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# Durable Polymeric Films for Increasing the Performance of Concentrators

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## 1. Introduction

Durable solar film technology can be used to create new concentrated photovoltaic (CPV) and concentrated solar power (CSP) designs which would, potentially bring the cost of generating electricity from solar energy to parity with the cost of electricity from fossil fuels. Polymeric films are typically an order of magnitude lower in cost than conventional photovoltaic cells and can be used to effectively replace relatively expensive photovoltaic cells resulting in lower overall module costs. 3M has made the world's most reflective all polymeric wavelength selective mirror films (Weber, 2000) which are thermoformable into useful low cost solar concentrator designs. These all polymeric mirror films can also be metal vapor coated to create broad band mirror films for concentrated solar thermal, CPV, and CSP designs. 3M micro-replication technology has also been shown to capture more light into a photovoltaic module by minimizing surface reflections and refracting light at low angles into the solar cell thus increasing power output. These solar films require extreme UV stability, abrasion resistance, dimensional stability, easy cleanability, and durable adhesiveness.

## 2. CPV (Concentrated Photovoltaics)

A major obstacle in the widespread adoption of concentrated photovoltaic designs utilizing mirrors has been the accelerated degradation of photovoltaic modules due to concentration of ultra-violet light and infrared light onto the photovoltaic cell encapsulating material. Metal coated mirrors have the disadvantage of reflecting ultra-violet and far infra-red light onto the photovoltaic cell which is not converted into electricity, but does contribute to overheating of the photovoltaic cell. Metal coated mirrors are also prone to corrosion. Since photovoltaic cell efficiencies are adversely effected by higher temperatures, thermal management designs are typically incorporated into CPV designs to remove excess heat. Expensive thermal management designs can be avoided, or minimized, with the use of infra-red transmissive mirror films made with dielectric interference stacks of polymeric materials (Hebrink, 2009). Infrared transmissive mirror films can be made with reflection band edges that correspond to the absorption band edge of any photovoltaic cell material as shown for silicon in Figure 1 and thus re-direct non-useful far IR light away from the PV cell as shown in Figure 2 to avoid over heating that can reduce photovoltaic cell power output and reduce module life. Degradation of most polymers, including adhesive and encapsulants used to assemble photovoltaic modules, accelerates with increasing

temperatures. Cooler photovoltaic module temperatures result in longer module life which equates to lower cost of electricity generated in \$/KWhr. As can be seen in Figure 1, these infrared transmissive mirror films will reflect useful light from 400-1150nm at intended angle of use, but transmit infrared light having wavelengths greater than 1150nm. If desired for safe non-blinding reflection in non-tracking CPV designs, mirror films can be made to reflect only a portion of the visible light. Temperature benefits are limited by reflection of Infra-Red light by some types of photovoltaic cells and even some transmission of Infra-Red light by others. Some silicon and CIGS(copper indium gallium selenide) photovoltaic cells reflect 20-30% of the infra-red light wavelengths greater than 1200 nm. However, often the encapsulants, and other materials, used to construct photovoltaic modules also absorb a portion of the infra-red light beyond 1200 nm which contributes to over heating of the photovoltaic module, especially in concentrating designs.

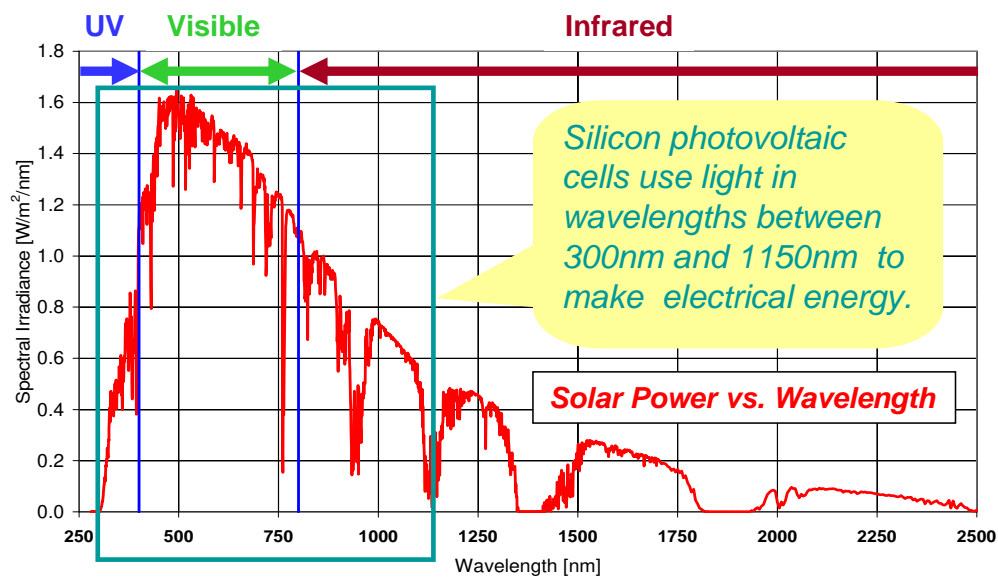


Fig. 1. Solar spectrum useful to silicon photovoltaic cell.

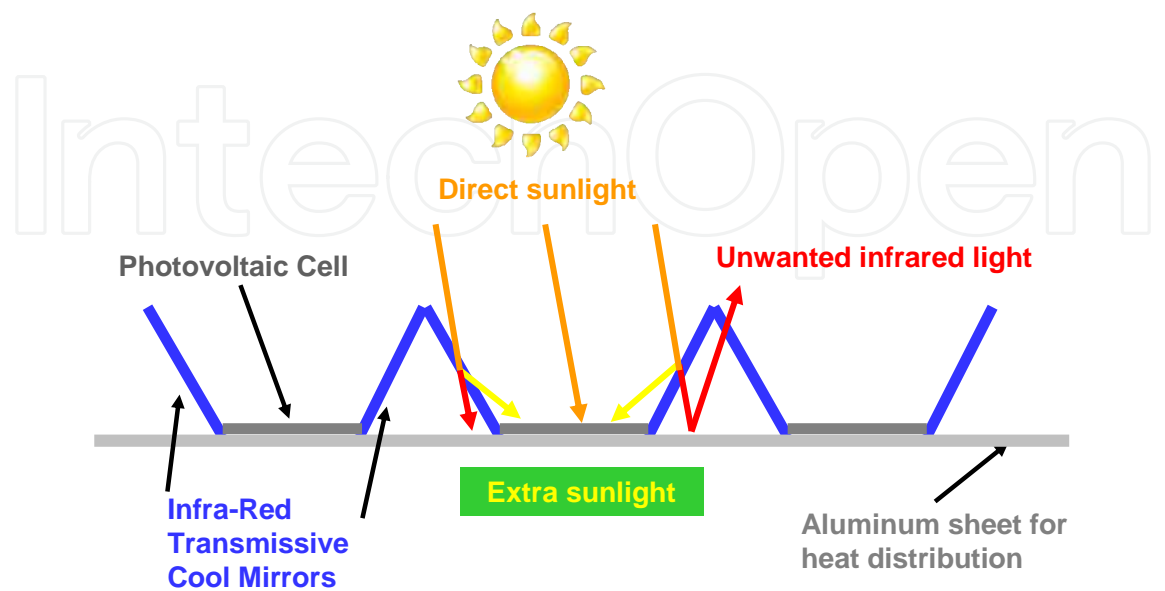


Fig. 2. LCPV design - Non-useful infrared light is redirected away from photovoltaic cell.

Ultra-violet absorbers incorporated into these mirror films will minimize concentration of UV light onto the photovoltaic cell encapsulant thereby extending the photovoltaic module life. Non-metallized polymeric mirrors are thermoformable, enabling innovative structural form factors and lightweight designs. These IR transmissive mirror films are also large-scale manufacturable at relatively low cost. Photovoltaic module costs can be reduced by replacing expensive solar cell material with relatively inexpensive mirror films. These infrared transmissive mirror films are being marketed as 3M brand Cool Mirror 330 and 3M brand Cool Mirror 550.

Infrared transmissive mirror films(3M brand Cool Mirror) have been demonstrated in multiple LCPV(low concentration ratio photovoltaic) non-tracking designs, single axis solar tracking designs, and dual axis tracking designs as shown in figures 3, 4, 5, 6, and 7. Non-tracking and single-axis solar tracking designs are particularly useful for flat commercial and sloped residential roof tops. In high irradiation regions, solar tracking devices could pay for themselves by producing 30-40% more energy per photovoltaic cell, while by increasing power production in the morning and late afternoon, as shown in Figure 3.

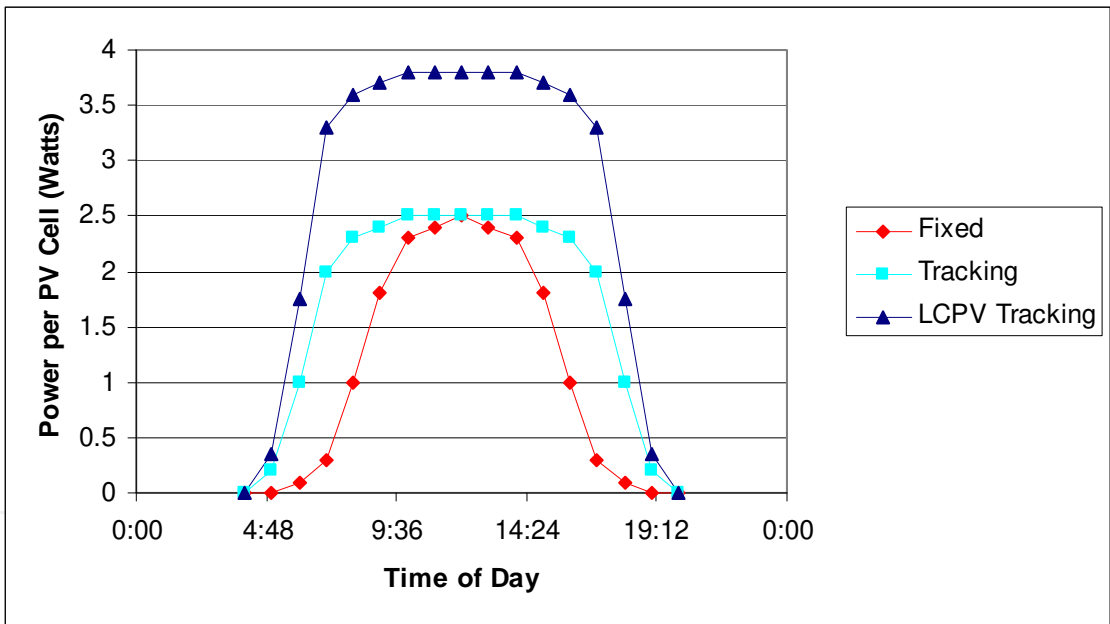


Fig. 3. Measured increase in photovoltaic cell power from solar tracking and 2x sun concentration with infrared transmissive mirror films.

Even though solar trackers are becoming more reliable every year, they are still not widely accepted due to concerns about maintenance costs. TenKsolar Inc. ([www.tenksolar.com](http://www.tenksolar.com)) has developed electronically smart photovoltaic modules for use in their RAIS® WAVE non-tracking LCPV design shown in Figure 4, and have increased power output by filling the already available space between rows of photovoltaic modules with reflector modules. Photovoltaic module array row spacing is used to prevent module shading during winter months at higher latitudes when the Sun’s path is lower in the sky.



Fig. 4. Non-tracking LCPV design with 3M Cool Mirror (photo courtesy of Ray Colby with Sundial Solar).

Peak power output increased by up to 60% as shown in Figure 5 with the use of 3M brand Cool Mirror 330 film in the reflector modules of the RAIS WAVE reflector design.

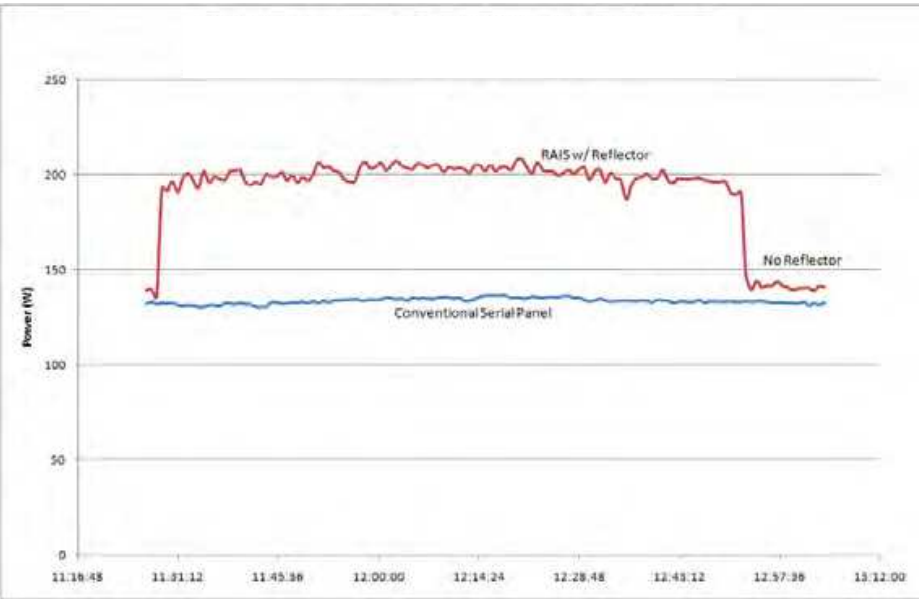


Fig. 5. Non-tracking photovoltaic peak power output increase with use of Cool Mirror reflector measured in Minneapolis, MN, USA on a clear sunny day in June, 2010.

3M brand Cool Mirror 330 reflects 650-1350nm at normal incidence and 550-1150nm at typical solar incidence for maximizing solar concentration without the blinding reflection of full visible light. RAIS® photovoltaic modules are designed to be tolerant of not only partial shading, but also non-uniform increases in solar flux provided by the non-tracking mirrors.



In latitudes where photovoltaic module row spacing is common, the value proposition for CPV with mirror films can be simply calculated by comparing the relative cost of mirror films to photovoltaic cells. For example, a 200 watt silicon photovoltaic module would cost approximately \$300/square meter, or \$1.5/watt. Mirror films with supporting structure can cost less than \$20/square meter, and increase the peak power of the photovoltaic module by at least 100 watts. With an average annualized power output increase of 50 watts/sqmtr, the additional cost of solar mirror film modules can be less than \$0.40/watt.

3M brand Cool Mirror film has also been demonstrated in an effective 3x Sun concentrator module designed by JX Crystals for use with their Solar Carousel single axis tracker( Fraas, 2008) on the flat roof of the Science & Engineering building at UNLV as shown in Figure 6. This low cost single axis solar tracker design is simple and functional for commercial flat roof tops. The 3x Sun concentrating mirrors are mounted between silicon photovoltaic cells cut into 1/3 cell size and separated by 2/3 cell size distance so that the total CPV module has a surface area that is equivalent to a conventional flat rigid photovoltaic module, however, each photovoltaic cell produces twice as much power from the area of the silicon solar cells due to the additional solar flux provided by the mirrors.



Fig. 6. Single Axis LCPV design with JX Crystal design using 3M Cool Mirror.

100% increases in power output of 1/3 cell photovoltaic modules have been measured at UNLV as shown in Figure 7 with increased solar flux from 3x sun mirror design.

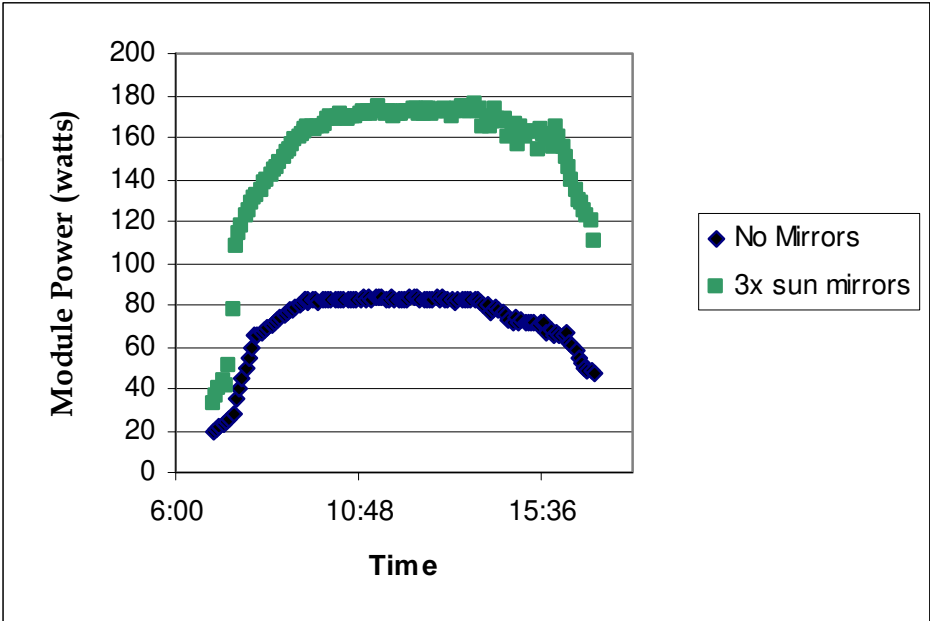


Fig. 7. Measured power output of PV modules designed with 3x sun Cool Mirror reflector measured in Las Vegas, Nevada, USA on a clear sunny day in June, 2011.

Design simplicity, and thus potential for low cost, of the JXC solar carousel tracker is shown below in Figure 8. Since racking is all ready used to mount rigid photovoltaic modules to rooftops, the additional cost entails a simple drive motor, solar sensor, and controller. Details of this design can be found in research papers (Fraas, 2008, 2009) and a book (Fraas, 2010)

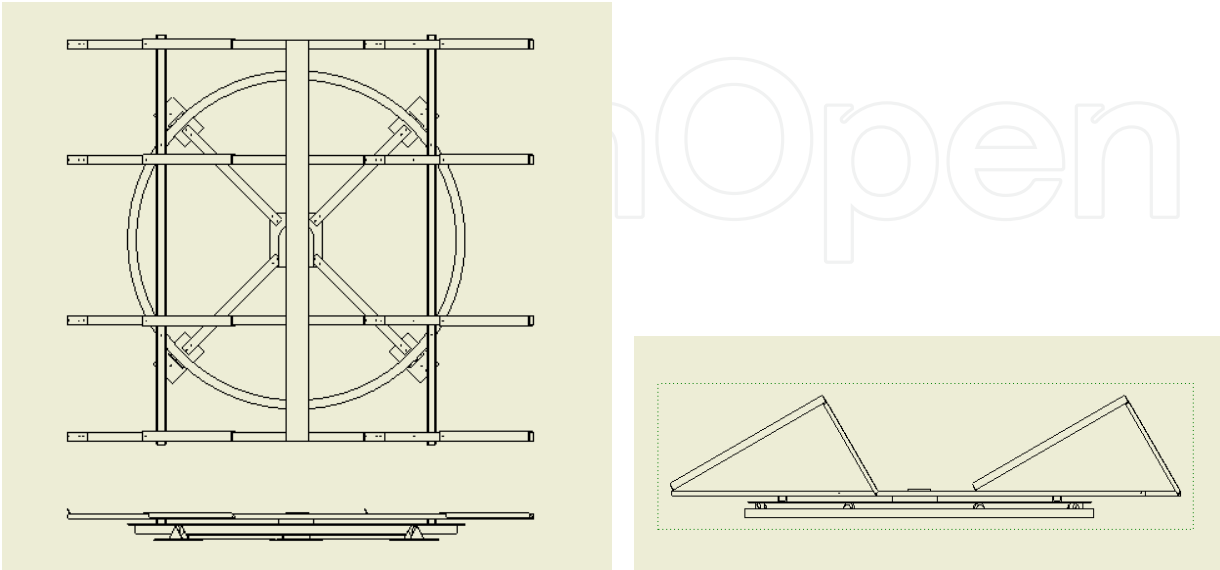


Fig. 8. Top and Side view of JX Crystal solar carousel single axis tracker.

Simple LCPV modules were also designed with 3M brand Cool Mirror linear 2x sun concentration reflectors as illustrated in Figure 2 and pictured in Figure 9 for educational and technology demonstration purposes at the Minnesota Science Museum. Cool Mirror 550 film reflecting 400-1150nm at incident sun light angles is attached to linear thermoformed prisms having 60 degree slopes and placed between rows of mono-crystalline silicon photovoltaic cells that are spaced 6" apart. Basically, every other row of photovoltaic cells is removed and replaced with less expensive mirror film prisms. A Wattsun brand AZ-125 azimuth driven 2-axis solar tracker was mounted on a pole 10 feet above the ground. Power output from each individual module is measured using Enphase M190 micro-inverters and recorded to a database. Two LCPV modules on the top of the array were made with 30% fewer photovoltaic cells than two conventional photovoltaic modules shown mounted below. On sunny days, the 2x sun LCPV modules consistently produce more power than the conventional PV modules. Increase in power output per photovoltaic cell with 2x sun mirror design is shown in Figure 3. As expected, performance is not as good on cloudy days. Concentrated photovoltaic designs require highly collimated direct sun light to be effective and during cloudy diffuse light conditions, photovoltaic power output is reduced by the inverse of the concentration ratio.



Fig. 9. Dual-axis solar tracking LCPV design with 3M brand Cool Mirror (Minnesota Science Museum).

For pole mounted solar tracking designs, the value proposition for CPV with mirror films can be simply calculated by comparing the relative cost of mirror films to photovoltaic cells. For example, a 200 watt silicon photovoltaic module would cost approximately \$300/square meter, or \$1.5/watt. Mirror films with supporting structure can cost less than \$20/square meter, and increase the peak power output of the photovoltaic modules by at least 100 watts thus producing additional electricity for only \$0.20/watt.



Real time effects of the environment (heat, cold, moisture, UV irradiation) on the polymeric mirror films are being monitored for an extended period of time in multiple climates.

Flat LCPV mirror size and angles can be calculated using geometric equations 1 and 2 below.

$$\text{Concentration Ratio} = 1 + 2 \cdot (W_m / W_p) \cdot \cos \theta \quad (1)$$

$$W_m / W_p = \tan(2 \cdot \theta - 90) / (\sin q - \tan(2 \cdot \theta - 90) \cdot \cos \theta) \quad (2)$$

Where;  $W_p$  = solar panel width,  $W_m$  = mirror width,  $q$  = mirror elevation.

For concentration ratios larger than 3:1, curved mirror designs are needed using quadratic equations. Concentration ratios larger than 3:1 will also need to incorporate additional thermal management to remove excess heat from the photovoltaic modules, and preferably, that heat is put to good use, as in hybrid photovoltaic solar thermal panel designs.

Unique solar louver tracker designs (Casperson, 2011) for sloped residential roof tops have also been created to demonstrate the efficacy of infrared transmissive mirrors (Hebrink, 2009) as shown in Figure 10. An advantage of these designs is that the more fragile photovoltaic cell strings are stationary while light weight mirror panels are driven to track the sun. 3M Company sponsored a senior project at LSSU (Lake Superior State University) where a multi-disciplinary team of electrical engineers, mechanical engineers, and computer software engineers designed, fabricated, and tested a solar louver tracker prototype utilizing 3M brand Cool Mirror film.



Fig. 10. Single-axis solar louver tracking design with 3M brand Cool Mirror (photo courtesy of Lake Superior State University).

Polymeric multilayer mirror films are also thermoformable into useful concentrating dish and other non-imaging optical designs for HCPV (high concentration ratio photovoltaic)

applications. Trough, symmetrical dish, and asymmetrical dish reflector designs have been thermoformed from these mirrors. Lamination of the multilayer mirror films to thicker sheets of polycarbonate or PMMA (polymethylmethacrylate) aids in thermoforming and provides structural rigidity to maintain the desired optical design in the intended environment of use. Additionally, these highly reflective mirror films can be attached to rigid metal or glass sheets formed into the desired concentrator shape.

### 2.1 Wavelength selective polymeric multilayer optical mirror films

Infra-red transmissive mirrors have been made utilizing constructive interference quarter wave multi-layer optical film technologies comprising hundreds of layers of transparent dielectric materials. Alternating layers of high refractive index polymers and low refractive index polymers are coextruded into optical stacks containing 100 to 1000 layers with layer thicknesses of approximately  $\frac{1}{4}$  wavelength of light to be reflected (Weber, 2000). Each polymer layer pair contains polymers of differing refractive indices and works constructively with the next layer pair to create broad reflection bands as illustrated in Figure 11.

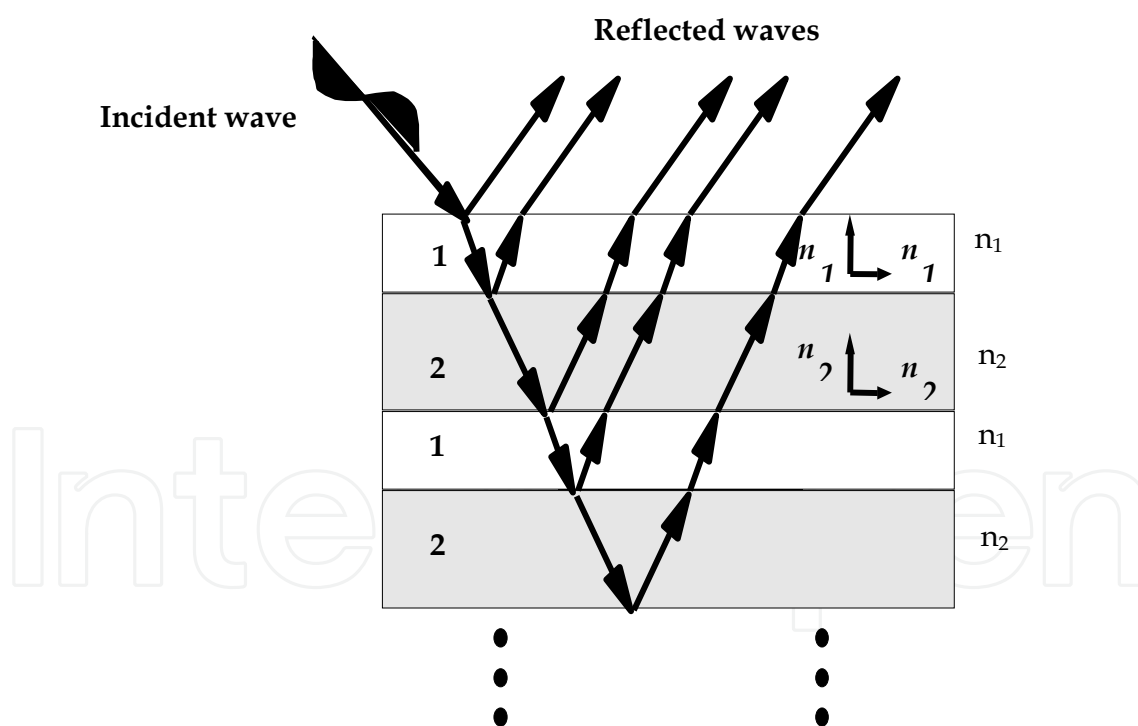


Fig. 11. Incident light reflected by polymer pairs with differing refractive indices.

Layer thickness control is critical for uniform reflection of light. 3M coextrusion and orientation process technologies have demonstrated layer thickness control at the nanometer scale as shown by the Atomic Force Analysis cross section in Figure 12.

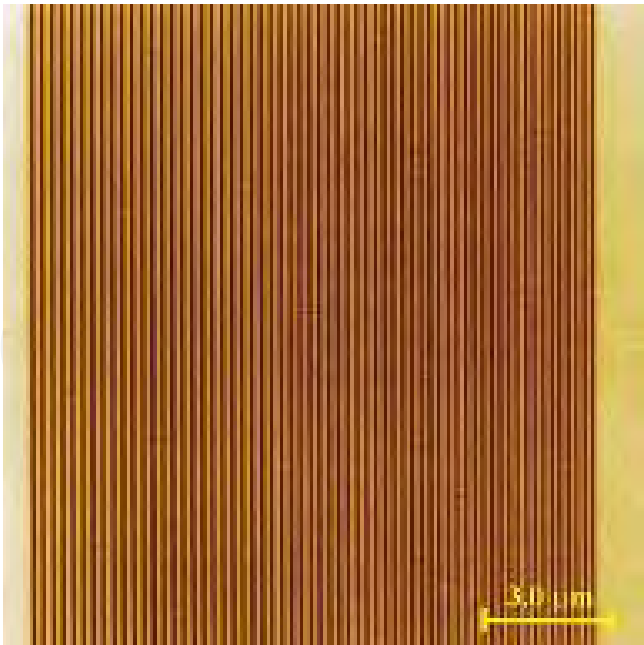


Fig. 12. Cross section of multi-layer optical film cross section containing alternating layers of PMMA and a birefringent polyester. Layers on the left side of the image are engineered to be about 25% thicker than those on the right side.

Tunability of the reflection bandwidth and band edges of these multi-layer optical film mirrors allows matching of the reflection band edges with the absorption band edges of any photovoltaic cell as illustrated in Figure 13 for CIGS(Copper Indium Gallium Selenide) solar cell and Figure 14 for CdTe(Cadmium Telluride) solar cell. Reflectivity and reflection band is controlled by adjusting layer count, layer thicknesses, and refractive indices of polymer layers.

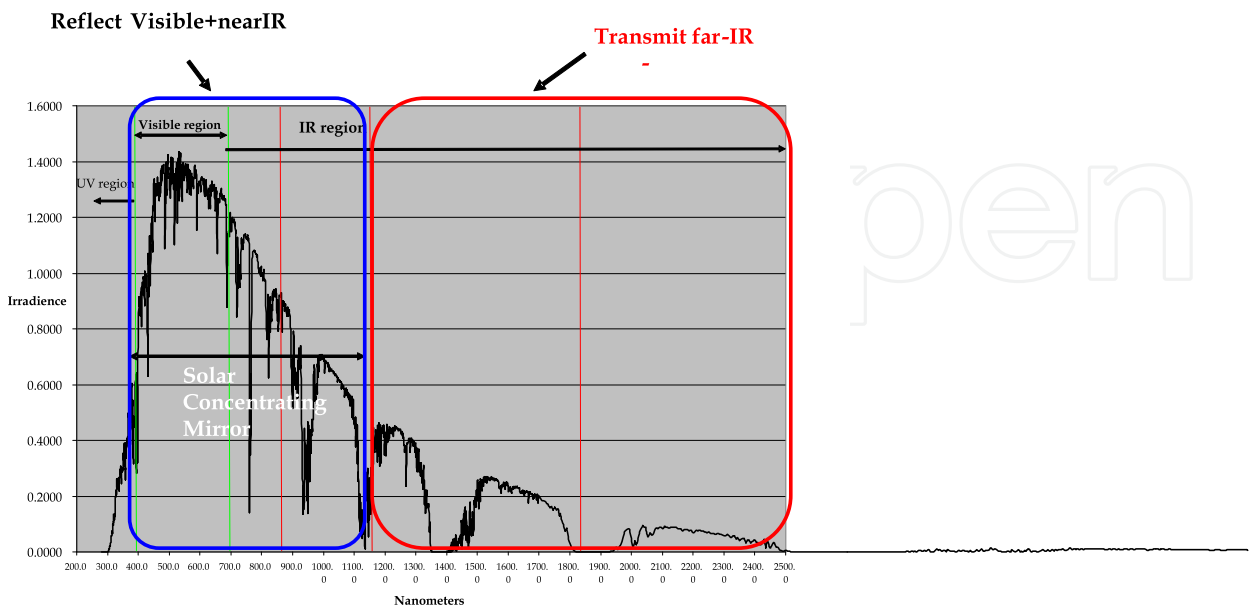


Fig. 13. IR transmissive mirror reflection band for CIGS PV cells.

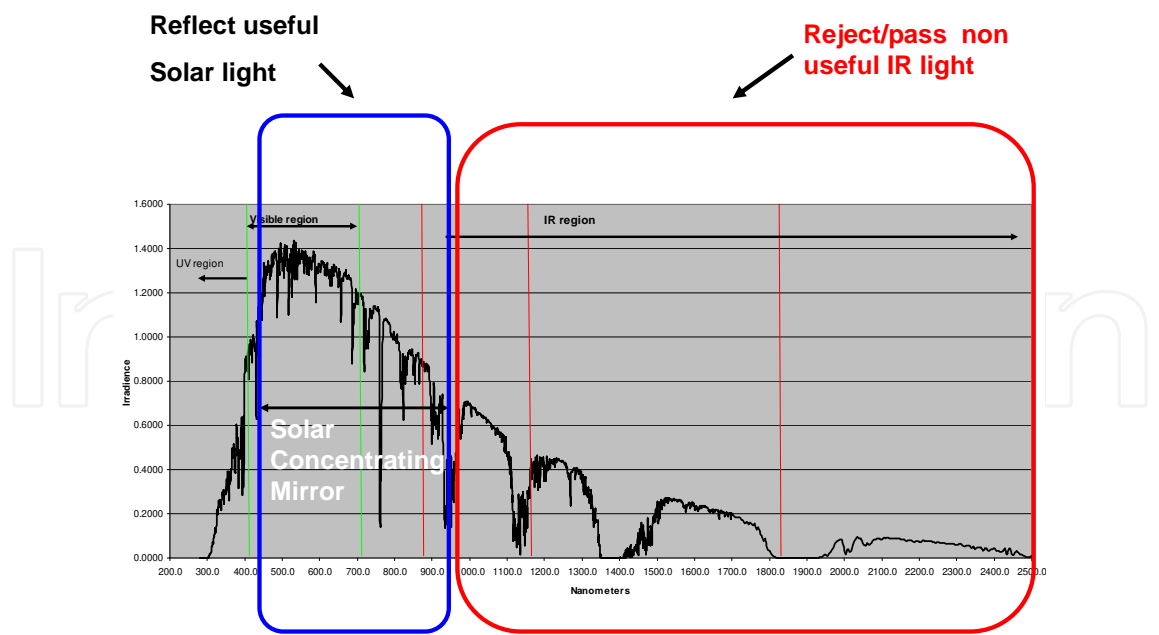


Fig. 14. IR transmissive mirror reflection band for CdTe PV cells.

Reflection band edges will shift to the left with changing incident light angle, as explained by Fresnel reflection and phase thickness equations as charted in Figure 15. Thus the exact reflection band edge will need to be optimized for every CPV design. More detailed physics of birefringent multi-layer optical films can be found in a research article titled “Giant Birefringent Optics in Multi-layer Polymer Mirrors” (Weber, 2000).

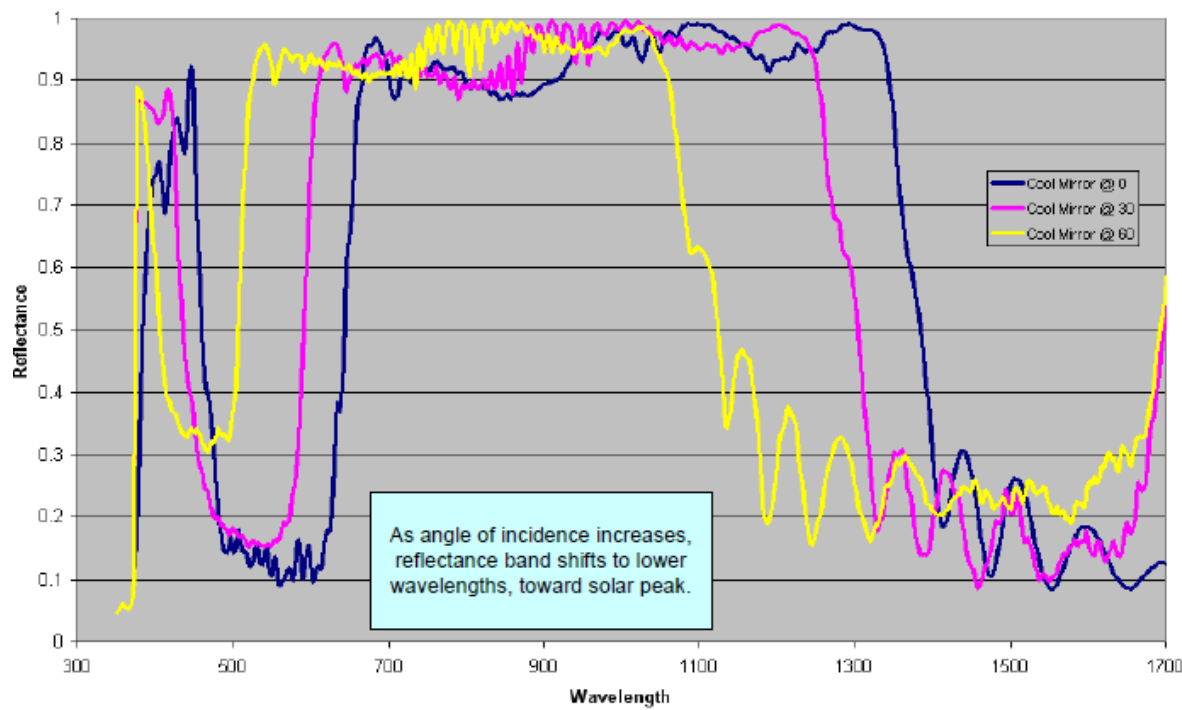


Fig. 15. Shift in reflection band with changes in incident angle of light.

## 2.2 UV (Ultra-Violet) light stability

Tunability of the reflection band also enables UV (ultra-violet) reflection layers to be included at or near the top surface of these solar concentrating mirrors. Incorporation of UVA (ultra-violet absorber) in the optical layers and skin layers of UV mirrors provides exceptional UV protection of any material positioned beneath them. When made with inherently UV stable materials such as PMMA (polymethylmethacrylate) and fluoropolymers, UV mirrors will provide extended UV protection even after the UV absorbers themselves extinguish.

Fluoropolymers typically are resistant to UV degradation even in the absence of stabilizers such as UVA, HALS (hindered amine light stabilizer), and anti-oxidants. Useful fluoropolymers include ethylene-tetrafluoroethylene copolymers (ETFE), tetrafluoroethylene-hexafluoropropylene copolymers (FEP), tetrafluoroethylene-hexafluoropropylene-vinylidene fluoride copolymers (THV), polyvinylidene fluoride (PVDF), and miscible blends of PVDF and PMMA. The multilayer optical film comprising fluoropolymers can also include non-fluorinated materials. Multilayer film substrates may have different fluoropolymers in different layers or may include at least one layer of fluoropolymer and at least one layer of a non-fluorinated polymer. UV protective multilayer films can comprise a few layers (e.g. 2 or 3 layers) or can comprise at least 100 layers (e.g., in a range from 100 to 2000 total layers or more). Polymer used to make the optical layers in the different multi-layer film substrates can be selected, for example, to reflect a significant portion (e.g., >50%) of UV light in a wavelength range from 350nm to 400nm or even 300nm to 400 nm.

Photo-oxidative degradation caused by UV light (e.g., in a range from 280 to 400 nm) may result in color change and deterioration of optical and mechanical properties of polymeric films. A variety of stabilizers may be added to the polymeric film substrate to improve its resistance to UV light. Examples of such stabilizers include at least one, or even better, a combination of ultra violet absorbers, hindered amine light stabilizers (HALS), and anti-oxidants.

A UV absorbing layer (e.g., a UV protective layer) aids in protecting the visible/IR-reflective optical layer stack from UV-light caused damage/degradation over time by absorbing UV-light (preferably any UV-light) that may pass through the UV-reflective optical layer stack. In general, the UV-absorbing layer(s) may include any polymeric composition (i.e., polymer plus additives) that is capable of withstanding UV-light for an extended period of time. A variety of optional additives may be incorporated into an optical layer to make it UV absorbing. Examples of such additives include at least one of UV absorbers (UVAs), HALS, or anti-oxidants. Typical UV absorbing layers have thicknesses in a range from 12 micrometers to 380 micrometers (0.5 mil to 15 mil) with a UVA loading level of 1-10% by weight.

A UVA is typically a compound capable of absorbing or blocking electromagnetic radiation at wavelengths less than 400 nm while remaining substantially transparent at wavelengths greater than 400 nm. Such compounds can intervene in the physical and chemical processes of photoinduced degradation. UVAs are typically included in a UV absorbing layer in an amount sufficient to absorb at least 80%, and even better, greater than 90% of the UV light in the wavelength region from 180 nm to 400 nm. Typically, it is desirable if the UVA is highly soluble in polymers, highly absorptive, photo-permanent and thermally stable in the



temperature range from 200 °C to 300 °C for extrusion process to form the protective layer. The UVA can also be highly suitable if they can be copolymerizable with monomers to form protective coating layer by UV curing, gamma ray curing, e-beam curing, or thermal curing processes.

Red-shifted UVAs (RUVAs) typically have enhanced spectral coverage in the long-wave UV region, enabling it to block the high wavelength UV light that can cause yellowing in polyester polymers. One of the most effective RUVAs is a benzotriazole compound, 5-trifluoromethyl-2-(2-hydroxy-3- $\alpha$ -cumyl-5-tert-octylphenyl)-2H-benzotriazole. Other exemplary benzotriazoles include 2-(2-hydroxy-3,5-di- $\alpha$ -cumylphenyl)-2H-benzotriazole, 5-chloro-2-(2-hydroxy-3-tert-butyl-5-methylphenyl)-2H-benzotriazole, 5-chloro-2-(2-hydroxy-3,5-di-tert-butylphenyl)-2H-benzotriazole, 2-(2-hydroxy-3,5-di-tert-amylphenyl)-2H-benzotriazole, 2-(2-hydroxy-3- $\alpha$ -cumyl-5-tert-octylphenyl)-2H-benzotriazole, 2-(3-tert-butyl-2-hydroxy-5-methylphenyl)-5-chloro-2H-benzotriazole. Further exemplary RUVA includes 2-(4,6-diphenyl-1,3,5-triazine-2-yl)-5-*tert*-butoxy-phenol. Some very effective UV absorbers for polymers include those available under the trade designations "TINUVIN 1577," "TINUVIN 900," and "TINUVIN 777." Some UV absorbers are available in master batch resin from Sukano Polymers Corporation, Dunkin SC, under the trade names of "TA07-07 MB" for polyesters and "TA11-10 MB" for polymethylmethacrylate. Another exemplary UV absorber available in a polycarbonate master batch from Sukano Polymers Corporation under the trade name "TA28-09 MB". In addition, the UV absorbers can be used in combination with hindered amine light stabilizers (HALS) and anti-oxidants. Exemplary HALS include those under the trade names "CHIMASSORB 944" and "TINUVIN 123." Exceptional anti-oxidants include those obtained under the trade names "IRGAFOS 126", "IRGANOX 1010" and "ULTRANOX 626".

The desired thickness of a UV protective layer is typically dependent upon an optical density target at specific wavelengths as calculated by Beers Law. When protecting polyesters from UV degradation, the UV protective layer should have an optical density greater than 3.5 at 380 nm. It is also very important that the optical densities remain constant over the extended life of the film in order to provide the intended protective function.

The UV protective layer can be a cross linkable hard coat selected to achieve the desired protective functions of UV protection and abrasion resistance. Inorganic additives that are very soluble in cross-linkable polymers may be added to the composition for improved properties. Of particular importance, is the permanence of the additives in the polymer. The additives should not degrade or migrate out of the polymer. Additionally, the thickness of the layer may be varied to achieve desired protective results. For example, thicker UV protective layers would enable the same UV absorbance level with lower concentrations of UV absorbers, and would provide more UV absorber permanence attributed to less driving force for UV absorber migration. Accelerated testing of the UV protected polymer films are being conducted in outdoor solar simulators at elevated temperatures and higher levels of UV irradiance than direct light from the sun.

### 3. Concentrated solar power

CSP(concentrated solar power) technology uses mirrors to direct sunlight at solar absorbing heat transfer fluid devices that heat up and whose thermal energy is then transferred for

heating purposes, or turned into electricity by use of a turbine electric generator. CSP reflectors can also be used to concentrate sunlight onto photovoltaic cells, especially photovoltaic cells that make use of a wide range of the solar spectrum such as triple junction gallium arsenide indium phosphide PV cells. Conventional CSP reflectors are made with silver coated glass, which currently reflect 94% of the solar spectrum. These glass CSP reflectors are heavy, prone to breakage, and relatively expensive. Polymeric multilayer optical mirror films have been metal vapor coated to create broadband solar mirror films for solar thermal, CPV, and CSP applications. Common reflective metals such as silver, copper, aluminum, and gold have high reflectivity in the red and infra-red wavelengths of light, but tend to absorb some visible light, especially in the blue wavelengths. Since multilayer optical mirror films can be tuned to be highly reflective of blue wavelengths of light, the combination of metal reflectors with multilayer constructive interference mirrors create a highly reflective and cost effective broadband mirror. An example of a broadband mirror is shown in Figure 16 made by vapor coating silver onto a multilayer optical film made with over 500 alternating layers of PET(polyethylene terephthalate) an CoPMMA(co-polyethylmethacrylate).

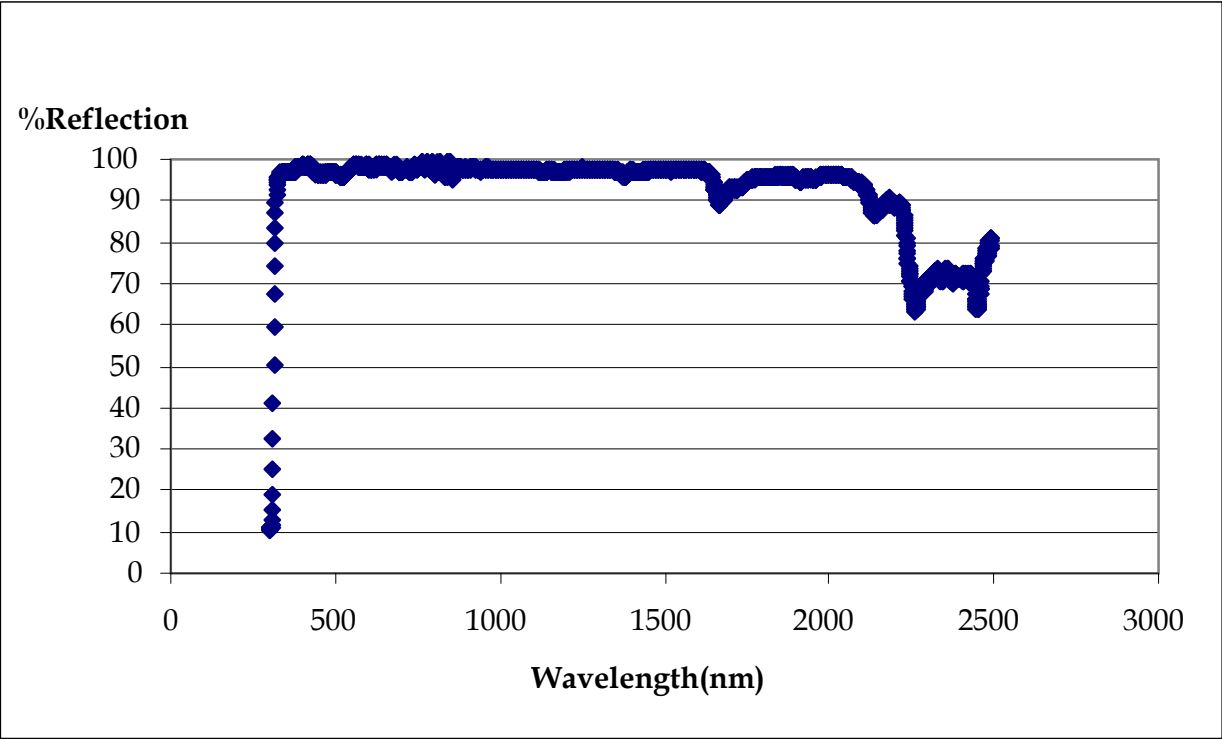


Fig. 16. Reflectivity of mirror film made by vapor coating silver onto back side of multi-layer optical film reflecting 380-800nm.

The polymeric multilayer optical mirror film reflects 97% of the light from 370 nm to 800nm while the silver reflects 96% of the available sun light from 800 nm to 2500 nm. Some losses in reflectivity are due to absorption of light in the 1600 nm to 1700 nm range by the PET and absorption of light in the 2200 nm to 2400 nm light range by the CoPMMA. Fortunately, only a small portion of the sun’s available light makes it through the earth’s atmosphere in these bandwidths of polymer absorption. Another 3% of the solar spectrum is wavelengths of light below 370nm which cannot be reflected by a PET based multilayer optical mirror due to absorption and degradation of the PET by UV light below 370 nm. However, UV light below 370nm can be reflected by a fluoropolymer based UV mirror with PMMA as the high refractive index optical layers. The PMMA/fluoropolymer UV mirror can be used to protect a PET/CoPMMA based visible mirror, or alternatively, a multilayer optical mirror film can be made which reflects both UV and visible light with PMMA as the high refractive index layers and fluoropolymers as the low refractive index layers. The PMMA/fluoropolymer based UV-VIS mirror can then be metal vapor coated with silver, copper, or gold to create a more reflective broadband mirror. Aluminum can also be used as the reflective metal layer. Another option for creating a broadband reflective mirror is to laminate the UV-VIS multilayer optical mirror film to a sheet of polished aluminum or stainless steel with an optically clear adhesive.

4. Structured surface anti-reflection

Front surface reflections account for 4-5% losses in conventional glass covered photovoltaic module output. These front surface reflections increase with incident light angle as illustrated in Figure 17 with a flat glass front surface having a refractive index of 1.50.

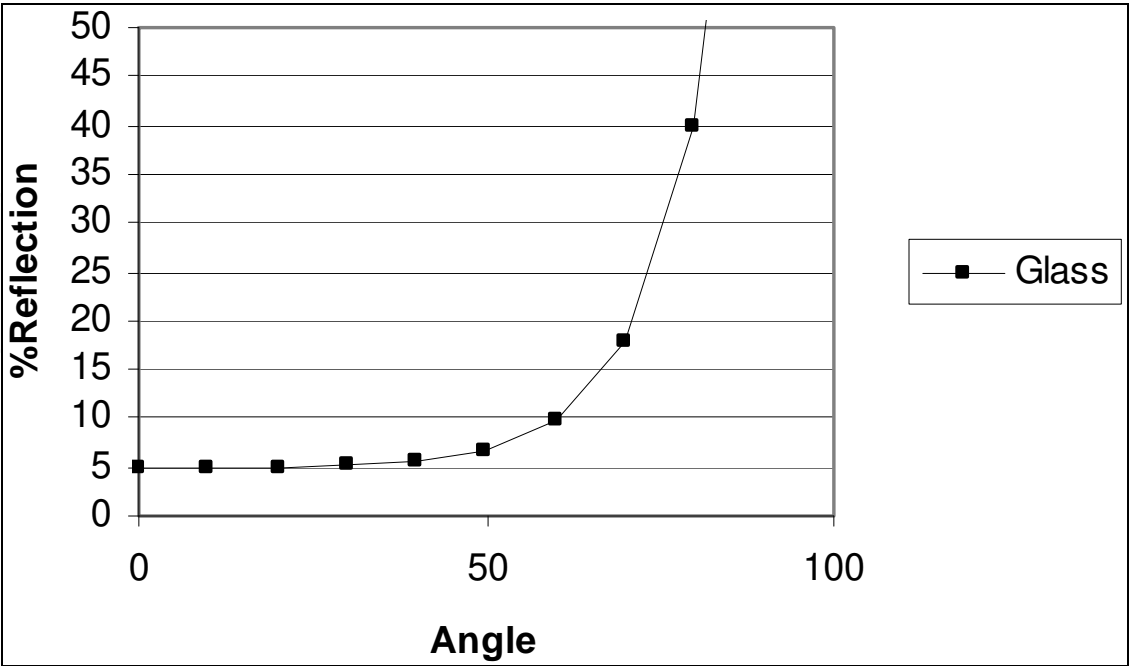


Fig. 17. Front surface reflection off flat surface.

By structuring the front surface, either with nanostructures or microstructures, the front surface reflection can be minimized. Improvements in transmission through a photovoltaic module front surface with micro-structures made with linear prisms having a range of prism apex angles were modeled with Fresnel equations and Snell’s law as shown in Figure 18.

Additional increases in photovoltaic cell efficiency are expected by increasing the path length of light rays through the photovoltaic cell material itself. Initial photovoltaic module power increases of 6-8% have been measured with 53 degree apex angle prism surface structures. However, the tendency of these v-groove valley prism structures to collect dirt can reduce their anti-reflection benefits over time. Dirt attraction has prompted the investigation of additional anti-soiling surface structure geometries and anti-soiling coatings. V-groove geometries trap dirt as well as light and thus larger valley angles can be implemented to minimize dirt accumulation. Both hydrophilic and hydrophobic surface coatings have shown promising dirt resistant properties depending on the composition of dirt and climate of the photovoltaic module installation. Polymer antistat additives can also be incorporated to minimize dirt attraction.

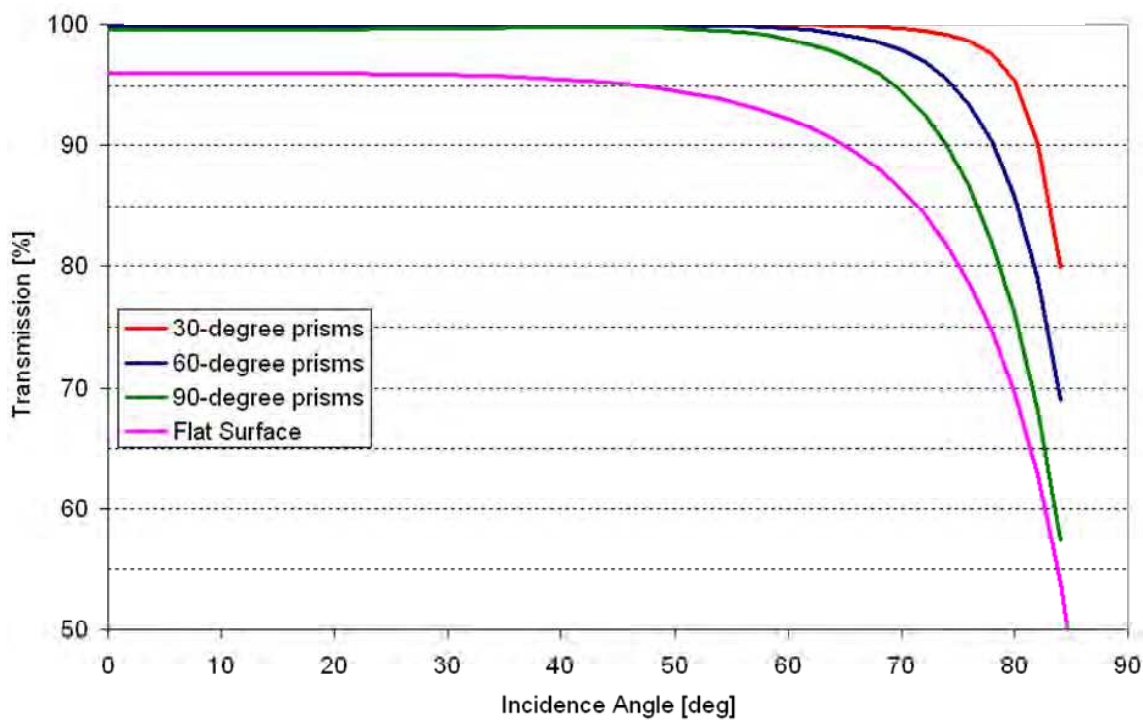


Fig. 18. Increase in light transmission dependance on prism apex angle.

Polymer films can be micro-structured at relatively high manufacturing speeds and thus low cost. Micro-structured fluoropolymers, silicone polymers, acrylate polymers, and urethane polymer films are being investigated due to their inherent UV stability. Minimizing front surface reflections off photovoltaic modules does increase the power output of a photovoltaic module. However, effective techniques for minimizing dirt attraction and soil build-up are needed for anti-reflective surface structures to truly reduce the leveled cost of generating electricity from the sun.

## 5. Conclusions

Durable multilayer polymeric mirror films have demonstrated significant (e.g. >50%) increases in photovoltaic cell power output in multiple CPV designs without overheating photovoltaic modules. Surface structured anti-reflection films and coatings have demonstrated 5-10% increases in photovoltaic module power output. Positive value propositions can be calculated for these polymeric mirror films and coatings when the photovoltaic power benefit they provide is greater than their additional cost per kWhr of energy produced.

## 6. Acknowledgments

The author wishes to thank the 3M Corporate Research Laboratory management for allocating resources to the development of durable films and coatings. Thanks are also due to 3M Renewable Energy Division management for sponsoring and funding this work. The technology demonstration partnerships with JX Crystal Inc., Lake Superior State University, University of Nevada Las Vegas, and tenKsolar Inc. are also greatly appreciated.

## 7. References

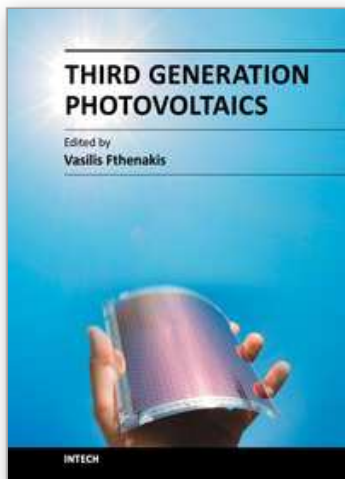
- Weber, M. F.; Stover, C. A.; Gilbert, L.R.; Nevitt, T. J.; Ouderkirk, A.J. (2000). Giant Birefringent Optics in Multilayer Polymer Mirrors, *Science Magazine*, Vol. 287, March 31, 2000
- Hebrink, T. J. (2009). Infra-red Transmissive Mirrors for Concentrated Photovoltaics, *Proceedings of 34th IEEE Photovoltaic Specialist Conference*, June, 2009, Philadelphia, USA
- Fraas, L.; Avery, J.; Minkin, L.; Huang, H. ; Maxey, C.; Gehl, A. (2008), Carousel Trackers with 1sun or 3sun Modules for Commercial Building Rooftops, *Proceedings of ASES Conference*, 2008, San Diego, California, USA
- Fraas, L.; Avery, J.; Minkin, L.; Huang, H.; Schneider, H.; Larson, D. (2010), Solar PV Carousel Trackers for Building Flat Rooftops; 3 Case Studies, *Proceedings of ASES Conference*, 2010, Phoenix, Arizona, USA
- Fraas, L.; Partain, L. (2010), *Solar Cells and their Applications*, Wiley, John & Sons, Incorporated, ISBN; 978047044631, USA
- Casperson, K.; Fill, C.; Gearin, M.; Greensky, R.; Lidbeck, K.; Weber, P.; Hebrink, T. J. (2011), Low-X Single-Axis Solar Louver Tracking System for Residential Rooftop



Applications, *Proceedings of 37<sup>th</sup> IEEE Photovoltaic Specialist Conference*, June, 2011,  
Seattle, Washington, USA  
TenKsolar, Inc., [www.tenksolar.com](http://www.tenksolar.com)

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### **Third Generation Photovoltaics**

Edited by Dr. Vasilis Fthenakis

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Photovoltaics have started replacing fossil fuels as major energy generation roadmaps, targeting higher efficiencies and/or lower costs are aggressively pursued to bring PV to cost parity with grid electricity. Third generation PV technologies may overcome the fundamental limitations of photon to electron conversion in single-junction devices and, thus, improve both their efficiency and cost. This book presents notable advances in these technologies, namely organic cells and nanostructures, dye-sensitized cells and multijunction III/V cells. The following topics are addressed: Solar spectrum conversion for photovoltaics using nanoparticles; multiscale modeling of heterojunctions in organic PV; technologies and manufacturing of OPV; life cycle assessment of OPV; new materials and architectures for dye-sensitized solar cells; advances of concentrating PV; modeling doped III/V alloys; polymeric films for lowering the cost of PV, and field performance factors. A panel of acclaimed PV professionals contributed these topics, compiling the state of knowledge for advancing this new generation of PV.

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