Nano particle coatings and applications in window film

Christy De Meyer, Robrecht Moerkerke, Sergey Lapshin, Jan Vaneecke, Peter Goemaere, Peter Persoone, Hugo Lievens

Bekaert Technology Center, NV Bekaert SA, Bekaertstraat 2, BE-8550 Zwevegem, Belgium.

There is a growing interest in nano particles in the atmospheric web coating technology for optimization or addition of functionalities to the deposited coatings, especially in the field of optically clear films where the very small light scattering of these particles is the main driver for their use. The discussion will demonstrate that a broad diversity of applications can be achieved by addition of nano particle oxides in polymeric coatings. An example will highlight the use of nano particles in a solar control window films and the performance comparison between the technology of nano particles in web coating and the technology of vacuum wet coating.

Introduction

Nano particles can offer very interesting functionalities for applications in window film, as their small size makes them invisible for the human eye while adding a desired property to the film. Probably the best know example, which will be discussed in-depth in this paper, is that of nano particles that provide light and heat control when incorporated as a coating or layer in the window film construction. As such, a solar control window film can be obtained in a cost effective way using standard wet coating technologies.

The major criteria for the use of nano particles in the functional coating of a spectrally selective solar control film are twofold:

1) High transparency in the visible range of the electromagnetic spectrum

2) Absorption in the infrared range of the electromagnetic spectrum

Both criteria will be explained in this article in view of obtaining a solar control window film. As an example of a nano particle functionalized window film, the performance and the properties of Ultra Performance 75 (UP75)* are given. Furthermore, this new technology based on absorption of heat by nano particles will be compared to the existing reflecting technology, achieved by vacuum deposition of metal layers and stacks. A comparison will be made with a high end commercial alternative solar control film based on an IR reflecting stack, i.e. Hilite®*.

High transparency in the visible range of the electromagnetic spectrum

Particles of micron range size tend to cause haze when used in an otherwise clear coating because of scattering. However, when making the particles smaller and smaller, scattering is reduced and in the case that the particles are not absorbing in the visible, the clear coating containing these particles will tend to become transparent. Based on Mie's theory, one can calculate the transparency for a layer of nonabsorbing spherical nano particles in a polymeric matrix.

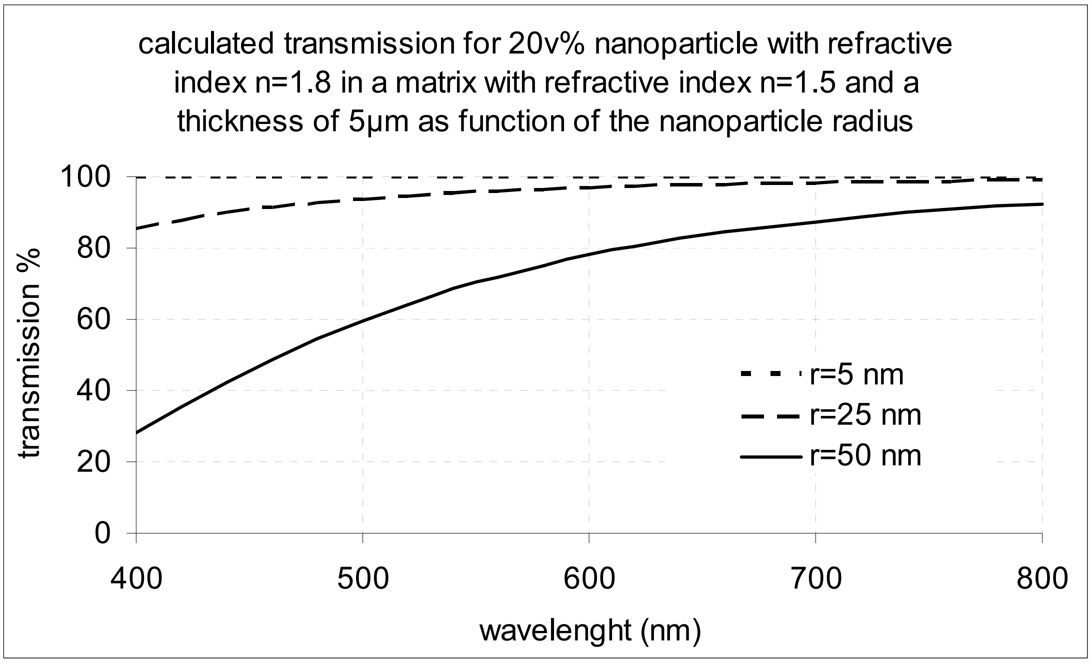

Figure 1 Theoretical transmission as function of wavelength calculated using Mie's theory

* Window film product of Bekaert Specialty Films, LLC

Based on this theory, we calculated the transmission in the visible range of the electromagnetic spectrum of a spherical nano particle as function of its particle size. In figure 1, the transparency is shown for a 5 µm and 20 volume percent nano particle filled coating with the matrix and the nano particles having a refractive index of respectively 1.5 and 1.8 for 3 distinct nano particle sizes. It is clear that the smaller the nano particle in the coating becomes, the more transparent the resulting coating will be. Similarly, one can calculate that nano particles with higher refractive index, require smaller particle size to obtain the same high transparency.

Absorption in the infrared range of the electromagnetic spectrum

Conducting nano particles exhibit surface plasmon resonance absorption caused by the excitation of surface plasmons (collective oscillations of free electrons at the surface). The spectral location of the resonance wavelength is the key issue, along with its bandwidth and strength. The resonance peak cannot be in the visible, if no impact on the visible transmittance is desired. Noble metal nano particles, like Ag and Au, have their surface plasmon absorption in the range of visible wavelengths. Materials of interest have moderate densities of mobile electrons so that they absorb in the infrared range of the electromagnetic spectrum. The best known nano particles for IR absorption are ITO, ATO and LaB_6. Literature data on the conductivity was related to the plasmon absorption peak for several materials in figure 2. Equation 1 gives the relationship between the charge carrier density, N, and the conductivity, σ.

Equation 1

$$\sigma = Ne\mu .$$

Where

μ is the mobility of the electrons

e is the charge of an electron

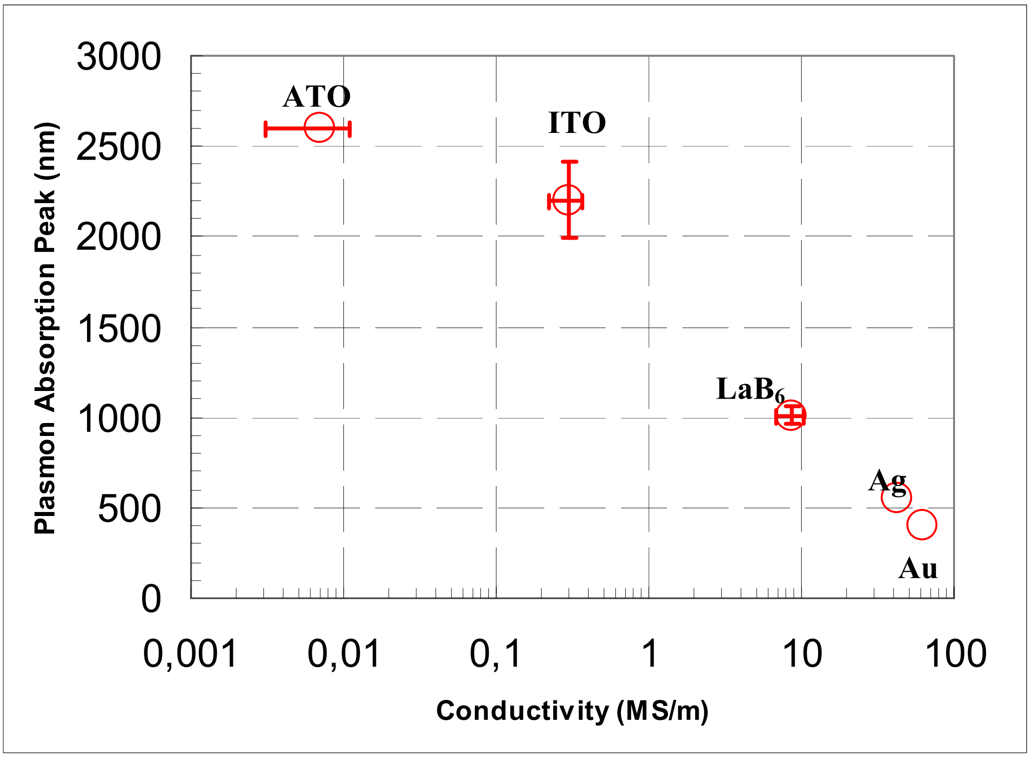

Figure 2 Graph illustrating the relationship between the plasmon absorption peak wavelength and the conductivity for some spherical nano particles. ATO, ITO and LaB_6 absorb in the IR range of the electromagnetic spectrum. Ag and Au absorb in the visible range.

For nano particles in a medium, the absorption peak depends not only on the particle but also on the medium. Furthermore, if the shape of the particle deviates from spherical to ellipsoidal, shifts in the absorption peak to longer wavelengths will be obtained. The absorption wavelength will split into two components: a transversal and longitudinal component in the case of rod like nano particles.

Parameters characterizing the performance of spectrally selective window films

A number of measures are used to compare different films to each other and help customers to select the right film for their use. Spectral data of glass installed with a window film, i.e. transmittance and reflectance, are usually collected as function of wavelength using a spectrophotometer. This data is then further used to calculate the performance parameters using CEN methodology and LBNL Window software. The most important parameters to qualify the spectrally selective window films are defined:

The Visual Light Transmission (**VLT**) is the weighted average of the transmittance over the entire visual wavelength range (380 nm to 780 nm). The weighting functions are (i) the spectrum of the illuminant (e.g. A, C, D65, …), and (ii) the color matching functions of the observer (e.g. x_bar, y_bar, z_bar or x_{10}_bar, y_{10}_bar, z_{10}_bar). These weighting functions have been standardized by the CIE (Commission Internationale de l'Eclairage or International Commission on Illumination).

The total solar transmittance, reflectance as observed form the outside (front) and absorptance, respectively abbreviated by $\mathbf{T_{sol}}$, $\mathbf{R_{sol}}$, $\mathbf{A_{sol}}$ are weighted averages over the entire UV/VIS/NIR range (300 nm to 2500 nm). The weighting function is the solar spectrum at sea level.

The Solar Heat Gain Coefficient (**SHGC**) is the fraction of incident solar radiation admitted through a window, both directly transmitted (T_{sol}), and absorbed and subsequently released inward by means of convection and radiation.

The Shading Coefficient (**SC**) is the ratio of the total solar heat gain through a specific window to the total solar heat gain through a single sheet of 3 mm double-strength glass under the same set of conditions.

The Total Solar Energy Rejected (**TSER**) equals the total (direct) solar reflectance plus the part of the total (direct) solar absorptance released outward by means of convection and radiation. It is clear that 100*SHGC + TSER = 100%.

The Light-to-Solar Heat Gain ratio (**LSHGC**) is the ratio between VLT and SHGC. This ratio provides a gauge of the relative efficiency of different glazing systems in transmitting daylight while blocking heat gains. The higher the ratio, the brighter the room is without adding excessive amounts of heat. For a spectrally selective solar control window film, the LSHGC ratio will typically be higher than 1.2, whilst for other solar control window films, the LSHGC-ratio will be smaller than one.

Performance of the new Bekaert spectrally selective automotive window film, UP 75.

Using the technology of IR absorbing nano particles, Bekaert Specialty Films LLC has designed a new spectrally selective window film, the Ultra Performance film, UP75. The spectral transmittance and reflection of a 3 mm clear glass installed with this window film is shown in figure 3. The data was collected using a Lambda 900 spectrophotometer from PerkinElmer.

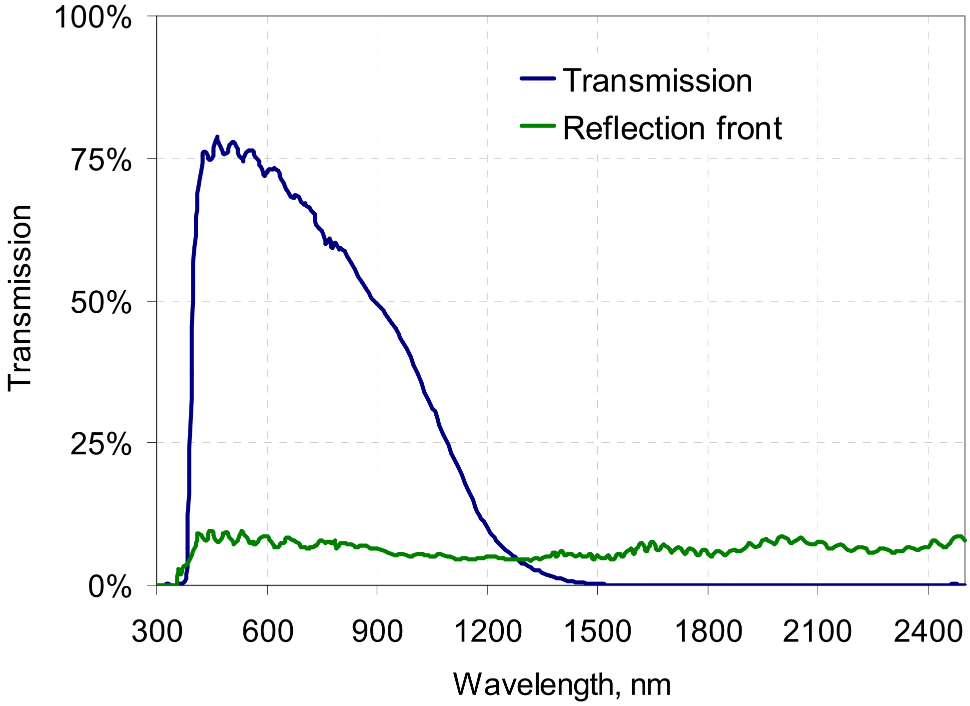

Figure 3 Spectral transmittance and reflectance of a UP75 film installed on 3 mm clear glass

The UV radiation (< 380 nm) is entirely blocked using a window film. In the visible range, the transmission is very high (VLT 75%) but it decreases sharply in the infra red range (800-2500 nm). As a result, this film has an infrared rejection of 89% due to the nano particles in the film.

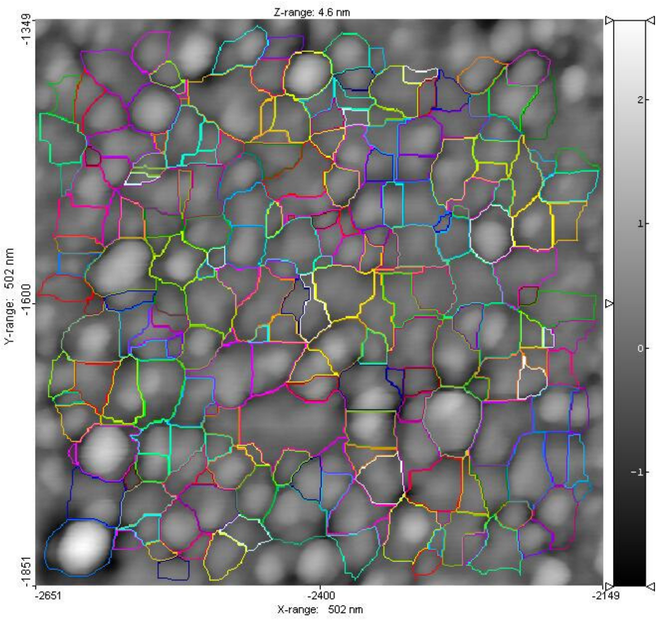

Figure 4 Particle size and counting image based on AFM analysis of the nano particle layer in UP75

The nano particles used for this film are a combination of ITO and ATO to optimize the performance. The average size of the nano particles can be obtained using atomic force microscopy, coupled with particle size and particle counting software. In Figure 4, an example of this is shown for the nano particles in the UP75 film. The average diameter of the particles, using this methodology, is 32 nm.

How does this film compare to the high performance spectrally selective reflecting films?

Currently, the retro-fit film with the highest spectrally selective performance (i.e. highest VLT combined with the lowest SHGC) that is commercially available for architectural applications is Hilite®. This is a spectrally selective film based on a multilayer stack formed by nano layers of vacuum deposited coatings of silver and TiO_x. The spectral transmittance and reflection of Hilite® installed on 3 mm clear glass is shown in figure 5. Compared to the spectrum of UP75 in figure 3, it is immediately clear that the high IR rejection of this film is based on the selective reflection of IR radiation whereas the UP75 film absorbs the IR radiation.

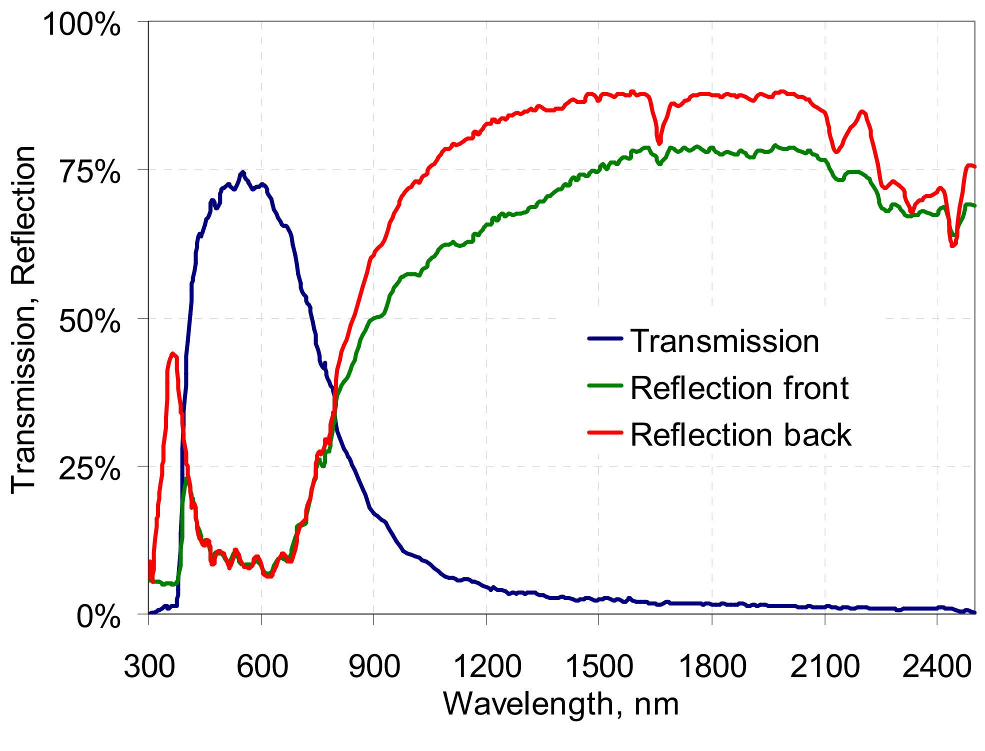

Figure 5 Spectral transmittance and reflectance (both front and back reflection) of Hilite® installed on 3 mm clear glass

In table 1, the performance properties of both films are compared. Both technologies can result in very high visual transmission combined with high IR rejection. However, the reflecting technology remains the best option in cases where there are concerns for glass breakage due to thermal stress as the solar absorption for the absorbing film is nearly twice that of the reflecting film. Due to this difference, Hilite® remains the best spectrally selective film in the market, however, UP75 based on IR absorbing particles, offers a good performing and lower cost alternative for Hilite® in cases where thermal stress in the glass panes is no issue.

Table 1 Performance comparison between Hilite® 70, as example for the reflecting technology and UP75, as example for the absorbing technology, using LBNL Window 5 software.

	Reflecting technology: ***Hilite® 70***	**Absorbing technology:** ***UP 75***
Visual light transmission	**72%**	**75%**
IR rejection	**95%**	**89%**
Solar Heat Gain Coefficient	**0.45**	**0.60**
Total Solar Energy Rejection	**55%**	**40%**
Shading Coefficient	**0.52**	**0.70**
Solar Absorption	**28%**	**44%**
Light to Solar Heat Gain Ratio	**1.59**	**1.23**

Summary and Conclusion

For optically clear films such as window films, the growing interest to use nano particle coatings results from the ability of these small particles to add functionalities while remaining optically clear and transparent. As example, the nano particle containing solar control window film UP 75, was demonstrated. This film is able to reject 89% of the IR heat while maintaining high visual transmission. The working principle is based on the selective IR absorption of the nano particles in this film. Other spectrally selective films are based on IR reflection, created by metal/dielectric stacks that are deposited using vacuum technologies. The comparison of the best films of both technologies indicates that there is a dissimilarity in performance due to the inherent differences of heat absorption versus heat reflection.

References

- A. Heilmann, Polymer films with embedded metal nano particles, Springer, Germany, 2003
- G.B. Smith et.al., Nano particle-doped polymer foils for use in solar control glazing, Journal of nano particle research, 2002, 1-2, 157-165
- S. Schelm et.al., Dilute LaB6 nano particles in polymer as optimized clear solar control glazing, Applied physics letters, 2003,82(24), 4346-4348
- M. Adeogun, Nanomaterials, SRI Consulting Business Intelligence, 2004.
- http://www.bekaertfilms.com