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Polarization transmission mechanism analyzation of bi-layer nanowire polarizer

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ABSTRACT

The polarization transmission of bi-layer nanowire polarizer is analyzed physically by using equivalent medium theory and Fabry–Pérot resonate theory. The principal of the two theories are explained briefly. The analyzation of grating period, duty cycle and metal height on polarization transmission can be also applied to other type of nanowire polarizers. The critical period of the grating is given. The effects of the grating parameters on polarization performance are analyzed systematically on physical level. The extraordinary optical transmission of TM and specially TE polarization light through bi-layer nanowire grating is analyzed. The analyzation of the polarization transmission mechanism will be helpful for the design and fabrication of the gratings with good polarization properties.

1. Introduction

Polarization imaging is a useful technology for cancer detection [1], wear analyzing [2], optical communication [3] etc. Polarizer is the most important component of polarization imaging device, and has been widely studied in previous researches [4–6]. Wire-grid polarizer (WGP) demonstrates good polarization efficiency, wide view angle, long-term stability and the potential to integrate with other thin film optical components. Therefore, WGP is getting more and more attention. Bilayer and single layer nanowire polarizer are two typical structures. Bilayer nanowire polarizer is much easier to fabricate than single layer nanowire polarizer, whereas the mechanism analysis of former is more complicated. The calculation theory of nanograting diffraction efficiency is relatively mature, and the effect of grating parameters on polarization property has been calculated and analyzed by many researchers [7,8]. However, the polarization transmission mechanism of bilayer nanowire polarizer is still quite complicated and abstract to understand. Mechanism analysis that could apply to different type of metal gratings would be very helpful for the design and optimization of nanowire polarizers. The equivalent medium theory (EMT) and Fabry–Pérot resonance (FPR) theory have clear physical implication, and the calculation equations are also quite simple. In this paper, EMT and FPR theory are used to systematically explain polarization transmission phenomenon and the effects of grating parameters on polarization performance.

2. Modeling and basic theory

Fig. 1 shows the grating structure of the bi-layer nanowire grating. The structure parameters include material of the grating and substrate, grating period, thickness of metal grating and dielectric grating, and duty cycle (DC). In visible spectrum, aluminum grating shows the best polarization performance [9]. SiO_2 is a common used dielectric material, and SiO_2 grating shows no fundamental difference with other dielectric gratings. In this paper, the substrate is set to be SiO_2, the metal is aluminum and the dielectric material is SiO_2. The wavelength of incident light is set to be 500 nm, the grating period, height of metal grating, height of SiO_2 grating and DC are set to be 200 nm, 100 nm, 280 nm, and 0.5, respectively. These specific data of the grating parameters is not strictly limited, different data affects the value of polarization transmission efficiency. However, the mechanism of polarization transmission is not affected.

As the grating period is much smaller than wavelength, the scalar method is inadequate to estimate the diffraction efficiency accurately. EMT is based on the premise that only zeroth diffraction order is propagating [10], and very small error is gotten when the period of grating is much smaller than wavelength. If the incident wave is polarized along the grating direction (TE polarization light), the conduction electrons are driven along the wires with unrestricted movement. The physical response of the metal grating is essentially the same as that of a thin metal sheet. The incident wave would be reflected and very little can be transmitted. On the contrary, if the incident wave is polarized

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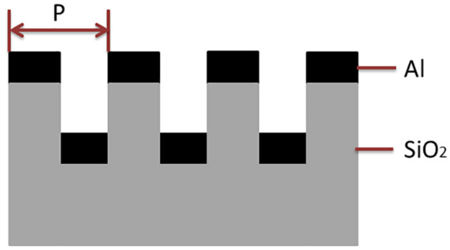

Fig. 1. Structure of bilayer nanowire polarizer.

perpendicular to the metal grating, there is considerable transmission of the incident wave. The nanowire grating behaves as a dielectric rather than a metal sheet.

Metal grating is composited by the metal–dielectric–metal structure. And this structure constitutes the waveguide, which is similar with the Fabry–Pérot (F–P) resonant cavity. The electromagnetic wave transmits in the slit and the transmission efficiency changes periodically because of the impact of resonant cavity.

According to FPR theory [11], when

$$h_{Al} \approx N \times \lambda_g/2 \tag{1}$$

transmission peaks would appear. Where N refers to integer, h_{Al} refers to the height of metal grating, and λ_g refers to the wavelength that transmits in the slit.

EMT and FPR theories both have clear physical concept, and the calculation is quite simple. In this paper, the two theories are used to explain the unique polarization transmission of bi-layer nanowire polarizer. Through analyzing the mechanism of effect of polarization light on polarization performance, clear understanding of bi-layer nanowire polarizer can be gotten. The design of bi-layer nanowire polarizer with good polarization performance can be more facilitate.

3. Simulation and discussion

3.1. Effect of grating period on polarization performance

The key factor that determines the performance of polarizer is the grating period. Metal grating shows good polarization property when the period is much smaller than wavelength of incident light, as is shown in Fig. 2. With other parameters unchanged, grating period is set to be 100–350 nm. The TM transmission efficiency and extinction ratio (extinction ratio equals to the ratio of TM and TE transmission efficiency) are calculated by rigorous coupled-wave analysis (RCWA) theory [12].

As is shown in Fig. 2, minimum point of TM transmission appears when grating period is at around 340 nm. According to the condition of existence of the first order diffraction light [11]

$$p = \frac{\lambda}{n_0} \tag{2}$$

Where p refers to grating period, λ refers to wavelength of incident light, and n_0 refers to the refractive index of the substrate. The minimum point just meets the condition of Eq. (2), and the grating period at the minimum point is also called the critical period. The minimum point of TM transmission can be explained as emerge of the first order diffraction light, and such conclusion can be also applied to other type of metal grating polarizers. With the increase of grating period, higher order diffraction light would arise. In order to get good polarization performance, grating period should be much smaller than the critical period.

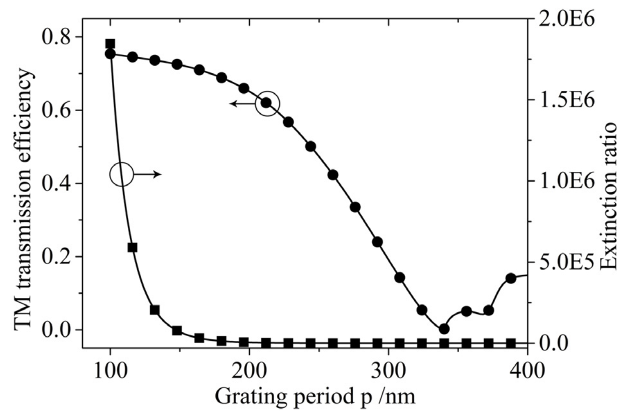

Fig. 2. The effect of the grating period on polarization performance.

3.2. Effect of grating duty cycle on polarization performance

As to bi-layer nanowire polarizer, three grating layers should be considered. In order to simplify the analyzation, DC of three layers changes synchronously. With other parameters unchanged, DC increases from 0.02 to 0.98.

Fig. 3 shows the TM and TE transmission efficiency with the increasing of DC. TM and TE transmission efficiency can get the peak transmission efficiency when DC is near 0.5. EMT can be applied to explain such phenomena. Firstly, as to upper metal grating, the proportion of metal increases with the increase of DC, and according to EMT, the upper layer behaviors more like metal sheet. Therefore, the TM and TE transmission efficiency drops. Secondly, as to lower metal grating, the proportion of metal decreases with the increase of DC, and according to EMT, the lower layer behaviors more like dielectric layer. Therefore, transmission efficiency increases. In summary, the polarization performance of upper metal grating and the lower metal grating change reversely with the increasing of DC. In order to get good polarization performance of bi-layer nanowire polarizer, DC of around 0.5 should be considered.

3.3. Effect of metal thickness on polarization performance

In this section, metal thickness varies from 20 nm to 300 nm, and the distance between two metal layers keeps unchanged. Fig. 4 shows the TM transmission efficiency and extinction ratio with the increasing of metal thickness. With other parameters unchanged, only metal thickness of metal varies. TM transmission periodically drops and extinction ratio increases.

As to TM transmission, absorption increases with the increasing of metal thickness. Therefore, TM transmission would drops. On the other hand, according to F–P theory, the length of the F–P cavity gets longer with the increasing of metal thickness, peak transmission would appear when the F–P cavity meets the condition of F–P resonance. In summary, because of the absorption and the influence of F–P resonance, TM transmission shows periodically decrease with the increasing of metal thickness.

As is shown in Fig. 4, TE transmission efficiency decreases exponentially. According to EMT, the two metal grating layers behave more like metal sheet with the increasing of metal thickness, and thus TE transmission efficiency would decrease exponentially. TE transmission efficiency drops far more than TM transmission, thus extinction ratio increases rapidly.