M-GLASS: INNOVATIVE COATINGS FOR SUN PROTECTION GLASSES BASED ON THE THEORY OF THE OPTIMISED SPECTRAL TRANSMITTANCE

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ABSTRACT

In this paper new coatings for sun protection glasses for windows and glass façades are presented. These coatings reduce the solar-thermal load of building's interior by one third in comparison to current sun protection glasses on the market. Apart of the comfort improvement for occupants the energy necessary for cooling of buildings is reduced and therefore these new coatings can contribute to the measures needed to reduce global climatic changes.

On the CISBAT 2005 Conference we presented a theoretical model for an optimised spectral transmittance τ_{min} for sun protection glasses [1]. This transmittance predicts a lower limit of the energy load coefficient τ_e/τ_v of 0.33.

The present contribution deals with the experimental realisation of the optimised spectral transmission $\tau_{min}(\lambda)$. Based on multiple cavity bandpass filters new multilayer coatings for sun protection glasses were developed. The transmittance of the new coating should be close to the optimal spectral transmittance and the transmitted light has to be colour neutral. In the course of our design studies for the optical multilayer stacks it turned out that the same coating materials can be used as for commercial sun protection glasses. The energy load coefficient τ_e/τ_v for the new coatings is between 0.34 and 0.40.

Currently the transfer of the M-Glass design to industrial production is performed by the Glas Trösch AG (Bützberg, Switzerland) in close collaboration with the University of Basel. Various prototypes of M-Glasses in the τ_v-range between 0.40 and 0.58 have been developed. New designs especially in a lower τ_v-range are currently examined and lower *g*-factors are envisaged.

INTRODUCTION

Overheating of buildings due to extreme heat loads by solar radiation has become a well known phenomenon caused essentially by architectural preferences for highly glazed façades on one hand and on the other hand by climatic changes. Measures to solve the problem of overheating could be appropriate architectural design, variable shading and blinds, switchable window glazing and sun protection glazing. For switchable window glazing, having a variable transmittance, first products are now available on the market. The investigation of two products are described in another contribution to this conference [2]. Sun protection glazing in comparison have a static, selective transmittance which ideally only transmits radiation in the visible wavelength range. Investigations on commercial sun protection glazing which are summarised in a database [3, 4] have shown that the blocking of the infrared radiation is not sharp and long tails with significant transmittance in the near infrared (NIR) region are present. The new developed multilayer coatings described here are based on the theory of the optimised spectral transmittance τ_{min} which reduces the unnecessary energy input to buildings [1]. This reduction is achieved by steep slopes of the transmittance function at violet and red wavelengths to reduce the fadeouts in the UV- and NIR-region. In order to obtain a colour neutral transmission, after cutting off part of the red and violet light, the amount transmitted in the green (around 550 nm) has to be reduced. This leads to the characteristic M shape of the optimised spectral transmittance.

METHOD

The thin film multilayer systems described here were deposited by magnetron sputtering on 4 mm thick float glass in the laboratory in-line plant of the Glas Trösch AG. The base pressure of the deposition chamber is 10^{-6} mbar. Before the deposition the float glass substrates were mechanically cleaned in a commercial glass cleaning plant. In order to obtain homogeneous and flat films the substrates were moved across the different magnetron cathodes with constant speed during deposition. Speed as well as the power applied to the magnetrons depended on the material to be deposited. As sputtering gas pure argon was used. For oxide layers, like zinc oxide, reactive sputtering from a metallic target was used, for which oxygen was let through a mass flow controller into the chamber. The thickness of the layers was controlled by deposition time and rate, after calibrating the deposition rate by ellipsometry measurements.

The optical characterisation of the coatings was performed on an UV-Vis-IR-spectrophotometer Cary 5 from Varian and the windows stand developed at the University of Basel [5]. The Cary 5 is equipped with an Ulbricht sphere and has a wavelength range from 250 nm to 2500 nm. With the window stand transmittance and reflectance can be measured over a wavelength range from 350 nm to 2150 nm and angle dependent for 0° to 75° angles of incidence.

RESULTS

The M-glass multilayer coatings described here are based on a double cavity bandpass filter, which contains ten layers made of silver (Ag), titanium (Ti), and zinc oxide (ZnO). Silver was chosen as metal as it is a very good infrared reflector and is transparent in the visible [6 - 10]. Further it is the standard infrared reflector used in industry for sun protection coatings. Zinc oxide as a wide band gap semiconductor (3.3eV) is transparent for visible and infrared radiation and has a relative high refractive index of n=1.8 - 2.0 [11, 12]. To prevent oxidation of freshly sputtered silver films during the following reactive sputtering deposition of the ZnO layers a thin blocking layer is needed. Titanium was chosen, as it becomes transparent for visible and infrared radiation if it is later oxidised to titanium dioxide (TiO_2) during the reactive ZnO deposition [13, 14].

The thicknesses for the individual layers of the multilayer coating were determined by simulations with the simulation software TFCalc and than adjusted during the deposition. The boundary conditions for the simulation and the deposited coatings were:

- the transmittance should be equal or at least close to the theoretical optimised spectral transmittance $\tau_{min}(\lambda)$
- the light transmitted by the coating should be colour neutral
- the colour properties of the coating should be stable for all angles of incidence
- the light transmittance τ_v for perpendicular light incidence should be 0.5 or greater

The measured spectral transmittance of such a thin film multilayer coating for perpendicular incidence is shown in figure 1. Further given in this graph is the theoretical curve of the optimised spectral transmittance τ_{min} and the simulated transmittance on the bases of which the layer thicknesses for the deposition were determined. It is obvious that measured, simulated, and theoretical transmittance are not identical. Other samples, not shown here, have shown, that a better agreement of the measured and the theoretical transmittance is only achieved when other boundary conditions of the list given above are not strictly fulfilled. The main discrepancies between measured, simulated, and theoretical transmittance are the absolute values of the peaks and the dip, and the slope around 650 nm which is shifted to higher wavelengths. This shift and the increase of the transmittance could be solved as it is based on the fact that the silver layers in the deposited multilayer coating are thinner than determined during simulation. For this coating the light transmittance τ_v is 0.561. The energy load coefficient τ_e/τ_v of this M-coating is 0.398 which is not as low as the theoretical limit of 0.334, but much lower than the value of 0.5 the currently obtained lower limit for sun protection glazing on the market. The reason for the increase of the energy load coefficient τ_e/τ_v for the measured in comparison to the theoretical transmittance is the shift of the slope at 650 nm to higher wavelengths. This shift increases the amount of near infrared radiation that is transmitted through the glazing, and therefore increases the value of the direct solar transmittance τ_e while it has a smaller impact on the light transmittance τ_v.

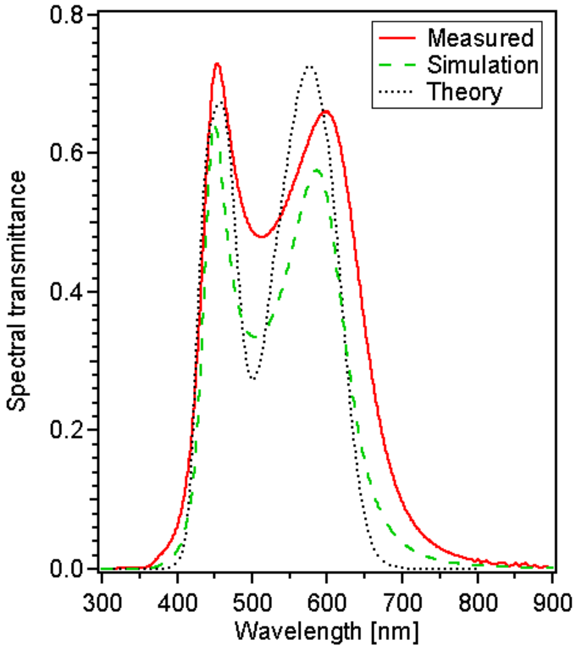

Figure 1: The measured spectral transmittance of the multilayer coating, the simulation used for the deposition, and the theoretical curve of the optimised spectral transmittance for perpendicular light incidence.

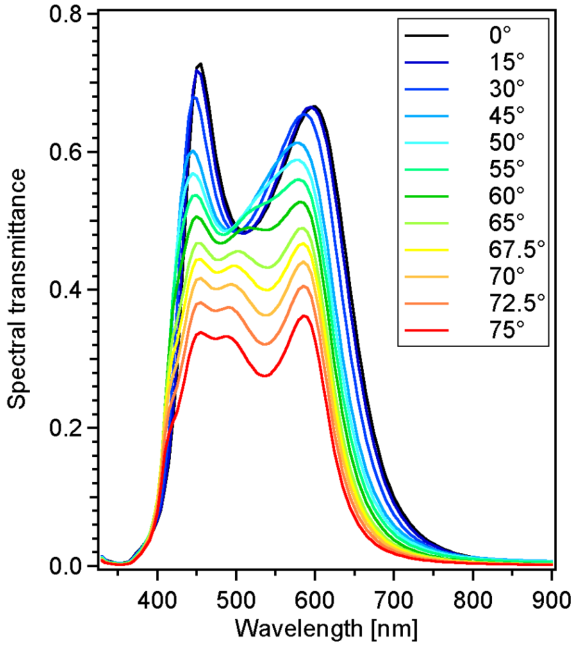

Figure 2: The measured spectral transmittance for different angles of light incidence.

To fully characterise the optical and energetic properties of a multilayer coating the angle dependency needs to be investigated. The measured transmittance for different incident angles (ϕ = 0° to 75°) is given in figure 2. Up to an angle of 55° the shape of the transmittance is barely changing. But it is getting narrower as the right slope is shifting to the left to smaller wavelengths. For larger angles of incidence the shape of the transmittance is changing, but the two initial peaks are visible independent of the angle of incidence. The shift of the right edge and the change of shape has influence on the values of the solar direct transmittance τ_e and the light transmittance τ_v and therefore on the energy load coefficient τ_e/τ_v of the coating as depicted in figure 3. With increasing angle of incidence the obtained values for the light transmittance τ_v (blue) and the direct solar transmittance τ_e (red) are continuously decreasing. The relative change of the two values is different which results in a reduction of the energy load coefficient τ_e/τ_v (green) when the angle of light incidence ϕ is increased. This is a welcome feature during summer, when the angle of incidence on a glass façade is higher than during winter. In other words the energetic impact is higher during winter than during summer, and therefore reduces heating costs in winter and cooling loads in summer.

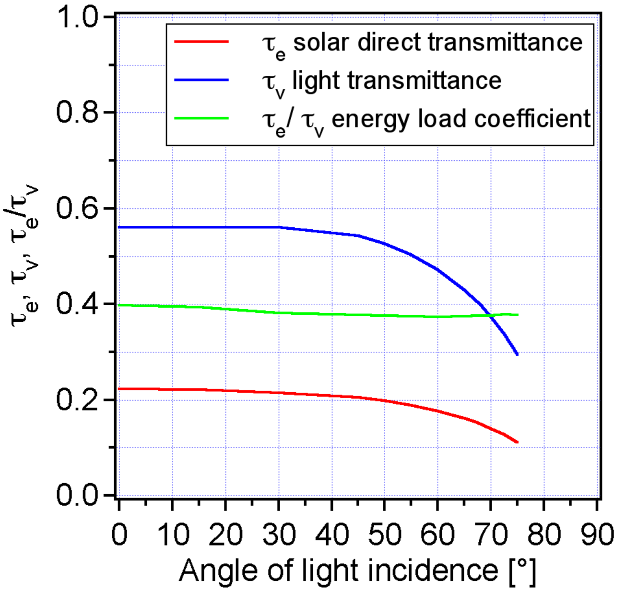

Figure 3: The evolution of the light transmittance $\tau_v(\phi)$ (blue), the solar direct transmittance $\tau_e(\phi)$ (red), and the energy load coefficient $\tau_e(\phi)/\tau_v(\phi)$ (green) for different angles of incidence ϕ.

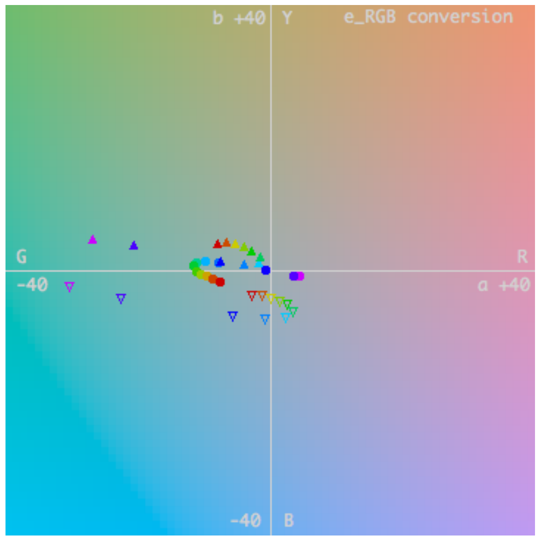

Figure 4: The colour evolution in the CIE Lab colour space at constant luminosity L of the transmittance (full circle, ●), reflectance glass side (full triangles, ▲), and reflectance layer side (empty triangles, ▽), if the angle of light incidence ϕ is changed. For the smallest angle a purple symbol and for the largest a red symbol is used.

Besides the optical and energetic properties the colour of the transmitted and reflected light plays an important role in the characterisation and during the selection procedure of sun protection glazing used for a building. One critical feature as already defined in the boundary conditions is, that the transmitted light should be colour neutral. Transferring this to the CIE *Lab* colour coordinate system, where *L* denotes the light intensity and *ab* the colour axis (*a*: red to green; *b*: yellow to blue), the colour values for the transmitted light should be a=0 and b=0. The angle dependent colour values determined from the measured transmittance and reflectance respectively are given in figure 4. In this graph the value for *L* was chosen arbitrarily to obtain a suited graphical representation and the angles of incidence are colour coded starting with violet for the smallest angle (0° or 15° for transmittance or reflectance, respectively) and going to red for the largest angle of incidence (75°). The colour values for the transmitted light are represented by the filled circles ●, whereas the filled triangles ▲ represent the light reflected from the outside, the glass side of the sample, and the empty triangles ▽ the light reflected directly from the multilayer coating surface. In figure 4 we see, that the values for the transmitted light (●) are located in the centre of the *ab*-plane and the light is therefore in an regime which is still recognised as colour neutral by the human eye. Therefore the boundary condition defined for the development of the new M-shaped sun protection coatings, which is also a general boundary condition for all coated window glasses, is fulfilled. The colour values of the light reflected from the outside (▲), which is relevant for the optical appearance of a building, are all located in the top left, the green quadrant of the *ab* plane. This means that the green hue of the reflected colour is not changing when the angle of incident is changed. The values of the layer side (▽) are of minor importance, as they change when a second glass pane is added to obtain an insulation glass.

DISCUSSION

With this experimental realisation it was possible to show, that multilayer systems consisting of ten layers using standard materials like silver, zinc oxide and titanium oxide are sufficient to achieve coatings which have a spectral transmittance that is close to the theoretical optimised spectral transmittance τ_{min}. Using different layer thickness combinations the value of the energy load coefficient of these coatings varies between 0.34 and 0.40. The above described coating has a relative high energy load coefficient but in this coating the focus during the realisation was on finding an optimum for all defined boundary conditions. The boundary conditions were a colour neutral light transmittance, angle independent optical properties and colour, the M-shaped spectral transmittance, and a light transmittance of 0.5 or greater.

The advantage of using a M-glass instead of a normal commercial sun protection glass can be shown illustratively by dynamic temperature simulations for a simple room in Zurich, where only the glazing is changed. Details concerning the assumptions made for this temperature simulation are given on the glass database of the University of Basel [3, 4, 15]. The used room (10 x 6 x 2.7 m^3) has a south facing glass façade of 21 m^2. When the temperature in this room is calculated over a ten day sunny period it is obvious that for both, a commercial sun protection glass (Pilkington, Insulight TM Sun Silber 37/32, τ_v= 0.41, τ_e/τ_v=0.681) and a M-insulating glass (τ_v= 0.44, τ_e/τ_v=0.412), the mean temperature increases. In fact, the rise of the room temperature with the Pilkington glass after this sunny ten day period is 10°C whereas it is only 5.1°C when the M-glass is used. This means the temperature increase is 1.96 times higher for the room with the Pilkington glass. In other words the energy needed for cooling is reduced by 51,2% when the M-glass would be used instead.

Currently the M-glass coatings are transferred to industrial production with the Glas Trösch AG (Bützberg, Switzerland) in closed collaboration with the University of Basel.

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