Calculation of silicon antireflective microstructures for mid-infrared applications

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Abstract- **Diffraction efficiencies of antireflective microstructures (AMSs) were calculated using a rigorous coupled wave analysis (RCWA) method for mid-infrared applications. The results show the effect of height, period, and shape of AMSs on the reflection. We also discuss optimum geometry of AMSs for mid-infrared application.**

I. INTRODUCTION

Fresnel reflection due to refractive index mismatch at the interface between two different media can significantly deteriorate the performance of many optic components (lens, optical fibers, windows, etc.) and optoelectronic devices (solar cells, photodetectors, light emitting diodes, etc.). Conventional thin-film antireflection coatings (ARCs) exhibit reduced reflection by their interference principle, however, it can only work in a limited wavelength range. For mid- or far-infrared applications, this fact becomes a strong obstacle. For broadband antireflection in the IR region, multilayer stacks with thickness of ~5 μm is needed, which causes increased fabrication time and cost. Moreover, thin film technology has inherent problems such as adhesion, thermal mismatch, and the stability of the thin film stack [1].

Originally inspired by the excellent antireflective capability of corneal of night active insects, the studies on biomimetic subwavelength structured AR surfaces have been developing rapidly. The basic idea is that the nanostructured coating-materials are capable of creating a gradient refractive index profile due to their tapered morphology, and consequently forms their unique broad wavelength antireflection property (Fig. 1). In recent years, various nanofabrication techniques and new antireflective materials have emerged [1-4]. Nevertheless, reported works mainly focus on the AR properties in the visible and near-IR wavelength ranges. It is known that the tapered structures with a taller height and a shorter period are desirable for broadband AR properties. From this point of view, nanotip arrays with a high aspect ratio (>20) are ideal, however, it causes complicated fabrication procedure. Hence, it is mandatory to determine an optimum geometry of AR structures within a reasonable aspect ratio. In this study, we have calculated the diffraction efficiency of the antireflective microstructures (AMSs) with different heights and periods. Optimum geometries are discussed in terms of reflectance and grating structures.

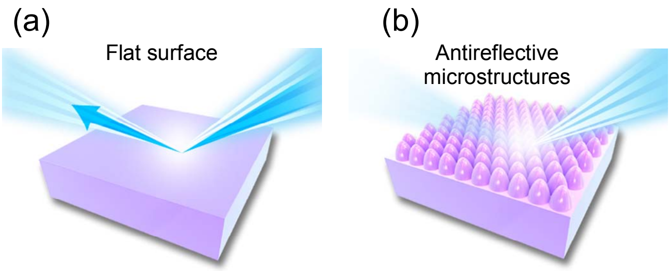

Fig. 1. Schematic illustrations of light reflection (a) at a bare substrate and (b) at antireflective microstructures (AMSs) on a substrate.

II. SIMULATION RESULTS AND DISCUSSION

Fig. 1(b) show schematic illustrations of AMSs on a silicon substrate. In this calculation, we used a crystalline silicon substrate as an infrared window material. Because silicon has absorption in the wavelength range of 8~14 μm and visible region, it is good candidate for mid-IR (1~5 μm) transparent materials. The theoretical calculations of reflectance were done by using a rigorous coupled wave analysis (RCWA) method and materials dispersion was considered [5]. To enhance the AR properties, parabola shape with a 6-fold hexagonal symmetry, which provides linear graded refractive index profile, was used [6].

Figure 2 shows the contour map of reflectance variation of AMSs as a function of height (0-5 um) and wavelength (1-5 um) for a period of (a) 1 um and (b) 5 um. The flat surface (height = 0 um) of silicon substrate exhibits the reflectance of ~32% as expected. As the height is increased, the reflectance tends to decrease. This can be explained by the fact that the effective refractive index is gradually changed. At the height of 5 um, the AMSs with parabola shape provide an average reflectance of less than 1.0% in both cases. In case of 1 um period, very low reflectance can be obtained in whole mid-IR ranges while the AMSs with 5 um period have higher order diffraction losses. The parabola shaped AMSs with 1 um period can be fabricated by laser interference lithography, thermal reflow, and subsequent pattern transfer process. If few-micron period is needed, conventional photolithography can be applied.

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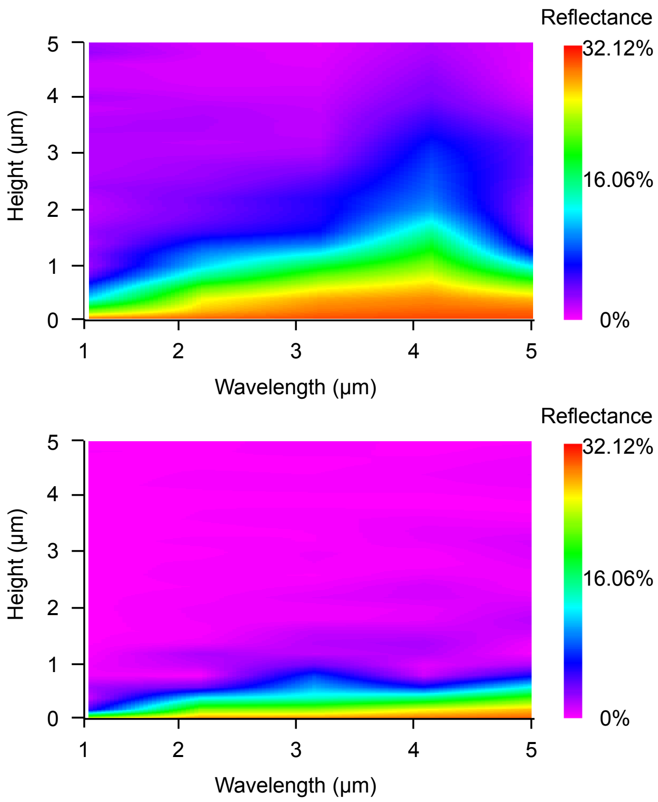

Fig. 2. Contour plot of the variation of reflectance of AMSs with a period of (a) 5 um and (b) 1 um, as a function of height and wavelength.

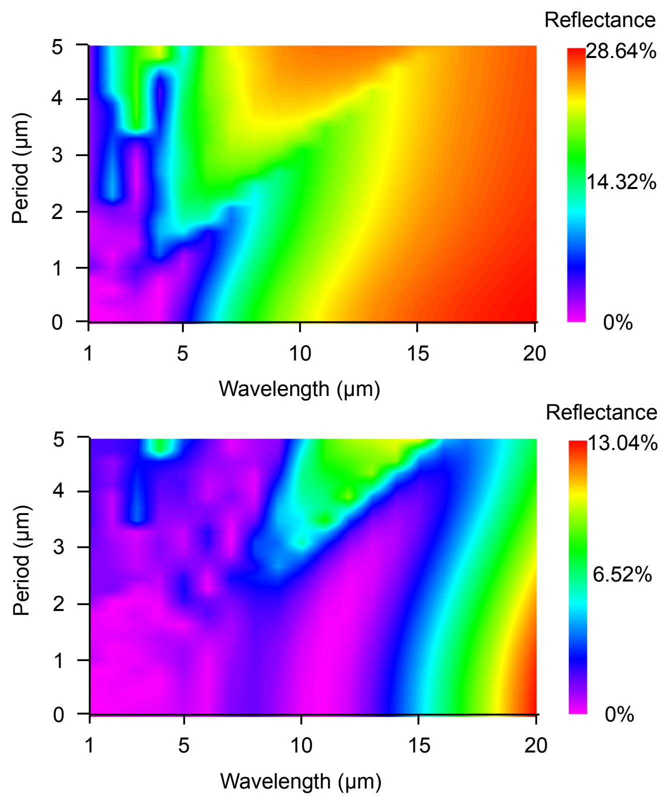

Fig. 3. Contour plot of the variation of reflectance of AMSs with a height of (a) 1 um and (b) 3 um, as a function of period and wavelength.

Figure 3 shows the influence of the height of the array on the reflectance as a function of the period and wavelength (1-10 um). When the grating period is smaller than one micron, the height of 1 um is enough to cover whole mid-IR ranges, as depicted in Fig. 3(a). If the height increases from 1 um to 3 um, the AR band is extended to far-IR ranges (>12 um). Other IR materials, such as Ge, ZnS, and ZnSe, can be used for this purpose. Because the aspect-ratio of 1-5 is acceptable in the dry etch process, we can choose the period and height from this contour plot by considering the target applications/spectra.

III. Conclusion

By considering the fabrication procedure and tolerance, we investigated optimum geometry of silicon AMSs with parabola shape for mid-IR applications. From the contour plots, the effects of the heights and periods on the reflectance were also analyzed. The silicon AMSs with optimized geometry can be used to applications including thermal imaging, motion sensors and forward looking infrared (FLIR) technology.

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References

[1] P. Lalanne, and G. M. Morris, "Design, fabrication and characterization of subwavelength periodic structures for semiconductor anti-reflection coating in the visible domain," *Proc. SPIE*, vol. 2776, pp. 300-309, 1996.

[2] Y. Kanamori, M. Sasaki, and K. Hane, "Broadband antireflection gratings fabricated upon silicon substrate," *Opt. Lett.*, vol. 24, pp. 1422-1424, 1999.

[3] Z. Yu, H. Gao, W. Wu, H. Ge, and S. T. Chou, "Fabrication of large area subwavelength antireflection structures on Si using trilayer resist nanoimprint lithography and liftoff," *J. Vac. Sci. Technol. B*, vol. 21, pp. 2874-2877, 2003.

[4] C. C. Striemer and P. M. Fauchet, "Dynamic etching of silicon for broadband antireflection applications," *Appl. Phys. Lett.*, vol. 81, pp. 2980-2982, 2002.

[5] M. G. Moharam, "Coupled-wave analysis of two-dimensional dielectric gratings," *Proc. SPIE*, vol 883, pp. 8-11, 1988.

[6] Y. M. Song, S. J. Jang, J. S. Yu, Y. T. Lee, "Bioinspired parabola subwavelength structures for improved broadband antireflection," Small, vol. 6, pp. 984-987, 2010.