innovation

The Spectrum of
Clean Energy Innovation

Fundamental Science
Market-Relevant Research
Systems Integration
Testing and Validation
Commercialization
Deployment

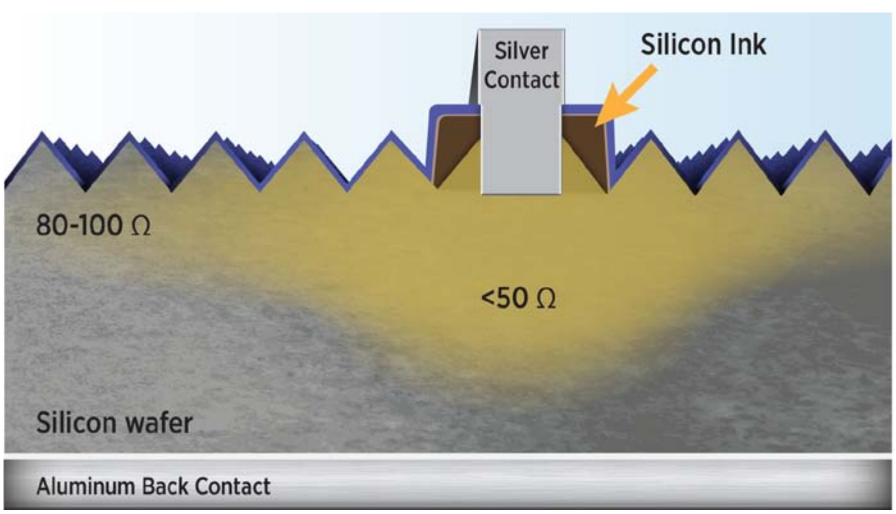
NREL Paves the Way to Commercialization of Silicon Ink

Reducing the cost of crystalline silicon solar cells is important for the industry to remain competitive. However, in recent years, manufacturers had reached a limit in the conversion efficiency, or output power, of silicon solar cells using current production methods. The problem called for an entirely different approach. Innovalight Inc. and the National Renewable Energy Laboratory (NREL) met the challenge with the combination of a new semiconductor material, Silicon Ink, and a simple production process.

Leaping Over the Conversion Efficiency Barrier

In 2008, Innovalight, a start-up company in Sunnyvale, California, invented a liquid form of silicon, called Silicon Ink. It contains silicon nanoparticles that are suspended evenly within the solution. Those nanoparticles contain dopant atoms that can be driven into silicon solar cells, which changes the conductivity of the silicon and creates the internal electric fields that are needed to turn photons into electrons—and thus into electricity.

The ink is applied with a standard screen printer, already commonly used in the solar industry. The distinguishing feature of Silicon Ink is that it can be distributed in exact concentrations in precisely the correct locations on the surface of the solar cell. This allows most of the surface to be lightly doped, enhancing its response to blue light, while heavily doping the area around the electrical contacts, raising the conductivity in that area to allow the contact to work more efficiently. The accuracy and uniformity of the ink distribution allows the production of solar cells that achieve higher power production at a minimal additional cost.



Cross-sectional view of a crystalline silicon cell showing the precise application of Silicon Ink. Most of the surface is lightly doped to minimize charge recombination and enhance the cell's blue response, whereas the region below the contact (in yellow) is heavily doped to minimize contact resistance. The heavily doped region has a sheet resistance of less than 50 Ohms, while the lightly doped region's resistance is 80-100 Ohms.

Through deep technical expertise and an unmatched breadth of capabilities, NREL leads an integrated approach across the spectrum of renewable energy innovation. From scientific discovery to accelerating market deployment, NREL works in partnership with private industry to drive the transformation of our nation's energy systems.

This case study illustrates NREL's innovations in Market-Relevant Research through Commercialization.

NATIONAL RENEWABLE ENERGY LABORATORY

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

However, Innovalight needed NREL's help in optimizing its Silicon Ink and proving to its customers and potential investors that the product could actually be applied in a precise manner, without spreading or overflowing, to yield significant efficiency improvements.

The Partnership Advantage

In work that spanned 4 years, Innovalight and NREL partnered in the "proof of concept" phase of developing Silicon Ink for optimal use with solar cells.

The first partnership between NREL and Innovalight was in 2008, in the form of a cooperative research and development agreement, or CRADA. Later, Innovalight won a competitive bid to enroll in NREL's Photovoltaic Incubator program. In this arrangement, the company had to meet stringent deadlines to deliver improvements in its technology in return for the help of NREL scientists in overcoming barriers.

Under the CRADA, NREL scientists confirmed that the Silicon Ink technology provides controlled, localized doping of the silicon, and they suggested process improvements to Innovalight. In addition, by using techniques called secondary ion mass spectrometry and scanning capacitance microscopy, NREL showed that the ink could be applied so that it stayed within preset boundaries. The lab used contrast imaging with a scanning electron microscope to verify that the Silicon Ink technology provided uniform doping of differently shaped microscopic surfaces on the cell (see sidebar). In 2010, Innovalight completed the final phase of its NREL PV Incubator subcontract, during which NREL helped the company improve the conversion efficiency of Silicon Ink.

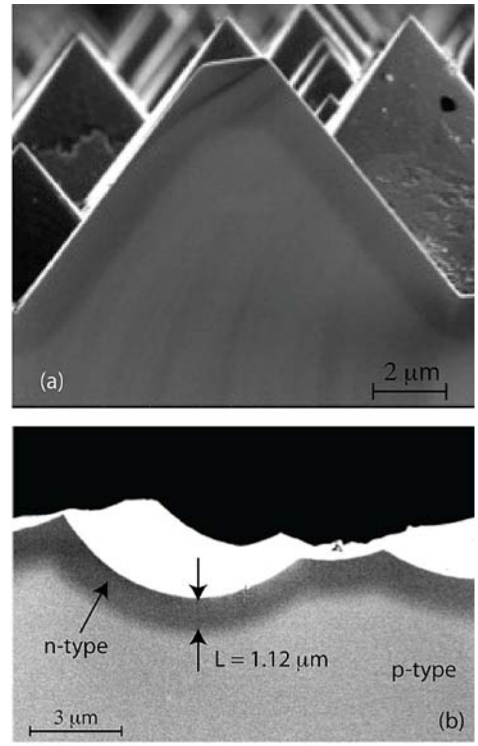
In the highly competitive world of solar cell production, efficiency improvements are generally measured by tenths of a percentage point. Typical silicon solar cells today have conversion efficiencies of about 16% to17.5%, with polycrystalline cells at the low end of the range and monocrystalline cells at the high end. NREL and Innovalight were able to demonstrate production-level efficiency gains, including a 17%-efficient multicrystalline silicon cell and an 18.5%-efficient monocrystalline silicon cell.

Put another way, Silicon Ink improves the sunlight-to-electricity conversion efficiency of monocrystalline solar cells by 1% or more absolute, which equates to a 6% relative improvement, based on a starting cell efficiency of 17.5%.

Clearly, this product represents very significant progress in the production of high-efficiency solar cells.

The Payoff: Commercialization

NREL helped Innovalight show its customers and investors that Silicon Ink could be applied in a controlled manner and would improve solar cell efficiency with minimal additional manufacturing costs, thereby lowering the cell manufacturer's cost per watt. The Silicon Ink technology won an R&D 100 Award for NREL and Innovalight in 2011, identifying it as one of the top 100 technological innovations of the year. Now, five of the world's leading solar companies are using this technology to make solar cells. And in July 2011, the global chemical company DuPont saw so much potential in Innovalight that it acquired the company, greatly advancing the prospects for innovative, cost-competitive solar manufacturing in the United States.



These NREL-produced scanning electron micrographs show the high levels of uniform doping achieved when Silicon Ink is applied to silicon with (a) a pyramidal surface structure and (b) an iso-textured surface. The doping appears as a dark grey layer along the surface of the cross-sections.

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