

## The Development of Window Film and Adhesive's Technology and International Recommendations for Future

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### Abstract

This paper reviewed the development course of the glass window film, introduced the film, near infrared ray absorption film, infrared reflective film and smart window, window film the latest progress.

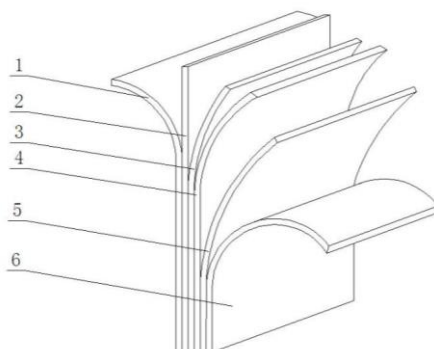
### Keywords

Window Film, IR Absorb Film, Exterior Window Film, Intelligence Window Film.

### 1. Development of window film

Window film is a type of multilayer multi-functional polyester composite optical special film product [1-2]. Generally, it takes PET(polyethylene glycol terephthalate) film as the base layer and is processed PSA composition. The application of the product on glass surface can improve the performance and intensity of glass, and endows the functions of heat preservation, heat insulation, energy saving, explosion-proof, ultraviolet light proof, privacy keeping and safety protection etc.. Particularly in automobile industry, 90% automobile users in China choose to use window film.

Window film can be classified into the following types based on the functions: heat-insulating film, security film, composite insulation security film and decorative film; and can be classified into indoor and outdoor type based on the working condition. The functional film is composed of PET film material, compound rubber layer, anti-scratch layer, install rubber layer and release liner protective layer as the basic structure. It is designed of heat reflection, conversion heat absorption and uvioresistant functions according to different rubber formulas, metallized magnetron sputtering, and coating technology of base material. In addition, it has high toughness, shock resistance security protection performance, color enrichment and other functions. Architecture window film is subject to structure design and manufacturing according to functional demands and environmental construction requirements. The structure of architecture window film is as shown in Fig. 1 [3]



1-Anti-scratch layer, 2-Special treated PET, 3-Compound rubber layer, 4-Special treated PET, 5-Highly transparent pressure type adhesive glue agent, 6-Highly transparent release liner

Fig. 1 Structure of architecture window film

The technology development progress and structure are as shown in Table 1 [4-5]. Due to the high requirements on optical property imposed on window film, all the materials are highly transparent

optical. Especially, adhesion agent shall be uv-resistant, and shall not present aging or yellow discoloration. It is the key raw material for window film production.

Table 1. Development progress of window film technology

Window film	Structure	Characteristics
Generation I	PET/PSA + dye	It is characterized of cheap price and short service life. And it is prone to color fading.
Generation II	Anti-scratch layer /PET aluminizing/laminated adhesive with dye/PET film/PSA	The price is cheap. And the service life is 3-5 years. It can be applied as automobile side baffle and architecture heat shielding film.
Generation III	Anti-scratch layer /PET magnetron sputtering/laminated adhesive/PET film/PSA	It is of high grade, long service life and high light transmittance. It can be applied as automobile front-baffle.
Generation IV	Anti-scratch layer /PET film/Nano insulation PSA /PET film/PSA	It is of high light transmittance and infrared rejection rate.

On the aspect of window film structure, solvent acrylate pressure-sensitive adhesive is required for recombination and installation. Pressure sensitive adhesive shall have excellent UV absorbent, dye solubility, high translucency, excellent UV-resistance, heat resistance and water resistance. The principal factor for preparation of such high-performance PSA is that it has various functional perssads and selection of allyl monomer with soft and hard monomer copolymerization. Copolymer crosslinking can be realized through functional monomer thus to improve cohesion strength, heat resistance, aging resistance and other properties of PSA [6]. And external crosslinking PSA can provide more outstanding comprehensive performance [7-8].

During coating process of window film PSA, it shall be free of appearance defects on glue point, glue line and coated corrugation due to the stricter requirements on coating. PSA batch has higher viscosity stability. In addition, it is required that the rubber-faced odor is light after coat drying. In view of the above requirements, common solvent type PSA cannot meet the requirements.

In recent dozen years, with the increasing of domestic diaphragm dosage, many window film manufacturers emerged in China, such as Changzhou Shanyou Dishan Protective Material Manufacturing Co., Ltd., Jiangxi Kewei and Shanghai Dichi etc. The domestic market coverage is close to 80%. In addition, a large amount of the products have been exported to Europe and the United States, Brazil and other countries and regions.

## 2. Development trend of window film

### 2.1 External film

Window film can be classified to internal and external film according to the application position. A majority of automobile film and architecture film are internal type which is convenient t for construction and safety. While external film is pasted outside the architecture window. It is mainly applied at special occasions or indoor places not convenient for construction. The film can be used as safety film to prevent glass breakage.

USP No. 6773778 disclosed an external film, the key technology of which is to apply a layer of scratch-resistant agent with high weatherability<sup>[9]</sup>. Generally, external film only works for 24 months, which is determined by the adhesion strength of the outmost scratch-resistant coating and basic film PET. Test the service life according to ASTM G 155. The scratch-resistant layer of external film can only work for 600-900 hours. After exceeding the duration, in case of 100% dropping of scratch resistant agent adhesion with 3 adhesive tapes, the test will be determined as nonconforming.

USP No. 6787236 disclosed an external film structure. Apply a layer of silane coupling agent between scratch-resistant layer and basement layer so that the scratch-resistant layer has high adhesive force and weatherability [10].

3M disclosed the structure and manufacturing method of an external security in USP No. 9303132 [11]. The structure is as shown in the Fig. below:

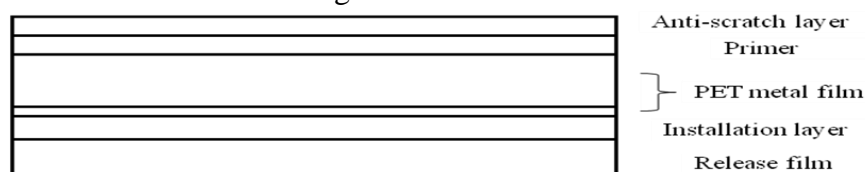


Fig. 2 Typical structure of external film

The structure is as shown in Table 2 10-15 $\mu$  scratch-resistant layer, 10-15 $\mu$  priming coat, 50 $\mu$ PET basement layer or metal film, 10-15 $\mu$  PSA installation layer and 23 $\mu$ PET release liner.

Typical scratch-resistant layer formula is as shown in Table 2:

Table 2. Typical scratch-resistant layer formula

Photoinitiator	0.5-5.0 parts	Irgacure 819
Organic UV stabilizer	1.0-3.0 parts	Tinuvin 477、Tinuvin 123
Inorganic UV absorber	1.0-3.0 parts	Zinc oxide, cerium oxide, silicon dioxide and aluminium oxide
PU oligomer	36-70 parts	CN983, CN963B80, CN985B88, and CN2920
Acrylic monomer	20-50 parts	Sartomer SR399、Sartomer SR833 S
Solvent	30-80 parts	Acetone, butanone, methyl isobutyl ketone, butyl acetate and ethyl acetate

Scratch-resistant layer contains at least a type of organic UV stabilizer or inorganic uv absorber. Inorganic uv absorber generally is Nano particle dispersion. The Nano particle size shall be smaller than 100 Nano, and can increase the surface hardness of scratch-resistant agent.

Typical primer formula is as shown in Table 3:

Table 3. Typical primer formula

UV initiator	0.4-2	Ciba-Geigy Irgacure 500, Irgacure 2959
UV absorber	3-6	Tinuvin 477-dw
Matrix resin	100	Rhodia rhodigard W 200

Priming coat is generally of water-based UV urethane acrylate or solvent type UV polyurethane acrylate system. UV-type system is to utilize the rapid aridity of UV to satisfy window film direct online winding but not affect coating appearance.

## 2.2 NIR absorbing film

At present, the common window film in the market is divided to Infrared absorption film and infrared reflective film according to heat insulation principle. The absorbing film is to realize thermal insulation by utilizing coat on the heat absorption infrared light of the heat absorption of infrared light; and reflective film is to reach thermal insulation by evaporation on transparent polyester film or magnetron sputtering of a layer of metal or nano-scale ceramic material. The heat insulation effect of the metal layer of reflecting film can be realized based on the loss of visible light transmittance on account of the big particle size, good reflection effect and small visible light transmittance. However, infrared absorption film will not lose visible light transmittance since near-infrared (NIR)-absorbing is uniformly dispersed in adhesion agent. Consequently, to select a good heat insulation and heat transparent material is a hot topic for the development and research of window film.

USP No. 5925453 described a specially designed window film for curved glass, such as the automobile front and rear baffle which can reduce infrared penetration to the maximum extent thus to realize thermal insulation. Its key structure includes a reflecting layer and an infrared absorption layer. Infrared absorbing agent material is mainly dispersed on window film adhesion agent, mainly as CoNPc and anthraquinone compound; or metal oxide, the particle size is about 5-100 nanometer [12].

If near infrared absorbent is applied on architecture, it shall have strong environmental stability related to thermal, humidity and ultraviolet radiation. Song Hee Koo et. al. of South Korea Institute of Chemical Technology and Soongsil University [13] studied the application of near infrared absorbing agent N, N, N', N'-4-dibutyl amino phenyl, -p-benzoquinone-double six fluorine antimonate imine on heat-insulating film, and prepared near infrared absorbing agent/crosslinking type composite membrane (NIR-film) with good weatherability which can realize crosslinking under ambient conditions. Composite film has good environmental stability to thermal, humidity, and uv radiation. The primary mechanism is that: The crosslinking network reduces the free volume of near infrared absorbing agent molecules embedded thus to increase weatherability.

NIR-film visible-infrared spectral spectrum is as shown in Fig. 3. It can be seen from the Fig. that the average light transmittance within visible light scope (400-780 nm) is 86-88%; the transmittance at near infrared region significantly decreased (780-1100 nm). The transmissivity at 1000nm is 32% which indicates excellent near infrared absorption performance.

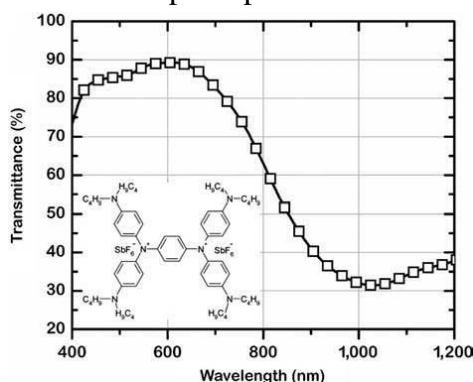


Fig. 3 NIR-film visible-infrared spectral spectrum

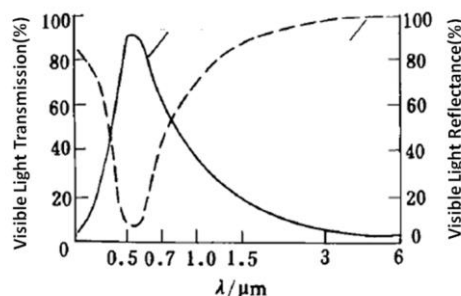


Fig. 4 Ideal characteristic curve of solar control film

### 2.3 Solar control film

Solar control film is a spectrum selective material. It has excellent translucency in visible light wave band. In addition, it has high reflectivity at infrared band. It is an important architectural energy saving material. Choose solar control film with appropriate wave length selectivity can reduce thermal radiation loss, improve heat insulation effect and will not obviously reduce the permeance of sunlight through windows. It should have high transmittance at visible region (400-780 nm) and inhibit infrared transmission with a wave length over 780nm [14].

The ideal characteristic curve of solar control film is as shown in Fig. 4.

USP 4634637 disclosed a solar control film, which is mainly applied on automobile film. The structure includes a nickel chrome layer PET metal film with magnetron sputtering. The nickel chrome layer is of high density. And the visible light transmittance has reduced to about 50-70% [15].

USP 7057805 described a solar control film including: a) Adhesive layer of solar light-control film base material; b) metalization layer; c) scratch-resistant layer containing carbon black particle [16].

According to the aforementioned key structure, infrared absorption rate can be improved, and ultraviolet light passing rate can be reduced. In addition, after adding carbon black to scratch-resistant layer, visible light reflectance can be reduced effectively. In addition, carbon black provides an aesthetic color. While comparing with organic dyestuff, color duration can be increased, generally about three years' effective service life.

The average particle size of carbon black particle dispersed in scratch-resistant agent layer is 200-500nm. The adding amount preferred is 2-4%. The typical formula is as shown in Table 4:

Table 4. Scratch-resistant layer formula

Raw material	Ratio
SR-295	26
Ebecryl 3720	4
Darocur 1173	1
Irgacure 184	1
Penn Color 6B380	12.5
Rapi-Cure DVE-3	2.6
Total	12
MEK	12

#### 2.4 Intelligent window film

Intelligent window film refers that the optical property of glass can be subject to bidirectional adjustment as required so that it can realize maximum utilization. Therefore, such product development has wide market value.

Wang Lanfang of Changzhou Shanyou Dishan Protective Material Manufacturing Co., Ltd. introduced the preparation process of intelligent window film with vanadium dioxide nano composite materials and performance test for the product. Apply vanadium dioxide nano composite materials to PSA according to certain proportion through dispersing agent after high-speed distribution. Coat on PET film to produce intelligent window film. The results indicate that vanadium dioxide nano composite materials can significantly improve the quality of window film. The prepared intelligent window film has visible light high transmission, ultraviolet light high resistance and other characteristics, as well as excellent intelligent heat insulation performance and weatherability. After further reducing the phase-transition temperature of vanadium dioxide material and solving material dispersibility, intelligent window film will have a wide market prospect.

Contrast test is to be performed on common white glass. The test sample takes common white glass pasted with vanadium dioxide intelligent insulation window film. The temperatures in the two rooms before testing are consistent. After that, turn on the heat source. After irradiating for 3min., record the temperature difference between the two test samples. The results are as shown in Table 5:

Table 5. Intelligent heat insulation performance test data

	Common white glass		Pasted with vanadium dioxide intelligent insulation window film	
Initial temperature/°C	10.5	33.7	10.5	33.7
Temperature rising/°C	26.7	44.3	24.3	37.2
Temperature difference/°C	16.2	10.6	13.8	3.5

The test data of aging resistant of vanadium dioxide intelligent insulation window film is as shown in Table 6:

Table 6 Test data of vanadium dioxide intelligent insulation window film

QUV aging duration (h)	$\Delta E^*_{ab}$	Visible light transmittance (%)	Infrared radiation rejection rate (%)	Ultra-violet rejection rate (%)
0	/	69	40	0.3
300	0.77	69	40	0.5
700	0.92	69	40	0.8
1000	1.93	68	41	1.1
2500	2.57	68	42	1.2

The results show that vanadium dioxide intelligent insulation window film has excellent weatherability of intelligent insulation film. After QUV aging testing for 2500h (equivalent to five years exposed outdoor in natural climate environment), the color of composite window film will remain bright without obvious fading. It has excellent color retention, high visible light transmittance, infrared and ultraviolet blocking rate.

### 3. Conclusion

The paper summarized technology development process of window film, introduced the latest progress of external film, near infrared absorbing film, infrared reflective film and intelligent window film. With the market and customer requirements becoming increasingly stricter, intelligent window film will be an orientation for the development of window film.

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