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Antireflection treatment of low-emitting glazings for energy efficient windows with high visible transmittance

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Abstract

The objective of this study is to increase the visible transmittance of a low-emittance (low-e) glazing as much as possible by antireflection treatment. This has been carried out by depositing thin porous films of silicon dioxide, SiO_2, on both sides of a commercial glazing with a pyrolytic low-e tin oxide-based coating. SiO_2 was chosen because its refractive index makes it suitable for antireflection treatment of both the uncoated glass side and the side of the tin oxide coating. The deposition of the antireflective films was performed with a dip-coating method, where the substrate was dipped in a sol–gel of silica. Two different silica sol–gels were used, one was manufactured in the laboratory and the other one was a commercial solution with a higher porosity. An increase of the integrated visible transmittance (T_{vis}) by 9.8% points up to 0.915 was achieved for a coating produced with the commercial solution. Calculations of U value, g value and T_{vis} for window configurations were also performed.

Keywords: Optical coatings; Optical properties; Dip coatings; Antireflection coatings

1. Introduction

The use of energy efficient windows is steadily increasing in Europe, although many new buildings are still equipped with uncoated standard windows. This is unfortunate since for every standard uncoated window fitted in new production, large amounts of energy will be wasted during the lifetime of this window. This fact is also pointed out in a report from GEPVP where it is claimed that 1.1 million gigajoules of energy would be saved every year if all single and double glazed uncoated windows in Europe were replaced by energy efficient coated windows [1]. In many European countries, coated low-e glazing is standard in new production and a key factor has been the introduction of new building regulations. In general it is true that the market for coated glazing products is steadily increasing [2,3].

One problem that could have led to the slow response of the market is the enormous choice of products. Among the vast number of different coated glazings on the market there are several with a fairly low luminous transmittance. These are often seen as dark or tinted, and a common misconception among the public is that all coated glazing products are tinted. In the hunt for low U-values, many combinations of glazings have been suggested and sometimes 'super windows' with triple panes and two low-e coatings are proposed. Sometimes such a combination leads to a light transmittance which is lower than what is desired.

Low-e coated products can be divided into two main categories: hard and soft coatings [4]. The hard coatings are based on tin oxide and are often also referred to as 'on-line' coatings due to the production process, which is in direct connection to the float line [5]. Soft coatings are usually based on a thin layer of silver surrounded by dielectric protective layers. Soft coatings are produced in a sputtering process, not necessarily at the same place as the float line. The materials used in the different coatings set limits on the optical properties. In general the soft silver-based coatings have higher infrared reflectance and lower solar transmittance than the hard tin oxide-based coatings. The impact of these coatings on the energy performance of the windows has been described in several papers [6–9].

While the oxide layers used for the protection of the silver in the soft coatings also act as antireflective layers, the tin oxide-based coatings have no antireflective layer. This leads to reflective losses and since tin oxide has a higher refractive index than glass, the

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reflection losses tend to be higher than that for uncoated glass. In this paper we have used a dip coating technique developed for the antireflection treatment of solar collector covers [10–12] to reduce reflection losses of tin oxide-coated glass. It is shown that using existing products and known deposition techniques it is possible to design windows with very low *U*-values without sacrificing the light transmittance.

There are several glazing products with antireflective coatings available on the market today. The Amiran glass by Schott is a well-known example with very high light transmittance in the visible range. It is made by a dip coating technique similar to the one we have used in this project. Other manufacturers offer sputtered products and they are usually based on double (or more) layers including silicon and titanium oxides (high–low refractive index stacks). These products are generally optimised for the visible range and have a higher reflectance in the near infrared than the uncoated glass. In order to obtain a reduction of the reflection losses throughout the entire solar spectrum it is necessary to use a single layer of low (less than that of glass) refractive index. This study has been restricted to single layers partly because of the fact that thickness control is less crucial when only one layer is involved and partly because of the wider range of antireflection. In Ref. [8] we included the Amiran glass in our study of antireflective coatings in windows.

The type of coating used in this study was primarily developed for solar collector covers. It is similar to the coatings manufactured by Flabeg in Germany which was developed in co-operation with Fraunhofer Institute for Solar Energy Research in Freiburg [13]. Another coating manufactured for solar collectors is the etched glass by Sunarc in Denmark, which was evaluated after 7 years of outdoor exposure in Älvkarleby, Sweden [14]. These two coatings can be expected to perform in the same way as our coating studied here, although it is uncertain if the etching technique will work on the tin oxide surface. The intention of this work is, however, not to compare coatings from different sources, but to investigate what level of performance is possible to achieve when using antireflective coatings and to verify this by experiments. Important factors such as coating homogeneity, haze and colour rendering have not been evaluated in this study. The porous nature of the coating is a possible source of light scattering, often noted as haze, which can be a problem. The scattering is not investigated in detail, but the haze from the antireflective layer is not more pronounced than the haze from the hard tin oxide coating. In fact, we have noticed a slight decrease in light scattering from the tin oxide glass when coated with the antireflective dip coating. These results are, however, preliminary and are not presented in this study.

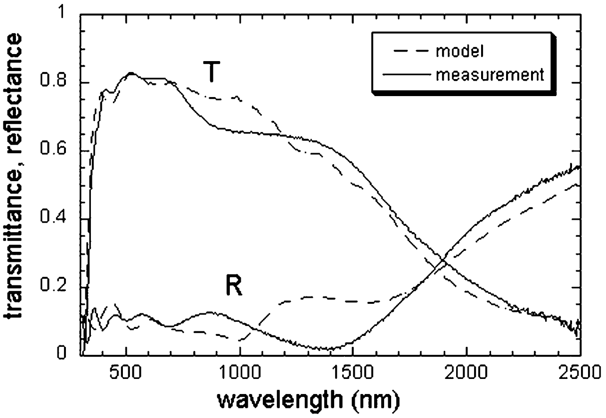

Fig. 1. Measured transmittance and reflectance of a low-e glazing together with modeled values for float glass with a 300-nm-thick layer of SnO_2:F with altered *n* and *k* values.

2. Modeling

The low-e glazing used in this study was a commercial glazing with a hard tin oxide-based pyrolytic coating [5]. A simplified optical model of the low-e glazing was developed to study the effect of the deposition of an antireflective coating on the sample. The exact composition of the low-e coating is not known, but it consists mainly of doped tin oxide, SnO_2:F. The model was built up from a substrate of 3-mm-thick float glass [15] coated by a 300-nm-thick layer of SnO_2:F. The *n* and *k* values of SnO_2:F experimentally acquired earlier [16] were modified to fit the measured *T* and *R* values for the low-e glazing. A comparison of the model and the measured spectra is shown in Fig. 1.

There are some differences between the model and the measurement, but the purpose here was not to determine the exact values of *n* and *k* of the low-e glazing, only to obtain values realistic enough to use for further calculations. Theoretical values of the visible transmittance for an AR coating with a varying refractive index placed on the glass side, the low-e side and both sides, respectively, on the model sample from Fig. 1 were then calculated. A plot of the calculated results is shown in Fig. 2, and a summary of the most important parameters is given in Table 1.

The T_{vis} maximum values in Table 1 should not be considered as a theoretical limit of what is achievable, since the model is only approximate. However, they should be rather realistic, since the visible transmittance of the model sample (0.814) is approximately the same as one of the commercial low-e glazing (0.817). Therefore, the maximum positions are also likely to be near the real ones. Regarding the refractive indices in Table 1, SiO_2 should be a good choice of material for the AR coating. Values of the solar factor, *g*, and the *U*-value

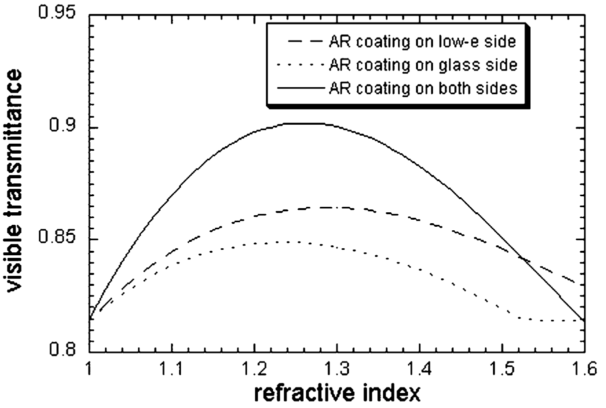

Fig. 2. Calculated T_{vis} values for an AR coating with a varying refractive index deposited on float glass with a low-e coating on one side.

have been calculated according to international standards [17–19].

3. Sample preparation

Silicon dioxide coatings were deposited on the low-e glazing by the use of a dip-coating method. The substrates were dipped in one of the two different silica sol–gels. One sol–gel was prepared in laboratory by mixing tetraethyl orthosilicate (TEOS), nitric acid, deionized water and propanol. The TEOS concentration was 7.5% per volume. Coatings manufactured using this sol–gel are referred to as coating 1. The other sol–gel was a commercial solution diluted with ethanol to a concentration of 10% per volume. Coatings manufactured using this sol–gel are referred to as coating 2. Apart from the low-e glazing, float glass was also coated with the same sol–gels to determine their refractive indices. The substrates were lowered into a container of the sol–gel, held for 1 min and then withdrawn at a constant rate. When coating only the low-e side of the substrate, the glass side was covered with tape, which was easily removed after the coating. All coated samples were cured at 300 °C for 10 min.

4. Results

4.1. Low-e glazing

The refractive indices of coating 1 and 2 were determined from measurements on coated float glass. For coating 1 the refractive index was 1.34 and for coating 2 it was 1.44 in the middle of the visible wavelength region. It should be noted that these values might not be exactly the same for the coatings deposited on the low-e side of the substrate. They should be rather similar though. A plot of the best results obtained when coating the low-e side and both sides of the low-e glazing with coating 1 and 2, respectively, is shown in Figs. 3 and 4. A summary of the results is given in Table 2.

Table 1
The results of the calculations shown in Fig. 2

AR coating deposited at	T_{vis} maximum	Refractive index at maximum	Thickness at maximum (nm)
Glass side	0.849	1.23	113
Low-e side	0.864	1.29	103
Both sides	0.902	1.26	107

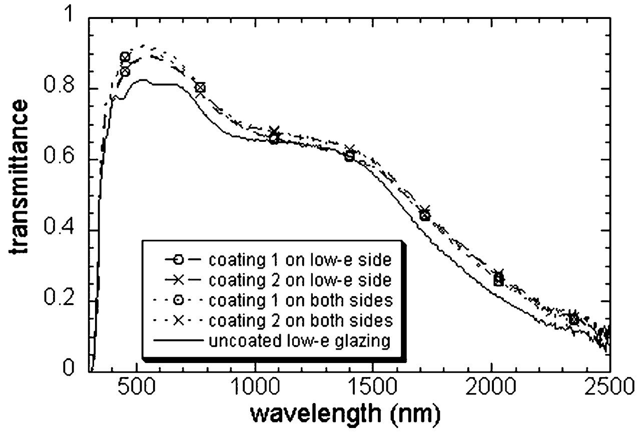

Fig. 3. Transmittance in the solar wavelength interval for the low-e glazing coated with coating 1 and 2, respectively.

As is seen in Fig. 3, the transmittance is increased in the whole solar wavelength region, and particularly in the visible region, see Fig. 4. As can be observed from Table 2, the best results originate from the case of coating 2 on both sides, for which the increase of the visible transmittance is 9.8% points and for the solar transmittance it is 6.3% points. It should be noted that the experimentally obtained maximum value 0.915 is

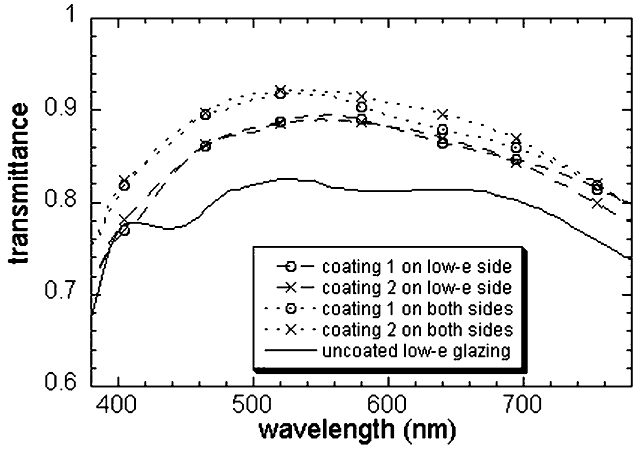

Fig. 4. Transmittance in the visible wavelength interval for the low-e glazing coated with coating 1 and 2, respectively.

Table 2
Summary of the results shown in Figs. 3 and 4

Coating	T peak	T_{vis}	T_{vis} increase	T_{sol}	T_{sol} increase
Coating 1, low-e side	0.8960	0.886	0.069	0.737	0.043
Coating 2, low-e side	0.890	0.884	0.067	0.740	0.046
Coating 1, both sides	0.919	0.908	0.091	0.750	0.056
Coating 2, both sides	0.922	0.915	0.098	0.757	0.063
Uncoated low-e	0.826	0.817	–	0.694	–

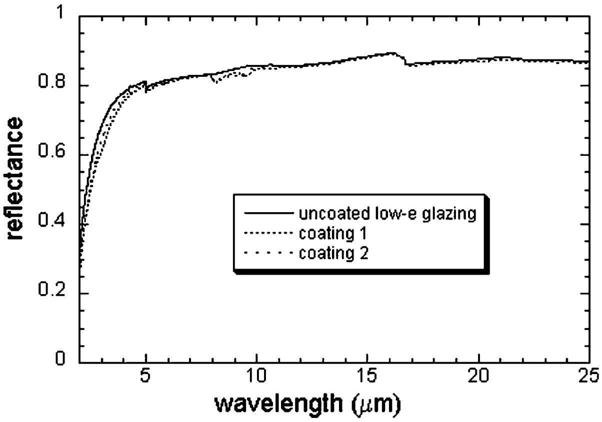

Fig. 5. Reflectance in the IR wavelength interval for a coated and an uncoated low-e glazing.

Table 3
The results for calculations of DGU and TGU window configurations

	Pane 1	Pane 2	Pane 3	T_{vis}	g	U
(a)	Float	Float		0.817	0.786	2.93
(b)	Float	Low-e		0.743	0.743	1.92
(c)	AR float	AR low-e		0.893	0.833	1.92
(d)	Float	Float	Float	0.746	0.713	1.95
(e)	Low-e	Float	Low-e	0.619	0.572	1.14
(f)	AR low-e	AR float	AR low-e	0.818	0.689	1.14

approximately 1% point higher than the theoretically calculated maximum value 0.902.

The ratio between the T_{vis} increase obtained when coating the low-e side and both sides was computed and the results for experiment and theory were compared. In experiment the quotient is 0.76 for coating 1 and 0.68 for coating 2. In theory (Fig. 2) the quotient 0.76 corresponds to a refractive index of 1.47 and the quotient 0.68 corresponds to $n=1.43$. These results are an indication that the values 1.34 and 1.44 mentioned above could be too low, but are themselves on the other hand only approximate.

It is very important that the low-emitting quality in the infrared is not affected by the AR treatment. The reflectance in the IR wavelength interval of the coated samples was, therefore, measured and the results are shown in Fig. 5. It is seen that the IR reflectance is hardly changed when the low-e glazing is coated. The emittance is thereby unchanged and the U-value of the coated glass is assumed to be the same as for the uncoated low-e glazing. The unevenness in the reflectance curve at 5 and 16.7 μm are caused by instrumental alternations of gratings.

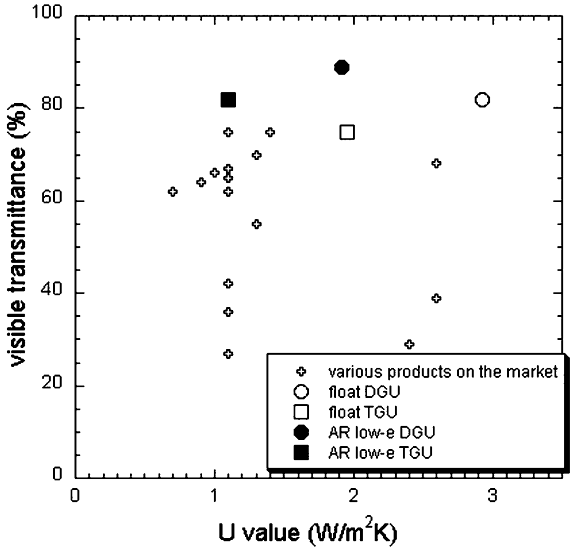

Fig. 6. Visible transmittance vs. U value for samples manufactured in this study and a number of products currently on the market.

4.2. Window configurations

To evaluate the effect of using AR-treated panes in a window, calculations were performed for some different configurations. Calculations of the g value, the U value and the visible transmittance were performed for three double glazing unit (DGU) and triple glazing unit (TGU) window configurations. The results are shown in Table 3 below. The calculations are based upon experimental data for single panes. AR float had a visible transmittance of 0.975 and a solar transmittance of 0.912. The visible transmittance as a function of the U value is shown for configurations a, c, d and f, together with other products on the market in Fig. 6.

It is seen in Table 3 and Fig. 6 that using an AR-treated low-e configuration instead of a standard DGU or TGU float glass configuration increases the g value and the T_{vis} value while decreasing the U value. It also shows that it is even possible to construct a low-e TGU configuration with the same visible transmittance as a float glass DGU configuration.

5. Conclusions

In this work it has been seen that the transmittance of a low-e glazing can be largely increased if it is antireflection treated by depositing a thin film of silicon dioxide on both sides of the sample. SiO_2 gives an efficient AR treatment both to the glass side and to the low-e tin oxide side of the commercial low-e glazing. This is the reason why an increase of the visible transmittance as high as 10% could be achieved. It has also proved possible to construct a TGU window with AR-treated low-e and float glass panes with the same visible transmittance as a standard float glass DGU window. The AR-treated TGU window thereby greatly decreases the *U*-value while not decreasing the visibility. It is probable that an even larger increase of the visible transmittance could be achieved if the sol–gels used for the AR layers are optimized regarding the refractive index, which was not the case in this study.

Acknowledgments

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