Look at Smart Glass in a Whole New Way

—— a long journey to outdoor applications

Although outdoor applications for liquid crystal smart window just become a hot topic, UV stability for outdoor applications is actually a resolved problem for 3G Switchable Film. An actual question should be how Scienstry to approve it. In 1990's of last century, stabilization technologies for UV radiation from the sunlight or weathering have been successfully developed, especially for automobile paints and coating materials for use of exterior walls. Coating stability is increased by many times. Since then, it is hard to see decolorized cars running in streets. The similar UV stability technologies have been also developed in Scienstry. Patented and/or patent pending technologies of UV stability becomes an important feature of 3G Switchable Film. Following information will show a solid proof for outdoor applications of 3G Switchable Film. It is needed to look at smart glass in a whole new way!

1. **A brief history.** There are three generations of liquid crystal smart film utilizing microdroplet technology so far. The generations are normally classified by independent patents, or patents creating types of products. One independent patent may follow with hundreds of improvement patents and technologies. LCMD (Liquid Crystal Micro Droplet) is a general term and encompasses three generations of LCMD film technologies, including 1G NCAP (Nematic Curvilinear Aligned Phase), 2G PDLC (Polymer Dispersed Liquid Crystal) and 3G NPD-LCD (Non-linear Polymer Dispersed Liquid Crystal Display) technologies.

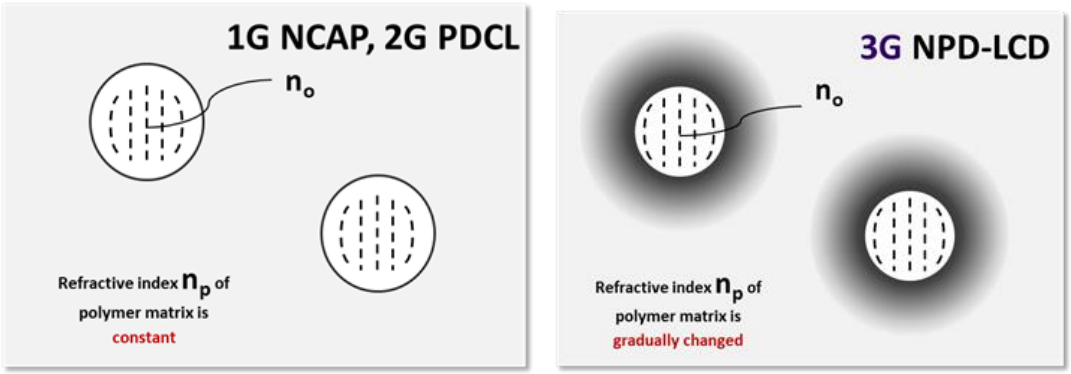


Figure 1A and 1B

As shown in above Figure 1A left, NCAP is characterized by a matrix of liquid crystal droplets dispersed in a uniform waterborne solid polymer, and PDLC is characterized by a matrix of liquid crystal droplets dispersed in a uniform solid polymer formed by a phase separation. As shown in above Figure 1B right, NPD-LCD is characterized by a matrix of liquid crystal droplets dispersed in **non-linear** solid polymer formed by phase separation. The common denominator among the three technologies is the use of liquid crystal micro droplets, which results in the use of "LCMD" to refer to those technologies generally. Although 1G and 2G films have been known for approximately three decades, no outdoor applications were heretofore known because of narrow temperature range and poor UV stabilities of such devices. This is because NCAP and PDLC technologies were unable to produce products with a wide working temperature range, as some inherent characteristics of the older technologies prevented these systems from having a wide working temperature range. Such internal factors include the fact that a required ratio for reactants is unable to be maintained for matching the refractive indexes between liquid crystal and polymer, resulting in impurities developing in the droplets. For about 30 years, NCAP and PDLC have only had a working temperature range from 0 °C to 50 °C, which is far narrower than what is required for outdoor applications. Outdoor application of LCMD requires a working temperature range of approximately -30℃ to 80℃ (click here for detail).

In contrast to NCAP and PDLC, NPD-LCD has a non-linear or gradually changing polymer phase with an onion-like structure and only requires refractive index matching between liquid crystal and an inner layer of the polymer phase. It does not need a matching with an entire polymer phase. Therefore, the contradictory between chemical requirement for curing and optical requirement for matching refractive indexes between liquid crystal and the main polymer body is no longer existed in NPD-LCD system. In the formulation of NPD-LCD, chemical requirement for curing can be easily met

to obtain a high degree of polymerization resulting in the droplets with high purity of liquid crystal. Actually, a wide working temperature range indicates a high purity level of the droplets of liquid crystal in 3G Switchable Film, because any impurity will reduce original temperature range of nematic phase of liquid crystal. With a wide working temperature range, outdoor applications become possible, which naturally leads to a need to further improve capabilities of anti-moisture, anti-heat and anti-UV.

According to chemical systems, each generation of LCMD has its expected life time. Obviously inherent chemical defects, such as waterborne polymer used in 1G NCAP film and a contradictory between chemical requirement and optical requirement existed in 2G PDLC film, shorten the life times of earlier generations. Oppositely, 3G Switchable Film had shown its great stability with an improved chemical system by its wider working temperature range. The pictures at above left show an early glass dome with an etched circuit. It still works fine today after about 25 years! Sure, it will continue to work many years to come. Furthermore, pictures in above right show an actual window film which has been installed in Scienstry and worked for 17 years so far. It should be noticed that this 3G Switchable Film is not laminated in glass, instead, only glued on an existing window facing to outside and north. It is important to point out that those samples shown in above pictures are only early developments of 3G Switchable Film, and do not include Scienstry's later patented technologies yet. However, it is very valuable to demonstrate essential differences between generations. If a technology is good in principle, three decades are enough time to develop its products. Oppositely, if a narrow working temperature range and short life time are existed for three decades, these must be principle problems which are impossible to be resolved within the old systems. It takes time to prove reliability, especially for outdoor applications. The solid proofs for outdoor applications not only need to show in independent patents with new theories and technologies, but also need to show with successful large projects and toughest tests.

2. **Inherent chemical defects are existed in earlier 1G and 2G generations.** Inherent chemical defects are responsible for a narrow temperature range and a short life for 1G NCAP. First, since there is always trace of water existed in waterborne polymer used, such as polyvinyl alcohol, in 1G system, liquid crystal in the NCAP system may undergo a hydrolysis reaction with the water. In following reaction, a molecule of liquid crystal reacts with a molecule of water to form a corresponding a carboxylic acid:

$$R_1C{\equiv}N + H_2O \rightarrow R_1CO_2H + NH_3$$

Here, $R_1C{\equiv}N$ represents a liquid crystal molecule and a carboxylic acid R_1CO_2H is a by-product. The hydrolysis of the nitrile group ($C{\equiv}N$) is a very typical reaction which can easily occur under a normal condition, especially in an elevated temperature.

Second, an esterification reaction is involved in the system, where the carboxylic acid reacts with a hydroxyl (alcohol) group in the polyvinyl alcohol to form an ester derivative $R_1CO_2R_2$ and water:

$$R_1CO_2H + R_2OH \rightarrow R_1CO_2R_2 + H_2O$$

Here, R_2OH represents an alcohol group in polyvinyl alcohol; $R_1CO_2R_2$ represents an ester produced.

It should be noted that in the first reaction, hydrolysis of the nitrile group, uses up a molecule of water, and in the second reaction or esterification produces a molecule of water. Overall no water is used up or produced, and the water is only acting like a catalyst. That means that if trace of water is existed in the system, it will promote the decomposition of entire liquid crystal to the end.

Due to these destructive reactions existed in the NCAP system, optically active molecules of liquid crystal are decomposed into non-active compounds, which make the liquid crystal film to lose its optical properties resulting a short life time. Being chemically unstable is a serious systematic problem, because both the liquid phase and the solid phase are destroyed by their own components.

There are inherent chemical defects existed in 2G PDLC system too. Since a PDLC system optically requires a reflective index matching between liquid crystal and polymer used, the chemical system used in PDLC practically can't support the optical requirement. In other words, there is a conflict between the optical requirement and the chemical requirement, because a chemically required simple ratio 1:1 or 1:2 between reactants can't produce a precision matching required by the optical requirement. To meet the optical requirement, chemical system must be adjusted from its ideal position. It is the adjustment that makes many problems for the system including a narrow temperature range, instable for moisture, heat and UV and short life. On the other hand, the optical principle of PDLC can't achieve a low haze and low voltage driving.

The manufacturers of PDLC film must shift the ratio away from the optimal ratio required by chemical equations. Although this shifting compensation can still cure the PDLC polymer system such as epoxy system, it makes the polymerization in a non-ideal condition. In other words, some extra reactants such as epoxy or hardener will remain in the system. More seriously, these extra reactants will have destructive reactions causing a series of problems for PDLC products.

The extra reactants of epoxy or hardener leave their active functional groups in the liquid crystal phase, and act like an impurity. These polar functional groups seriously affect the purity of the liquid crystal in droplets resulting a narrow temperature range. This situation has more destructive effect than water in 1G NCAP system, because these functional groups, like acid ($-CO_2H$), amino ($-NH_2$), thiol (-SH) or epoxy ($-CHOCH_2$) groups are more reactive to cyanogroup ($-C\equiv N$) in molecule of liquid crystal and to electrochemical reactions. Electrochemical reactions may occur with polar molecules. These polar molecules are first ionized through a redox reaction on electrodes. The ionized molecules can induce liquid crystal molecules to change. Liquid crystal with a conjugated structure is vulnerable to be attacked by ionic impurities. The more impurities the greater the current is; the higher voltage the higher rate of induced redox reaction will occur. Therefore, the necessary formulation of PDLC becomes a reason causing a narrow working temperature range and shortens a life time. The PDLC principle also requires a high voltage driving as shown in following figure.

Beside problems created by the formulation, optical principles of PDLC and NCAP also have problems preventing their products to reach a high-performance level. First, orientation or alignment of liquid crystal molecules inside a droplet is determined by the joined forces, or surface energy and electrical energy. In the power-off state, illustrated in Figure 2A, liquid crystal molecules are basically aligned parallel to a film surface. Due to shrinkage during curing and thermal process, droplet have a slight ellipse shape. There is an important characteristic for the normal mode of LCMD, that is, liquid crystal molecules prefer parallel alignment with an elongated surface of a droplet to keep a minimum internal energy. When an electrical field is applied to the droplet, the liquid crystal molecules in the droplet turn to a vertical alignment, illustrated in Figure 2B. However, in this situation, some liquid crystal molecules still prefer a parallel alignment with the droplet surface, resulting in a tilted alignment to the film surface (horizonal line), especially at the two ends. The tilted alignment produces haze, because there is no matching between liquid crystal no and polymer np. Since the vertical alignment is voltage dependent, increasing voltage can extend center region of vertical alignment, illustrated in Figure 2C, therefore increase the transparency. The higher voltage applied the better transparency that can be obtained. Of course, this applied voltage must be controlled within the limitation of the ITO coated film. Therefore, PDLC and NCAP need a high driving voltage, normally 5 - 7 times higher (such as 70 -100 V) than 3G Film, to create the configuration in Figure 2C and obtain an acceptable transparency. Since surface tension always exists and influences the liquid crystal, configuration D is impossible. In this imagining configuration D, all liquid crystal molecules are aligned perpendicular to the film surface, so the constant polymer refractive index (np) could perfectly match the constant refractive index of liquid crystal (no), and then a haze-free clear state would be obtained. Under the actual situation where liquid crystal molecules in the center part of the droplet are perpendicular to the film surface but tilt near the two ends of the droplet, as shown in Figure 2B and 2C, matching the refractive index in PDLC is only achieved in the center area of the droplet. The areas near the two ends of the droplet are always mismatched and produce haze. In other words, the constant polymer refractive index (np) never matches with the varied liquid crystal refractive index (no). This optical situation determines that in PDLC, it is theoretically impossible to match the refractive index for an entire droplet. NCAP has this exact same problem. That is why both PDLC and NCAP do not have haze-free and wide viewing angle states. It is very understandable that for about thirty years NCAP and PDLC's quality have not been improved much. These principle problems have been recognized for many years, but there is no way to solve them within the systems.

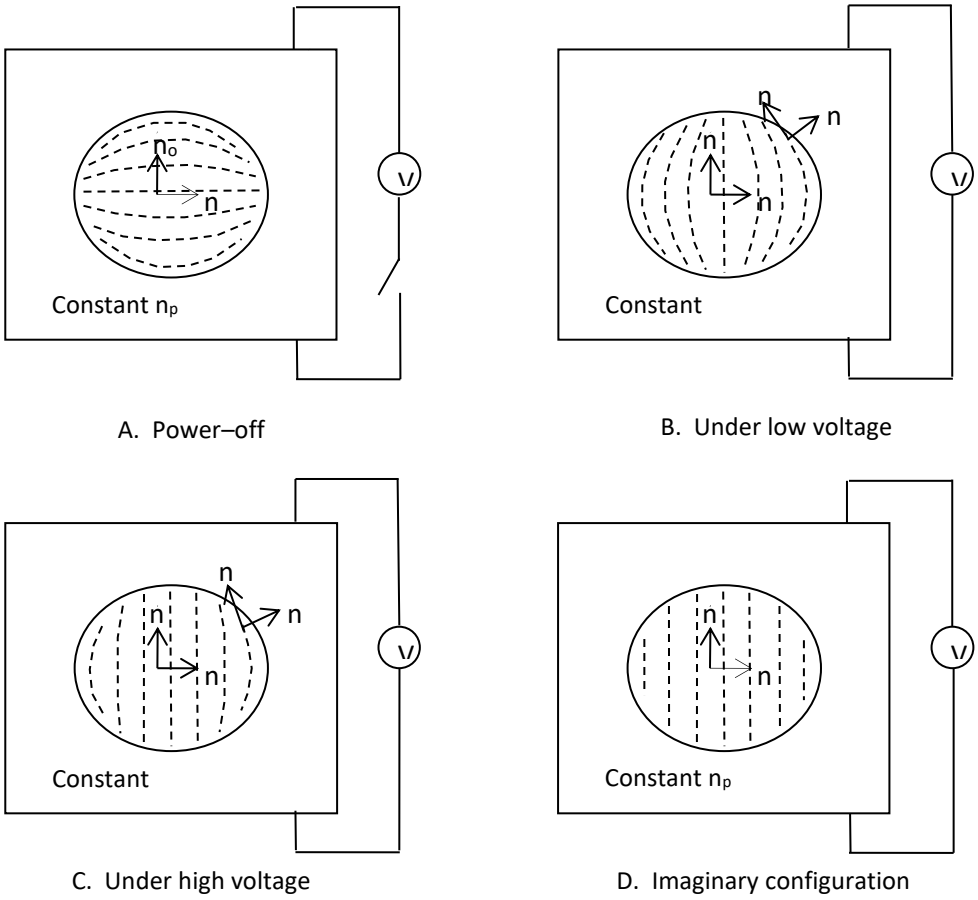


Figure 2

Furthermore, polymer used in PDLC system is chemically too close to liquid crystal, therefore, the polymer phase has considerable solubility to the liquid crystal. Both liquid crystal or unreacted extra reactants may be existed in the solid phase like a plasticizer and easily exchange in both the solid phase and the liquid phase, resulting the unwanted side reactions occurred in everywhere in the system. The above explanations briefly disclose the relationship between PDLC's principle and its physical and optical properties. Due to these conflicts and limitations, it is extremely difficult to find a good formula for PDLC products. Practically, it is impossible to meet all optical, physical and chemical requirements at the same time. Therefore, it is so difficult to obtain a wide temperature range or a good clarity with a low driving voltage. These are reasons which prevent NCAP and PDLC to reach a high-performance level and outdoor applications.

3. **How does NPD-LCD technology solve these problems?** Since 1G and 2G of LCMD invented, many articles paid attentions on physics and optics of the microdroplet displays. Little attention is paid on chemistry. Actually, to reach a high-performance level, a long-life time or outdoor applications, chemistry plays a key role. NPD-LCD technology was invented based on a deep study of NCAP's and PDLC's problems. A main purpose of NPD-LCD is to solve the principle problems in the old systems, to extend their performances and applications, and to establish a unified system and theory for both normal mode and reverse mode of microdroplet displays. Although reverse mode of NPD-LCD is too expensive as a commercial product now, the technology to form a reverse mode is very important to understand the non-linear or onion-like structure. According to physicochemical FCK (Friedel-Creagh-Kmetz) rule for multi-liquid phases, it is allowed to form droplets of liquid crystal if surface energy of encapsulating polymer is greater than surface energy of liquid crystal, but forbidden to directly form droplets of liquid crystal if surface energy of encapsulating polymer is lower than surface energy of liquid crystal. It only needs to meet FCK rule for making a normal mode of LCMD. However, it needs to meet both FCK rule and reverse mode requirement. The reverse mode requires that surface energy of encapsulating polymer is smaller than surface energy of liquid crystal in droplets. Due to contradiction of these two requirements, many people thought impossible to make reverse mode of LCMD. Scienstry overcame this difficulty by a cleverly designed non-linear system, of which an encapsulating copolymer has a higher surface energy at beginning of droplet formation and then surface energy of the encapsulating copolymer is reduced to smaller than surface energy of

liquid crystal in droplets. Actually, droplet formation and conversion of surface energy are smoothly conducted in a single curing step. The non-linear or onion-like structure gradually changes its surface energy from a high surface energy to low during the formation of droplets. Therefore, forming microdroplets of reverse mode is a solid proof of the non-linear system. If first and second generations are valuable for successfully introducing basic products into the market, the third generation is valuable for solving the common problems and optimizing LCMD system and bringing 3G Switchable Film to outdoor. NPD-LCD overcomes PDLC's major problems, such as low transparency, narrow working temperature, high driving voltage and short lifetime, by ingenious designs in chemistry. Since those intrinsic problems cannot be resolved within the older principles, a new principle or new theory must be created first. All of breakthroughs of NPD-LCD are made with new optics and new chemical approaches.

In a NPD-LCD system, the copolymers form a non-linear solid phase or non-homogenous phase. A multiple layer shell structure of droplets is formed like an onion, which is different from a consistent polymer phase in PDLC system. The refractive indexes of the non-linear phase gradually change from the inner layer to outer layer while remaining totally transparent. Liquid crystal polymers may be used as an inner layer material. A single process may produce not only normal mode NPD-LCD products but also reverse mode products. Reverse mode NPD-LCD products are transparent without a power, and can turn to milk-white under an electric field. This non-linear system has many advantages for high-performance.

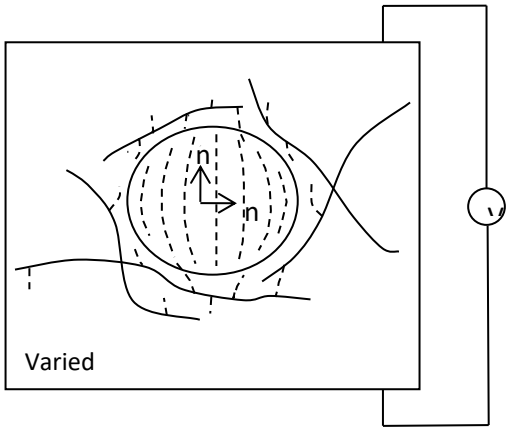
First, there is only a need to match the refractive index of the inner layer of the polymer (n_p) with the refractive index of the liquid crystal (n_o). When a liquid crystal polymer and/or comb shaped polymer are used as inner layer materials, this matching becomes an "automatic" process, because liquid crystal and liquid crystal polymers have similar molecular structures, and the liquid crystal molecules may insert into branches of the comb polymer. Therefore, the phase boundary becomes blurry. The refractive indexes are much easier to be matched. This automatic matching occurs at the molecular level, so a high transparency become possible.

Second, matching refractive indexes between inner layer of polymer and liquid crystal and curing the entire system of the polymers become two independent things, no constrain is existed between them anymore. Not only polymers in same family group may be used, but also copolymers from different family groups may be used in NPD-LCD system depending on their reactivities. Therefore, a high-purity of liquid crystal droplets may be easily obtained, and this high purity in the droplets is a foundation for obtaining a wider working temperature rang. The independent curing opens a door to use different polymer families in one system. In order to build a stronger polymer matrix and have additional features involved, such as anti-moisture, different polymer families such as polyurethane, acrylate, epoxy, polycarbonate, polyethylene, silicone and fluoride containing polymers may be used in the system. Such copolymer may combine highly active polymers and inert polymers together to block penetration of liquid crystal through membranes of the polymer matrix. NPD-LCD utilizes inert polymers to effectively increase anti-moisture capability, because the inert polymers have widely used in non-stick cooking ware and underwater cable. The inert polymers also have relatively lower reactivities which are naturally fit the non-linear theory. Theoretically, there are no extra reactants existing in both the polymer phase and the liquid phase, therefore, liquid crystal molecules are no longer vulnerable to be attacked by ionic impurities. This situation greatly improves the operational condition and make a long service life possible. A clean polymer phase also offers a high insulation level. 3G Switchable Film has been tested in water without a notable change (click here for video) and even conducted a underwater projection without any protection in edges (click here for video)

Third, light travels straightly through a normal transparent media but penetrates a non-linear media in a curved way. Once light can turn inside a non-linear media, incident angle losses its meaning. This is an important new means for widening the viewing angle. When a liquid crystal polymer or comb shaped polymer is used as an inner layer material, the border between solid and liquid phases becomes highly similar in molecular structure. This high similarity allows light to pass through without scattering. This technique not only widens the viewing angle, but may also theoretically eliminates haze. Since the non-linear system does not require liquid crystal near two ends in a droplet to be perpendicular to the substrate to create a clear state, NPD-LCD do not need a high voltage driving neither.

As illustrated in Figure 3, the third generation of LCMD or NPD-LCD system creates a highly similar boundary interface including the areas near the two ends, and it allows liquid crystal molecules to align with branches of the comb shaped polymer to achieve a match within an entire droplet. In this way, although there is a boundary, there is no sudden change in the refractive index, so that light can pass through the boundary without scattering. This technique uses a varied polymer refractive index (np) to match a varied liquid crystal refractive index (no). Theoretically, such system can achieve a match within an entire droplet; therefore, provide possibilities for features of haze-free clarity and wide viewing angle. On the other hand, there is no need to create extended center region of vertical alignment in a droplet to increase

clearness, and overdriving is not necessary for NPD-LCD, so a low voltage driving is possible. A low voltage driving is very important feature for outdoor applications, not only because of technical advantages, but also government regulations.



LC align with polymer branches at a highly similar

Figure 3

Pursuing a low voltage driving is a long dream in the field. The feature of low voltage driving not only saves energy, but also extends the lifetime, because it reduces electrochemical reactions to a low level. However, the driving voltage is not only depended on droplet boundaries but also depended on sizes of droplets. The diving voltage is inversely proportional to sizes of droplets. It is known that driving voltage is related to sizes of single droplet by the following equation:

$$V_s = \frac{d}{3a}\left(\frac{\rho_p}{\rho_{lc}} + 2\right)\sqrt{\frac{K(l^2-1)}{\Delta\varepsilon\ \varepsilon_o}}$$

where Vs is switching or driving voltage for a bipolar droplet, d is sample thickness, a is the droplet radius, l is the droplet aspect ratio, K is the mean elastic constant of the liquid crystal, ρ_p and ρ_{lc} are the resistivities of polymer and liquid crystal regions respectively, and $\Delta\varepsilon$ is the dielectic anisotropy of the liquid crystal. All droplets in an LCMD do not switch simultaneously because of different droplet sizes and shapes. The above equation shows that switching voltage is inversely proportional to droplet size (radius a). The larger the size is, the lower the voltage required. When a system has a large range of size distribution, the electric-optical cure is less steep (click here for detail).

For a long time in this field, there is no way to control droplet size. It is so challenge, even the physiochemistry principles do not allow to form same sizes of droplets in any of normal phase separation. It is impossible for 1G NCAP or 2G PDLC film to achieve a low voltage driving with this inherent limitation in the principle. 1G NCAP uses a mechanical dispersion technique to form droplets and sizes of droplets could be several times difference. 2G PDLC uses phase separation, a physicochemical process, to form droplets and it is also impossible to form uniform droplets, because according to phase diagram, droplets separated at different time have different surrounding environments and droplets formed earlier are earlier to glow their sizes than droplets formed later.

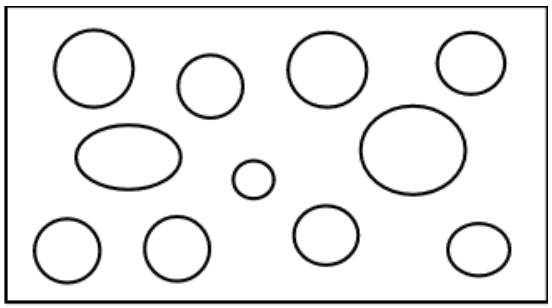


Figure 4A PDLC

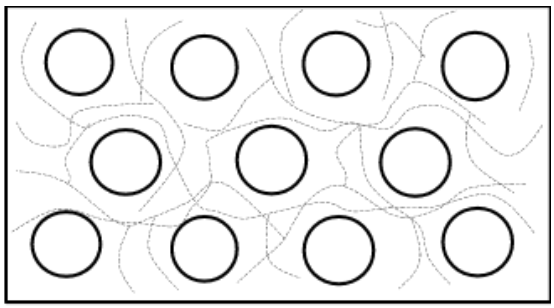
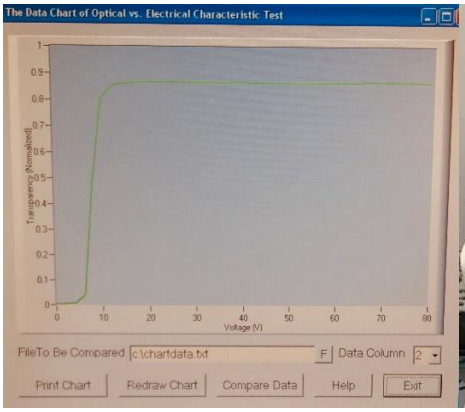
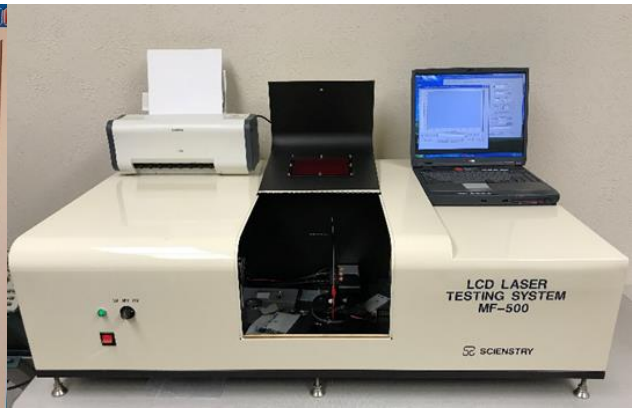


Figure 4B NPD-LCD

It is very challenge situation to solve this problem because of lack of theoretical possibility. Again, with ingenious design in chemistry by utilizing a cage theory of soluble polymer, 3G NPD-LCD successfully achieves a way to form uniform droplets and achieves a low voltage driving in both principle and production. The Cage theory utilizes a dissolved soluble polymer to form a uniform network in entire system at early state of phase separation. When this network has enough density, separated droplets are isolated by the network formed earlier like many micro cages. Each cage only allows to form one droplet of liquid crystal. Since this system begins with a uniform state, or everywhere is identical, and each cage and its surrounding environment has same conditions for droplet formation. Therefore, all droplets can be formed in identical sizes. Of cause, all of theories created for NPD-LCD have tough jobs to find optimal combinations and conditions. Although we still have to conduct thousands of experiments, it is much better situation in comparing with the old generations lack of possibility. The theories and practice are not only tenable in optics, but also proven with products. The experiments form a foundation of mathematical modeling for prediction. Following test on a full size of 3G Switchable Film shows that driving voltage is about 10 VAC. A linear rising straight line indicates the non-linear theory and the cage theory work fine.

As shown in bellow pictures, the testing equipment was designed and made by Scienstry in 1990's. The testing system is able to obtain data for transmittance, opacity/haze, response time, viewing angle, voltage effect, frequency effect, power consumption etc. Near 20 years passed, there is still no comprehensive LCD testing equipment in the market for sale like this multi-functional testing system. Actually, no one can always generate smart ideas and great theories without experiments and testing. Great achievements of Scienstry are based on a long term of R&D. Key members of Scienstry R&D team were from Nobel prize winner's lab with credits of finding three new organic reactions and experience of synthesizing very complicated compounds. Most parameters which we are monitoring are unfamiliar with LCD colleagues, because of a deep study on chemistry. In LCD field, there are a lot of scientists and engineers in physics, optics and electronics, but little in chemistry, especially scientists at decision making positions.

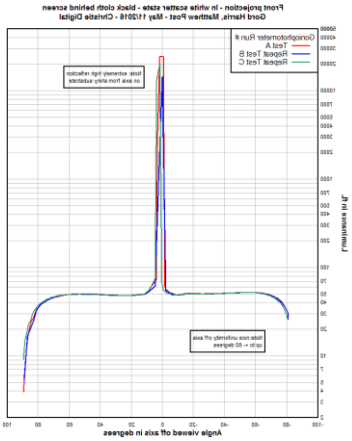




We often met such cases of which we need to produce products with some special features, but there is no equipment available in the market, therefore, we have to design and make those equipment by ourselves. For past 25 years of business, Scienstry created over 50 types of LCD manufacturing machines with special functions, and some of equipment worth over a million USD. Scienstry also resolved many top challenges and made many innovations in LCD machine design. For example, we were first successfully to distribute millions of dry micro spacers on LCD glasses without two of spacers contacting each other. We are also first to pair LCD panels in submicron level. Scienstry still have an entire LCD production line including manufacturing equipment of glass LCD display. Over 25 years, our R&D covers synthesis and purifications and testing for raw materials, equipment design, process design and control, new displays, testing design and control. Due to deeply understanding in chemistry, we understood and blocked all possible destructive side reactions in 3G Switchable Film. That is why NPD-LCD not only has a great non-linear theory as a foundation, but also may produce products with great features exactly predicted by the theory, and shows its reliability and advantages from beginning. Other manufacturers of the older generations of LC films normally only monitor less than 10 parameters in their film productions, but we monitor and control over 100 parameters in film manufacturing. We even invented new manufacturing methods for glass manufacturing and window manufacturing business, such as Switchable Projection Window and Switchable Projection Panel. New methods allow to reduce 50% manufacturing cost. The technologies developed in Scienstry have many real-world applications such as entire building advertising and liquid resin lamination.

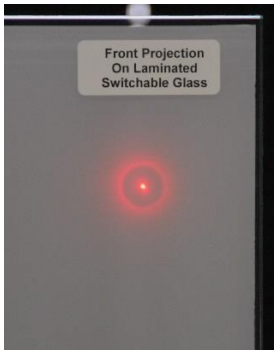
With many of Scienstry's innovations, inventions and patents over 25 years of efforts, 3G Switchable Film eventually overcomes all of limitations and defects in principles of the earlier generations and resolve all of fundament problems. 3G Switchable Film achieves a wide working temperature range from -30 to 80℃ and supper stabilities for moisture, heat and UV, and enable to be used on outer windows for a long term. Using in outer windows not only has a privacy function, but also has energy saving function. Unlike other energy saving functions for windows, it saves energy by scattering sunlight, instead of absorbing sunlight. Therefore, window surfaces are not hot and no need to use additional energy to cool the windows down. Importantly, 3G Switchable Film/Glass does not change spectrum of natural light and provide a healthier lighting for human's activity and plant growing. On the other hand, more energy saving may be achieved through its dynamic control of opacity in daytime and night time, as well as summer and winter. It is unique to save energy by scattering which does not change quality of natural light. No other window treatments like window tinting film or low-e glass or other switchable window technologies have same function and efficiency (click here for detail).

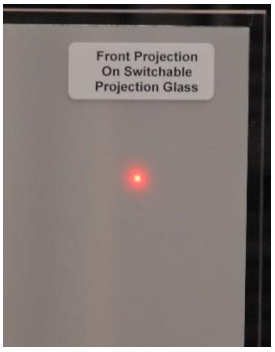
In order to add value to outer windows, window projection technology was developed in Scienstry too. It was extremely difficult to solve the viewing angle problem of projection, because all known optics even can't provide a solution. It was also difficult to show clear projected images in both sides of a window with equal brightness and absolutely wide viewing angle. This challenge includes two tough difficulties, one is that the film itself must have absolute view angle first and then switchable glass panel needs to clearly display projected images in both sides. The former was considered impossible, because projection setting is asymmetrical, or a projector is placed in one side of projection film, and there is no known optical theory and projection screen supporting such effort. The latter is a long-lasting problem existed in smart glass field and no one knows why front projection always generate blur since liquid crystal smart glass was invented. With a strong R&D capability, Scienstry loves to meet such challenges. As mentioned before, the non-linear system created by Scienstry is a great tool which enables to create such optical miracles. Theoretically, although projection situation is asymmetrical, it is possible to generate a symmetrical spherical scattering, that is, a scattered energy is uniformly distributed in the space. We fully utilized characteristics of cervical propagation of non-linear system to increase chaos level of internal scattering within active layer of 3G Switchable Film. A high level of optical chaos may compensate asymmetrical difference from an asymmetrical setting of projection, so that any incident light beam coming from any angle may generate a spherical scattering like a ball. A projected image has same brightness and same sharpness at any viewing angle, which is called VAI (viewing-angle-independent) brightness and sharpness. With lots of mathematical modeling and experiments, such effort is greatly successful. Following picture in left is a testing result from a large projection company and shows exact 50% gain for a front projection. Such result shocked the projection world. No projection screen ever had this function, which is exactly predicted by the NPD-LCD non-linear optic theory and matched with measurements. Following picture at right provides a visual experience of absolute wide viewing angle. It is a reason why 3G Switchable Film becomes best for front and rear projections (click here for article) and (click here for video) and 360 degrees view (click 1 here & click 2 here for videos). NCAP film does not have projection capability at all. PDLC film normally has an oval scattering, that is, a rear projection has 70% - 80% scattered light which is too bright and a front projection has only 20% - 30% scattered light energy which is too dark. A major advantage of spherical scattering is that a short-throw projector may be used to avoid a strong reflection from a projector to viewers. Oppositely, there is a serious problem for both front projection and rear projection with an oval scattering, because a projector must have a horizonal setting which generates a strong reflection to viewers.



Spherical scattering provides an additional proof for the non-linear optics of NPD-LCD technology. First proof is that NPD-LCD technology may form a reverse mode NPD-LCD device. The unique capability of spherical scattering is also a foundation for energy saving by rejecting infrared (click here for detail). It is first time to utilize switchable scattering function for purpose of energy saving. Many advantages are introduced in the field of energy saving, for example, unlike absorbing function of low-e glass or window tinting, scattering infrared does not make windows hot and a full spectrum of visible lights getting into rooms is better for living and plants grow.

Since liquid crystal switchable glass was invented three decades ago, no laminated smart glass may be used for front projection, because images of front projection are always very blurry. No one knows a reason how the blur is generated. It is proven that 3G Switchable Film itself has 360 degree view and same sharpness and same brightness of projection at any angle. However, none of laminated glass panel with a liquid crystal switchable film may provide clear projected images in a front projection. This situation had been lasted for near three decades since liquid crystal microdroplet display was invented. Scienstry used a laser test and "Wang Ring" shown in following picture (left) to prove a laminated smart glass generating blur by a total internal reflection. It is obvious that Wang Ring is an interference signal, because an incident laser beam is only in central point. Scienstry discovered an optical mechanism of blur generation on projected images and revealed that the blur is generated by a total internal reflection. A mechanism of generating blur is discovered and method of avoiding the blur is introduced, therefore, we resolved this long-lasting problem with multiple patented technologies. An improved front projection may be proven by same laser testing shown in following picture (middle) with only a central bright point. And a comparison of clarity of front projection between a laminated smart glass and Switchable Projection Glass (SPG) is presented below at right with a single projected image on two different types of glass panels. The improvements are obvious, the blurry image is shown on left side of the picture and a clear image is shown on right side of the picture. Besides resolving the problem of blurry images, Switchable Projection Glass™ also has many other advantages including a lower haze and 50% reduction of production cost (click here for detail).





With ingenious designs and many years of hard work, NPD-LCD technology eliminates all conflicts from physical, optical and chemical requirements by creating an open system with great freedom to improve all properties. This freedom is extremely important for improvement. In the close systems of the earlier generations, optical, chemical and physical relationships are tied together, changing any component will destroy a balance which is obtained with a great effort, therefore, a formula must be kept for many years. In NPD-LCD system, optical, chemical and physical relationships are independent and do not constrain and conflict each other. Any component can be changed or adjusted. Many new materials for new features, such as anti-moisture and anti-UV, can be easily added into the NPD-LCD system without affecting its optical performance. That is why 3G Switchable Film has released many series of products from NPD-100 to NPD-500 series with continually improved features. In fact, the open system creates a huge space for future development, so that 3G Switchable Film/Glass is no longer limited for indoor use, instead, goes to very broad area of outdoor applications. Having freedom is good for continually developing new features to meet new challenges, although using more novel or complicated materials often increase the cost. However, manufacturers may digest the increased part of cost by an enlarged production to meet greater demands from the emerging markets.

In the field of liquid crystal switchable film, it is easy to emphasize one feature by scarifying other features, such as providing a better transparency with a poorer opacity, called shifting, but it is difficult to improve all features, such as a better transparency and a better opacity, called net improvement. Scienstry offers net benefits to customers with higher series of products, that means a higher series will include improvements in some of features, but no feature is reduced. For example, since each droplet contributes scattering at an opaque state and also contributes haze at a clear state, reducing

usage of liquid crystal or density of droplets will automatically provide a better clarity but cause a poorer opacity. Such trade-off is not involved in the different series of 3G Switchable Film, because the NPD-LCD open system has a great freedom to provide a net improvement. Actually, making a shifting is very easy and bring a net improvement is difficult. Since reducing feature is always easy, therefore, there are many choices for 3G Switchable Film if reducing feature is preferred.

3G Switchable Film is most features rich product in the market. It ends a history of LCMD with a high haze, low opacity, over driving, unsuitable for projections and short lifetime, and create great emerging markets for various outdoor applications with advanced features, NPD-LCD technology first allows LCMD products for permanent use. Basically, NPD-LCD resolves four fundamental problems in the field of LC smart window, that is, unstable for moisture, heat and UV and unusable for projection. Once these problems are resolved, applications and markets are greatly increased. We may just look at a room for usage of glass, indoor use only includes mirrors and partition, but outdoor has much greater use, such as outer windows. Unique front and rear projection capability makes 3G Switchable Film very useful for storefront advertising (click here for video) tradeshow and mall advertising (click 1 here & click 2 here for videos).

Although market practice in past three decades has proven that without a good theory definitely can't obtain a good result, going to outdoor is very serious movement. Ten years ago, Scienstry had already success on major features, but could not say that NPD-LCD technology had already resolved the old problems and already for outdoor applications, even NPD-LCD technology was developed to solve those problems of the old generations. This is not conservative but highly responsible, because Scienstry pursuits a near-zero defect in all applications. Therefore, we never have massive defects happened in UAE and China, when some PDLC manufacturers attempted for outdoor applications. Scienstry's approach is doing tough testing first (click here for detail), and following with small projects and then taking large projects. Although it takes a much longer time to do so, Scienstry does not need to outdate the older series of products too soon, because Scienstry is a leader in quality for a long time.

4**. On UV stability for outdoor applications**. A best way to prove that UV stability for outdoor application of 3G Switchable Film is conducting a weathering test or simulation test or field test. Many testing companies may provide such tests. The industry already has a system to predict a lifetime with standardized testing procedures. Many companies had already conducted and passed such tests for 3G Switchable Film for a various of purposes including applications of sunroof, building wall, train, cruise ship and automobile. It is necessary to point out that the toughest application and testing is for automobile, because it has the smallest space and highest temperature. In past six years, hundreds of cars equipped with Scienstry's smart glass have already field tested worldwide.

Type of LCMD Film	1 month	4 months	28 months	52 months
1G NCAP film	Failure			
2G PDLC film	Failure			
3G NPD-LCD film Without patented technologies	Good	Reduced	Failure	
3G NPD-LCD film With patented technologies	Good	Good	Good	Failure

Besides UV simulation testing, Scienstry had conducted a real sun test with the toughest condition, or put 3G Switchable Film directly under sunshine in Texas, USA without any protection. Above pictures show actual situation of the sun test at summer (left) and winter (right). The testing lasted four years and four months, and the result is listed above. This test provides very valuable information for glass industry to evaluate outdoor applications, because the result reaches a similar level of UV stability like an interlayer material. Therefore, by cross reference, a laminated glass panel with 3G Switchable Film for building, boat and car uses may be reasonably considered.

Analysis for outdoor applications. Since 3G Switchable Film is usually used indirectly under the sunshine, Scienstry's sun test data provide a foundation for a calculated lifetime of 3G Switchable Glass. As we know, weathering mainly deals with UV radiation from the sun, both glass and interlayer material may provide some protections to 3G Switchable Film, because glass and interlayer may absorb considerable amount of UV. In a laminated glass, there is a mutual helped structure, a glass layer may provide 100% absorption for harmful UVB and 25% absorption for UVA, and an interlayer may absorb 98% UV. An overall UV intensity after filtration of glass and interlayer is only 0.005 or 0.5% of original UV intensity of sunlight. If taking half lifetime 26 weeks of 3G Film as a base to calculate, a calculated lifetime of a laminated 3G Switchable Panel will be 5,200 weeks (26 week / 0.005) or 433 years. This result shows that most challenge for outdoor applications of liquid crystal switchable films actually is a temperature range, but 3G Switchable Film has already resolved the problem of working temperature range a long time ago. It is necessary to know that automobile application is tougher than the sun testing, because temperature in a car is higher than ambient temperature. However, 400+ years of calculated lifetime from the sun testing should have enough room to compensate a high temperature for 10 years of lifetime for automobile application, which is equal to only 2.5% of calculated lifetime with the sun test result, plus automobile application is in a laminated or sealed structure, and plus less than 1% defective rate (even not film problem) of field tests on hundreds of cars also support to above analysis.

5. **3G Switchable Film has many successes.** We passed many tests or qualifications for the world-class projects. Of cause, large companies may build a great confidence to use 3G Switchable Film for their large projects for outdoor applications through comprehensive tests and reviewing our successful history.

(a). About 15 years ago, 3G Switchable Film has been widely used in all kinds of outdoor applications like outer windows, sunroofs, building walls, cars, yachts, trains, airplanes etc. as small projects. Since almost no defect was reported within last 5 years of such outdoor uses, plus third party comprehensive testing, 3G Switchable Film has gradually built its reputation for outdoor uses. As a film manufacturer, if a defect is found, we are always first to be noticed for analyzing and resolving problem or replacing a defective part. Those practices on small projects actually become true field testing and great results have built a great confidence on both Scienstry and its customers. Therefore, Scienstry was ready to win large projects, and then we took a journey to set and break the world records in smart glass field.

(b). For Beijing Summer Olympics 2008, 3G Switchable Film/Glass as a new world record were installed in 24 major airports in China, including the largest Beijing Capital Airport and Shanghai Pudong Airport (click here for video).

(c). In 2010, 3G Switchable Film was qualified and exclusively used in World Expo Shanghai 2010. Within total five gold medal winners for design of pavilions, 3G Switchable Film/Glass were heavily used in two of the gold medal winning designs. (click here to see detail)

(d) In 2011, a super luxury cruise ship called SWIFT 141 (a multi-hundred-million USD project) was built in UAE, with 100% coverage of 3G Switchable Glass (curved and laminated glasses) from inside to outside, with functions of touch clear, touch opaque. It has zero-defect report in 6 years after its launching in a high temperature and high humility region. This project has proven that a high quality has win a big market and set a new world record for the largest project in business of smart film/glass and replaced the old record of 24 Chinese airports. This project also proclaims a new era of outdoor applications for liquid crystal switchable film/glass. Attempts of using PDLC glass in same conditions were quickly failed, even surprisingly failed under a shield of 3G Switchable Glass. Following pictures show the luxury ship.

(e) In 2012, 3G Switchable Film had passed comprehensive tests and obtained a certificate from CNAS (Chinese National Glass Quality Supervision and Inspection Center) for application on high speed trains. About a hundred thousand USD and over 200 square meters of laminated glass were used for the comprehensive tests including impact test and vibration test. Near-zero defects is found since then.

(f) Since 2012, 3G Switchable Film/Glass has been tested by several large glass companies for automobile application and passed their internal tests with all requirements of OEM, several famous car manufactures. Hundreds of cars equipped with smart glass were field tested in serval countries from cool region like Norway to hot region like South Africa. Near-zero defects is found in five years of test use. Massive application is on the way internationally. It is necessary to mention, these tests were initiated with most of other brand names of liquid crystal switchable films available in the market, but after a few of tests, only 3G Switchable Film left for further testing.

(g) Started in 2013, 3G Switchable Film/Glass has been used as traffic signs in Norway. Those signs replaced old signs to make sure that any displayed information is currently meaningful. For example, a sign on a bridge with “Be Careful with Slippery Road” may be only displayed in bad weather. Pictures at below show that at certain time of a day, a road may be used. It has been proven that the signs of 3G Switchable Film/Glass work well at - 30℃. Zero-defect is reported. The projects are for updating laws for traffic signs in EU region. If updated, market size could be over hundreds-millions USD.

(h) In the early of year 2014, Scienstry’s president Dr. Wang was invited to give a keynote speech in Energy Harvesting Europe 2014, international convention and tradeshow in Berlin. It is first international convention especially held for the sector of smart glass in the world. Dr. Wang reviewed most achievements in the field and explained how Scienstry overcome most of problems in the field of LC smart film and introduced new outdoor applications of 3G Switchable Film/Glass. The title of his speech is “New Applications of 3G Switchable Film

Face Huge Markets". The markets gave a great response to the speech (click here for the speech). Since then, outdoor applications of LC smart film become a hot topic. In the end of year 2014, USGlass magazine readers selected the Laminated Switchable Glass from Scienstry Inc. as one of the most significant products of 2014. 3G Switchable Film has been involved in a fair portion of outdoor applications such as sunroofs and outer windows worldwide and has a near-zero defect rate for many years.


(i) Started in 2016, 3G Switchable Film/Glass has been used on a new world record project and outdoor application, or a project for building advertising with a coverage of multi-tens-thousands of square meters with smart ceilings and smart walls. Scienstry's patented technologies turned the $3 billion dollars' worth architectural complex in Manila, Philippine into TV displays. Forbes magazine (Oct. 2016 edition, Philippine) uses six pages to introduce this unique project. All of ceilings and walls in commercial areas are made with 3G Switchable Panels for projection and energy saving. Scienstry cooperated with the world top projector manufacturers and projection companies who enable to syncretize thousands of industrial projectors together to generate a single picture. Testing showed that 3G Switchable Film/Panel should have a long term of use with Scienstry's patented stabilization technologies for moisture, heat and UV. Each of the world-class projects had conducted comprehensive tests and calculations before 3G Switchable Film was qualified for those large projects. Picture at below-left shows that 3G Projection Films/Panels are at clear mode in day time in this building and picture at below-right shows that 3G Projection Films/Panels are at projection mode, which enables to turn entire building to displays with front projection (or rear projection) and to allows 360 degree view. Six industrial projectors are installed in each of polygonal box hanged from the ceiling. Each of the industrial projector is 10 times more powerful than a home use projector. Building advertising without bothering use of internal spaces may generate a good income for a building.


6. **3G Switchable Film faces great emerging markets.** What market effect do we have once 3G Switchable Film is suitable to be used in outdoor? The emerging markets may be 100 times bigger than the traditional market. Scienstry had made several fundamental breakthroughs to enlarge temperature range from -30 °C to 80 °C (or from -22 °F to 176 °F) which allows to use it in any place suitable for human activities, to resist moisture and water which allows 3G Switchable Film to be used either in laminated glass or in air for a long term, and to improve UV stability over 50 times which have been hoped for decades for outdoor applications. It is importance to know that these successes open a door for many types of outdoor applications including automobile. Scienstry has turned predicted emerging markets into reality. Through strong demanding, we know what kinds of products the emerging markets like and how big demands are and where new world records are. What we would like to mention here is an important philosophy: **a new product determines its new applications which in turn determine the emerging markets**. Without a breakthrough in principle and property, it is

impossible to have these new applications, because smart glass market has already been developed for over 30 years. With this philosophy, Scienstry keeps making records for world largest projects, from multi-thousand square meters of single project to multi-tens-thousand square meters, especially for outdoor applications.

We may understand such emerging markets from analyzing a few of industrial sectors. Figure 5 shows 16 industrial sectors which 3G Film has been used. If we calculate one percent of each of selected markets, 1% of the calculated market size is around billions USD. For example, the sector of laminated LC smart glass is listed at top right of Figure 5. With three decades development, this traditional market is about 1 billion USD. In past, LC smart glass can't be used on outer windows. If we look at normal glass usages for indoor and outdoor (including outer windows), it is not difficult to find out that normal glass is mainly used for windows facing to outside and internal uses are only small portion like partition and shower bath. A main function for the old generations is switchable privacy and a main use of the old generations is internal window for conference room. An embarrassing situation is the major function of old generation films can't be used where the privacy is mostly needed, or outer windows. If entering the traditional market from here or outer windows with 3G Switchable Film, the traditional market will be immediately enlarged several times. The suppliers should not feel much competition, because other films can't do this job.

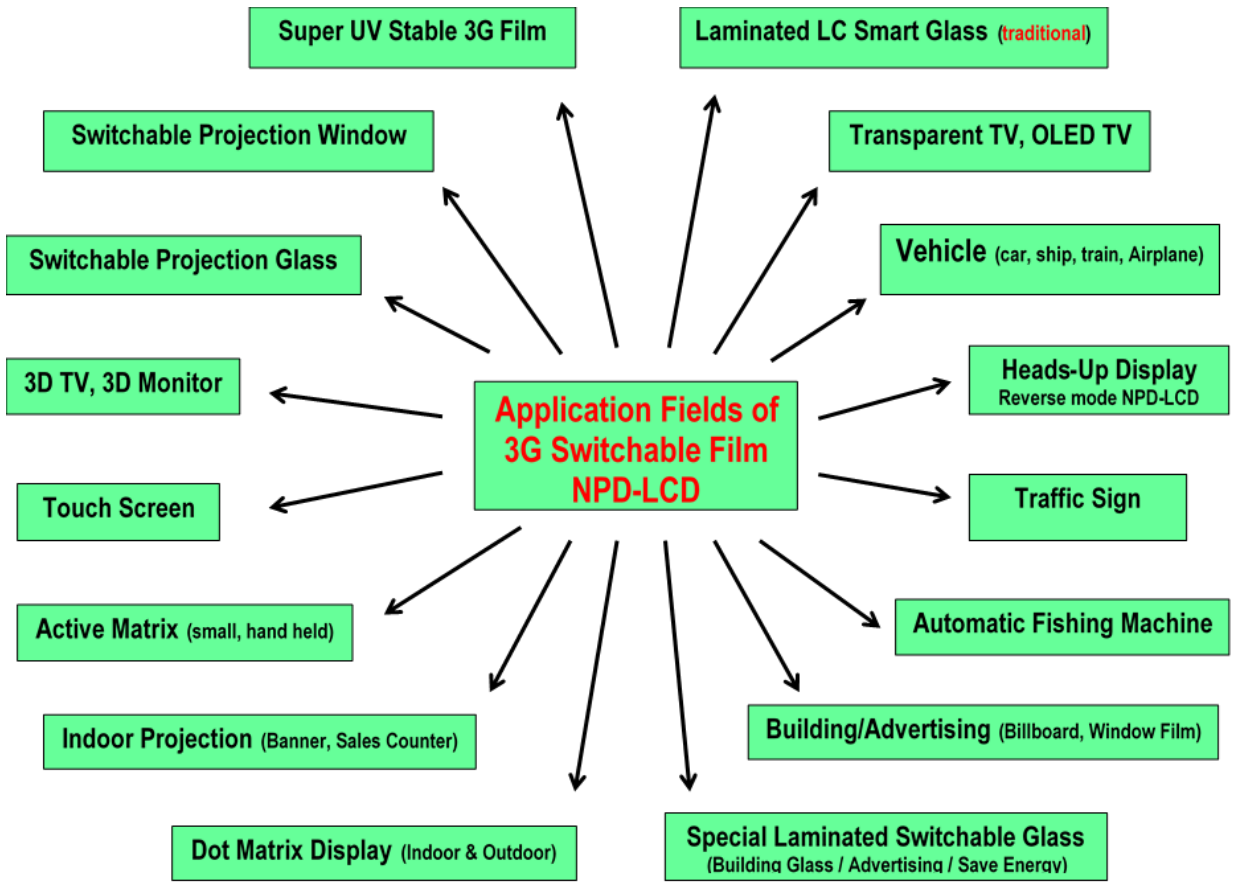


Figure 4.

Switchable Projection Window (SPW) is a newly invented product and its application is very useful in many places. Unlike regular windows with simple open and close functions, it has 12 functions including writing board and TV. If 1/1000 homes and offices in US use SPW, that is billion-dollar market, even much greater if including public uses in stores, schools, hospitals, companies, malls, airports and buildings. And other countries have similar markets too. You may review this application in details, click here for video and click here for article.

Let's look at application in automobile field. Automobile application is interested with major glass companies originated with famous car manufacturers. The market size of automobile is $1500 billion USD with annual production of 78 million of cars. Each of the large glass companies is only able to handle a few of brand names of cars. With the leading of the

large glass companies, automobile application of 3G Switchable Film will be never limited in a few of famous brand names of cars. Basically, all of car manufacturers will follow, just like other modern technologies used in automobile industry, such as antilock brake or airbag. Therefore, new participants for mass production may take advantages of the market effect and join this business. The new application has a huge market. After a few of years of field testing with large companies, such application has been basically accepted by OEMs through large glass companies. Several famous automobile brand names are involved in this application. Size for each brand name normally has multimillion or multi-tens-millions USD. One percent of market size of smart automobile glass is multibillions USD. This market is actually competing for a super stability.

It is important to emphasize another breakthrough for projection capability on laminated liquid crystal switchable glass. Since LCMD types of display/film/glass were invented 30 years ago, 1G (NCAP) and 2G (PDLC) film/glass have almost no or poor projection capability, therefore, their major application is privacy glass for indoor use only. Although 3G (NPD-LCD) film has a good projection capability, its laminated glass can't do front projection either. In other words, a laminated glass panel with any type of LC switchable films does not have front projection capability. However, if a laminated switchable panel is used as a window, a front projection is mainly needed, because a projector needs to be installed inside of a room. No one knew a reason why a laminated switchable panel can't be used for front projection before Scienstry's discovery and invention. Scienstry discovered an optical mechanism of blurry generation on projected images and resolved this problem and obtained multiple patents for this application. The projection capability perfectly combines with its original switching capability and privacy function when used as walls or outer windows. Now such walls and windows have a strong performance features with wide operational temperature range, high stabilities for heat, moisture and UV. Therefore, window advertising and building advertising become available. In addition, a few years ago, major projector manufacturers knew our achievements on projection, and developed commercial projectors which are about 10 times or 100 times more powerful than a home use projector. Projection companies or projector manufacturers are able to synchronize thousands of projectors to generate a single picture. Now, this technology has been used on building advertising to convert multibillion dollars' worth architectural complex into displays. This technology first utilizes building surface as a display without blocking windows for day time, therefore, does not reduce value for office spaces and may generate additional 10% revenue for a commercial building by advertising. Some of these emerging markets are patent protected for making, using and selling. For some of the applications, a free licensing is possible, if 3G Switchable Film is used.

It is first time to show that glass building surface is so valuable. This application is so welcome for projection, advertising and real estate business. Since building surface is much greater than internal glass, this market is so optimistic, because it is a new way to generates money with an old resource, plus it has great energy saving function (click here for detail) and privacy function. Switchable Projection Window (SPW) and Switchable Projection Panel (SPP) have energy saving function too. Unlike an absorption function of low-e coating, SPW and SPP do not absorb light, instead, reject over 50% infrared by scattering, therefore, window surfaces are not hot as low-e glass. Unlike passive function of low-e glass, in winter, a low-e glass also blocks heat resulting more energy use from a heater. SPW and SPP may save energy in both summer and window and both day time and night time by adjusting its opacities. It is considered by some professionals as best energy saving material with its dynamic functions (click here for detail).

With above analysis, an overall picture of emerging markets should be clearer. One may easily find out that there is a big difference between a growth model of the old market and new growth model of the emerging markets. In general, **the bottom line of yesterday's standards is really difficult to meet today's requirements**. In past, a major application of privacy glass was for glass for conference room. Such use is hardly to have a large project, but now applications like building wall, automobile and building advertising are belonged to large business. Once a door for outdoor applications is open, the projects usually are large, and large companies are willing to participate. Therefore, its jumping growth model is totally different from past slow growing model. With a common knowledge, who first recognize the advanced technologies, who may get a great benefit from the emerging markets. With above mentioned achievements, Scienstry plays an important role in leading the industry with its independent patents and patent pending technologies, covering over $50 billion of emerging markets. That is why we think that all of these new applications are depended on new features and new properties of new products. On the other hand, traditional smart glass market is also growing with more smart film manufacturers joining in the market, but they are in a tough situation with tough price competition. The markets are clearly divided into two ends, a low end with traditional pure indoor use and a high end with advanced features for privacy, energy saving, projection and outdoor use. **New features determine new applications which determine new markets.**