Implementation of Broadband Visible Antireflection Coating on Flexible Polyethersulfone Substrate Using Ion-Assisted Deposition

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Abstract --- In this work, a vibrating search algorithm is applied to design a normal-incidence broadband visible antireflection (AR) coating on the flexible Polyethersulfone (PES) substrate, and then AR coats PES using ion-assisted deposition (IAD). The average visible spectral reflectivities of calculated and experimental AR performances are reduced to below 0.321 and 0.327%, respectively, revealing very acceptable and comparable.

Keywords: Vibrating search algorithm, Normal-incidence, Visible AR coating, Flexible PES substrate, IAD

INTRODUCTION

AR coating plays a very important role in thin-film optics [1] for reducing the undesirable reflection of an optical device and/or increasing its transmittance. Without using AR coating on optical devices, the partial reflection of light that back and forth from the uncoated surface will result in ghost image, which reduces the contrast of optical images. Therefore, a low-loss broadband visible (VIS) AR coating is essential for an optical display system to eliminate ghost image in order to improve the quality of optical image. The use of AR coatings exceeds the sum of all the other types of optical coatings [2], and it has the greatest impact on optics [3, 4]. In recent years, the flexible PES substrate is applied to many photovoltaic devices, such as plastic liquid crystal display [5-8]; however, the flexible substrate is normally required to be treated under a low temperature fabricating process.

In this work, we apply a vibrating search algorithm [9] to design a broadband VIS AR coating for the PES substrate, and then use the IAD technique to implement this VIS AR coating on PES. It is shown that the average residual visible reflectivities can be reduced from 6.018% (for the uncoated PES) to 0.321 and 0.327% for the calculated and experimental results, respectively, revealing that the broadband VIS AR performances are quite acceptable and very agreeable to each other.

BROADBAND VISIBLE AR COATING DESIGN

A design algorithm based on a vibrating search [9] was applied to design a normal-incidence broadband VIS AR coating for the flexible PES substrate using a two-material system. The films materials used in the design were TiO$_2$ and SiO$_2$ with the high and low refractive indices $n_H$ and $n_L$, respectively. In the search process, the dispersion of film materials and substrate, obtained from their transmission spectra, was accounted in the calculations. The initial point was a 10-layer system with a total physical thickness 170 nm, and the tuning thickness was 0.1 nm. After 55 passes of vibrating search operation and zero pass of different elimination operations, the results were obtained and are shown in Fig. 1.

The final design, shown in Fig. 1(a), is a six-layer structure with a total physical thickness 243.9 nm. Its corresponding broadband VIS AR performance, shown in Fig. 1(b), reveals very acceptable and its average residual VIS reflectivity is reduced from 6.018% (for the uncoated PES substrate) to lower than 0.321%.

![Figure 1](image-url)

Figure 1. (a) Refractive index profile of vibrating search VIS AR coating design for PES substrate. (b) Broadband VIS AR performance of design in (a); the average VIS reflectivity is reduced to below 0.321 % and
the dotted curve denotes the reflectivity of uncoated substrate.

**Table 1.** Dispersive values of optical constants of TiO$_2$, SiO$_2$, and PES substrate used in calculations.

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>TiO$_2$</th>
<th>SiO$_2$</th>
<th>PES substrate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$n_H$</td>
<td>$k_H$</td>
<td>$n_L$</td>
</tr>
<tr>
<td>400</td>
<td>2.6391</td>
<td>0.00627</td>
<td>1.4915</td>
</tr>
<tr>
<td>450</td>
<td>2.5135</td>
<td>0.00424</td>
<td>1.4803</td>
</tr>
<tr>
<td>500</td>
<td>2.4383</td>
<td>0.00285</td>
<td>1.4708</td>
</tr>
<tr>
<td>550</td>
<td>2.4016</td>
<td>0.00239</td>
<td>1.4631</td>
</tr>
<tr>
<td>600</td>
<td>2.3710</td>
<td>0.00237</td>
<td>1.4568</td>
</tr>
<tr>
<td>650</td>
<td>2.3468</td>
<td>0.00227</td>
<td>1.4517</td>
</tr>
<tr>
<td>700</td>
<td>2.3319</td>
<td>0.00203</td>
<td>1.4474</td>
</tr>
<tr>
<td>750</td>
<td>2.3176</td>
<td>0.00178</td>
<td>1.4439</td>
</tr>
</tbody>
</table>

**EXPERIMENTAL**

The broadband VIS AR coating design of Fig. 1(a) was then coated on PES substrate using an IAD system, shown in Fig. 2, which comprised a 10 kW electron-beam gun and an end-Hall ion source (Veeco Mark I) with a diameter of 3 cm. The distances for the electron gun and the ion source to substrate were 47 and 18 cm, respectively, and the incident angle of the ion beam was 35°. The coating materials were TiO$_2$ and SiO$_2$ with a purity of 99.99% and the physical thickness of the films was monitored using a crystal quartz thickness monitor. The area and thickness of the PES substrate were 2×2 cm$^2$ and 0.1 mm, respectively.

Prior to the deposition, the base pressure of 2×10$^{-5}$ Torr was established using a cryopump. During the deposition, the working pressure of 2×10$^{-4}$ Torr was maintained by introducing the mixture of O$_2$ and Ar into the coating chamber. Film materials TiO$_2$ and SiO$_2$ were evaporated using an e-gun and IAD with ion beam voltages of 130 and 130 V, and beam currents of 0.5 and 0.5 mA, respectively. The growth of film thickness was controlled at a deposition rate of 0.1 nm/s and substrates were mounted on the substrate holder and rotated at 21 rpm; the substrate temperature, measured using a thermal couple, varied from 100 to 140℃ during the deposition. When the AR coating was coated on the PES substrate, its visible reflection spectrum was measured using a UV-VIS spectrophotometer and the result is shown in Fig. 3.

![Figure 2. Ion-assisted deposition system](image)

**RESULTS AND DISCUSSION**

The average residual reflectivities for the calculated and experimental VIS AR coating on PES, shown in Fig. 3, are reduced to lower than 0.321 and 0.327%, respectively, which shows that the broadband VIS AR performances are quite close and comparable to each other. The maximum VIS reflectivity of the experimental AR coated substrate, reduced to smaller than 1%, is superior to the calculated AR performance, and that the average VIS reflectivity for the uncoated PES substrate 6.018% can be reduced to 0.327%, indicating a good and very acceptable broadband VIS AR performance is achieved. Even through the AR coating design and the AR coating in Fig. 3 are devoted for the normal incidence; however, these normal-incidence AR coating design and AR coating also demonstrate a wide-angle and broadband VIS antireflective effect as shown in Fig. 4. The average VIS reflectivity in Fig. 4 is reduced to 0.627% for the AR coated PES at the incident angle 30°, which is closes to the average reflectivity 0.502% for the calculated AR performance and is much lower than the uncoated...
reflectivity 6.167%. Thus, this normal-incidence AR coating also reveals a quite acceptable wide-angle and broadband VIS AR effect with the incident angle up to 30° from the normal.

![Figure 3. Broadband VIS AR performances of the calculated and experimental AR coated PES substrates at the normal-incidence.](image)

![Figure 4. Broadband VIS AR performances of the calculated and experimental AR coated PES substrates of oblique incidence at the angle of 30°.](image)

CONCLUSIONS

We have design a normal-incidence broadband VIS coating for the flexible PES substrate using a vibrating search algorithm, and then AR coats this soft PES substrate with a low temperature IAD technique. It is shown that the results of calculated and experimental AR performances are very comparable and satisfied, and their average residual VIS reflectivities can be reduced to below 0.321 and 0.327%, respectively. Moreover, this normal-incidence AR coating also reveals an acceptable wide-angle and broadband VIS AR performance with the angle ranging in 0-30°.

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