How to Evaluate Smart Glass and Liquid Crystal Switchable Film

1. A Brief History

Smart glass is also called magic glass, switchable glass, privacy glass, smart window, switchable window and privacy window. There are three generations of smart glass in the market. Generations of smart glass are determined by manufacturing technologies of liquid crystal (LC) switchable film. In the industry, independent patented technologies are usually used to classify generations of products. For about three decades, there are only three independent patents in the field of LC switchable film. LC switchable film is also called liquid crystal film, LC film, smart film, privacy film, intelligent film or PDLC film. First generation (1G, US Patent 4435047, patent expired) utilizes water soluble polyvinyl alcohol to disperse liquid crystal droplets, called Emulsion Technology or Nematic Curvilinear Aligned Phase (NCAP) technology. Second generation (2G, US Patent 4688900, patent expired) utilizes epoxy to disperse liquid crystal droplets, called Polymer Dispersed Liquid Crystal (PDLC) technology. Third generation (3G, US Patent 5270843, still in force) utilizes a non-linear polymer to disperse liquid crystal droplets, called Non-linear Polymer Dispersed Liquid Crystal Display (NPD-LCD) technology. A general term for all of generations is Liquid Crystal Microdroplet Display or LCMD. Both 1G and 2G LC switchable films invented over quarter of century ago have similar features. 1G film must be laminated between glasses to prevent absorption of moisture from the air. There are some improvement for 2G film but basically same as 1G film. 3G Film has great improvements in all classic features, like ultra-clear, lower driving voltage, water-proof and high ultraviolet (UV) resistance, high heat resistance and extremely long lifetime, and also has many new special features, like front and rear projection, Viewing Angle Independent (VAI) brightness and super light diffusion functions, switchable projection glass™ and switchable projection panel™. In recent years after 1G and 2G patents expired, more manufacturers of LC switchable film joined the market. There are many differences of product qualities that exist on the market. For a long time, consumers had a difficulty to evaluate LC switchable films. Here, we introduce some easy testing methods for LC switchable films. First, it is easy to recognize LC switchable films by manufacturers. Besides MUM (Japan) and Citala (US) use 1G Emulsion Technology and Scienstry (US) uses 3G Non-linear Technology, everyone else, such as Polytronix (US/China/Taiwan), DMD (Korea, UV process), Singyes Solar (China), use 2G technology. Second, it is also easy to identify products. LC switchable films may be recognized by peeling. After separating two layers, if one layer is clear and another layer is opaque, this is 1G film; if both layers are opaque, it is either 2G film or 3G film. A hairdryer or heat-gun can be used to identity 2G film and 3G film. By heating LC switchable films, a film turning clear below 70 °C or 158 °F is 2G film. Some 2G film made from UV process can be turned to clear by near body temperature (37 °C or 99 °F). 3G Film will hold considerable opacity at 90 °C or 194 °F.

For over two decades, 1G and 2G films can be only used in laminated glass and worked in only indoor at room temperature, additionally, cannot used on windows facing outside. 3G Switchable Film has much broader application scopes. With 3G Switchable Film, there is a wide variety of applications in larger markets, such as windows facing outside, glass walls of building, ceiling glass, switchable projection windows, storefront projection panels, entire building advertising, touch screens, uses on cars, trains and yachts. However, due to lack of effective evaluation methods published, some smart glass and LC switchable films are mistakenly used in different conditions, causing defects. Many users want to know why some smart glasses installed on windows facing outside lose opacity; why some smart glasses installed on boats lose opacity and turn to yellow. These losses may be avoided if knowing features and limitations of different LC films. With a full evaluation, increased defective rates, especially in Asia market where some manufacturers do not have warranty policy, may be controlled. There is an urgent need to provide simple evaluation methods for consumers.

This article introduces some testing methods which allow evaluating LC switchable films in a company, office or even at home without special instruments. Although LC switchable films may be evaluated by professional testing companies, it is costly. We may first reference professional testing methods and understand their testing principles, and then utilize available conditions and tools to do it by ourselves. In professional testing, a tougher condition is usually applied on a testing sample to shorten testing period and then calculate a result like lifetime or UV stability. For examples, UV light may simulate sun test and an environment chamber may be used to find out moisture stability or water-proof property or lifetime. After analyzing the professional testing methods, we may find out that we can do many tests by ourselves, but do not know how to calculate for a lifetime. For evaluation purposes, comparing results among different

films is more important than precision prediction on each film. Therefore, we can obtain many test results through comparison.

2. One Week to Evaluate UV Stability

Comparison not only reflects relative qualities among different generations of LC switchable films, but also may increase testing sensitivity. Since UV stability of a LC switchable film directly associates with its lifetime, UV stability is very important for smart glass used on windows. A sun-test is usually conducted directly on LC switchable films. Since defects like color change or lose scattering gradually show up, it is difficult to see enough difference in short period of sun-test. However, comparing with its original may increase sensitivity of sun-test without any special instrument. The following is the testing procedure: Prepare three (or more) testing samples of different generations of LC switchable films in about A4 or US letter size with two electrodes on two long edges, hand cut each sample into half along with its long edges. Each cut piece still has two electrodes on it. Put one half of the testing sample in outdoor directly under sunlight without any protection. Keep another half indoor for comparison. After one or two weeks, all 1G and 2G films will have noticeably changed in color and opacity and response time (turning speed) as well as transparency in comparison with their originals. 2G film made with UV process has greater change than other films, because it already undergoes a strong UV exposure through the manufacturing process. 1G film without a high quality of dehydration process is vulnerable for sun-test too, because trace water may promote UV decomposition process. That is the reason why some laminated 1G smart glass loses clarity in indoor condition. 3G Film does not have any change after two weeks of the sun-test at all. Actually, 3G Film does not have any noticeable change after one year of the sun-test. 3G Switchable Glass has passed tests for automobile application by China National Accreditation Service (CNAS) and automobile glass manufacturers. Hand cut with some curve is helpful in finding their original pieces. Since this experiment requires free protection, and as expected, older generations of LC switchable film are sensitive to moisture and rain, some edge damages may be temporarily ignored. Such comparison is quite sensitive and very easy to find out difference before and after the sun-test.

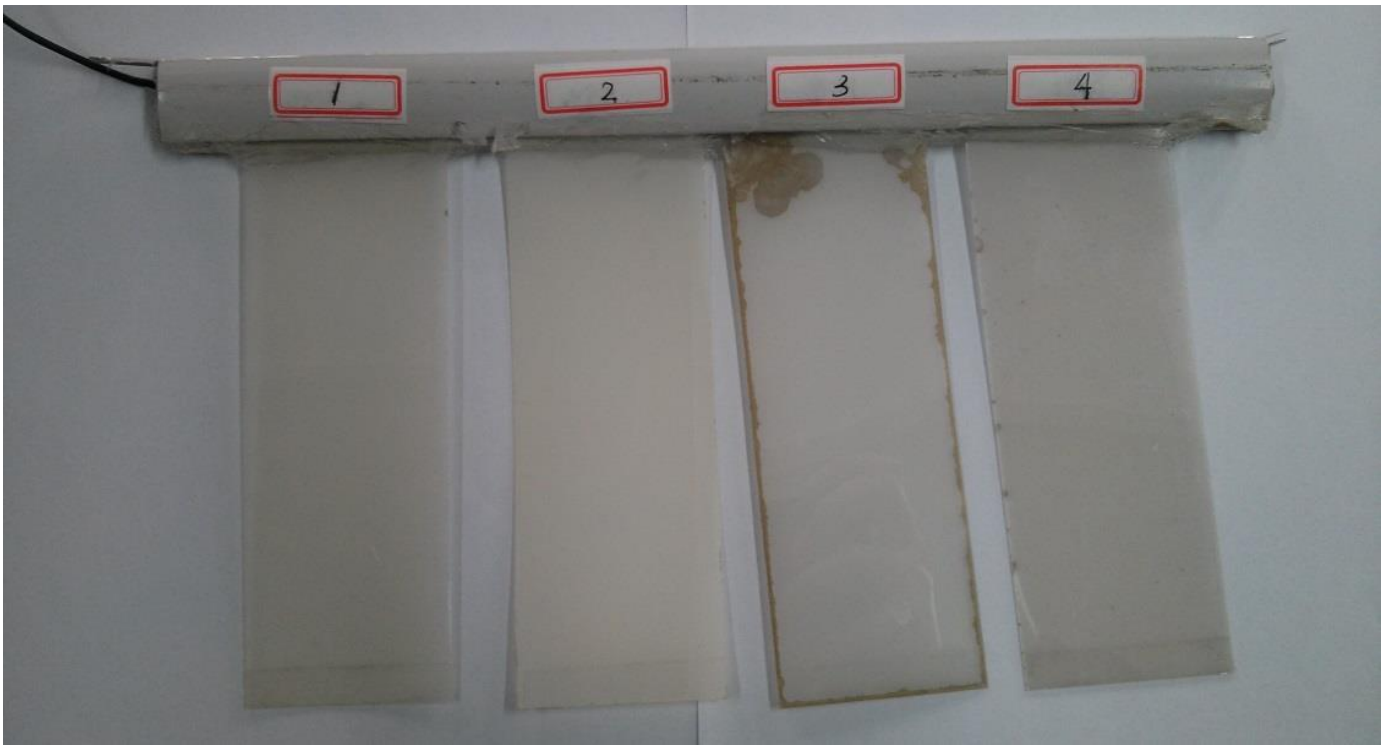
The lifetime of smart glass can be estimated from the sun-test. Since regular glass and interlayer may help to block considerable UV ray, for example, Polyvinyl butyral (PVB) may blocks 96% of UV from sun light. So, this test condition is about 25 times stronger than an actual condition in using smart glass. An estimated lifetime can be calculated as follows. For LC film survived for 1 week sun-test, lifetime of smart glass is about half year (1 x 25 weeks). If LC film survived for 2 weeks, the lifetime of smart glass is about 1 year. One month, the lifetime is about two years. One year, the lifetime is about 25 years

The reason that a LC switchable film loses its opacity is because liquid crystals are decomposed by UV ray in sunlight. Liquid crystal molecules usually have a rod-like molecular structure and prefer alignment together. Oriented long-shaped molecules usually show white color unlike common liquids showing transparent. Such orientation characteristic allows liquid crystals to have optical activity. An electrical field can change or control the orientation. Common liquid like water or oil do not have such capability. UV ray may break down liquid crystal molecules into small pieces causing them to lose optical activity and have no response to voltage anymore. This is why these LC switchable films lose opacity and become clear without power. The rod-like molecules also have a head, body and tail. The head is usually formed by a functional group which is most sensitive and vulnerable for UV ray from the Sun. Many dyes are formed from same molecular family of this functional group. When UV ray destroys the head functional group, it forms dye-like deviants showing yellow or dark colors. The above instructions are not intended to report a comparison result among different LC switchable films; it is intended to introduce a useful method to understand different qualities among LC switchable films. Users should conduct similar experiments to find out their own results.

3. One Day to Evaluate Lifetime

Moisture stability is very important for all electronic devices. Almost every electronic device needs to undergo a moisture test. In professional testing, moisture tests are usually conduced in an environment chamber which can provide different percentage of humidity and temperature. Although lamination may slow down penetration of moisture, moisture will always penetrate the interlayer and get into LC switchable films over time, especially at the edges. In rainy day, relative humidity reaches up to 100%. An environment chamber may also simulate 100% humidity condition in which water may be condensed on testing samples. Condition of 100% humidity is similar to a condition in water. If we move a regular film testing with a low voltage in air into water, it becomes a good testing method which matches professional

testing principle and avoids using an environment chamber. The test of Driving-Underwater may quickly provide a lot of information on LC switchable films with almost no cost. The following is the testing procedure: Prepare three (or more) testing samples of different generations of LC switchable films in about 10cm x 25cm size (or other sizes) with two electrodes (bussbars) in one edge, connect all testing samples together, seal electrodes with a silicone glue. Put this testing group into water at room temperature and then apply 55 - 65V AC voltage to all of the samples for several hours. A small step down transformer with 3 - 50 watts is used to limit voltage and current for safety. In this way, even alive fishes do not feel AC voltage during the test (click here to watch a video). Picture 1 shows a result from eight hours testing. Although electrodes are sealed with silicon glue, it is not necessary to immerse electrode part into water to see same results.



Picture 1

As we know, 1G film is made of water soluble polymer. This test is obviously too tough on 1G film. For one hour in water, edges of 1G film will be swelling and dissolved. Therefore, this test is mainly for comparison among 2G films and 3G Film. Since 2G films may be made with different processes, such as UV process and thermo process, three 2G films made by different manufacturers are included in this test. Sample 1 is 2G film made in Korea (D). Sample 2 is 3G Film made in US by Scienstry. Sample 3 is 2G film made in US (P), and Sample 4 is 2G film made in China (S). The test results listed in Table 1 disclose a lot of information on samples' chemical stability, electro properties, electro-chemical reactions and lifetime.

Sample Code	Types of film	Country of Origin	Testing results
1	2G	Korea	All edges turn clear. Sample turns dark and stops working.
2	3G	US	Work normally and no noticeable change
3	2G	US	Serious burnout in all edges and inside. Sample turns dark and stops working.
4	2G	China	All edges burnout. Sample turns dark seriously but still works. There are many small burning spots over entire surface.

Table 1

Through the test of driving-underwater, there are many defects on 2G films as shown in Picture 1 and Table 1. The professionals may clearly explain what reasons causes these defects with known knowledge. The manufacturers know

the reasons because they know what purity of materials used to make the LC films. Although 2G technology has limitations on quality and it is difficult to improve the quality within the technology, understanding the reasons causing these problems is helpful to avoid misuse of the products. 1. As shown in Picture 1, liquid crystals decomposition causes clear edges in sample 1. Electricity and water may accelerate the decomposition similar as moisture promotes decomposition of food. Decomposed liquid crystals not only lose optical activity but also increase their conductivity. Therefore, two layers of the films are shorted out or electrically connected with these clear edges, so sample 1 stops working. 2. All 2G samples turn to dark colors. Dark color indicates that functional groups of liquid crystals are destroyed. Most liquid crystals used in LC films contain a functional group called Nitrile group or Cyano group with a triple bond structure (-C≡N). The Nitrile group is very sensitive to ultraviolet ray and moisture. The Nitrile group may convert into many dye-like products with colors. Degree of color change is proportional to destructive level or degree of decomposition. Nitrile group may be destroyed by hydrolysis or decomposition with trace water, especially with acid as a catalyst. 3. Edge burning indicates that polarity of liquid crystal layer in sample 3 is very high and cause short out between the two layers. Liquid crystals usually are non-conductive like oil. Polarity normally comes from epoxy curing agents such as acid or acidic sulfur containing compounds. The trace acidic curing agents may greatly increase conductivity of liquid crystal layer same like that dirt or salt may greatly increase conductivity of distilled water. Such high conductivity destroys LC switchable film by hydrolysis reaction. In use of smart glass and LC switchable film, high polarity may cause many other electric problems like edge burnout or losing function of bussbars. The polarity also promotes UV and thermo decomposition causing short lifetime. 4. Small burning spots inside of film in sample 4 are caused impurity and polarity from liquid crystal layer and Indium Tin Oxide (ITO) layer. The reason for multiple black spots is caused by regional burnout. If burned in laminated glass, the spot sizes could be many times larger causing by produced gas. This phenomenon reveals an important concept, that is, moisture/water penetrates everything and anything. As we know, plastic Polyester (PET) film used to form LC films is basically considered water-proof material. It is used in many electronic devices. However, when a little of moisture can have a great effect, everything is considered as penetrable. This case is similar as a high vacuum system, in which all steel tubing and glass tubing are considered leaking for air molecules from surface. A vacuum pump must keep working to maintain a high vacuum. All 2G samples in this test have large surface defects, which indicate that the PET film of 2G films cannot protect liquid crystal layer at all, therefore, 2G films are not suitable to be used in air. This conclusion matches many years' of experiences, or 1G and 2G must be laminated into glass to prevent moisture.

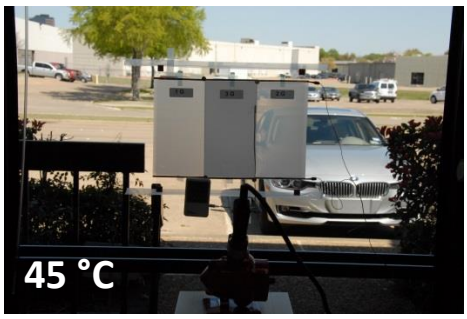
3G Film is made of silicone and fluoride containing polymer, which is similar to anti-sticky coating on cookware and underwater cables. Liquid crystals in 3G Film are well protected. Moisture and water could not penetrate 3G polymer, otherwise, same defects would occur on 3G Film and underwater cable would have serious electrical problems. On other hand, liquid crystals used in 3G Film are not sensitive for moisture or water at all, because the liquid crystals are protected by several high technologies. All known destructive reactions have been blocked. Since all 2G films are failed in the basic test in room temperature, there is no way to show comparison results on other common environmental tests at higher levels, such as underwater at raised temperature, spray salty water, under salty water, spray warm salty water and under warm salty water. In order to continually improve quality to meet more and more industrial requirements, Scienstry has done all kinds of tough tests on 3G Film and studied over one hundreds parameters which are possible to affect the quality.

As we know, moisture is everywhere and may penetrate interlayer and film. Electricity is used to operate LC switchable films. Anything happening in this experiment will always happen in actual uses of LC switchable films and smart glass, but in a slow pace. The test of driving-underwater qualitatively discloses a relative reliability and durability for lifetime of LC films and shows how far from the defects. 1G and 2G films have been used for over quarter of a century. In the past, all kinds of tests had been done by many users. The classic applications of 1G and 2G films for indoor and air-conditioned room in sealed form are based on many users' experience and attempts. In general, without passing environment test, a manufacturer should not claim a LC film for use in air without lamination or any outdoor application. Although patent expiration provides more chances for production, it does not automatically enlarge scope of applications. Understanding the background of the application may reduce blindness and failure of application. Above experiment strongly indicates that moisture will greatly affect 2G films in any application; therefore, sealants such as lamination are absolutely necessary. If 2G films are used to broader range such as used in air or on window facing to outside, it could mean a great risk. On the other hand, it is not necessary to repeat all attempts which had tried a long time ago. If there is a possibility, such an application should be very popular by now.

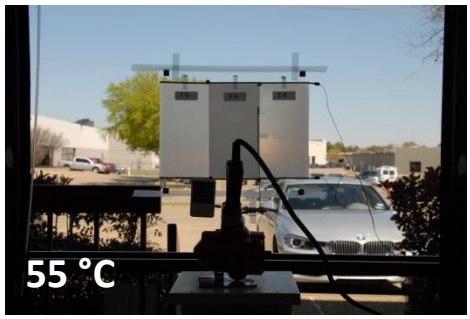
4. One Minute to Evaluate Thermo Stability

LC switchable films have been developed for many years. In past two decades, 1G and 2G films are mainly used as a laminated privacy glass and used indoor and in air-conditioned room. A major difference of 3G Film from older generations is its wide range of application from -30 °C to 80 °C or -22 °F to 176 °F and high UV and moisture stability. Testing thermo stability is very easy: Put all three generations of LC switchable films on a window with or without a thermometer. Use a hairdryer or heat-gun to heat the films with or without applying an electric power. Different films turn to clear at different temperatures. 2G film made by UV process usually turns to clear at the lowest temperature about 40-50 °C or 104-122 °F, because UV process utilizes very strong UV intensity such as 400W/inch mercury light to form LC-polymer layer. The product seems to undergo a sun-test already and some portion of liquid crystals are already damaged and decomposed through the UV process. Decomposed liquid crystal molecules no longer have rod-like shape and become smaller molecules like water. Therefore, LC layer is diluted and not pure enough. Diluted liquid crystals cannot hold their orientation at a high temperature and turn to isotropic state earlier by showing transparency. Other 1G and 2G films turn to clear at higher temperature about 50-60 °C or 122-140 °F. At last, only 3G Film holds opacity at a very high temperature until 100 °C or 212 °F. Such test results are shown in pictures 2, 3 and 4. It is interesting to see that a heat-gun points to 3G Film in center, but 1G and 2G films at both sides turn to clear. Since this test is conducted in an open area, the heat-gun can only heat up a center area and temperatures indicated in the pictures reflects readings in center area. For company evaluation, sample sizes may be smaller, so that, it takes a shorter time to see a result. Thermo stability test can be reviewed in detail in article Haze Comparison. The test may be also reviewed on a video (click here).

Picture 2



Picture 3



Picture 4

The video shows an interesting phenomenon, that is, in "off" state without a power, opacity of 1G film is reduced with a rising temperature, but in "on" state with a power, haze of 1G film is increased with a rising temperature. This phenomenon is opposite to behaviors of 2G and 3G films, of which haze of 2G and 3G films is decreased with a rising temperature. This phenomenon of 1G film may indicate that water molecules disturb orientation of liquid crystal molecules with a power, similar as a behavior of intensively vibrated water molecules under microwave.

5. High Quality and Its Value

Operational temperature range is the most important index and directly reflects a quality and lifetime for a LC switchable film. Temperature range is proportional to purity of liquid crystals and other chemicals used to make the LC switchable film. The higher purity, the wider the application temperature range is. Impurity often acts like bacteria to promote destructive reactions, causing problems such as shortened lifetime. There are different grades of purity in industry, such as industry grade, reagent grade and analytical grade. Purification is costly. In general, upgrading purity to each level, the cost of chemicals will be almost doubled. However, it is high purity that stops all destructive reactions from happening, similar to non-contaminated foods lasting longer. Liquid crystals and chemicals used in 3G Film are not sensitive to moisture or water at all, because they are different kinds and well protected. Of cause, these treatments increase cost, but gain much greater value. In the market, there are many companies that can make great products with great features and functions, but almost no one can make the best product with the lowest cost. However, this will not automatically lead a conclusion, that is, pursuing a lower cost must use cheaper materials. This is not true if considering a cost in entire lifetime of a product.

Although price is important to everyone, one always associates a price with quality and applications as well as product's lifetime cost. Whether or not a price is good, it not only depends on the buying price but also depends on maintenance costs and warrantee cost. Let's consider a case with two products, product A and B have 10% (or more) price difference; product A has a higher purity, higher price and zero defect and product B has a lower purity, lower price but 10% defect rate. In considering a total cost in lifetime, product A actually has a lower cost than product B, because handling 10% defect requires much higher cost than 10% of the material price. To handle the defects, it not only uses10% additional materials but also includes other expenses like labor and shipping and travelling. Defect causes a great inconvenience in end-user side too. If product A has double lifetime, product A has double value than product B. If product A has ten times longer lifetime and much broader applications, product A has much greater value than product B. This is only economical measurement. There are great differences in reputation and business scope and capability. Defects also hurt reputation. High quality is good for brand name and reputation. High quality may handle more applications and create more business. LC switchable film manufacturers should provide correct information and suggestion to consumers, it is also necessary for consumers to do some "homework" and understand LC films available in the market. Above introduced methods are so simple and so efficient to evaluate LC switchable films. These methods are very close to professional tests but without a need of special equipment. Preventing defects is important for a company's cost, reputation and business. After clearly knowing durability difference among LC films, selection is depended on supplier's and user's policies. Someone companies pursuit a high-end policy to reduce all possible risks, and others may prefer to take a chance and go with a low price. Difference in quality actually functions like an insurance. An insured situation is always better but don't have to. New manufactures and suppliers should know limitations of their own products. At least consumers should have a right and chance to know what they choose. We suggest every customer find out who is a LC film manufacturer and fully test and compare LC switchable films before purchasing and using them. Reducing defects may promote a healthy grow for this industry and benefit for both suppliers and users.

In order to improve quality of smart glass and LC switchable films, it is not enough to have good electrical and physical properties. Optical features need to be improved too. Pursuing great features in wider range could trace back to entire history of liquid crystal display development. Transparency in clear state of LC switchable film can be easily achieved by reducing thickness of liquid crystal layer, but such treatment will also reduce opacity in opaque state. Similarly, it is easy to increase opacity by increasing thickness of liquid crystal layer, but it will also increase haze in clear state. It is difficult to create a net wider range for any feature, such as better clarity and also better opacity. It is extremely difficult to broaden many features! Scienstry is very successful in R&D by conducting over ten thousand experiments and discovering three new chemical reactions (equivalent to physical laws in physics or equations in mathematics). It is easy to see that the highest clarity comes with the highest opacity of 3G Film. Its clarity is 4 to 8 % better than any of other films. After studying over one hundred parameters which may affect quality of LC switchable films in production and use, Scienstry establishes the broadest ranges with eight major features:

1. **Best optical properties**
2. **Low driving voltage**
3. **Highest stability for moisture, heat and UV**
4. **All weather applications from -30 °C to 80 °C from indoor to outdoor**
5. **Both front and rear projections**
6. **Super diffusion**
7. **Saving energy and green**
8. **Longest lifetime**

3G Switchable Film has a near-zero defect rate worldwide. With many tests and actual uses for many years, Scienstry has officially announced that NPD-400 series of 3G Switchable Film may be used in outdoor conditions with lamination. It is even not required to use low-E glass for lamination. Scienstry's specifications and warranty will support such outdoor applications. A major difference of 3G Switchable Film™ from older generations is its non-linear system. The non-linear system is an open system which allows adding new features without bothering existing features. It is very hard to make any change to close systems of older generations. That is why 3G technology can keep moving forward while 1G and 2G basically had no change for over two decades. With such great features of 3G Switchable Film, suppliers may cover broader applications for their business, and users may enjoy the best quality with many advanced features and a great reliability. It is a contribution of high quality. It is obviously to see its great value of the high-end product.