# Energy efficient IGUs with polymeric near-infrared reflecting films

Dr. Raghu Padiyath, Dr. Jayshree Seth
3M Company

Keywords

1 = insulated glazing unit 2 = metal free3 = suspended film 4 = polymeric ir reflecting film 5 = ir absorbing coating

## Abstract

With the increased awareness and need for energy efficient windows, the use of sputter coated low-e glass within insulated glass units (IGU) is on the rise. These coatings, referred to as "soft coatings", are applied to glass using complex vacuum deposition machinery and highly sophisticated control schemes to ensure performance and uniformity. IGUs made from sputter coated glass are ideal for both heating and cooling dominated climates since they can have low U-value as well as low solar heat gain coefficient. The downside to such coatings is their low scratch resistance. Pyrolytic low-e coatings, referred to as "hard coatings," are comparatively easier to handle due to their improved scratch resistance and easier to produce cost effectively, but are most beneficial only for heating dominated climates.

This paper discusses the use of new polymeric, clear, near infra red (NIR) reflecting film technology in combination with pyrolytic low-e coatings for a cost effective IGU solution with significant improvement in solar heat gain coefficient and negligible impact on appearance or visible light transmission. These polymeric films may be adhered to #2, #3 or #4 surfaces of a double pane IGU or be used in a suspended configuration to construct a "triple pane" IGU. In addition to being highly efficient NIR reflecting, these films also reflect significantly in the UV region providing additional benefit to the end users. The transmission characteristics of the glazing may also be altered by incorporating neutral or NIR absorbers in the film to further impart glare reduction and solar heat gain reduction.

## Introduction

Since the invention of insulated glazing in 1921 [1], their use has been increasing around the world. New energy requirements for glazings are being put in place in Europe and elsewhere that necessitate the use of insulating glazing to achieve the desired performance. Demand for insulated glazing is growing even in Asian regions, traditionally a consumer of single pane glazing. However, until fairly recently, the use of IG units has not been popular in geographic regions having warm to hot climates, e.g. those climates characterized by seasons requiring extensive periods of operating air conditioners, because the primary functionality required of windows in such regions is solar heat load reduction, not insulating value.

In order to address the needs of hot climate consumers, solar-control glasses have been introduced into the market. Such glasses achieve solar heat load reduction by decreasing the amount of solar energy (in the visible and/or near-infrared portions of the electromagnetic spectrum) that is directly transmitted, often by absorbing large amounts of the incident energy, irrespective of the wavelength.

Alternatively, glass may be coated with a thin layer of metal that reflects the incident solar energy. More recently, certain silver-based low emissivity (low-E) coatings have been recognized as also having a significant degree of solar-control functionality in addition to their insulating properties. These silver-based solar-control/low-E coated glasses can be used not only in climates characterized by long heating seasons (for their low-E/thermal insulating performance) but also in climates characterized by long cooling seasons due to their solar heat gain reduction benefits.

The low e coatings may be broadly categorized into two types. Pyrolytically applied low E coatings of materials such as, Fluorine doped Tin Oxide(FTO), are referred to as hard coats. While these improve the U-value of the windows, they do not provide sufficiently low solar heat gain coefficient (SHGC), important in cooling load dominated regions. Improvement in the performance of IG Units is obtained by using magnetron sputtered layers of aforementioned materials such as Silver or Silver sandwiched between layers of NiCr. These sputtered coatings are typically referred to as "soft coats". Often, multiple silver layers may be bounded by dielectric materials such as SiN, ITO, InO, etc., designed to minimize reflectivity in the visible part of electromagnetic spectrum. While these coatings do lower SGHC and have low emissivity, they add significant complexity and cost to the resulting glass and windows. Such coated glass is often referred to as "spectrally selective" low E glass. The low E coatings are typically applied on an interior surface of one of the two glass panes (typically surface 2 or surface 3).

Tempered glass is used widely in commercial applications due to higher safety standards and regulations compared to the residential sector. However, demand for tempered glazing is increasing in residential applications also due to increased use of large windows in homes. Since highly energy efficient glazing is only possible with sputter coated glass, coated tempered glass is also in high demand. Coating of tempered glass is a very inefficient operation requiring a variety of different glass sizes to be coated simultaneously. Temperable sputter coated glass solutions have been proposed to overcome the technical issues such as edge effect and logistical and production problems of accommodating a variety of pre-tempered glass sizes in high capacity plants[3].

The sputtered coatings are susceptible to mechanical as well as chemical damage from atmospheric elements. As a result, these coatings have limited shelf life (unless stored in a controlled atmosphere) and extraordinary measures must be taken to handle them. Furthermore, the soft coatings are expensive and may suffer from lot-to-lot consistency. Often, more than five layers have to be deposited sequentially to get the desired final performance.

A simple way to boost the U-value of insulated glazing was demonstrated by Lizardo [2]. A thin plastic film was used in between the two glass panes to create an effective triple pane structure. A triple pane insulating window is now offered by many window manufacturers using Southwall Technologies' sputter coated spectrally selective films sold under Heat Mirror™ brand. Coated glass as well as Heat Mirror™ contains metallic layers that may interfere with communication devices. GPS, cell phones and electronic toll services are increasingly used in vehicles around the world. The sealing surface must be cleaned prior to assembly since these coatings containing silver are highly susceptible to corrosion. Thus there is a need for non-metallic efficient glazing solutions.

Presence of UV in the incident solar radiation not only leads to fading of upholstery, carpets and fabrics, it is also a health risk. The link between exposure to UV and skin cancer is well established. Therefore, there is strong demand for solutions that eliminate transmission of UV into the building. An advantage of using polymeric films in glazing systems is that the films may be loaded with UV absorbers resulting in greater than 99% reduction in UVB and UVA radiation.

## Polymeric IR reflecting films

IR reflecting polymeric multilayer films was developed by 3M for use in automotive windshields and other applications [4,5]. Earlier, Alfrey et al had shown that polymeric films consisting of hundreds of layers of two materials differing in refractive index can be co-extruded to form iridescent films [6]. The use of polymeric multilayer films using birefringent optics was further developed at 3M Company [7,8]. Use of birefringent materials in these structures result in several unique properties not possible with sputter coated thin film optics[9].

In these films, the bandwidth and location of band edges is determined by the thickness of each layer pair. Thicknesses of these layers are chosen such that the primary reflection band occurs in the infrared portion of the electromagnetic spectrum. With an appropriate choice of left and right band edges and accurate control of thicknesses of the layer pairs, highly effective NIR reflectors having high visible light transmission may be created. Optical properties of NIR reflectors constructed from polymeric materials benefit from their low optical absorption, small optical dispersion, and birefringent optical constants. These films can have high visible transmission, sharp reflective bandedges, and low offband ripple. In a simple ¼ wave ABAB layer structure, where A and B are two polymeric materials with different refractive index, design considerations restrict the reflection band between 800 nm and 1200 nm. Widening the bandwidth further will result in higher order reflection bands in the visible imparting color into the film. Since the incident solar spectrum spreads well beyond 1200 nm, means for reducing the solar gain beyond 1200 nm must be devised.

IR absorbing nanofillers have been studied for use in glazing applications [10,11]. These materials have fairly high transmission in the visible but are strongly absorbing in the NIR portion. Such materials may be coated on the IR absorbing polymeric films to further improve the solar heat gain coefficient of the glazing system. Antimony tin oxide (ATO) based coatings is particularly attractive since its absorption band is further out in the NIR. The optical transmission spectra of IR reflecting film used in this study are shown in Figure 1. The highly efficient IR reflecting film covers the 850 – 1200 nm band while ATO absorbs > 95% of incident solar radiation beyond 1500 nm.

A number of IGU configuration utilizing IR reflecting films with or without ATO coatings are presented here. These films are shown to be particularly useful in combination with pyrolytic low E coated glass. Thus another option for IG manufacturer, especially ones without integrated sputter coating facility, is available. Results on the use of these films in a suspended film configuration as well as laminated configuration are presented. An added advantage of the laminate construction is safety in case of glass breakage.

*Figure 1*

*Optical transmission spectrum of polymeric IR reflecting film with and without ATO coating*

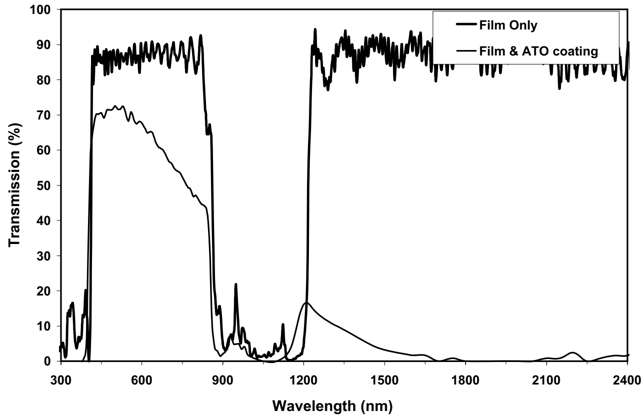



*Figure 2*

*Optical transmission spectrum of ATO coated polymeric IR reflecting film measured at normal incidence and 60 deg. from normal.*

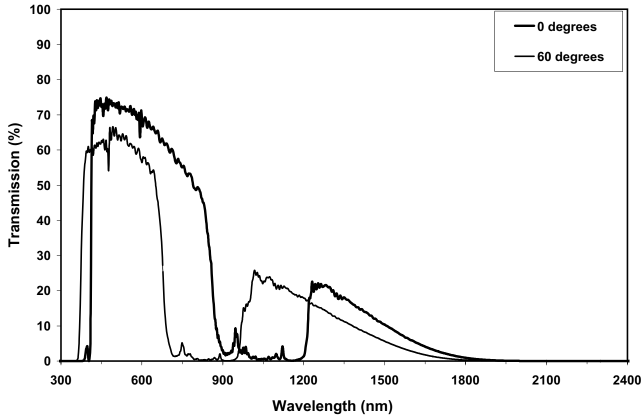
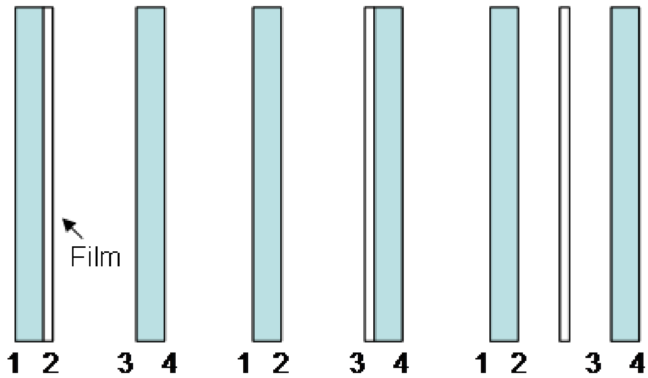



*Figure 3*

*Three different configurations in which polymeric IR reflecting film may be used within an IG unit. Optical and thermal characteristics are shown in Table I and II.*




One unique aspect of these polymeric films is that the reflection band shifts to lower wavelengths as the angle of incidence is increased. This effect is demonstrated in Figure 2 where transmission spectrum at normal incidence (denoted 0 deg) and 60 deg from normal are shown. Since the reflection peak shifts to the lower wavelengths where higher amount of incident solar energy exists, the solar heat gain is also reduced. While there are no industrially accepted standards for off-axis measurements, the authors believe that these films give an added boost to the solar performance. The off-axis effect of similar polymeric IR reflecting film was also reported earlier [5].

## Methods and IG construction

IR reflecting film may be laminated to either surface 2 or surface 3 or used as a “third pane” in a suspended film configuration. These are schematically shown in Figure 3. Window 5.2 software along with the glass data available in International Glazing Database (IGDB), both available from Lawrence Berkeley National Laboratory was used for calculating the performance characteristics of the IG constructions presented here[10]. Optical spectra of the IR reflecting film were measured on a Perkin Elmer Lambda 9 spectrophotometer and imported into Optics 5. NFRC 100-2001 standard environmental conditions were used for all calculations. The spacing between was fixed at 0.5 inches and the air was used as the medium. All values reported here are for center-of-glass calculations.

## Results and discussion

Table I shows the key performance characteristics of the various IG units simulated using Window 5.2. An IG unit made with two clear 6mm glass sheets, spaced 12.5 mm apart and filled with air results in a U-value of 0.47 Btu/hr ft2 hr. Use of a soft coated low E glass reduces the U-value to 0.31 Btu/hr ft2 hr while pyrolytic low E results in a U-value of 0.35 Btu/hr ft2 hr. As seen from ID # 4 & 5, application of the polymeric IR reflecting film on surface 3 and using pyrolytic low E on surface 2, results in the same U-value but a significant reduction in SHGC. The effect of using the film on surface 3 and low E coating on #3 results in a slightly higher SHGC. With the use of ATO coated IR reflecting film, further reduction in SHGC without significantly affecting the visible light transmission is possible (see example # 7).

A comparison of optical and U-values using three different types of film is shown in Table II. Clearly, even an uncoated PET film within an IG unit gives the same U-value as a sputter coated Heat Mirror™ HM88 film. However, the SHGC is much higher for such an IGU. Comparing cases 1 and 2, a slightly improved SHGC can be obtained using the polymeric IR reflecting film. It may be noted that all three types of film may be loaded with UV absorbing material and the resulting IG unit has UV transmission of approximately 0.1%.

As mentioned above, all the optical characteristics reported here are using the industry standard normal incidence. As the incidence angle increases, an improvement in SHGC of up to 10 points may be expected with incidence angle of 60 deg. or higher. Indeed a variable angle solar calorimeter is required to completely document the benefit of the “overall” performance of these IG units since the SHGC can also change with the incidence solar spectrum. It is well known that the solar spectrum may change from one place to another and depends on factors including time of the day/year, ground reflectance, and precipitable water, among others. Gueymard presents a comprehensive model for calculating the solar irradiance under any given condition [13]. An extensive discussion of the effects of incident solar energy is out of the scope of this presentation. However, an account of such effects may be found elsewhere [14].

| ID | Description of IGU | | $T_{vis}$ (%) | SHGC | U-value (Btu/hr ft² °F) | UV trans (%) |
|---|---|---|---|---|---|---|
| | Pane 1 | Pane 2 | | | | |
| 1 | Cardinal 6mm clear float glass | Cardinal 6mm clear float glass | 80 | 0.71 | 0.47 | 64 |
| 2 | Cardinal low E-178 on clear 6mm glass. Low E coating on surface 2. | Cardinal 6mm clear float glass | 76 | 0.55 | 0.31 | 20 |
| 3 | PPG Sungate® 500 pyrolytic low E on 6mm clear glass. Low E coating on surface 2. | PPG 6mm clear float glass. | 74 | 0.63 | 0.35 | 41 |
| 4 | PPG 6mm clear float glass. | PPG Sungate® 500 pyrolytic low E on 6mm clear glass. Low E coating on surface 3. | 74 | 0.66 | 0.35 | 41 |
| 5 | PPG Sungate® 500 pyrolytic low E on 6mm clear glass. Low E coating on surface 2. | IR reflecting film laminated to PPG 6mm clear float glass on surface 3. | 70 | 0.48 | 0.34 | 0.1 |
| 6 | IR reflecting film laminated to PPG 6mm clear float glass on surface 2. | PPG Sungate® 500 pyrolytic low E on 6mm clear glass. Low E coating on surface 3. | 70 | 0.51 | 0.34 | 0.1 |
| 7 | 3M Prestige 70 aftermarket applied film product laminated to PPG 6mm clear float glass on surface 2. | PPG Sungate® 500 pyrolytic low E on 6mm clear glass. Low E coating on surface 3. | 62 | 0.40 | 0.34 | 0.1 |

*Table 1*

*Optical and thermal performance characteristics of IG units incorporating polymeric IR reflecting films in a laminate configuration*

| ID | Description of IGU | | | Tvis (%) | SHGC | U-value (Btu/hr ft2 oF) | UV trans (%) |
|---|---|---|---|---|---|---|---|
| | Pane 1 | Suspended Film type | Pane 2 | | | | |
| 1 | PPG Sungate® 500 pyrolytic low E on 6mm clear glass. Low E coating on surface 2. | Heat Mirror™ HM88 | Cardinal 6mm clear float glass | 66 | 0.5 | 0.31 | 0.1 |
| 2 | PPG Sungate® 500 pyrolytic low E on 6mm clear glass. Low E coating on surface 2. | Polymeric IR reflecting film | Cardinal 6mm clear float glass | 66 | 0.46 | 0.32 | 0.1 |
| 3 | Cardinal 6mm clear float glass | 50 micron clear PET film | PPG Sungate® 500 pyrolytic low E on 6mm clear glass. Low E coating on surface 2. | 69 | 0.61 | 0.32 | 0.2 |

*Table 2*

*Optical and thermal performance characteristics of IG units incorporating polymeric IR reflecting films in a suspended film “triple pane” configuration*

## Conclusions

The use of metal-free NIR reflecting films within an IG unit is presented here. These films based on 3M’s multilayer film technology may be used in a laminate or as a suspended film. In either case, the use of these films in combination with pyrolytic low E glass offer IG manufacturers further options to create unique energy efficient and cost effective value proposition.

## References


1. I.M. Kirlin, “Insulating-Pane”, US Patent 1,370,974, 1921.
2. R.A. Lizardo and R.G. O’shaughnessy, US Patent 4,335,166, “Method of manufacturing a multiple pane insulating unit”, 1982.
3. M. List, J Fiukowski, S. Nadel P. Greene and M. Andreason, “A new generation of temperable coatings”, p. 174, Glass Processing Days, 2005.
4. J. Boettcher, M. Scott, B. Koster and M. Kominami, “Metal-free, Solar Reflecting Film Performance Results in Laminates”, p. 513, Glass Processing Days, June 2001.
5. J. Boettcher, M. Kominami and M. Scott, “Laminate Performance Results of Metal Free and Color Neutral Solar Reflecting Film”, p. 538, Glass Processing Days, 2003.
6. T. Alfrey Jr., E.F. Gurnee and W.J. Schrenk, “Physical Optics of Iridescent Multilayered Plastic Films”, 9(6), 400, Poly. Eng. Sci, 1969.
7. J.M. Jonza, M.F. Weber, A.J. Ouderkirk and C.A. Sover, “Optical Film”, US patent 5,882,774, March 16, 1999.
8. J.A. Wheatley, M.F. Weber, A.J. Ouderkirk, “Optical Film with Sharpened Bandedge”, US patent 6,157,490, Dec. 5, 2000.
9. M.F. Weber, C.A. Stover, L.R. Gilbert, T.J. Nevitt, and A.J. Ouderkirk, “Giant Birefringent Optics in Multilayer Polymer Mirrors”, Science, 287, 2451, 2000.
10. S. Schlem and G.B. Smith, “Dilute LaB6 Nanoparticles in Polymer as Optimized Clear Solar Control Glazing”, 82(24), 4346, Appl. Phys. Lett., 2003.
11. G.B. Smith, M.J. Ford, C. Masens and J. Muir, “Energy-efficient Coatings in the NanohouseTM Initiative”, 4, 381, Current Applied Physics, 2004.
12. http://windows.lbl.gov/software/window/window.html
13. C.A. Gueymard, “Advanced Solar Irradiance Model and Procedure for Spectral Solar Heat Gain Calculation”, 113(1), ASHRAE Trans, 2007.
14. R. Padiyath, C. Haak and L. Gilbert, “Spectrally Selective Window Films”, presented at the 50th annual conference of the Society of Vacuum Coaters, Kentucky, 2007.