Design of hollow silica nanospheres for high efficiency optical devices applications

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***Abstract*- We present diffraction efficiencies of hollow silica nanospheres coated layer by calculation using a rigorous coupled wave analysis (RCWA) method. The results show the effect of inner ratios, diameters on the diffraction efficiency. We also compare reflection / transmission characteristics with conventional antireflection coatings.**

I. INTRODUCTION

Reflection due to refractive index mismatch at the interface between two different media cause a significant loss of transmitted light, which can deteriorate the performance of many optical devices. Antireflection(AR) coatings are used to reduce this loss by destructive interference principle. AR properties are determined by both the low refractive index and optical thickness of a coating layer. However, conventional AR coatings have difficulties to find materials with adequate refractive indices.

As a way to obtain two main factor of AR coating, the studies on various synthesis method of hollow silica nanospheres have been studied. Diameter and inner ratio of hollow silica nanospheres can be controlled to satisfy the AR conditions for various substrates. While many experimental studies to generate hollow silica with different sizes and shapes were reported over the last few years, only few researches on the theoretical modeling of hollow silica were reported [1-3]. In this study, we have calculated the diffraction efficiency of hollow silica nanospheres for AR coatings on an optical material. Optimum design issues are discussed in terms of reflectance and hollow silica nanospheres.

II. SIMULATION RESULT AND DISCUSSION

Fig. 1(a) shows schematic illustration of hollow silica nanospheres coated substrate. In this calculation, we used the borosilicate glass BK7 substrate as a extremely common glass, which has a refractive index of ~1.5(n). The theoretical calculations of reflectance were done by using a rigorous coupled wave analysis (RCWA) method and materials dispersion was considered [4]. To obtain AR properties, monolayer of hollow silica spheres with a 6-fold hexagonal symmetry, which provide a low effective index, was used [5].

Fig. 1(b) shows the effective index variation of a hollow silica sphere with a diameter of 100nm and a inner ratio of 70% as a function of height. At the border of silica inside the shell, The effective index is sharply reduced. Due to this reduction, the low effective index can be obtained, which can be controlled by tuning the pore size.

Figure 2 shows the contour map of reflectance variation of hollow silica coated glass as a function of inner ratio (10-90 %) and wavelength (300-1100 nm) for a period of 100 nm. The flat surface of glass substrate exhibits a reflectance of >4%. As the inner ratio is changed, the reflectance tends to decrease in particular wavelengths. This can be explained by minimum reflection from the coated surface given by the Fresnel equation, as a function of refractive indices [1]. In the inner ratio from ~50% to ~90%, the hollow silica nanospheres coated layer provide a reflectance of less than 1.0% in some range of wavelengths. At the inner ratio of ~70%, the most wide range can be obtained.

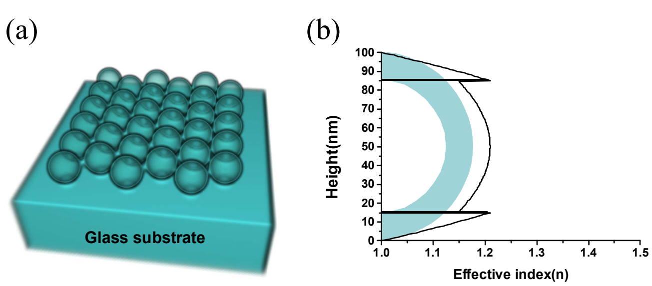

Fig. 1. (a) Schematic illustrations of hollow silica nanospheres coated substrate and (b) Effective index of hollow silica nanospheres with a diameter of 100 nm and a inner ratio of 70%, as a function of height.

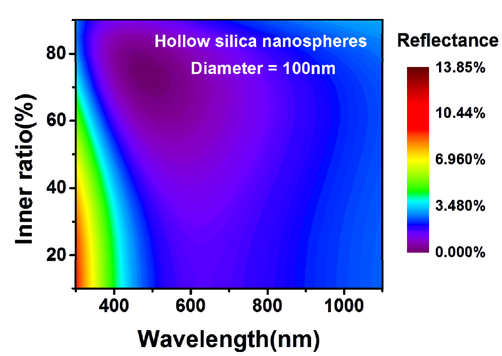

Fig. 2. Contour plot of the variation of reflectance of hollow silica nanospheres coated layer with a diameter 100 nm, as a function of inner ratio.

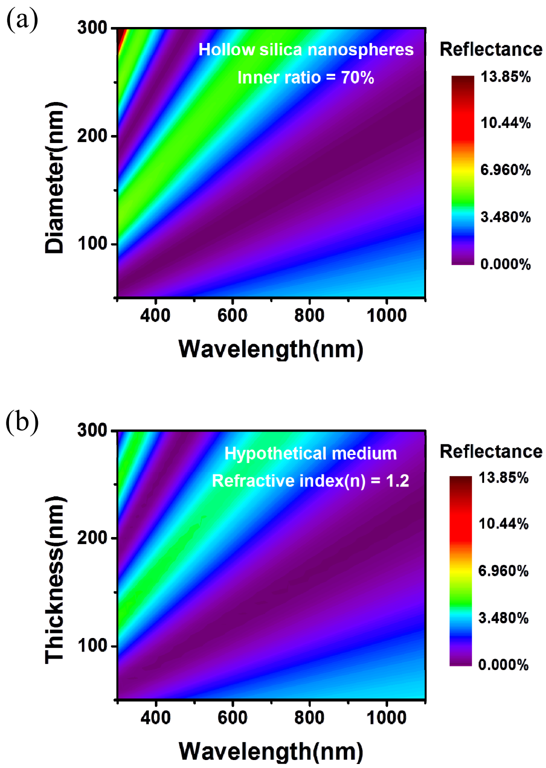

Fig. 3. Contour plot of the variation of reflectance of (a) hollow silica nanospheres coated layer with a inner ratio of 70%, as a function of diameter, and (b) hypothetical medium coated layer with a low refractive index for AR coating on glass, as a function of thickness.

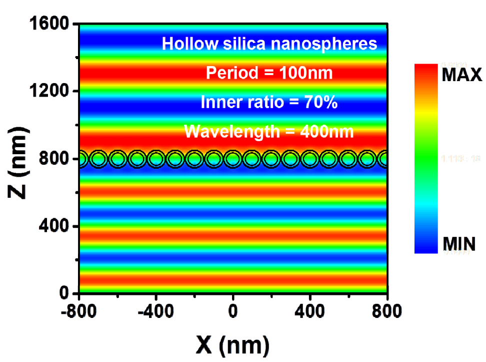

Fig. 4. Electrical field intensity distributions of hollow silica nanosphres coated layer with a diameter of 100 nm and a inner ratio of 70%.

Fig. 3(a) shows the influence of the diameter of hollow silica nanospheres on the reflectance for a inner ratio of 70% as a function of the diameter and wavelengths. As the diameter is increased, the AR range is moved to longer wavelengths. Also, the pattern by constructive and destructive interference of between incident beam and reflective beam appeared. When the inner ratio is 70%, the diameter of ~100 nm is enough to cover whole visible ranges. This result is similar to a result of calculation of using hypothetical medium coated layer with a low refractive index for AR coating on glass, as depicted in Fig. 3(b).

Figure 4 shows the electrical field intensity distribution of hollow silica nanospheres coated layer with the diameter of 100nm and the inner ratio of 70% at the wavelength of 400nm. When designing AR coating layer using periodic structure, scattering also must be considered, which is caused by high order diffraction. The coated layer with the diameter of 100nm and the inner ratio of 70% provides only zeroth order diffraction without scattering, because the diameter of hollow silica nanospheres is sufficiently smaller than the wavelength [6]. If the inner ratio is changed by tuning the pore size, hollow silica nanospheres can be used for AR coating to other optical materials. Also, by tuning the diameter of hollow silica nanospheres, different AR range can be obtained.

III. Conclusion

By calculations of diffraction efficiencies of hollow silica nanospheres coated glass substrate using RCWA method, we investigated optimum design of hollow silica nanospheres in AR coating for visible ranges. From the contour plots, the effects of the inner ratios and the diameters on the reflectance were analyzed. The hollow silica nanospheres with optimized design can be used to variable optical devices on AR coating applications.

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