses especially in the visible and near-infrared regime, resulting in a low-quality resonant response. Fortunately, all dielectric nano- or microstructures with high refractive index material indicate less loss and support high-quality resonance. These resonant performances with both electric and strong magnetic resonances are frequently supported by high index dielectric nanoparticles. For example, spheres, cubes, cylinders, and rods [4–8] were frequently investigated with their resonant characteristics. The strong electric and magnetic Mie resonances can be applied to realize perfect reflector [8], electromagnetically induced transparency [5], and near-zero refractive index, and so on [7].

However, most previous studies have concentrated on single high index dielectric nanoparticles. The strong electric and magnetic Mie dipole resonant performance for one-dimensional all dielectric grating in terahertz frequency was a less research. In our work, it was found that a series of high-qualify electromagnetic fundamental and high-order Mie resonances can be excited in both electric and magnetic modes in the one-dimensional silicon-based grating. Besides, it is known that in subwavelength nanostructure devices the retrieval and determination of the constitutive parameters are important and have aroused extensive attention [9]. Previously, the effective constitutive parameters of components including negative refractive index material, zero refractive index devices, and

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https://doi.org/10.1016/j.ijleo.2018.06.038
Received 19 December 2017; Accepted 7 June 2018

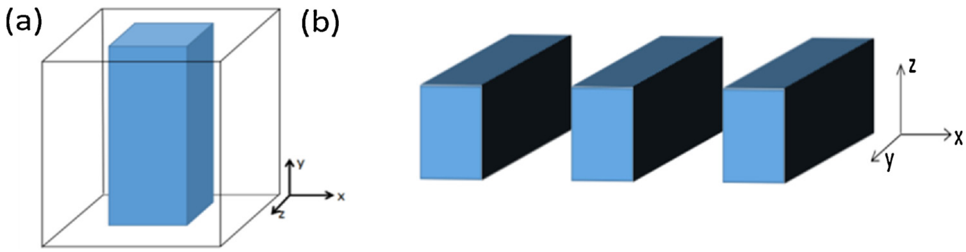

Fig. 1. (a) is a silicon pillar and (b) is the 1D silicon grating without substrate.

high refractive index, were frequently investigated in some structure composed of an array of thin metal wires and split-ring resonators [10,11]. In our work, the effective constitutive parameters characteristics for all dielectric one-dimensional grating were extracted. The resonant effective parameters in Mie resonances were analyzed.

2. Resonant response of all dielectric grating

Fig. 1 shows a one-dimensional grating. The unit cell is composed of a single rectangular-shaped silicon pillar surrounded by air, as demonstrated in the inset of Fig. 1(a). And many silicon pillar like this are periodically arranged to form a 1D grating in Fig. 1(b). The width (in the x direction) and the thickness (in the z direction) of each rectangular silicon pillar of the all-dielectric grating are defined as p and h, respectively. The period of the grating is defined as T and the complex permittivity of the silicon pillar is $e = 11.6 + i0.1$ [12]. In our simulation, the x-polarized THz pulses are parallel (TE wave) or perpendicular (TM wave) to the grating lines, respectively, as shown in Fig. 1(b). The transmission characteristics and the distributions of the electric and magnetic fields at the resonant frequencies were numerically calculated based on finite-element method.

In order to maintain a subwavelength region of the grating, the period T of the grating is defined as 60 u m, the width p of the rectangular silicon pillar is 50 u m. The thickness h of the rectangular silicon pillar is changed, and its value is changed from 20 u m to 50 u m. Fig. 2(a) shows the resonant performance for incident TE-polarized THz wave. It can be seen that the resonant peaks are red-shift with increase of grating height, and the width of peak is decreased leading to the increase of Q-factor. The first resonant mode can be confirmed to be magnetic dipole resonance by electromagnetic field, and the second resonant mode is electric dipole resonance. Also, the high order resonance with high Q-factor occurs in calculated region. It is interesting that the amplitude of resonant mode for electric dipole and magnetic dipole is nearly same. For TM-polarization in Fig. 2(b), the amplitude of first two resonant modes is different. Next, the width of the rectangular silicon pillar p can be changed from 20 u m to 50 u m with the period of 60 u m and the thickness value of 50 u m in Fig. 3. Accordingly, the grating duty cycle is changed from 1/3 to 5/6. It can be found in Fig. 3(b) for TM polarization that the resonant modes nearly disappear, and the broadband transmission performance is revealed at the grating duty cycle of 1/3.

Fig. 4 shows the resonant characteristics with changing grating period. It can be found that for TE polarization the change of grating period slightly influences the resonant modes. But, for TM polarization in Fig. 4(b), the amplitude of the first resonant mode decreases as the period of grating increases, but the amplitude of the second resonant peak increases with increase of grating period. It is interesting that when the grating period reaches to 75 um, a broadband resonant mode of electric dipole is revealed, and the broadband high reflection performance is demonstrated. This performance can be applied in broadband electric dipole resonance reflector. Simultaneously, for TE polarization at about 1.75 THz the high transmission is obtained, then this grating can be designed to be a polarization beam splitter.

In order to study the electromagnetic coupling characteristics of the all-dielectric gratings in a better and more comprehensive

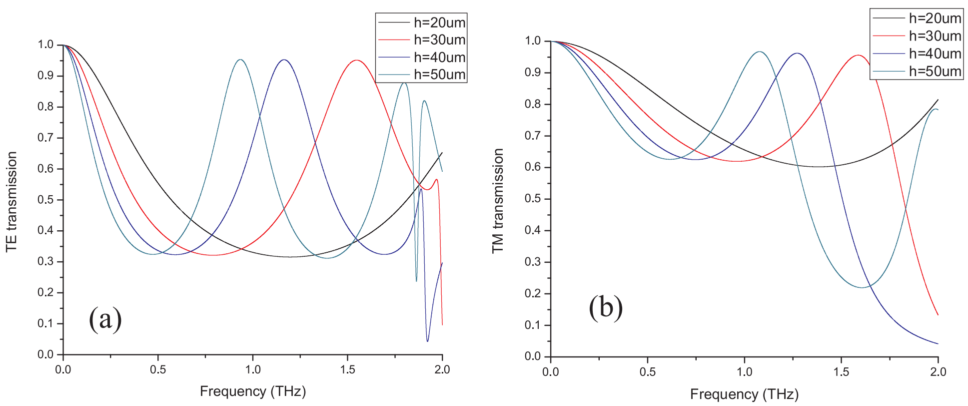

Fig. 2. Simulated TE (a) and TM (b) transmission for the dielectric 1D grating with different thickness of the silicon pillar.