innovation

The Spectrum of
Clean Energy Innovation

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

Pioneering Inkjet Printing Technology Produces Thin-Film Photovoltaics

You might think that an inkjet printer can only be used to print your word-processor documents. But in fact, at the National Renewable Energy Laboratory (NREL), scientists have been pioneers in developing inkjet printer technology to produce thin-film solar modules.

A major application of these modules—in which the solar absorber can be deposited on virtually any type of material and in any shape—is in the huge building-integrated photovoltaics (BIPV) market. For example, NREL's patented inkjet printing technology allows hybrid copper indium gallium diselenide (CIGS) material to be deposited directly onto common building materials such as metal, glass, plastic, foil, and composites. The thin-film solar modules produced this way can be integrated directly into the building's structure—turning entire buildings into clean energy power plants.

Developing Inks for Metal Grids

For this solar inkjet printing technique, special liquid precursor inks are required that can be reliably delivered onto some type of substrate. Solar cell technologies may use conductive grids, which are thin metallic strips across a cell that collect free electrons produced when sunlight shines on the solar cell. Traditionally, these grid lines have been applied to a cell using a screen lithography method. However, the downside of using this technique includes slow throughput in the manufacturing line and less-than-desired sharpness of the lines.

To overcome these shortcomings, NREL scientists created metals that can be deposited by metal-organic decomposition using inkjet printing. Here, the conductive metal is attached to an organic molecule that delivers the metal, which then remains after low-temperature drying. Depending on the ink composition, one can deposit metal grids that are copper, silver, nickel, aluminum, platinum, or palladium. For thicker inks, NREL has developed metal-organic inks that also contain metal nanoparticles. The technique has numerous benefits—such as

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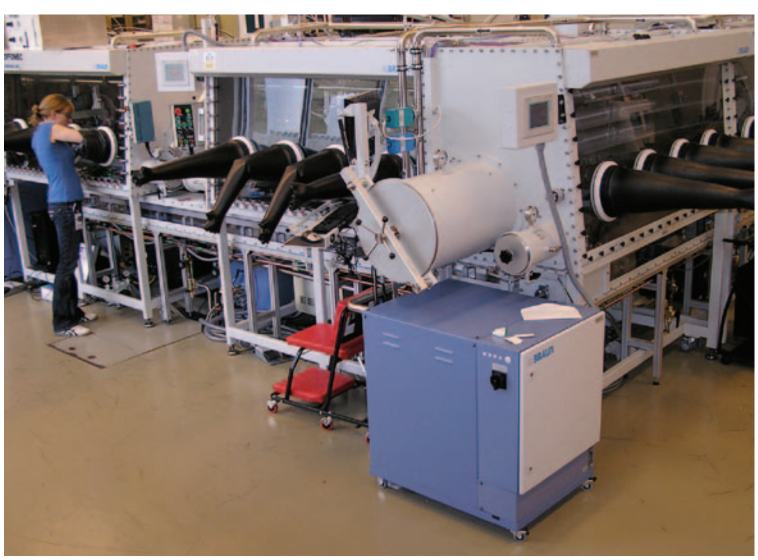
This case study illustrates NREL's contributions in Market-Relevant Research through Deployment.



Part of NREL's Atmospheric Processing Platform, showing the spray deposition and inkjet printing units to the left and sample preparation and rapid thermal processing units to the right.

PIX 17119

NREL
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not requiring contact with the substrate, producing high-resolution features, requiring only a low-temperature and nonvacuum depositional environment, containing stable materials, and allowing large-area deposition for rapid-throughput manufacturing.

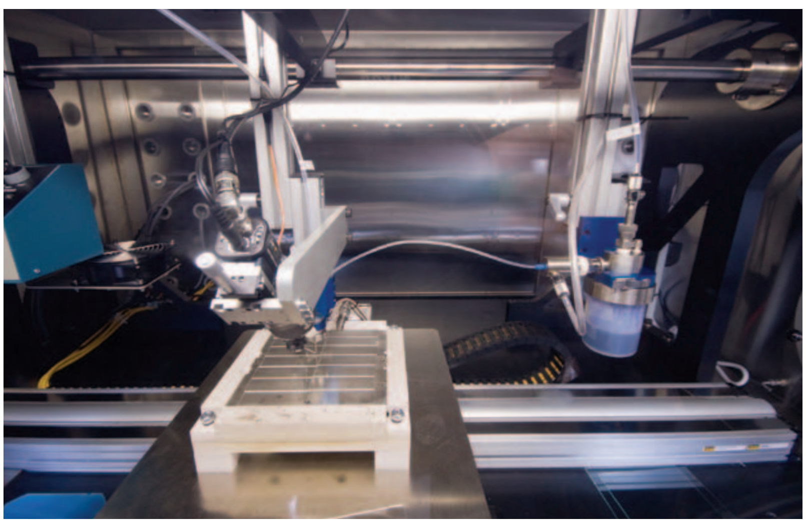
…and Inks for Solar Absorbers

Inkjet printing can also be used to create the actual solar absorber, which is the layer in a solar cell in which the sunlight's energy generates free electrons. For example, one way to produce the thin-film semiconductor material of CIGS employs inkjet printing in conjunction with HelioVolt Corporation's field-assisted simultaneous synthesis and transfer (FASST) process (see sidebar). Using NREL's indium-gallium selenide and copper selenide inks, the FASST approach can produce large-grain, high-quality CIGS material within the manufacturing environment.

The inkjet printing technique is not limited to CIGS but can also be applied to other solar thin-film materials and organic photovoltaics. For example, cadmium telluride (CdTe) is an absorber layer material being developed for deposition by a liquid precursor. The nanoparticulate-based ink is spray-deposited to form a film. NREL has successfully produced optically dense thick films—up to 10 micrometers with no cracks—of pure CdTe.

…and for Transparent Conducting Oxide

Many solar cell technologies collect freed electrons using a very thin layer of transparent conducting oxide (TCO) rather than metallic grid lines. NREL uses its special inks with ultrasonic spray deposition to lay down thin, high-quality TCO layers such as indium zinc oxide. Scientists continue to improve this technique so that conductivities will rival those of conventionally deposited TCOs.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Close-up view of the inside of the inkjet printing unit.

Putting NREL's Atmospheric Process Platform into Action

NREL has used inkjet printing for contacts on organic photovoltaic (OPV) devices, as well as on CIGS devices. For OPV, however, the temperature at which the contacts can be printed is lower than the ideal temperature for the inks already developed by NREL. Unfortunately, using higher temperatures leads to reduced conductivity of the metal and poor cell performance. Therefore, one research focus is to develop an ink that will be compatible with OPV contact formation, using the Atmospheric Processing Platform in NREL's state-of-the-art Process Development and Integration Laboratory. The platform has capabilities for inkjet printing and for spray deposition, rapid thermal processing, sputter deposition, and evaporation.

A FASST Approach for Making CIGS Thin-Film Modules

NREL partnered with HelioVolt Corporation of Austin, Texas, to develop a revolutionary thin-film manufacturing process using inkjet printing to produce thin-film copper indium gallium diselenide (CIGS) photovoltaics. In 2008, *R&D Magazine* selected the technology for an R&D 100 Award, as well as the magazine's Editor's Choice Award as one of "the most revolutionary technologies of the year."

The thin-film PV manufacturing process combines NREL's precursor inks with a rapid reactive bonding technique commercialized by HelioVolt, which opened its first commercial-scale factory to produce CIGS solar products in October 2008.

NREL's precursor inks were first licensed in October 2007 for production into CIGS photovoltaic devices using HelioVolt's field-assisted simultaneous synthesis and transfer—or FASST—process. HelioVolt has been awarded eight patents related to this technology, while NREL has applied for three patents and has documented its intellectual property in five additional records of invention. The hybrid CIGS technology advances are the result of four years of Cooperative Research and Development Agreement collaborations between NREL and HelioVolt.

Using NREL's inks, HelioVolt developed the FASST proprietary processing system that quickly bonds the film layers under heat and pressure to form large-grain CIGS crystals. The process takes seconds to complete at substantially lower temperatures than other conventional solar cell manufacturing, which requires hours at temperatures of 500° to 700° Celsius or higher, as well as vacuum processing, evaporation, and other steps that are capital-intensive. These thin films can be manufactured at a fraction of the cost of crystalline silicon—$1 of crystalline silicon can be replaced with $0.03 of CIGS thin film to achieve the same electrical output.

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