

# OPTICAL PROPERTIES OF DIELECTRIC MIRRORS, PRODUCED BY LARGE AREA GLASS PVD COATING TECHNOLOGY

**Gy Viktor**, product supporting engineer  
*Guardian Orosháza KFT, Csorvási út 31, 5900 Orosháza*

**Abstract:** Using Physical Vapor Deposition magnetron sputtering in large area glass coating technology, so-called semi reflective mirror, has been developed. Due to the fact that only dielectric layers are used in the layer stack, these mirrors are also called dielectric mirrors (DM). The method provides wide combination of reflection-transmission properties of the coated glass. DM opens up whole spectra of new applications in the informatics and computer technology. Due to the lack of metal layers in the layer stack, these products show high level of chemical durability.

## 1. INTRODUCTION

The production of highly reflective surfaces used as mirrors could be classified into wet coating and Physical Vapor Deposition (PVD) coating.

In case of wet coating, the metal used as reflective substrate is silver. It is deposited onto the glass surface, via certain chemical process as result of chemical reaction of two chemicals. The deposited Ag is protected (covered) by Cu, and one or two additional protective layers (painting), to provide chemical and mechanical durability of the thin (roughly 80-100 nm thick) silver layer. This kind of mirror is the so-called second surface mirror (SSM), having the highly reflective active material on the back side of the substrate. In order to get better adhesion of the Ag, the glass surface has to be polished and washed carefully before the silver is deposited on it. The final reflection of such mirrors is mainly determined by the transmission properties of the glass substrate (its specific absorption and thickness). As second surface mirror Al and Cr could be used instead of Ag, however, these two materials are mainly deposited by PVD technique, and not by wet coating. The overall surface quantity of mirrors made from Al and Cr is less than that of the Ag mirrors.

According to the substrate's optical properties, The SSM might induce certain optical distortions of the reflected light (dispersion and absorption). Therefore this mirror is not the best solution for highly true optical reflection (for example large telescopes). The First Surface Mirror (FSM) is free of optical distortions caused by the substrate, The FSM is made with PVD; therefore this kind of mirror is much more mechanically sensitive product. They are used mostly for scientific purposes, or for solar plants, where the high reflection rate, as well as the distortion free reflection is very important.

Mirrors described above are not transparent at all. Their properties are described with their reflection rate. (Reflection rate is the rate of the optical intensity of incoming and reflecting visible light). In case of SSM, taking into

account the reflection rate, the highest rate is given by Ag material (slightly above 90%), and the lowest by Cr (around 53%). The Al is somewhere in the middle (85%).

Analyzing the case for FSM, the situation is slightly better (from the reflection point of view). For Ag the reflection is as high as 98%, for Al around 96%, and in case of Cr it is about 65%. However, it is well-known that the mechanical durability of FSM is much lower, therefore, their application is greatly limited.

In case of mirrors, the light reflection takes place on one surface, while the contribution of the optical interference is negligible. However, the translucent mirror property is based on optical interference effect that takes place in several steps, as the light moves from one layer to another, and back. The translucent, or semi transparent mirror properties, is based on multilayer structure of dielectric materials, combining the high and low refractive indexes. Semi transparent mirrors are also called beam-splitters. This type of coating is available, mainly in precision optics. Our contribution is to move it to large area coater (LAC) technology too. However, in LAC technology, these mirrors are called Dielectric Mirrors (DM). Some of applicable high refractive index materials are TiOx, NbOx, ZrSiNx, and as low index material SiOx is used. Combining their thickness, one can get a certain ration of optical transmission and reflection. Due to the fact, that even in case of DM, the most important property is the reflection; therefore, the reflection rate of the product is indicated in its name. For example, DM70 means 70% reflection (and 30% transmission roughly). As the rate of the positive and negative optical interference of the incoming light depends on the relative thicknesses of the individual layers in the stack, the color of the reflected and transmitted light depends also on the number of layers in the stack.

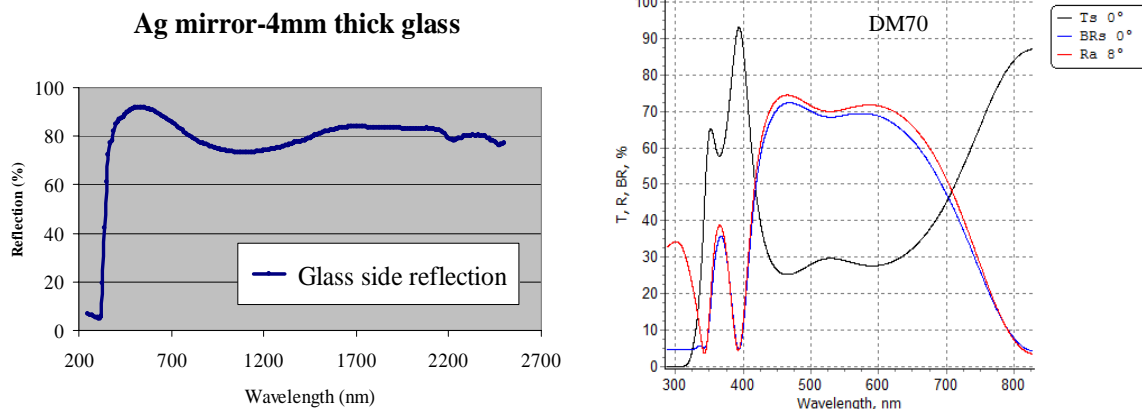


Figure 1: Reflection curve of the Ag mirror, compared with Reflection ( $R_g$  and  $R_f$ ) and Transmission curve of DM70

The more layers are present in the stack, the more neutral could be the reflected and transmitted light, not only in normal direction, but for whole angular range (from 0 till 90 degree). The main difference between the anti-reflective (AR) PVD coating and DM coating is the nature of the interference of the reflected light. Negative interference at AR and positive interference in DM case is dominating. While the

goal of the AR coating is to maximize the transmission and minimize the reflection, in case of DM, the rate of transmission and reflection is adjusted accordingly.

## 2. DIELECTRIC MIRROR (DM) PROPERTIES

The PVD coater section at Guardian Orosháza plant produces DM products with reflection from 70% down to almost any values (in our case the lowest reflection is 30%). It means that we produce five different products: DM70, DM60, DM50, DM40 and DM30. The reflection higher than 70% with neutral colors is beyond of our reach for layer stack containing five layers, as it is in our case.

The DM product is a one-sided coated product; therefore, we differentiate glass side and film side of these products. The intensity of reflection between the glass side and film side could be different, depending on the light absorption of the glass substrate. The higher the substrate absorption is, the lower is the intensity of glass side reflection compared to the film side reflection (in case of DM). It also means that using gray glass (high light absorption in the visible range) as a substrate, provides non symmetric reflections; while using thin substrate of ultra-clear or extra-clear glass, the intensity of glass side reflection has (almost) the same value as the film side reflection.

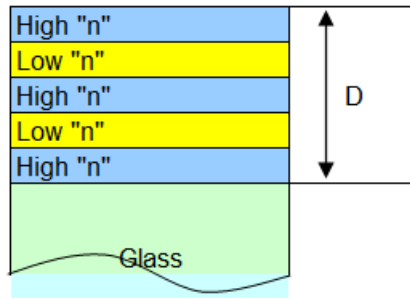


Figure 2: Schematic layerstack of the Dielectric Mirror (DM)

The DM layer stack produced in Orosháza, as it was mentioned already, contains maximum five layers, combining the low and high refractive index materials respectively. (Figure 2) The interface medium for the incoming light is the high refractive index material. Opposite to this, for AR case the interface medium is always a low refractive index material. Physical descriptions of these coatings are presented in details in Ref. 1 and Ref. 2. The overall thickness of the used layer stack varies according to the reflection rate. While in case of DM70 the overall thickness (D) is almost 400 nm, for DM30, is only 110 nm. DM products developed by Guardian Orosháza are the subject of a pending patent application (Ref. 3).

One of important properties of DM is the fact that DM is highly transparent for IR radiation, so any kind of remote control unit (used for TV sets, motion detectors etc.) is highly applicable through this mirror.

The goal of the DM products is, to approach the Ag mirror reflective colors. Therefore, Table 1 contains the specification for Guardian Orosháza DM products, satisfying the “silver-like” reflection impression.

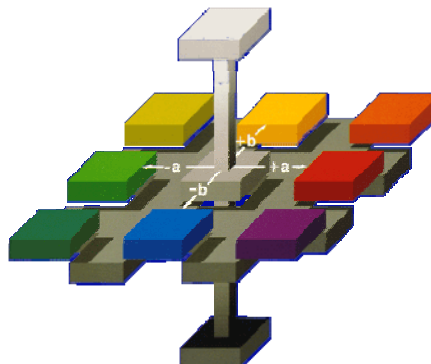
According to Figure 3, neutral colors correspond to  $a^*=b^*=0$ , while  $L^*$  represents the intensity of the light.  $L^*=0$  means intensity is zero,  $L^*=100$  means no

lost appears in transmission or reflection. This coordinate system explains that  $a^*$  represents color from green to red, while  $b^*$  represents colors from yellow to blue. For  $a^*=b^*=0$  means that all colors are present with the same level, so the overall color is white, or neutral.

Ag_Mirror_4mm	$a^*$	$b^*$	Y
<b>Rg</b>	<b>-2.35</b>	<b>1.67</b>	<b>90.28</b>
DM70_4mm	-1	4	69.5
DM60_6mm	-1	4	58
DM50_4mm	-1	4	49
DM40_4mm	-2	2	39
DM30_4mm	-1.5	0	27

Table 1: Reflection color coordinates listed for Ag mirror and five different DM products. To satisfy the “Ag mirror reflection color feeling”,  $a^*$  and  $b^*$  should approach reflected color values measured for Ag mirror.

CIE -  $L^*$ ,  $a^*$ ,  $b^*$



Figure\_3: The  $L^*$ ,  $a^*$ ,  $b^*$  color space used in determining colors of light intensity of any object.

### 3. DIELECTRIC MIRROR APPLICATIONS

The semitransparent mirrors (DM) opened up several new opportunities for their application. As it is mentioned, due to their existing certain transparency, behind the DM could be mounted any motion sensor, video unit or any monitor, even touch panel that in many cases offer new commodity in the computer aided world. Short videos from YouTube (References 4-9, YouTube screen shots are downloaded in third week of January 2015) show vast range of their applications.

In many hotels, the invisible TV is becoming popular. The flat TV device is placed behind a certain semitransparent (DM) mirror. In these cases an attached manual explains how to switch on the TV set: directing the remote control towards the mirror, the TV device could be activated.



Photo 1: Screen shot from Mirrus-made advertisement application (Ref. 7).

YouTube contains many advertising videos on DM applications that are mainly to make shopping more comfortable, or to increase versatility of some products, like hidden TV set.



Photo 2: Interactive (DM) mirror in a clothing (Puma) shop. (Ref. 9)

#### 4. REFERENCES

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