innovation

The Spectrum of Clean Energy Innovation

Fundamental Science

Market-Relevant Research

Systems Integration

Testing and Validation

Commercialization

Deployment

An Upside-Down Solar Cell Achieves Record Efficiencies

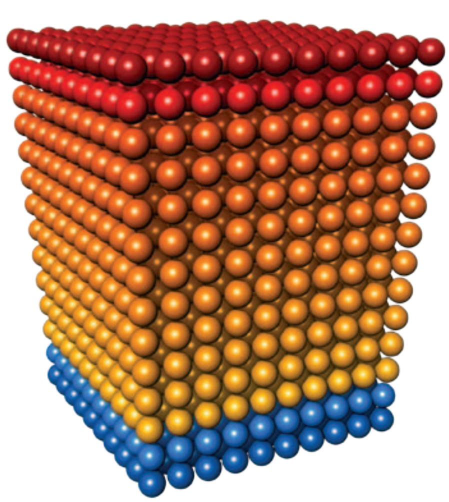
The inverted metamorphic multijunction (IMM) solar cell is an exercise in efficient innovation—literally, as the technology boasted the highest demonstrated efficiency for converting sunlight into electrical energy at its debut in 2005. Scientists at the National Renewable Energy Laboratory (NREL) inverted the conventional photovoltaic (PV) structure to revolutionary effect, achieving solar conversion efficiencies of 33.8% and 40.8% under one-sun and concentrated conditions, respectively.

The IMM solar cell's advanced ultra-light, highly flexible design earned it a 2008 R&D 100 Award and a 2009 Award for Excellence in Technology Transfer by the Federal Laboratory Consortium. The cell's inventors pioneered a new class of solar cells with marked advantages in performance, engineering design, operation, and cost, achieving previously unseen efficiencies while resolving some of the major issues that have surrounded multijunction PV cells since their inception.

NREL Takes PV to the Next Level

NREL has long been a leader in research and development of PV technology—particularly for complex multijunction cells. These cells convert solar energy more efficiently than single-junction cells by including multiple layers of semiconductor materials that capture the energy of different portions of the solar spectrum. However, multijunction cells can be rigid, heavy, and expensive, with their performance and cost-effectiveness limited by their configuration.

Having contributed fundamentally to the development of the standard triple-junction cell, NREL scientists knew further success—and higher efficiencies—could be reached with a new approach to device construction.



To build a solar cell from two materials with different lattice spacings, such as gallium arsenide (shown in blue) and gallium indium phosphide (shown in red), the IMM solar cell incorporates a metamorphic layer that gradually changes in composition, creating a transition between the mismatched materials.

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 contributions in Fundamental Science through Commercialization.

NREL
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.

NREL's Innovative—and Inverted—Design

NREL's breakthrough approach is founded on the use of high-quality "lattice-mismatched" materials to achieve high-performance crystal structures with optimal bandgaps. A bandgap is the range of energies that will excite the electrons within each semiconductor, and it corresponds directly to the portion of the solar spectrum that the semiconductor can convert into electricity.

For multijunction solar cells, the semiconductor materials with the ideal bandgaps often have mismatched crystal structures with dissimilar atomic spacings—and thus can experience critical defects when grown in a monolithic configuration. Such "lattice-mismatched" materials have historically challenged PV researchers, particularly because defects in the bottom mismatched layers can propagate through the upper layers as they are deposited. Principal Scientist Mark Wanlass of NREL's Concentrating Photovoltaics group was able to answer the lattice-mismatch challenge by inverting the "normal" deposition process of cell layers to invent the IMM solar cell.

Growing the layers in reverse order limits the mismatch challenge to just the "bottom" subcells, which are the final layers added to the inverted cell. Between each subcell, the IMM cell uses a transparent, compositionally graded layer to allow the growth of one subcell on another with a different crystal structure. With this added "metamorphic" layer, crystalline materials with the necessary bandgaps can be paired without compromising efficiency.

Two additional design advantages are incorporated into the IMM cell. First, mounting a supporting carrier or "handle" to the cell allows it to be engineered optimally for a given application. Next, selectively removing the parent substrate—the material the cell is grown upon—creates an ultra-light, ultra-thin device with great flexibility, increasing the cell's power-to-weight ratio tenfold. The parent substrate can be reused, thereby reducing materials usage and cost.

The original implementation of the IMM cell concept, a triple-junction cell with a structure of gallium indium phosphide/gallium arsenide/gallium indium arsenide (GaInP/GaAs/GaInAs), established two record efficiencies in 2005: 31.1% at one-sun intensity and 37.9% under concentrated light equal to 10 suns. In 2008, an improved variant of the IMM design set a new world record of 40.8% efficiency under 326 suns at NREL.

In Space, On Land: Versatile Application

With its ultra-high efficiency and flexibility, the IMM cell is a natural candidate for use in the space satellite market. The highly pliant cell could be included in the very skin and structure of a satellite, thus eliminating the need for traditional—and bulky—wing-shaped solar arrays.

The same traits that render the IMM cell viable for space applications also open doors for its terrestrial use—particularly in concentrating photovoltaic (CPV) systems, which use lenses or mirrors to focus sunlight onto solar cells. The IMM cell enables the use of a small amount of highly efficient material to generate utility-scale solar power, thus helping to drive down costs while increasing power production.

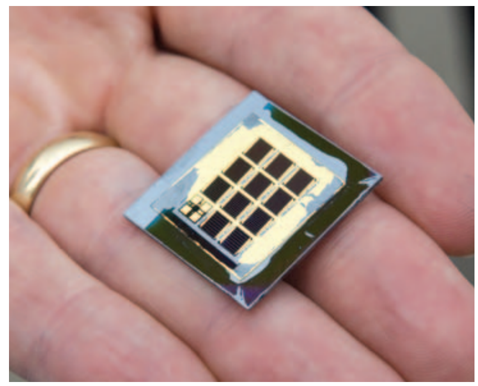
In a remarkably short time span, NREL and its partners (see sidebar) have contributed indelibly to solar cell progress with their IMM technology—and further development is on the horizon. In 2010, Wanlass and his NREL colleagues began work on a new quadruple-junction IMM cell, which could approach 50% efficiency at high solar concentrations.

Taking IMM to the Market

IMM solar cell technology has been on fast track to commercialization since its invention. The transfer of the technology to industry started in 2005, when Albuquerque-based Emcore, a leading provider of PV components and subsystems for space and terrestrial deployment, made the IMM cell the centerpiece of its business plan and technology roadmap.

In 2009, NREL partnered with California CPV company GreenVolts in a 2-year cooperative research and development agreement (CRADA) to continue to commercialize the IMM solar cell design. Through its Technology Commercialization and Deployment Fund, the U.S. Department of Energy has committed $500,000 for GreenVolts to co-develop NREL's patents and bring the technology to market.

Also in 2009, NREL entered into a multi-year CRADA with RF Micro Devices, Inc. (RFMD), a telecommunications-chip giant based in Greensboro, North Carolina. RFMD's goal is to produce IMM PV cells commercially.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The IMM solar cell boasts a light weight and high flexibility, as well as an ultra-high efficiency, making it optimal for space and concentrated terrestrial applications. Credit: Patrick Corkery, NREL

National Renewable Energy Laboratory

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