Dyes Convert Light into Electricity — The Next Generation Solar Cell

Research and Development on the Dye-Sensitized Solar Cell Taking Full Advantage of the Characteristics of the Materials and Aiming to Open New Markets

Pictures painted with colors on glass plates are like stained glass and absorb light to generate electricity.
The dye-sensitized solar cell has characteristics that simply do not exist in current silicon solar cells; reduced costs due to materials and manufacturing methods and increased flexibility for application design.
Thus there are high expectations for this device as the next generation solar cell that will create new applications.
Sony is moving forward with research and development that takes advantage of Sony coating and printing technologies fostered in the development of video tape and lithium-ion batteries.
The Sony prototype dye-sensitized solar cell module has already achieved the world's top class of energy conversion efficiency, and at the same time as aiming for even further performance improvements, Sony is searching for new possibilities for solar cells that can blend seamlessly into our daily lives.

Prototype dye-sensitized solar cell panel. Screen printing is used for each of the four dyes, and a picture of marigolds is formed by applying colors with four levels of density.

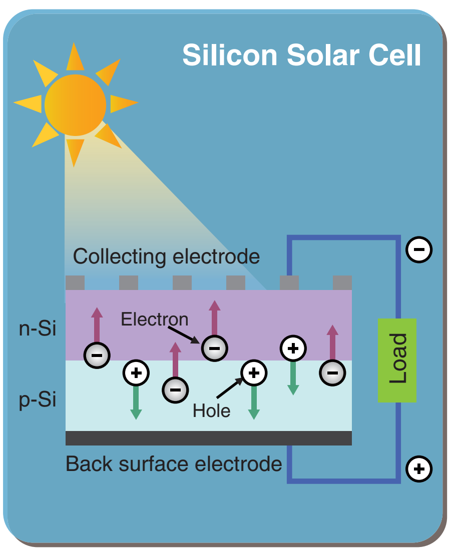
The panel generates enough electricity from interior ambient light to drive a propeller.

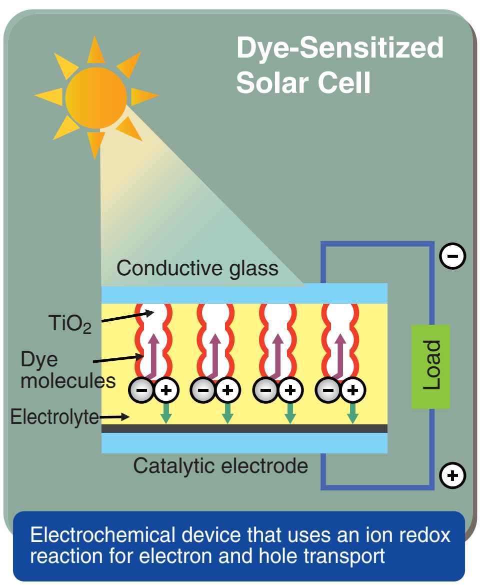
The world's highest level of energy conversion efficiency —— Sony's dye-sensitized solar cell

Energy conversion efficiency: 8.2%

*: This value was measured by Japan's National Institute of Advanced Industrial Science and Technology (AIST). The module aperture area is 18.5 cm²
(June 2008)

150 mW Class Module





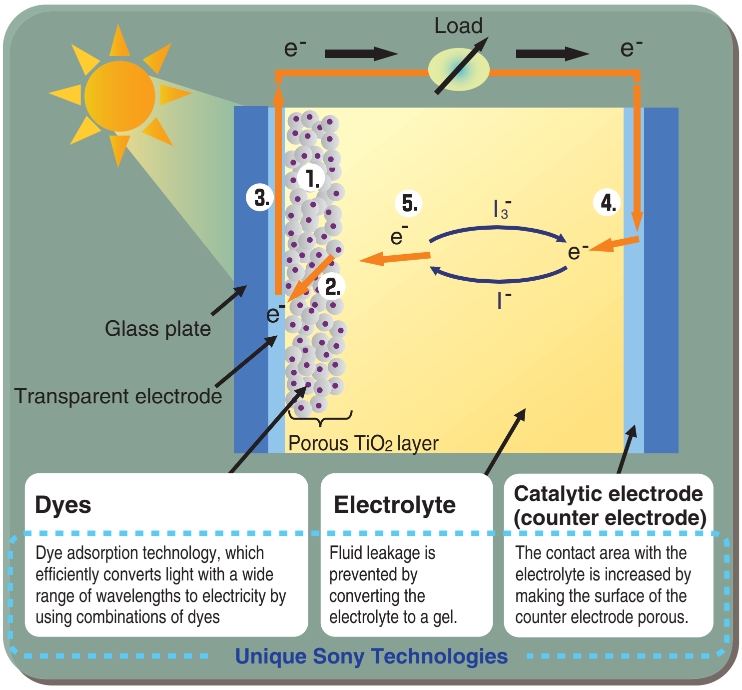
■Figure 1 Comparison of Solar Cell Device Structures

Dye-Sensitized Solar Cell Features

- Low-cost source materials (mainly TiO_2 and dyes)
  * No silicon is required and the device layer is thin (a few tens of microns)
- Low-cost manufacturing process (coating and printing of the materials)
  * No larger-scale vacuum equipment is required
- Stable electrical generation even under weak lighting or indoor ambient lighting
  * Visible light is absorbed efficiently and there is only a minimal dependence on the angle of incidence
- Wide flexibility in end product design, including the ability to form colors and patterns (Flexible panels using plastic substrates can also be created.)

Issues Facing Dye-Sensitized Solar Cells

- Further improvements in electricity generation performance
- Assuring the reliability required for practical application



■Figure 2 Electricity Generation by Dye-Sensitized Solar Cells

1. The dye absorbs light and electrons are thus raised to excited states.
2. The excited electrons are injected into the conduction band of the TiO_2.
3. The electrons disperse in the porus TiO_2 layer and are conducted outside the cell through the transparent electrode.
4. Triiodide ions (I_3^-) are reduced at the counter electrode, and iodide ions (I^-) are produced.
5. The iodide ions supply electrons to the dye from which electrons were removed.

Structure of the Dye-Sensitized Solar Cell

The dye-sensitized solar cell is often compared to photosynthesis in plants. This is because both convert the energy in light absorbed by dyes or pigments into other forms of energy.

In plants, light is converted to chemical energy, and glucose is produced. In contrast, the dye-sensitized solar cell converts light to electrical energy. First, let's look at the structure of the dye-sensitized solar cell. (See figure 1.) This device is like the LCD display, in which liquid materials and circuits are sandwiched between two glass plates, but in the dye-sensitized solar cell, the following four main materials are sandwiched between two conductive glass plates.

(1) TiO_2 (semiconductor electrode)

The white areas in figure 1 on the previous page

In figure 1, there is a reason these areas are drawn to look like snowmen consisting of stacked spheres. When TiO_2 paste is applied to the conductive glass and sintered at around 500°C, the solvent included in the paste is removed, and tiny particles (with diameters of 10 to 30 nm) of TiO_2 are connected to each other. This forms a porous film with many tiny holes.

(2) Dye

The red areas in figure 1 on the previous page

The dye is applied to the porous TiO_2 layer.

The energy conversion efficiency (the efficiency with which light is converted to electricity) is increased by the dye being attached in a three-dimensional manner to the TiO_2, whose surface area has increased radically. This is thought to make stable generation possible without being significantly affected by the angle of incidence of the light. Actually, it turns out that it is possible to generate electricity with just TiO_2. However, as one might expect due to its use as a sunscreen, TiO_2 only absorbs UV, and does not absorb other wavelengths. Therefore, the energy conversion efficiency is increased by adding a dye that absorbs light with wavelengths in the visible light range. That is, these devices are, as the name indicates, sensitized using dyes.

(3) Electrolyte

The yellow area in figure 1 on the previous page

Electrolyte refers to materials in which a material (the solute) is disassociates into positive and negative ions when dissolved in a solvent. Electrolytic solutions conduct electricity by the action of ions accepting and releasing electrons.

Through the development and manufacture of lithium-ion batteries, Sony has accumulated a rich store of know-how about these electrolytes. Sony has verified that there is almost no change in the energy conversion efficiency when the electrolyte solvent is made into a gel (is semi-solidified). Sony has created whole new classes of applications for dye-sensitized solar cells by increasing their reliability in a variety of ways, including using gels.

(4) Catalytic electrode (counter electrode)

The black area in figure 1 on the previous page

The counter electrode returns the electrons taken from the cell back to the ions.

Electricity Generation Principles and Issues

Figure 2 shows the mechanisms and flows that occur during electricity generation. When the dye absorbs light and ejects electrons (oxidation), those electrons pass through the TiO_2, the transparent electrode, the external circuit, the catalytic electrode, and the electrolyte, and are returned once again to the dye (reduction). Electricity flows as a result of this cycle.

Sony has succeeded in increasing the conversion efficiency to 8.2% in a prototype module. Sony is currently working on several issues, including the following three, to improve the performance even further: (1) increasing the current density by using an even wider range of wavelengths, (2) reducing the dark current to increase the cell voltage, and (3) suppressing the internal resistance by increasing the conductivity of the electrolyte.

Creating New Markets by Fusing Technology with Design

Hana-Akari

The Hana-Akari is a solar powered lantern. This is an interior lighting product concept in which solar cell panels are used to form the lampshade. The concept of this prototype is that it catches sunlight and room light to charge rechargeable batteries in the daytime and lights its own bulb using the stored electricity at night. This is the story of the creation of this prototype, which the designers Natsuki Kimura and Megumi Miki feel affection for. ("Hana"=flower, "Akari"=light in Japanese language)

Functionality that Inspires Design

Suzuki: I understand that the designer Natsuki Kimura had been interested in the dye-sensitized solar cell since two years before this project started. I remember that she came to several of Sony's internal research presentations. I think that this has become the foundation of the project and what made it possible to create this prototype in such a short period.

Kimura: I'm glad all these oppotunities brought us together for this project. After this collaboration was decided on, in the process of learning the basics of this technology from the engineers, I felt once again that this technology draws a clear line from other existing methods of photovoltaics. This system is inspired by nature and is very close to the way plants grow through photosynthesis. I could feel the researchers' enthusiasm. Then started a period of trial and error. At each week's brainstorming session, we'd argued heatedly in a good sense. This is only natural, since we designers have a different standpoint from that of the researchers. However, we did share the same goal of creating a product that does not exhibit the harshness normally associated with technology, no matter how high-level the technology is.

Yusuke Suzuki

Assistant Manager
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Sony Corporation

Morooka: Designers presented various design sketches in brainstorming sessions. The instant I saw the original artwork for the marigold pattern, I knew it was the right thing. "We can do this", I thought. I really wanted to go with it. So I committed to casting this idea into shape by the next meeting.

Kimura: That was very encouraging. We wanted to explore a variety of possibilities within a single image, such as color contrast and dot pattern. When, however, we tried with real materials, I found that the color contrast could be very different even in the same pattern depending on the dye. We put a lot of effort into searching for attractive color combinations for each of the four colors.

Morooka: We have created as many as 100 patterns of colors from the four dyes.

Kimura: We went so far as to have color samples made.

Morooka: They specified the colors for each part of the pattern, like the color of this petal is number fifty-something, we then followed it and made it up.

Kimura: I had never before seen color samples that actually had functionality. Based on the colors chosen, they built up the pattern divided into four layers carefully, not to misalign which could spoil the beauty of the picture. The work by the researchers and manufacturing process engineers was extremely precise, and we were impressed by this every day.

Masahiro Morooka

Assistant Manager
Group No.2
Environment & Energy Technology Laboratory
Advanced Materials Laboratories
Sony Corporation

Suzuki: The process of building up layers while positioning with extreme precision is something we have a lot of experience with on a regular basis in creating the actual structures of the batteries. But I have the impression that our understanding of this process was deepened by actually creating artwork by this layering process and by seeing the artwork.

Satoshi Uchida, associate professor of the University of Tokyo, who is the leader in the field of dye-sensitized solar cell research, made a comment on the prototypes .

Satoshi Uchida, Ph. D

Associate Professor
Research Center for Advanced Science and Technology (RCAST)
The University of Tokyo

There are probably 200 or 300 companies involved in developing dye-sensitized solar cells, and we have now reached the stage where actual applications are in sight. We have, however, focused solely on increasing performance and have not turned to the issue of how this technology will be used from the user's standpoint. In that sense, this prototype was a big surprise to me. While existing solar cells have been limited to be used by those who have a high awareness of environment issues, I think this prototype shows us an extremely concrete application that can be an intimate part of our daily lives. I am not the only one saying this is something that only Sony could have done.

Aesthetics Stimulated by Technology

Morooka: First, we were able to generate electricity by painting a picture on glass, so what's next? In our next brainstorming session, we considered how to use this idea to increase the appeal of the technology. Although there were proposals for a foldong screen and other items, we finally decided on this solar powered lantern. Oh, what was it that Ms. Kimura said? "I think it should have texture, and the feeling of being an object."

Natsuki Kimura

Producer/Designer
Sustainable Design Team
Crossover Design Group
Creative Center
Sony Corporation

Kimura: Right. It should be an object with atmosphere. The lantern, which its gentle light, is expressive and emotive. The lantern exudes an air of naturalness from its very presence, which I thought would match the characteristics of the dye-sensitized solar cell. It would catch sunlight or ambient room lighting and generate electricity, and then emit light at night using that electric power. And when people go to sleep, it would turn off by itself. Through the process of the brainstorming sessions, I came to really want to adopt this concept of natural coexistence with people.

Miki: That idea really grew!

Morooka: If you take a closer look at this picture, you see that the pictures connect to one another seamlessly when the panels are put together. But perhaps Ms. Miki can explain that better than I can.

Miki: No, you're doing fine. Please, continue.

Morooka: You wanted to have some sort of continuity of the pictures projected onto the surface the lantern is on, right?

Miki: Yes, that's right. I also started with the idea of tiling, and wondering if there was something that could be done with these panels lined up together. Wouldn't it be interesting if they all formed a connected pattern and in that state could generate electricity? Also people tend to have the image of solar panels as thick, black panels mounted on rooftops. These solar cells are not like that, but rather can be placed casually in interior settings; the lantern encourages you to use them in your interior spaces. As a result, what became our long term theme was that it would be an item that fits in with interiors, and that could be used flexibly as a unit.

Megumi Miki

Sustainable Design Team
Crossover Design Group
Creative Center
Sony Corporation

Morooka: I suppose it's because I have an engineering background, but I find the concept of a picture that can go on infinitely like a fractal to be appealing, and can understand it. However, when we first heard the requirement that the panels be frameless, we saw it as a headache. We stayed late at the office and agonized over it. We came up with a lot of ideas, but due to the need for space for the frame wires and the strength, the frameless concept seemed unreasonable at that point. OK, if that's unreasonable, how about 1.5 mm? But it turned out not to work. OK, at the very least give us 3 mm (the current state) to work with. Please...

Miki: We certainly had a few clashes. We once spent two hours just discussing this issue.

Morooka: There were several other difficult issues that also raised their heads. The layered coating issue she mentioned previously was one. We were asked to position each layer with a 0.1 mm accuracy. That was really hard. However, it was not completely impossible. That made us want to try and achieve it. When engineers from other companies see this prototype, they quickly realize the heights of the walls we had to get over. They say "This is something only Sony could do."

Lifestyles which Technology can Blend into

Kimura: A major point that makes this technology inspiring to me as a designer is that something, that has design characteristics of its own like stained glass, can itself generate electricity. Design does not have to be sacrificed for the function. I think in that purity and honesty lies the possibility to change the way the world looks.

Suzuki: A large part of the cost of solar cells, including silicon solar cells, lies in the glass used. For this reason, if the glass can have design value as well, it could have a large impact in increasing the use of the panels. Also, when dye-sensitized solar cells are used to power mobile devices, those devices must be taken out and placed in the sun. In creating such a culture, collaborations with designers will be necessary. As these devices get closer to actual use, the number of constraints on them will increase even further, so we will need the support from you designers even more.

Kimura: I think our role as designers is not limited to just the design aspects, but also includes viewing technologies from the standpoint of everyday living and proposing lifestyles that incorporate those technologies. Therefore I hope that we can continue to have such mutually stimulating relationships with engineers in the future.

Morooka: Yes, I hope we can inspire and enhance each other's ability through further collaboration.

Miki: I feel that I have grown through my experience in this project, and I am thankful to have had the chance to participate. I would like to work on even higher level issues together for the next step.