# A nano coating material that generates more electricity in solar power systems

Japan Nano Coat Co. Ltd.

# Purpose of this technology

- In the areas affected by the Fukushima nuclear accident, at a reactor run by TEPCO, mega-solar power projects have been undertaken one after another with the aim of effective land use.
- The introduction of a feed-in tariff system for renewable energy since 2012 has accelerated the trend.
- This technology aims to introduce and disseminate coating material that is expected to reduce maintenance costs of mega-solar power systems and improve durability of solar panels.
- Key constituent technologies of this coating material:
- ･Anti-static, soil resistance effects
- ･Improvement in transmittance (anti-reflection)
- ･Heat dissipation

# Effects and purposes of constituent technologies

Anti-static, soil resistance technology

・Anti-static effect prevents adhesion of soil (yellow sand, volcanic ash, PM 2.5, etc.) on a surface, allowing for offsetting decrease in power generation.

Technology for improving transmittance (anti-reflection technology)

・Surface coating reduces light reflection and absorbs more light, allowing for generating more electricity.

Heat dissipation technology

・Heat dissipation coating lowers the temperature of a solar panel, allowing for offsetting the decrease in power generation caused by temperature rise of the panel, and preventing aging/thermal deterioration of the panel.

# Requirements for soil resistance (anti-static effect, surface properties)

Locations of mega-solar systems and types of soil

Decrease in power generation occurs when mega-solar systems are installed:

- a – In areas where volcanic ash falls (Sakurajima, Shinmoedake, etc.). Major soil: volcanic ash
- b – Along highways with high traffic. Major soil: exhaust gas and iron powder
- c – In areas with high pollen counts. Major soil: pollen
- d – In areas where yellow sand falls. Major soil: yellow sand and exhaust gas
- e – In areas where sandstone beds are exposed. Major soil: sand
- f – In industrial areas. Major soil: exhaust gas, iron powder, etc.

## ■ Need for anti-static coating

Yellow sand requires particular attention among soils because it is electrically charged while floating in the air in the form of microparticles, and flows into Japan in a state wherein it readily adheres to materials.
During peak periods when yellow sand is always falling, it adheres to solar panels more readily when water used for cleaning panels dries out and undermines cleaning effects. On the other hand, increasing cleaning frequency results in higher maintenance costs. Therefore, if solar panels are installed in such an area where they are always exposed to soil with little cleaning effect, they need to have anti-static coating with improved soil resistance that reduces the need for cleaning. In this regard, the solar panel market around the world has faced a challenge of decreased power generation caused by sand in desert areas. In deserts with little rainfall and dry air, sand is electrically charged and readily adheres to solar panels. This situation requires solar panel glass that has a soil resistant surface with anti-static effect.
When several types of soil combine with each other, they adhere to materials more readily. For example, in industrial areas in China where both exhaust gas and yellow sand are generated, sticky, hard-to-remove organic soil consisting of oil from exhaust gas and yellow sand accumulates on solar panels, resulting in decline in power generation by more than 20%.
Furthermore, in terms of maintenance, the use of tap water, not deionized water, for cleaning causes a problem. When solar panels are cleaned with running water, minerals such as chlorine and calcium contained in tap water accumulate on the panel surface, resulting in a decline of light transmittance.

Solar panel with yellow sand accumulation

Solar panel on which yellow sand accumulated again after cleaning water had dried out

## ■ Features required of anti-static coating

Anti-static coating of solar panels is required to have the following features:

• Long-term weather resistance

In general, solar panels are installed at an angle of 20º to 40º, and are required to have resistance against soil accumulated on the surface. Solar cell modules are claimed to have a lifetime of 20 to 30 years and, therefore, surface coating is also required to ensure this durability.

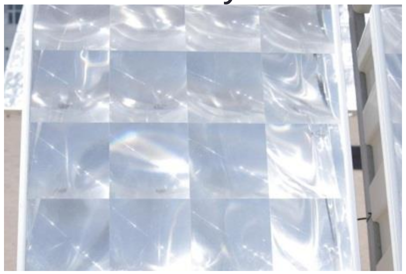
• Heat resistance

In general, solar panels are installed at an angle of 20º to 40º, and are required to have resistance against soil accumulated on the surface. Solar cell modules are claimed to have a lifetime of 20 to 30 years and, therefore, surface coating is also required to ensure this durability. The surface temperature of solar panels often reaches 70°C to 80°C due to absorption of heat. If long-term heat resistance is an important factor, it is desirable to use inorganic materials for solar panels. It is difficult to use organic materials because of the requirements for durability in high-/low-temperature cycles and resistance to ultraviolet rays.

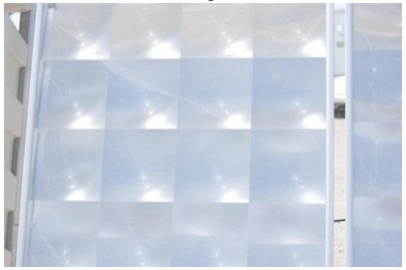
• Anti-static effect

According to test results in a desert in China, an anti-static solar panel with a surface resistivity of $10^8\Omega$ generated over 10% more electricity as compared to that of $10^9\Omega$ and an uncoated solar panel. Therefore, it is desirable to use solar panels with a surface resistivity of $10^8\Omega$ or less to ensure anti-static effect.

Coated panel with a surface resistivity of $10^8\Omega$



Coated panel with a surface resistivity of $10^9\Omega$

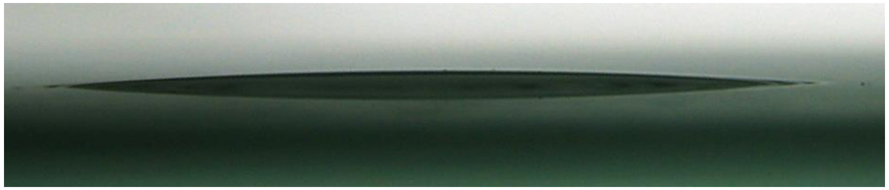


• Evenness of panel surface
If a panel surface has asperities larger than the size of soil particles, they adhere to the panel more readily. Therefore, it is required to minimize surface asperities. For example, the smallest size of yellow sand that travels to Japan is less than 1 micron. To prevent adhesion of such small soil particles on solar panels, it is required to remove asperities on the nanometer scale.

• Light transmittance
The surface coating that decreases transmittance means a decline in power generation. Therefore, coating material that may deteriorate transmittance must not be used. It is desirable to use a low-refractive-index material that increases transmittance as discussed later.

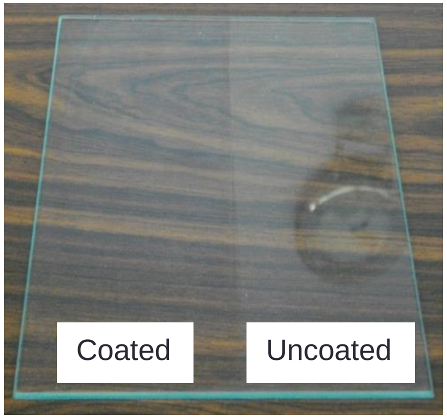
• Hydrophilic surface
It is desirable to use a hydrophilic coating. On a hydrophobic surface, soil tends to gather into water spots generated when water evaporates, and remains on the surface. In a comparative test of solar panels for two months in China, a hydrophilic, anti-static solar panel had a less than 1% decline in power generation, as compared to about 6% of an uncoated panel and more than 10% of a water-repellent panel. Most water-repellent coatings are fluorine-based, and the insulation properties of fluorine may affect the adhesion of soil. Water-repellent coatings that help remove soil are effective when maintenance is done with a higher frequency, but hydrophilic anti-static coatings have a greater effect against accumulation of soil from the air.

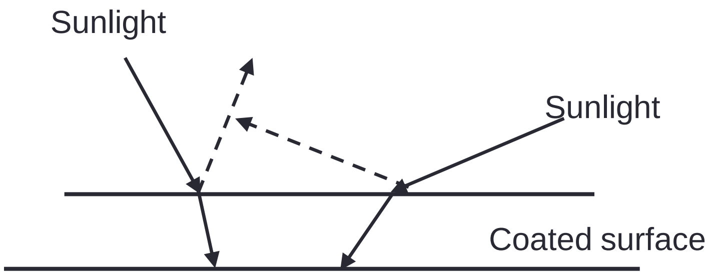
Hydrophilic surface with contact angle of 5° or less



■**Increase of transmittance by Anti-Reflection (AR) function (multi-layer coating of low/high refractive films that improves transmittance at a particular wavelength)**
**Increase of transmittance by low-refractive film**

To increase the amount of power generation as much as possible, a solar panel needs to control refraction so as to reduce reflection of sunlight from a glass surface and loss in energy. Using the characteristic that light refracts at an interface between two different materials increases transmittance through the glass surface of a solar panel.
As shown in the figure below, a low-refractive-index film with special coating allows light that normally reflects on a surface to pass through it. Like this, just by applying a special coating on a transparent substrate such as glass increases light transmittance. The lower a refractive index is, the more transmittance a substrate gains. Therefore, it is desirable to apply a coating with as low a refractive index as possible.

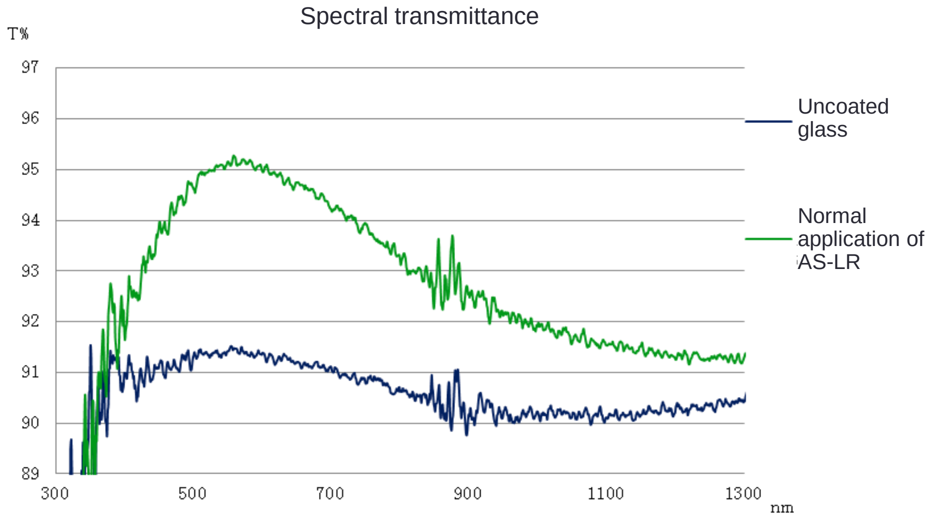


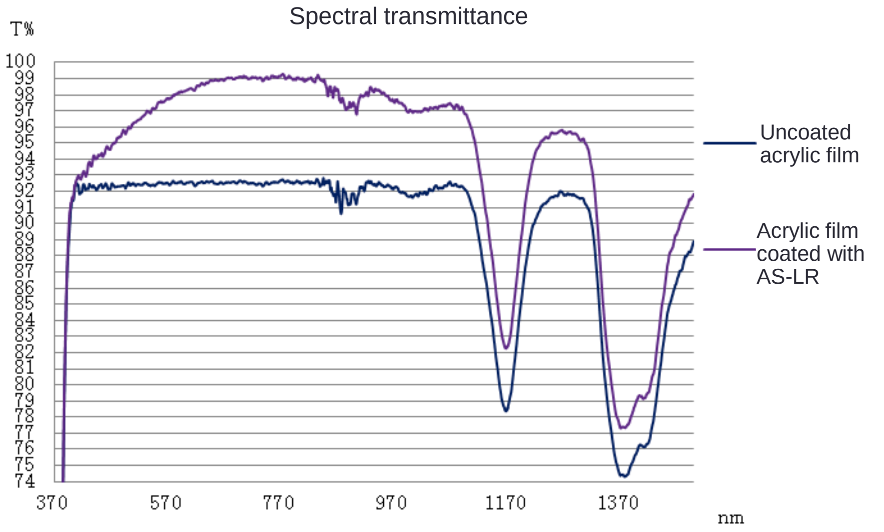




Left: Coated surface looks black with less reflection and increased transmittance.

## ■Advantages of AS-LR coating

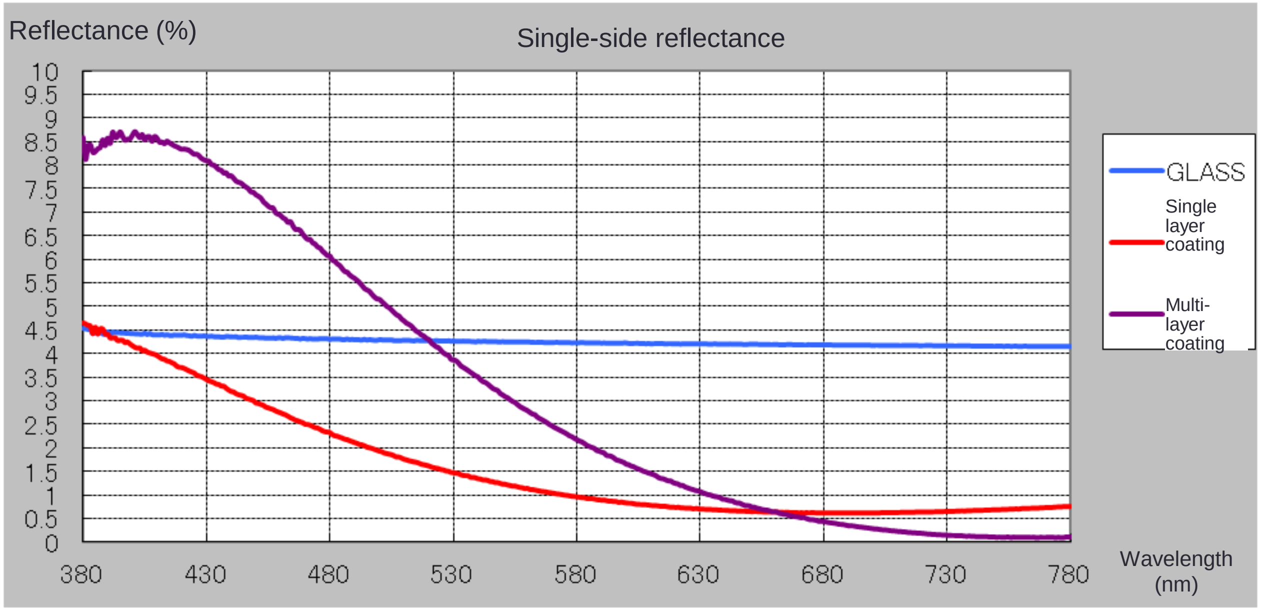
An Anti-static Low Refraction (AS-LR) coating is designed for solar panel glass with an anti-static effect and a low-refractive-index (patent application filed in April 2010).
The AS-LR coating combines an anti-static (soil resistant) effect and a low-refractive index with the advantages of an inorganic silica binder of high transparency, fast-drying and curing at room temperatures, excellent adhesion, weather resistance and super-hydrophilic properties. These features are achieved by use of silica particles of different sizes less than 10 nanometers and tin oxide particles with a diameter of 2 nanometers. A low-refractive index coating increased visible light transmittance through glass by more than 3% from 91% by single-side application, and by more than 7% by double-side application.
On an acrylic panel, 99% of transmittance was observed by double-side application.
Similarly, an increase in transmittance by more than 4% was observed on a PET film from 85% to 89%, and on a polycarbonate film from 90% to 94%.



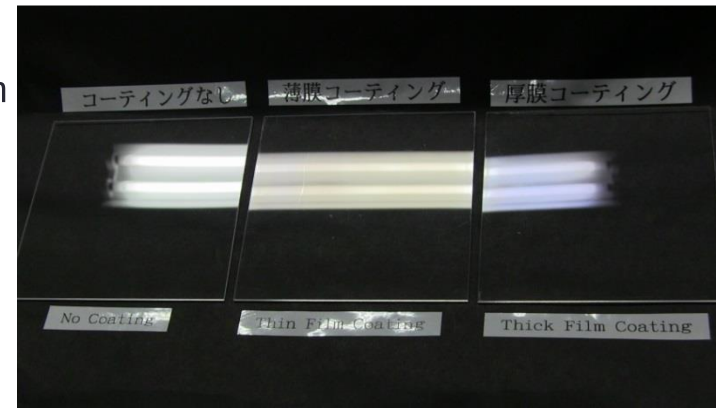
# Multi-layer coating of low/high refractive films that improves transmittance at a particular wavelength

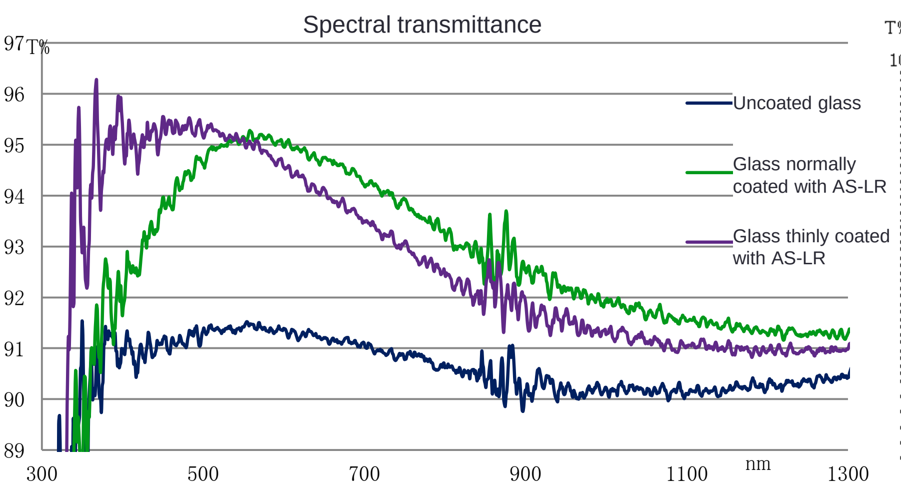
The wavelength at which solar cell modules generate power depends on manufacturers and types of modules. For example, a thin-film solar module generates power at 500 nm, a polycrystalline one at a near-infrared wavelength of 800 nm to 900 nm, and another at 700 nm to 800 nm. Using a multi-layer coating consisting of low- and high-refractive films allows for increased transmittance at any wavelengths that individual module manufacturers use, and accommodates different types of solar panels. The figure below shows a single-side reflectance of a low-refractive single layer coating, a double layer (multi-layer) coating of low/high refractive films, and a glass substrate.
The data shows that a low-refractive single layer coating has lower reflectance on the whole as compared to a glass substrate, meaning that transmittance increases through the entire wavelength range. A decrease of reflectance by 2% broadly means an increase of transmittance by 2%. Strictly speaking, light energy is a total of light transmittance, reflectance and absorption, but absorption is negligible in white glass panels used for solar cells. In a comparison between a glass substrate and a multi-layer coating, a glass substrate has lower reflectance up to 520 nm, while a multi-layer coating has lower figures at a higher wavelength, particularly below 0.5% at 669 nm and higher.

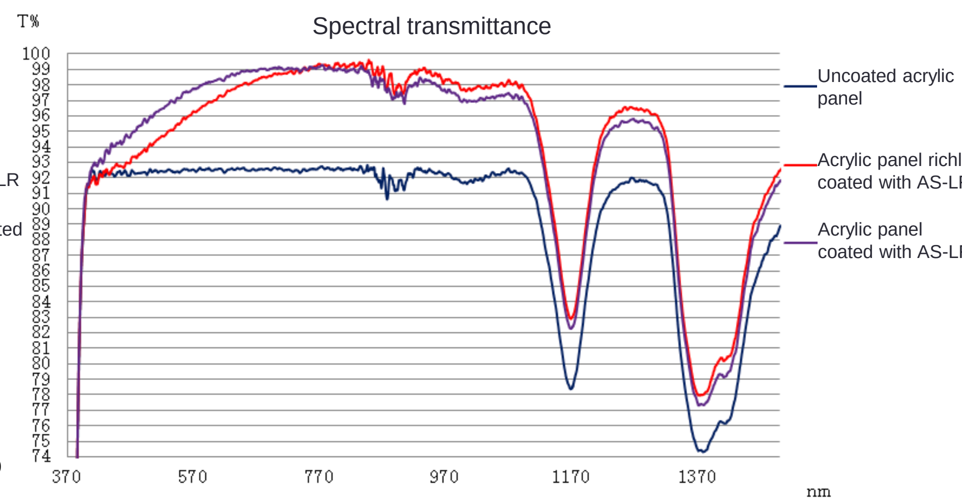


## ■Changes depending on film thickness of AS-LR coating

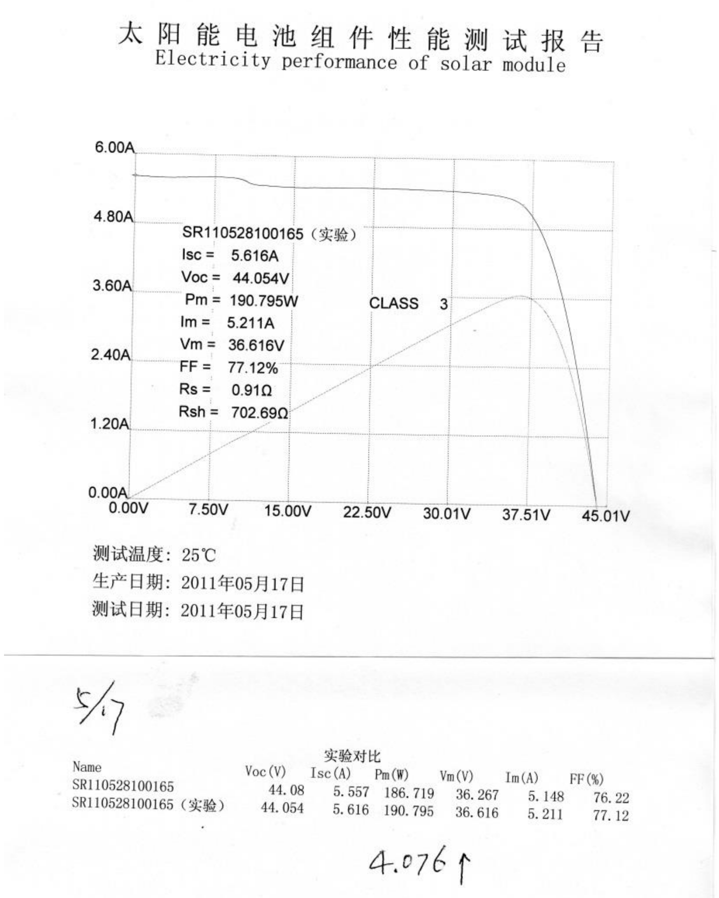
The wavelength at which solar panels generate power depends on manufacturers.
In general, thin-film solar panels achieve the highest power generation efficiency in the visible light range around 550 nm, while polycrystalline ones work best at 800 nm to 900 nm. Therefore, the amount of application of coating needs to be controlled so that individual solar panels have higher transmittance at suitable wavelengths.
The graphs below show the changes of transmittance depending on coating film thickness. As more coating is applied, the wavelength with the peak transmittance shifts from ultraviolet through visible to infrared range.
The right picture shows changes in color depending on film thickness. It is important to control the film thickness of an AS-LR coating evenly on the nanometer scale.



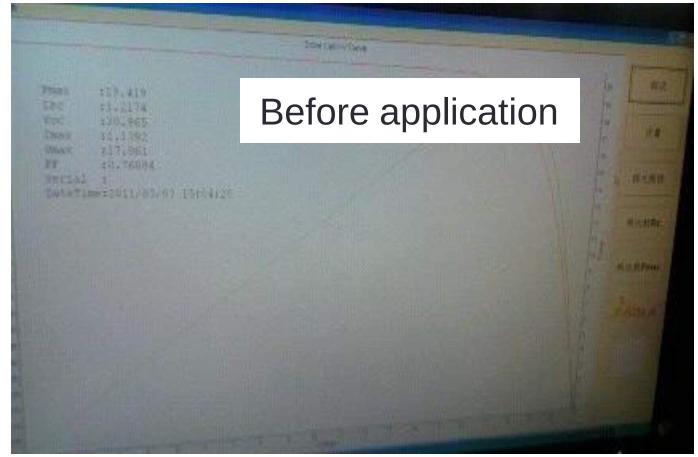



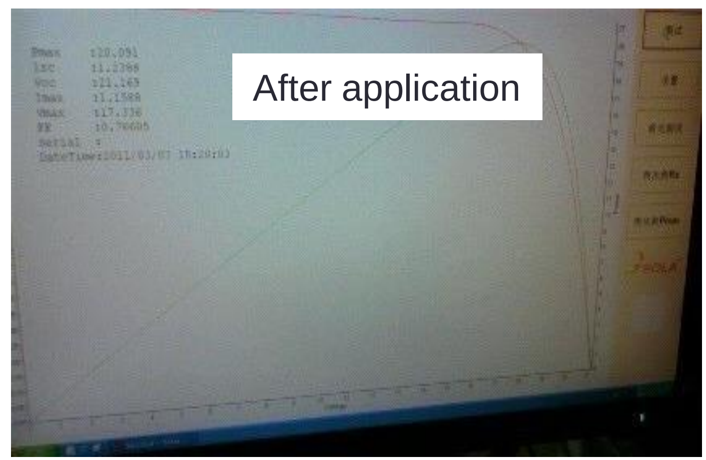



## ■ Application of AS-LR coating: Example 1




| Name | Voc (V) | Isc (A) | Pm (W) | Vm (V) | Im (A) | FF (%) |
|---|---|---|---|---|---|---|
| SR110528100165 | 44.08 | 5.557 | 186.719 | 36.267 | 5.148 | 76.22 |
| SR110528100165（实验） | 44.054 | 5.616 | 190.795 | 36.616 | 5.211 | 77.12 |




A Chinese solar panel manufacturer achieved an increase in power generation by about 2.2% from 186.719 W to 190.796 W by use of an AS-LR coating. Another manufacturer in Northeast China achieved an increase by about 3.4% from 19.419 W to 20.091 W.
A manufacturer in Southeast Asia achieved an increase by 2% in an environmental exposure test, and by 4% by mechanical application.

## ■ Application of AS-LR coating: Example 2

Before application

After application

The pictures show an example of application of AS-LR coating in a mountainous area in Northeast China. At six months after application, an effect against sand soil was clearly observed. Before application, the glass panel was covered with sand and had a lower power generation efficiency by more than 10%.

| | | | Voc (V) | Isc (A) | Pmax (W) | Vpm (V) | |
|---|---|---|---|---|---|---|---|
| SCE011029-1345 | 2012/1/31 | 10:36:08 | 44.78484 | 5.63483 | 191.4011 | 36.62565 | 塗り前 |
| SCE011029-1345 | 2012/3/22 | 12:32:53 | 44.5863 | 5.636312 | 189.9544 | 36.19965 | 塗り後 |
| | | | | | -0.76% | | |
| SCE011029-1347 | 2012/1/31 | 10:37:15 | 45.01142 | 5.621938 | 192.539 | 36.98962 | 手塗り前 |
| SCE011029-1347 | 2012/3/22 | 12:33:26 | 44.52917 | 5.693213 | 191.6658 | 36.16331 | 手塗り後 |
| | | | | | -0.45% | | |

结果显示，使用同一批次同一档位生产的手工涂防尘膜组件与普通组件，经过大约2个月室外暴晒，手工涂膜组件功率衰减情况优于普通组件。但手工涂膜工序较复杂，需要专业人员进行涂膜。

**テスト結果表示、同じ時間と同じ状況で生産された手塗りパネルと一般パネルを約2ヶ月室外日照テストを致しました、手塗りのパネルの功率削減状況が一般パネルより優することが証明できる。但し、手塗り膜の工程が更に複雑で、専門な作業員が必要になる**

Test result: An outdoor weathering test was performed for about two months on a general panel, and a panel coated with AS-LR by hand. Both panels were manufactured at the same time under the same conditions. As compared to the general panel, the coated panel had little decline in power generation efficiency. However, application by hand is complicated work and requires a skilled worker.

The result of an outdoor exposure test in Shanghai (see left) demonstrated that solar panels with an AS-LR coating individually had a decline in power generation of only 0.76% and 0.45% after two months of application. On the other hand, an uncoated panel had a decline of 6% in the same period.

Please watch a video about the AS-LR coating at:
[http://www.youtube.com/user/MiyakoRoller](http://www.youtube.com/user/MiyakoRoller)

## ■Application of AS-LR coating: Example 3

SolarSoul

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| 实验名称 | 组件功率 |
|---|---|
| 实验过程 | 1、选取2块180W普通钢化玻璃组件，1块250W普通镀膜玻璃组件，将其中1块钢化玻璃组件表面均匀涂上AS-LR镀膜液，并将该3块组件进行功率测试，并做好记录。<br>2、将测试后的2块180W组件安装在楼顶系统中，另外1块250W组件进行暴晒（不通电）。<br>3、10天后对该3块组件在次进行功率测试，并做好记录； |
| 实验数据 | 由上表可看出AS-LR镀膜组件功率衰降率最低。 |

| 测试日期 | 普通钢化组件 | AS-LR 镀膜组件 | 普通镀膜组件 |
|---|---|---|---|
| 11 月 7 日 | 182.271W | 180.807W | 253.329W |
| 11 月 16 日 | 177.409W | 178.666W | 245.418W |
| 功率衰降率 | 2.67% | 1.18% | 3.12% |

浙江环球光伏科技有限公司实验中心

| 测试日期 | 普通钢化组件 | AS-LR 镀膜组件 | 普通镀膜组件 |
|---|---|---|---|
| 11 月 7 日 | 182.271W | 180.807W | 253.329W |
| 11 月 30 日 | 175.942W | 177.419W | 239.841W |
| 功率衰降率 | 3.47% | 1.87% | 5.32% |

ults of Generated Power (Summary)

2013. 11. 27

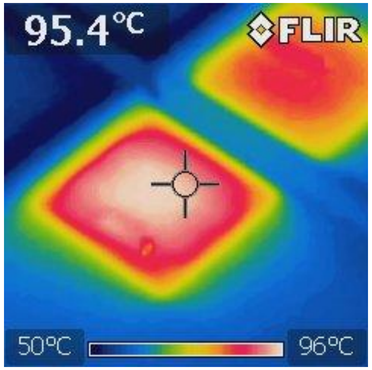
| | Date | April | | May | | June | | August | Average |
|---|---|---|---|---|---|---|---|---|---|
| | | 10th | 25th | 12th | 30th | 15th | 24th | 6th | |
| Non-Coating | Wh | 618 | 360 | 717 | 1,125 | 657 | 747 | 93 | 617 |
| | % | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Coating | Wh | 656 | 371 | 748 | 1,158 | 656 | 764 | 97 | 636 |
| | % | 106.2 | 103.1 | 104.3 | 102.9 | 99.9 | 102.3 | 104.2 | 103.3 |

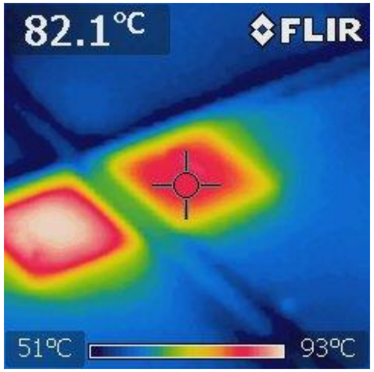
- Pmax : 250W
- Coating Date : 13. 4. 9

The tables show the comparison of the decline rate of power generation between an uncoated panel, an AS-LR coated panel and an existing AR coated panel (with improved transmittance). It was demonstrated that our AS-LR coating had the lowest decline in power generation. In addition, an AR coated panel had a larger decline in power generation than that of an uncoated panel. This demonstrated that an AR coated surface gets dirty more easily as compared to a glass surface. It is probably because application of AR coating increases insulation properties and surface area, resulting in more adhesion of dirt.

The table shows the test result in South Korea. There was a difference of 3.3% in the amount of power generation between an uncoated and a coated panels in a four-month average.

## ■Application of AS-LR coating: Example 3: Measures against hot spots

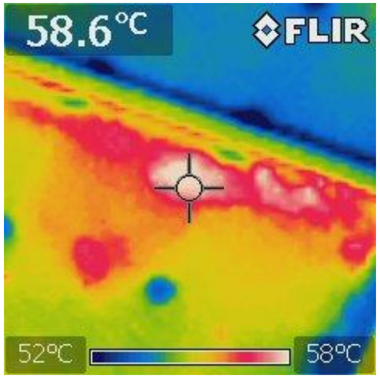


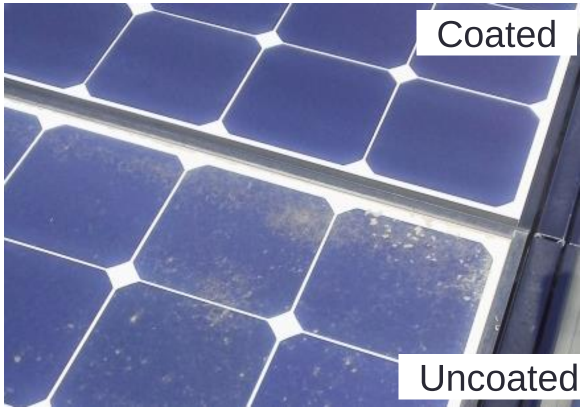




Test conditions: September 3, 2013
Weather: Sunny
Measurement time: From 10:00 to 11:00
Test place: Hachioji, Tokyo, Japan

In the right picture above, the areas with stickers were hot spots that had higher temperature by 30 ºC to 45 ºC than that of other cells.

This is probably because sand and other soil that had accumulated at the ends of the cells caused a sharp increase in temperature as compared to the surrounding areas (see picture below). As shown in the upper area of the picture below, areas to which sand and soil adhered had an increase in temperature of more than 5 ºC as compared to those without soil.

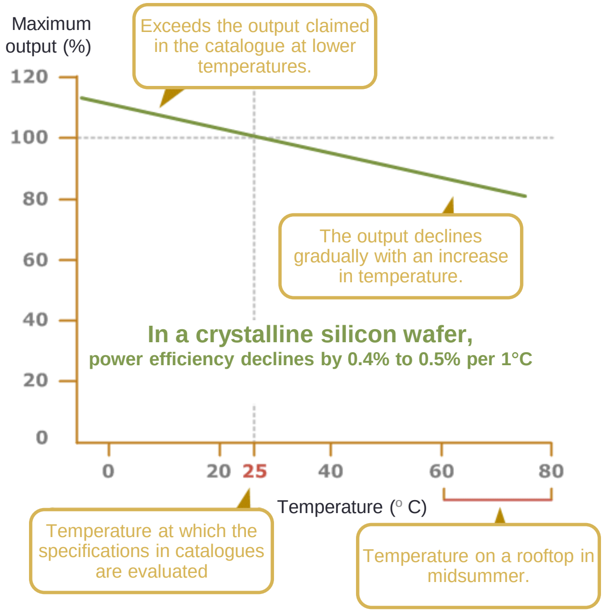


# ■Room-temperature heat dissipating technology

Solar panels generate more power with a decrease in temperature while generating less at high temperatures. This means that the output varies depending on temperature (decreasing with a rise in temperature), even if solar panels of the same size receive light of the same intensity. An international standard requires that the specifications of solar panels described in catalogues be measured at 25 ºC. With reference to 25 ºC, the output changes by 0.4% to 0.5% with a temperature change of 1 ºC. For example, at 35 ºC, the difference in temperature of 10 ºC decreases the output by 4% to 5%.
Based on this, solar panel manufacturers claim that their panels have a 20% loss in power generation in summer and 10% in winter. A technology to dissipate heat is required to control a rise in temperature. Heat moves by means of conduction, transfer and radiation.

Japan Nano Coat has blended a heat-dissipating coating made of carbon nanotubes (CNT) with the highest thermal conductivity (heat transfers easily) and good emissivity with our inorganic binder that can be used at room temperatures to develop coating materials designed for a variety types of substrates. As shown in the table of thermal conductivity, air is a key factor that influences the performance of a heat-dissipating coating. Air (pores) left inside a coating film and on a bonding plane has a thermal insulating effect and undermines heat dissipation. Japan Nano Coat developed a coating film with as small pores as possible by filling the spaces between CNTs with particles to improve thermal conductivity.



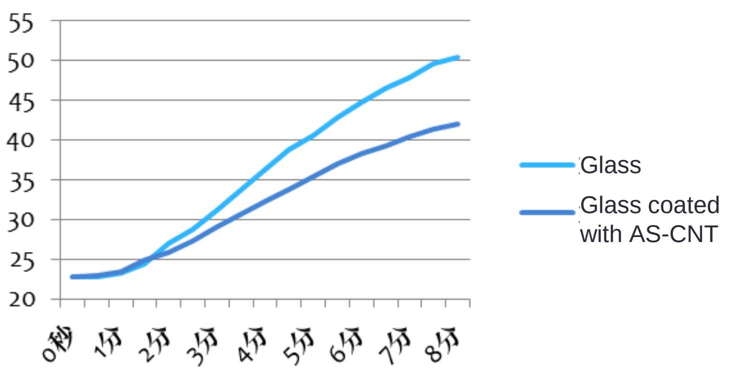

| Thermal conductivity | |
|---|---|
| Material | (W/m·K) |
| CNT | 3000 – 5000 |
| Diamond | 1000 – 2000 |
| Ag | 420 |
| Cu | 398 |
| Au | 320 |
| Al | 236 |
| Fe | 168 |
| Stainless | 16.7 – 20.9 |
| SiO2 (crystal) | 8 |
| Glass | 1 |
| Polycarbonate | 0.24 |
| Acrylic | 0.21 |
| Air | 0.0241 |

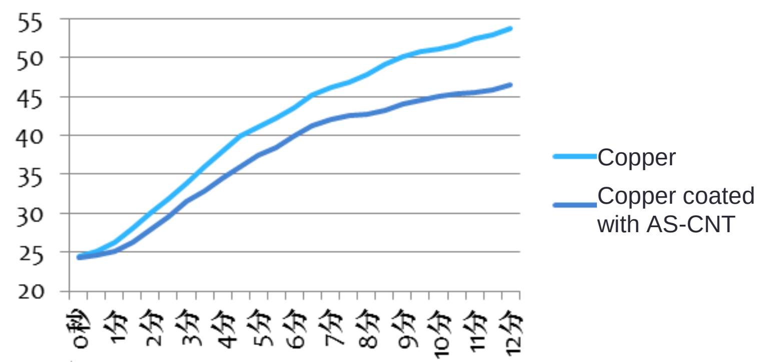
## ■Advantages of AS-CNT coating, and room-temperature heat-dissipating coating

Anti-static Carbon Nano Tube (AS-CNT) coating can be applied at room temperatures. It offers thermal dissipation, static prevention, abrasion resistance and chemical resistance (patent application was filed in January 2013).
When applied to a glass plate as anti-static coating, AS-CNT achieves a surface resistivity of $10^5\Omega$ at a visible transmittance of 70%. As a heat-dissipating coating, it offers a significant decline in temperature at low temperatures, and is useful to prevent burn by electrical home appliances. The coating film is formed at room temperatures, allowing for use in plastic articles that cannot be processed with much heat, including solar cell backsheets.
AS-CNT also delivers good adhesion to acrylic, PET, PC and other substrates.
*Primer needs to be used in some cases.
Please watch a video of the heat-dissipating effect of AS-CNT at:
[http://www.youtube.com/user/JapanNanoCoat](http://www.youtube.com/user/JapanNanoCoat)

### Heat-dissipating effect depending on substrate material

0 seconds
1 minute
2 minutes
3 minutes
4 minutes
5 minutes
6 minutes
7 minutes
8 minutes

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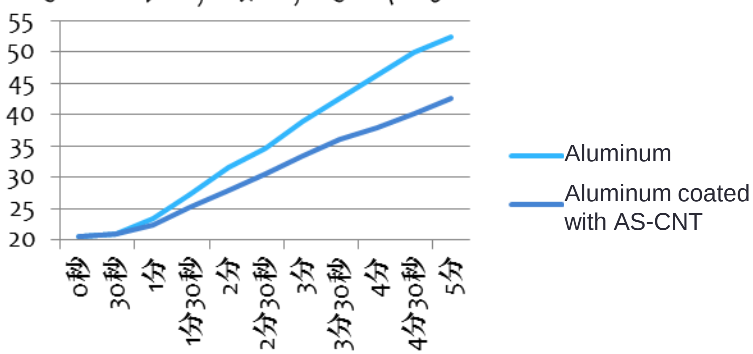


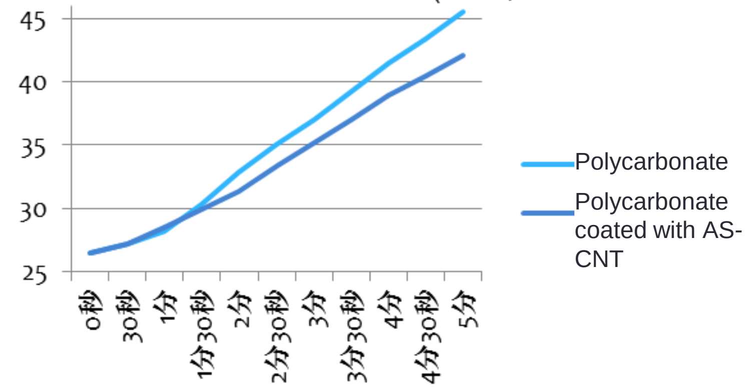


0 seconds
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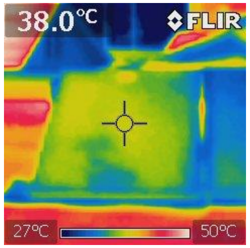
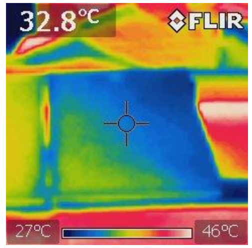
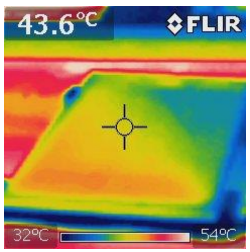
4 minutes
4.5 minutes
5 minutes

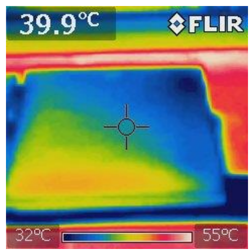
# Thermography of heat dissipation test of solar panels



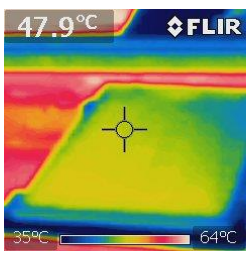



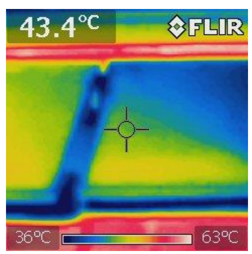

Temperature difference of 5.2ºC



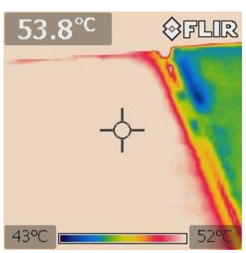



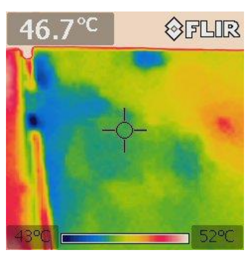

Temperature difference of 3.7ºC



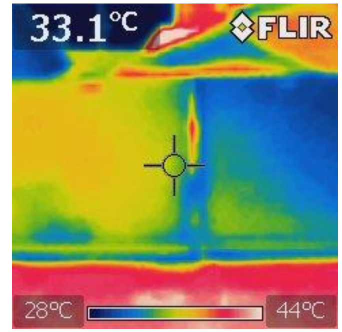



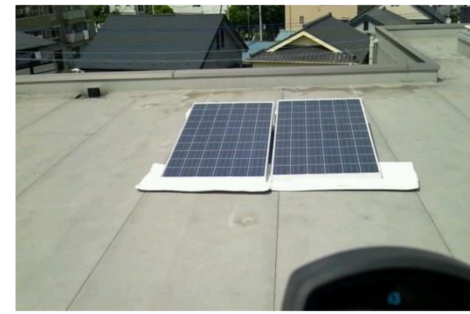

Temperature difference of 4.5ºC




Additional test Temperature difference of 7.1ºC



Test conditions: June 28, 2013; Temperature: 26ºC;
Wind velocity: 4 m
Weather: Cloudy, occasionally sunny
Measurement time: From 14:00 to 15:00
Test place: On the rooftop, Miyako Roller Industrial Company

(Left) Uncoated solar panels (Right) Solar panels with heat-dissipating coating. Temperature differences of 4ºC to 8ºC were observed around 40ºC.

There is a variation in temperature differences because measurements were performed during a short sunny period under the effect of wind, but it is obvious that the coated panels had a decrease in temperature.

Additional test: September 12, 2013; Temperature: 31ºC;
Wind velocity: 3 m
Weather: Sunny; Measurement time: 14:40
Test place: On the rooftop, Miyako Roller Industrial Company

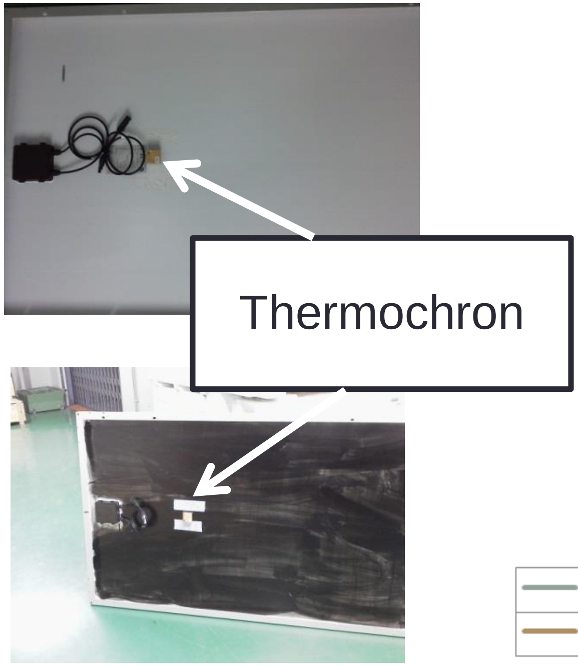
Please watch the video of tests on YouTube:

http://www.youtube.com/watch?v=d_zAjLDrtZQ

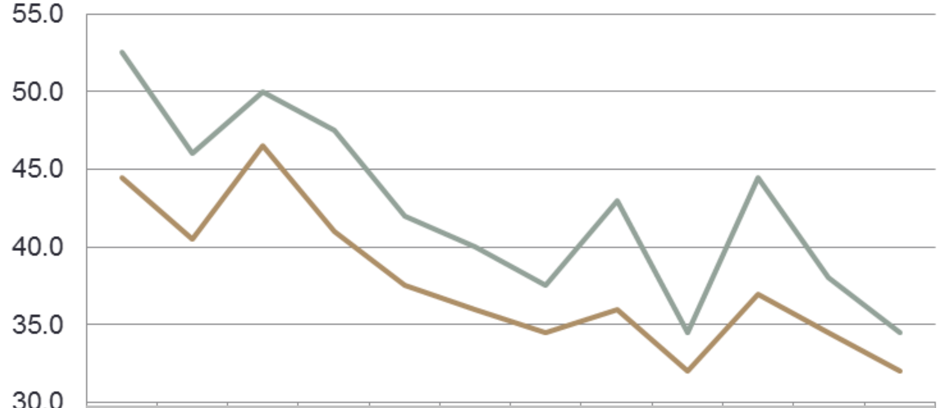
http://www.youtube.com/watch?v=sczXHvTvz5A

# Evaluation of heat dissipation from solar panel with time

Test conditions: July 27, 2013, Saturday; Daily maximum temperature: 31ºC; Wind velocity: 3 m
Weather: Cloudy and occasionally sunny with thunderstorms (for about 30 minutes from about 14:40)
Measurement time: From 11:00 to 16:30
Test place: On the rooftop, Miyako Motor Industrial Company
Measurement method: Temperature data logger “Thermochron”
Measurement position: On the top center of the panel (see pictures below)
Direction of panel: Westward (see picture on right)



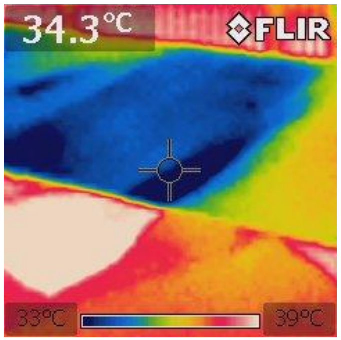

Test of heat-dissipating coating; Date: July 27, 2013; Place: Souka, Saitama, Japan; Weather: Cloudy

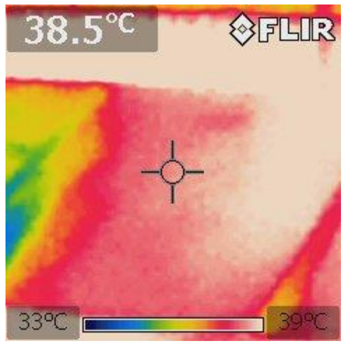



| | 11:00 | 11:30 | 12:00 | 12:30 | 13:00 | 13:30 | 14:00 | 14:30 | 15:00 | 15:30 | 16:00 | 16:30 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Uncoated | 52.5 | 46.0 | 50.0 | 47.5 | 42.0 | 40.0 | 37.5 | 43.0 | 34.5 | 44.5 | 38.0 | 34.5 |
| Heat-dissipating coating | 44.5 | 40.5 | 46.5 | 41.0 | 37.5 | 36.0 | 34.5 | 36.0 | 32.0 | 37.0 | 34.5 | 32.0 |

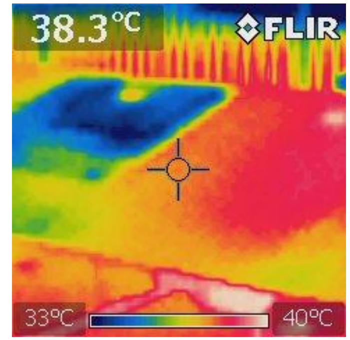
A maximum difference of 8ºC and average difference of 4.8ºC were observed.

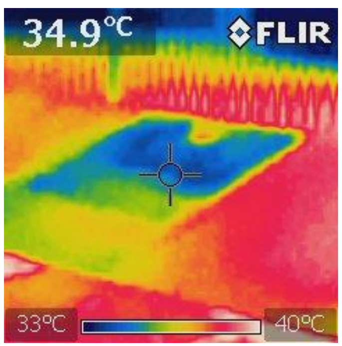
# Thermography of heat dissipation test of solar panels

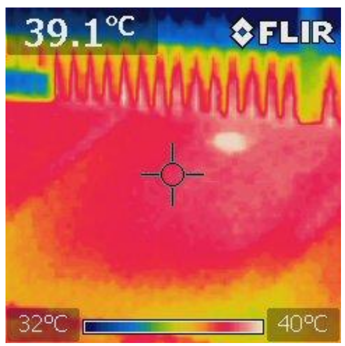


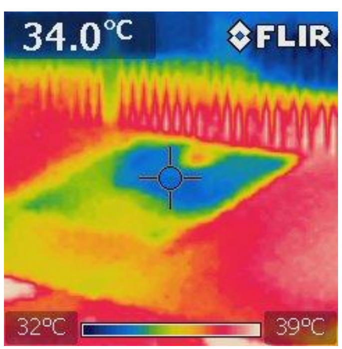

Temperature difference of 4.1ºC after cleaning with water

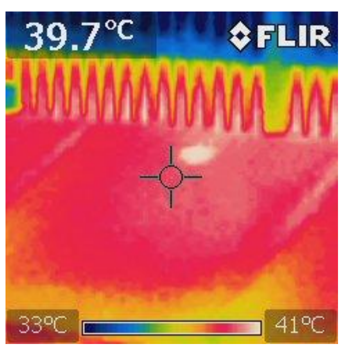



Temperature difference of 5.2ºC




Maximum temperature difference of 5.7ºC

Test conditions: July 31, 2013; Temperature: 32ºC;
Wind velocity: 3 m
Weather: Cloudy; Measurement time: From 13:30 to 14:30
Test place: Sasebo, Nagasaki, Japan

(Left) Uncoated solar panels (Right) Solar panels with heat-dissipating coating. Temperature differences of 4ºC to 5ºC were observed below 40ºC.

It is obvious that coated panels have lower temperatures.

The higher temperature in the lower part of the panels was due to a variation in the amount of application because of poor workability in coating.

An increase of temperature was observed in some areas where heat concentrated on connecting parts that transmit power.

■Properties of AS-LR and AS-CNT

| | AS-LR | AS-CNT |
|---|---|---|
| Test items | Glass substrate | |
| Optical properties | | |
| Visible light transmittance, single-side application | > 95% | > 70% |
| Visible light transmittance, double-side application | > 99% | > 50% |
| Haze | < 0.5 | < 1 |
| Refractive index | 1.30 - 33 | No data available |
| Physical properties | | |
| Surface resistivity | $10^8$Ω/☐ | $10^4$-$10^5$Ω/☐ |
| Contact angle (water) | < 5º | < 10º |
| Cross-cut adhesion test (by removal of tape) | 100/100 | 100/100 |
| Pencil scratch hardness test | > 6H | > 6H |
| Adhesion (immersed in boiling water for an hour) | No abnormalities | No abnormalities |
| Adhesion and moisture resistance (exposed to steam for an hour) | No abnormalities | No abnormalities |
| Environmental resistance | | |
| Weather resistance (an accelerated durability test for 200 hours) | No abnormalities | No abnormalities |
| Constant-temperature and high-humidity test (at 85ºC, 80%) | No abnormalities | No data available |
| Heat resistance (exposed to 100ºC for an hour) | No abnormalities | No abnormalities |
| Cold resistance (30-minute cycle between -18 ºC and 20 ºC, five times) | No abnormalities | No abnormalities |
| Chemical resistance | | |
| Etching by 30% HCI solution/30% NaOH solution for five minutes each | No abnormalities | No abnormalities |

*AS-CNT has fine control of binder depending on substrate material, and may have slight variation in performance.