The Thickness Effects on the Lamellar Grating Waveguide Sensors with TE-Polarization Incidence

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Abstract: This paper has investigated the thickness effects on sub-wavelength (period <λ) Lamellar grating waveguide sensors with TE polarization incidence. Also, the thickness effects of Lamellar grating and its influence on the sensor sensitivity are studied. Simulation results reveal that as the thickness of Lamellar grating is increased, the more resonance modes will be induced as well. However, it is difficult to recognize the peak shift of the fundamental mode while the thickness of grating is different and the thickness of waveguide is the same.
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1. Introduction

Recently, advancing accuracy of micro-fabrication has made photonic crystal devices become very practically and reliably applied to label-free DNA, protein, bio-resource, sensors and actuators fields. [1,2,3] Sub-wavelength photonic crystals can filter the high order optical Bloch modes (or leaky modes) transmitted (or reflected) optical waves and narrow its wavelength spectrum sideband. The high spatial confinement of resonant photons within the device structure leads to a strong interaction between the structure and adsorbed biomaterial; in the meantime, the ability to perform high imaging resolution of protein and cell attachment [4] will be upgraded. [5,6,7]

Since Lamellar grating is a very simple line shape photonic crystal, it can be easily designed, simplify the manufacturing process and become a very popular component in the sensor field. The spectral characteristics of Lamellar grating are mainly affected by its period, thickness, filling factor and refractive index. The Bloch Mode will be influenced by the depth of the grating and results in reflection (or transmission) spectral characteristics change. [8] In recent years, many researchers have devoted to explore the depth effects on the high refractive index Lamellar grating but only few of them note the effects on the low refractive index. [9]

In this article, we have discussed reflective wavelength spectrum introduced by TE polarization incidence to different thickness of Lamellar grating layer. The purpose of this study is to find out the relationship between the grating thickness and sensitivity. We use the low refractive index thin film to replace bio donor and acceptor and attach the film to these surfaces of sensors to examine the sensitivity of the sensor.

Because of improved convergence and stability, the rigorous coupled wave analysis (RCWA) method has been widely utilized to solve the problem of electromagnetic wave propagating in sub-wavelength structure.[10,11,12,13] Also, RCWA possesses very quick convergence in solving diffraction questions; it is popular in the use of thicker or surface relief gratings.

2. Reflection spectrum of Lamellar grating

The proposed structure is composed of two layers: grating and waveguide, a simple resonant sensor. Fig. 1 shows the scheme of such a sensor that consists of Lamellar grating and a waveguide layer surrounded by air (n_{air} = 1). The simulation parameters are designed as followings: the refractive index of grating and waveguide ($n_g = n_{WG}$=1.55), the periodic of grating (Λ=0.5μm), filling factor (F= 0.5), the thickness of grating d_g and waveguide d_{WG}. In addition, we set a homogeneous thin film layer to replace the bio donor and acceptor attached layer; the refractive index and thickness of thin film are defined as n_f =1.334 and d_f. Filling factor is defined as the ratio of the high refractive index material of grating.

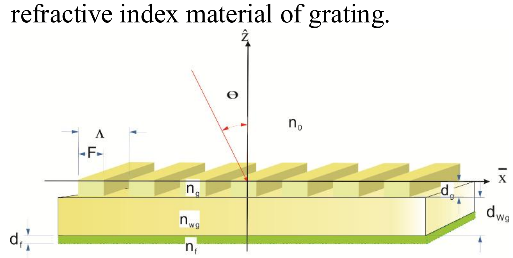
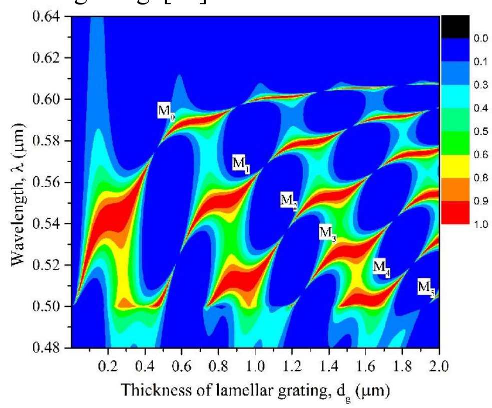
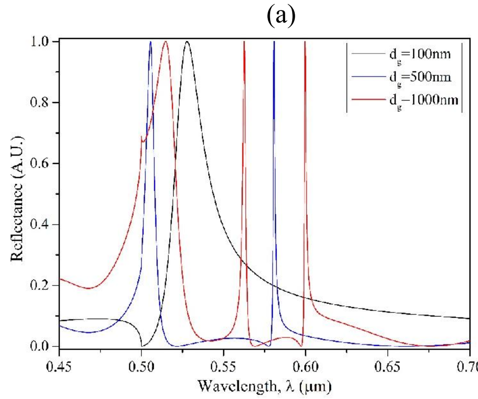


Figure 1. The proposed structure is composed of two layers: grating and waveguide layer, a simple resonant sensor.

The reflected wavelength spectrum introduced by variable thickness of Lamellar grating is illustrated as Figure 2. The illustration shows the numbers of optical reflected mode, which is increased by the thickness of grating, d_g. There is only one reflected mode (R > 99%) as the grating thickness is below 200nm (d_g<200nm). Nevertheless, the thicker grating would increase more numbers of modes. With the defined thickness of Lamellar grating d_g=100nm, 500nm and 1000nm, the reflected optical mode numbers are 1, 2 and 3. The mechanism of Lamellar grating can be treated as the fixed effective index of refraction (n_{eff}) waveguide layer. The thickness of waveguide layer will increase existing guided modes. As the grating thickness has been increased to 1000nm, the peak wavelength shifts 110nm for the fundamental mode (M_0), which is the longest wavelength (or lowest frequency) of the reflection spectrum. No matter how, the optical modes have the threshold, which is limited by the periodic, Λ=0.5μm of the grating. [14]



(a)



(b)

Figure 2. (a)The spectrum versus variable depth of Lamellar grating. (b) The reflection wavelength introduced by d_g=100nm, 500nm, and 1000nm.

3. Reflective spectrum of different thickness of Lamellar grating

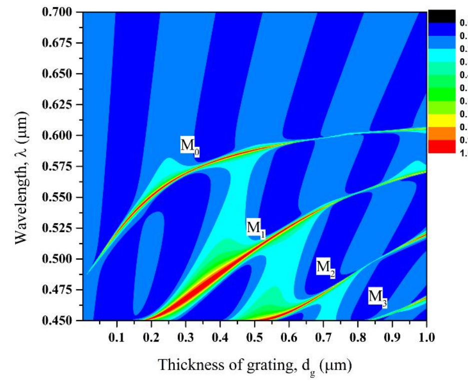


Figure 3(a)

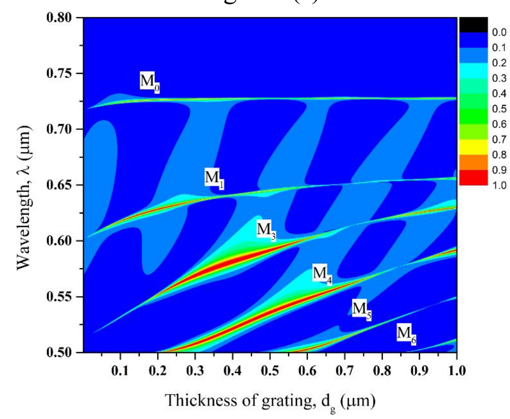


Figure 3(b)

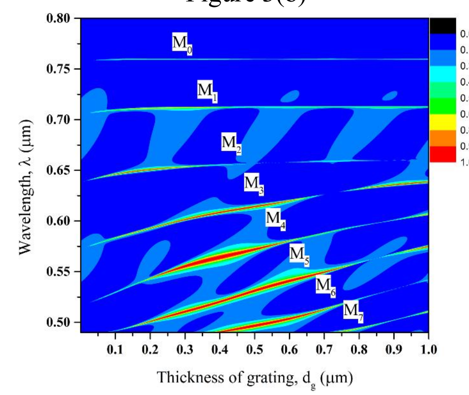


Figure 3(c)

Figure 3. Reflective spectrum of the increasing thickness of grating (d_g). Figure 3(a) is the reflective spectrum vs. d_g under d_{WG} = 100nm. Figure 3(b) Reflective spectrum vs. d_g under d_{WG} = 500nm. Figure 3(c) Reflective spectrum vs. d_g under d_{WG} = 1000 nm.

In order to find out the spectrum effects of increased grating layer on different waveguide layer (d_{WG}=100nm, 500nm, and 1000nm), we calculate the reflective spectrum of increasing grating layer. The simulation results are plot as Fig.3 (a) to (c). First of all, we note that the number of optical modes of thicker grating (i.e. d_{WG}= 500nm and 1000nm) are more than the thinner one (i.e. d_{WG}=100nm). Secondly, the fundamental mode of the thinner grating (i.e.

d_{WG}=100nm) varies more than the M_0 of the thicker ones (i.e. d_{WG}= 500nm and 1000nm). For each case, the thickness of grating presents more like a generally homogeneous waveguide layer.

Fig. 3(d) shows the reflected wavelength spectrum of grating waveguide regime of different grating thickness (i.e. d_g=100nm, 500nm, 1000nm) under d_{WG}=500nm. It explicitly reveals that the low order mode, especially fundamental mode (M_0), still remains the high reflectance (R > 99%).

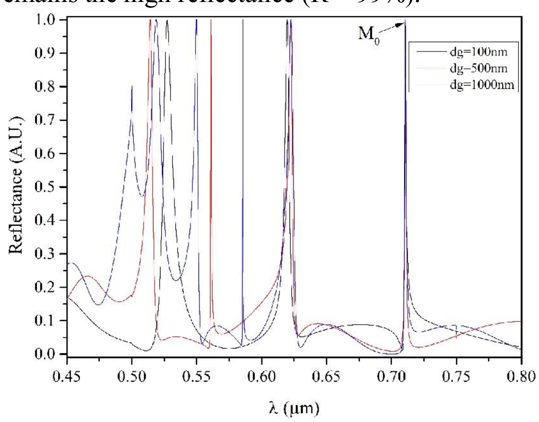


Fig.3 (d) The reflected wavelength spectrum of different grating thickness (i.e. d_g=100nm, 500nm, 1000nm) under d_{WG} = 500nm. M_0 is the fundamental mode.

4. Sensitivity affected by grating thickness:

To prove the validity of our simulations, the 500nm waveguide layer has been used for three different grating thickness, d_g=100nm, 500nm and 1000nm. Thin film of the refractive index n_f = 1.334 is used statistically instead of the bio donor and acceptor layer. The fundamental mode peak shift and its FWHM have been selected for advancing comparison of the sensitivity.

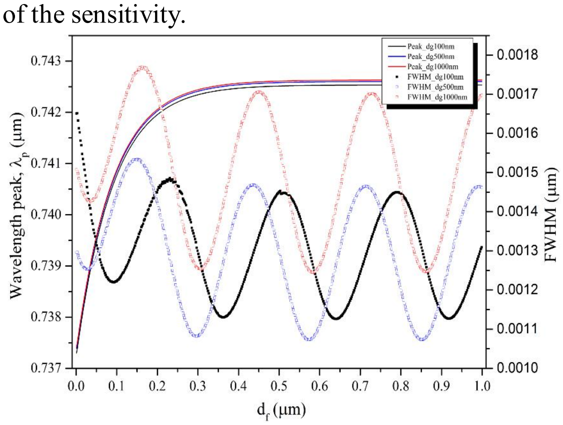


Figure 4 Wavelength peak shift and their FWHM of different grating thickness of sensors. The black, blue and red lines and square dot are respectively referring to the sensor under d_g=100nm, d_g=500nm,d_g=1000nm.

Figure 4 illustrates the wavelength peak shift and FWHM variation as the thin film thickness increases with different grating thickness (d_g=100nm, 500nm and 1000nm) sensors. The peak shift curve lines of these three grating thickness looks very much alike. The maxima peak shift, $\delta\lambda_{max} = \lambda_{P.\ Longest} - \lambda_{P.\ shortest}$ = 742.48-737.38, is 5.1 nm. It reveals that the peak shift of three fundamental modes (M_0) affected by the attached low index of refraction (n_f=1.334) thin film are hardly to be recognized.

5. Conclusion

In this paper, the thickness effects on sub-wavelength Lamellar grating have been studied. Calculation results show the thicker grating would increase more number of modes; in the meantime, the fundamental mode variation of the thinner grating is more obvious than the thicker ones. Physically speaking, the Lamellar grating can be treated as the effective index waveguide layer.

Finally, we have presented the relationship between grating thickness and sensitivity in Lamellar grating waveguide sensors. Referring to the calculation results, we have found that the fundamental mode peak shift of the same thickness waveguide is similar. In other words, the characteristics of fundamental mode are not only dominated by grating thickness but also waveguide thickness.

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