Experimental Study of a Silver Layer on an Antireflection Subwavelength-Structured Surface

Chia-Jen Ting, Chi-Feng Chen, and C. P. Chou

***Abstract*—The optical characteristics of a silver layer deposited on an antireflection subwavelength-structured surface are investigated. The experimental results of the reflectance and the transmittance of several different thicknesses of silver layer on the subwavelength-structured surface are carried out. A subwavelength structure with the spatial period and diameter of about 230 nm and height of about 150 nm on polyethylene terphthalate film is fabricated by microreplication process. It is shown that such an element with the suitable silver layer deposited on an antireflection subwavelength-structured surface has high transmittance and low glare in the visible spectral range and high reflectance in the infrared range. Obviously, the optical film with silver layer can not only obtain the high performance of heat insulation but also give an application in automobile and house windows.**

***Index Terms*—Antireflection, heat insulation, nanostructure, subwavelength structure.**

I. Introduction

THE development of coating optics to lower the reflected light and thereby to omit or suppress some disadvantages for many optical systems, such as reducing the share of transmitted light, deteriorating the contrast of displays, and generating the formation of ghost images in imaging systems, has been a very important issue for many years. In general, methods of lowering reflection can be divided into two solutions: one is a multilayered alternation of high and low refractive index layers, such as thin-film technology [1], [2]; the other is an inhomogeneous film with a gradual change of index, such as antireflection structure technology [2], [3]. Although thin-film technology is maturely used on different surfaces, it still has problems associated with limitations in the coating materials and various physical and chemical properties that will affect adhesion, thermal mismatch, and the stability of the thin film stack [3]. Antireflection structure technology can be realized by placing a plurality of antireflection subwavelength structures onto the element surface, called an antireflection subwavelength-structured (ASS) surface. Recently, the ASS surface has been proposed as an applicable alternative based on both the theoretical and experimental studies [2]–[6]. Under target of zero reflectivity, the functional dependences of the reflectivity on filling factor, groove depth, angle of incidence, and polarization for rectangular groove with high spatial-frequency dielectric gratings were calculated using rigorous coupled-wave analysis [4]. The gratings were shown to be capable of exhibiting zero reflectivity. An antireflection surface in silicon was designed by rigorous coupled-wave analysis and fabrication by using binary optics technology [5]. In long wavelengths of the infrared region, the results showed the transmittance increases significantly. The fabrications of the 2-D antireflection nanostructures in the visible spectral range have been reported for semiconductor materials [6]. And, a 2-D ASS surface upon a crystal silicon substrate was fabricated by electron beam lithography and etched by an SF_6 fast atom beam [3]. A conical profile structure was shown with the period of 150 nm and the groove depth of about 350 nm.

For a long time, sustainable energy has been a dream. The technology of green energy has always been a focal point. There is a simple method to reduce the consumption of energy so that the window of a building or car has the function of a bandpass filter in that the transmittance of daylight in the ultraviolet and infrared spectral ranges is quite low and one in the visible spectral range is high enough. It can be realized that the window is gummed by the film with the foregoing function, usually called heat insulation film. However, the common article of heat insulation film cannot meet the current target. For this reason, we wish to develop a cost-effective and efficient way to bring the idea to function or improve the common trade article.

In this letter, we investigate the effect of the silver layer deposited on the ASS surface. Several samples with different thicknesses of deposited silver layer are fabricated and measured. The measurement results of optical characteristics are shown that such optical films have heat insulation function and can serve the high performance of heat insulation film.

II. Experiments

First, we prepare the optical films with the subwavelength-structured surface that consists of a plurality of subwavelength conical structures with the spatial period and diameter of about 230 nm, and height of about 150 nm, which are fabricated by microreplication process. The microreplication process combines the original structure template fabrication with interference lithography, Ni mold electroplation, and replication by using UV imprinting into plastic on a polyethylene terphthalate (PET) substrate [7]. The size of fabricated optical films with subwavelength-structured surface is over 70×35 mm^2. Fig. 1 shows the atomic force microscope (AFM) image of the fabricated subwavelength-structured surface. The AFM image is taken by Digital Instrument D3000.

A silver layer is then deposited on the obtained subwavelength structures by using a conventional plasma-enhanced

Manuscript received October 28, 2007; revised March 31, 2008.

C.-J. Ting is with the Mechanical Engineering Department, National Chiao Tung University, Taiwan 300, R.O.C. and also with the Mechanical and Systems Research Laboratories, Industrial Technology Research Institute, Taiwan 310, R.O.C.

C.-F. Chen is with the Department of Mechanical Engineering/Institute of Opto-Mechatronics Engineering, National Central University, Chung-li, Taiwan, R.O.C.

C. P. Chou is with the Mechanical Engineering Department, National Chiao Tung University, Taiwan 300, R.O.C.

Color versions of some of the figures in this letter are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/LPT.2008.925185

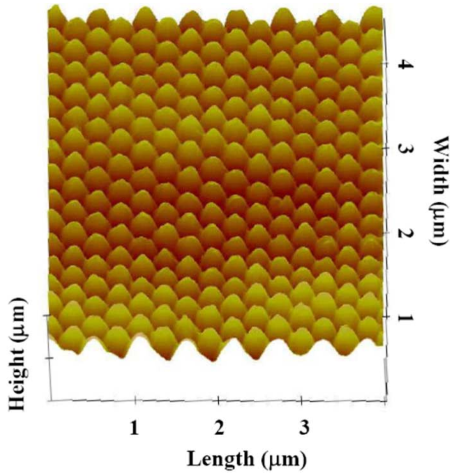
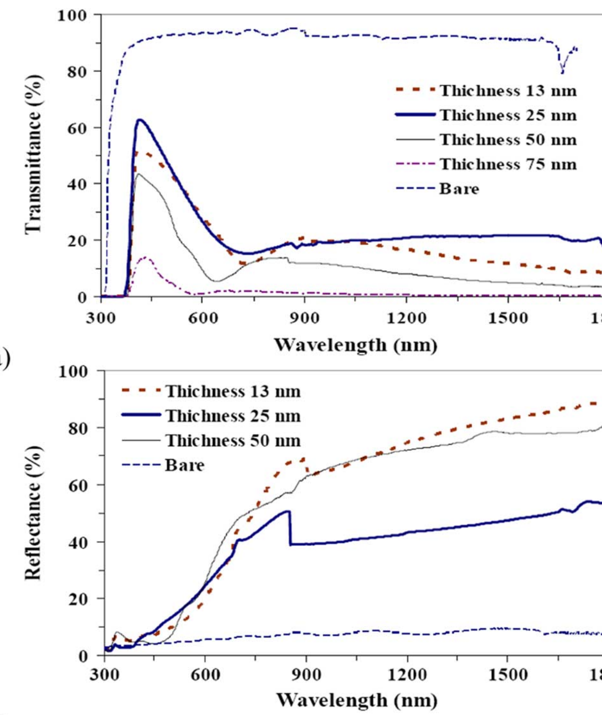


Fig. 1. AFM image of the fabricated ASS surface.

Fig. 2. Photograph of the optical film with the ASS surface covered with the 50-nm thicknesses of silver layer.



(a)

(b)

Fig. 3. Variances of (a) transmittance and (b) reflectance of light propagating through the optical films with the ASS surface covered with the different thicknesses of silver layer and the bare ASS surface.

sputtering system. In order to understand the optical characteristics of the silver layer on the subwavelength structure, a silver layer is deposited on the PET substrate with subwavelength structures of thickness 13, 25, 50, or 75 nm. In this letter, we use a commercial spectrophotometer of model Jasco V-570 to measure the transmittance and reflectance. The measurements of transmittance and reflectance belong to the zeroth order range.

III. Results and Discussion

Several optical films with the ASS surface covered with 13-, 25-, 50-, or 75-nm silver layers are successfully fabricated. The AFM images of the fabricated subwavelength-structured surfaces with different thicknesses of the silver layer are almost the same as without a silver layer, as shown in Fig. 1. Fig. 2 shows the photograph of an optical film with the ASS surface covered with the 50-nm thickness of silver layer. The size of this sample is about 70×35 mm^2. Fig. 3 shows the variances of (a) transmittance and (b) reflectance of light propagating through the optical films with the ASS surface covered with the different thicknesses of silver layer and the bare ASS surface. One can see that the transmittances are largely decreased when the silver layer is deposited on the ASS surface. Except for the 75-nm thickness case, the transmittances are kept at a certain large value of above 20% in the range of visible waveband. The reflectance of the ASS surface covered with silver layer is largely increased, especially in the infrared range. The averages of (a) transmittance and (b) reflectance of light propagating through these optical films in the spectrum ranging from 400 to 700 nm and from 750 to 1800 nm are shown in Fig. 4. The results show that, when the silver thickness is up to 75 nm, the average transmittance is only 4.6% in the spectrum range from 400 to 700 nm. The power of transmitted light becomes smaller with increasing the metal layer thickness when the incident light though the metal layer. That is, the 75-nm-thick silver layer is perhaps too thick so that the light power is mostly reflected. For the 13- and 25-nm cases, the average transmittances are above 35% in the 400–700-nm spectrum range and nearly below 20% in the 750–1800-nm spectrum range. For the 50-nm case, the average transmittances is about 21.3% and 7.8% in the spectrum ranges from 400 to 700 nm and from 750 to 1800 nm, respectively. Except for the 75-nm thickness case, the reflectances are less than 21% in the spectrum range of 400–700 nm. It is a significant effect that the optical film has antiglare function. From the above results, it can be easily understood that the metal film effectively lowers the transmittance in the spectrum range of 750 to 1800 nm. To show the effect of such optical film, a photograph is taken by digital camera while the front of camera lens is with and without an optical film with the ASS surface covered and with the 50-nm-thick silver layer and shown in Fig. 5.

Generally, for different applications, the ideal values of transmittance and reflectance are not the same. For the applications of a car front window and house window, the desired functions are higher transmittance and lower glare in the visible spectral range and higher reflectance in the infrared range. A 25-nm or less than 25-nm thickness of silver layer on the ASS surface is a suitable choice. For the application of the other window of the car, the desired functions are enough high transmittance and lower glare in the visible spectral range and higher reflectance in the infrared range. A 50-nm-thick silver layer case becomes a

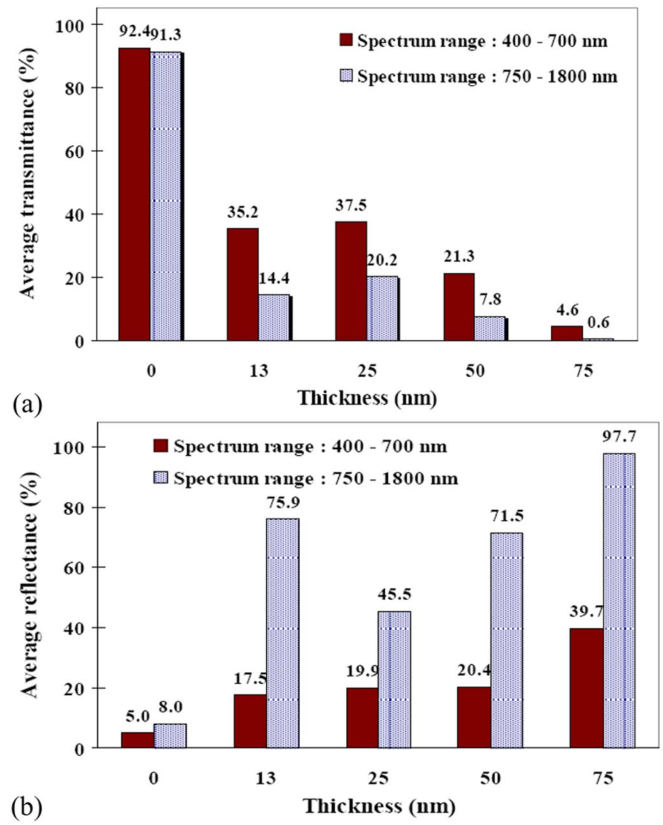


Fig. 4. Averages of (a) transmittance and (b) reflectance of light propagating through the optical films with the ASS surface covered with the different thicknesses of silver layer and the bare ASS surface in the spectrum ranges from 400 to 700 nm and from 750 to 1800 nm.

Fig. 5. Photograph taken by digital camera while the front of camera lens is with and without an optical film with the ASS surface covered with the 50-nm-thick silver layer.

better choice. To further realize the advantage of the optical film with silver layer, we compare three products of thermal insulation film which are suggested for use on a car front window. One is the type AL-608 produced by RALon company; the others are K-100SR and SA-100SR, produced by SunMark. Fig. 6 shows the variances of the transmittance of light propagating through three products of thermal insulation film. One can see that for the cases of K-100SR, SA-100SR, and AL-608, the average transmittances are about 56%, 40%, and 18% in the 400–700-nm spectrum range and nearly 42%, 36%, and 21% in the 750–1800-nm spectrum range, respectively. These commercial products cannot meet the aim that the transmittance of daylight in the ultraviolet and infrared spectral ranges is low and one in the visible spectral range is high enough. Obviously, our

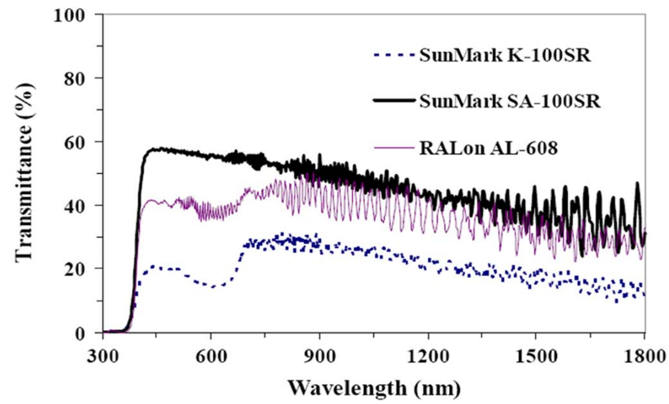


Fig. 6. Variances of the transmittance of light propagating through three products of thermal insulation films.

fabricated thermal insulation films are much better than those products.

IV. Conclusion

We investigate the optical characteristics of a silver layer deposited on ASS surface. The experimental results of the reflectance and the transmittance of several different thicknesses of deposited silver layer on the subwavelength structures are carried out. The subwavelength structure with spatial period and diameter of about 230 nm, and height of about 150 nm, on PET film is fabricated by microreplication process. For the 25-nm-thick silver layer on the subwavelength structure, the average transmittances are about 37.5% and 20.2% and the average reflectances are about 19.9% and 45.5% in the spectrum ranges of 400–700 nm and 750–1800 nm, respectively. It is shown that when the suitable silver layer is deposited on the ASS surface, such an element has high transmittance and low glare in the visible spectral range and high reflectance in the infrared range. Compared with the heat insulation film articles, the properties of the optical film with silver layer are much better for the applications in car and house windows.

Acknowledgment

The authors would like to thank Dr. T. C. Wu and J. H. Tsai at MIRL of ITRI, Taiwan, for their guidance and assistance.

References

[1] H. A. Macleod, *Thin-Film Optical Filters*, 3rd ed. Bristol and Philadelphia: Inst. Physics Pub., 2001.
[2] U. Schulz, "Review of modern techniques to generate antireflective properties on thermoplastic polymers," *Appl. Opt.*, vol. 45, pp. 1608–1618, 2006.
[3] Y. Kanamori, M. Sasaki, and K. Hane, "Broadband antireflection gratings fabricated upon silicon substrates," *Opt. Lett.*, vol. 24, pp. 1422–1424, 1999.
[4] T. K. Gaylord, W. E. Baird, and M. G. Moharam, "Zero-reflectivity high spatial-frequency rectangular-groove dielectric surface-relief gratings," *Appl. Opt.*, vol. 25, pp. 209–214, 1986.
[5] M. E. Motamedi, W. H. Southwell, and W. J. Gunning, "Antireflection surfaces in silicon using binary optics technology," *Appl. Opt.*, vol. 31, pp. 225–229, 1992.
[6] P. Lalanne and G. M. Morris, "Antireflection behavior of silicon subwavelength periodic structures for visible light," *Nanotechnology*, vol. 8, pp. 53–56, 1997.
[7] C. J. Ting, C. F. Chen, and C. P. Chou, "A subwavelength structured surface for broadband antireflection application," *Opt. Commun.*, submitted for publication.