NREL
NATIONAL RENEWABLE ENERGY LABORATORY

New Multijunction Design Leads to Ultra-Efficient Solar Cell

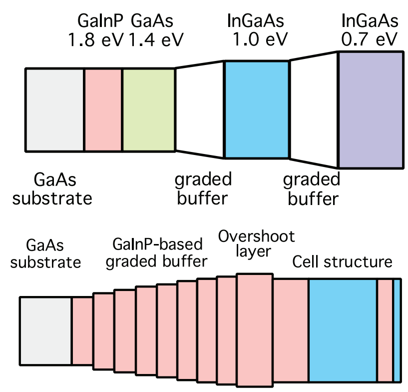
Highlights in Research & Development

Four-junction III-V multijunction cell uses buffer layers and other innovations to reach 45.6% efficiency at 690 suns

NREL scientists have shown that four-junction solar cells grown as inverted metamorphic multijunctions—a design concept invented at NREL—can achieve extremely high efficiency by using lattice-mismatched subcells.

Two layers are lattice-mismatched if the spacing between atoms in one layer differs from the spacing in the other layer. Such mismatched layers introduce crystal imperfections—defects known as dislocations—into the device that can drastically degrade device performance. However, NREL scientists have learned how to control these dislocations, confining them to inactive regions of the devices. The result is that even highly mismatched materials can be used to create highly efficient multijunction cells.

In NREL research, one-sun devices—which do not concentrate the light illuminating the cell—achieved a 35.3% efficiency under the space spectrum and 37.8% efficiency under the global spectrum at 25°C. Concentrator devices achieved a 45.6% peak efficiency under 690 times the direct spectrum at 25°C.



Top: Four-junction inverted metamorphic multijunction structure; profile indicates variations in lattice constants between subcells. Bottom: General structure of compositionally graded buffer and lattice-mismatched solar cell. Illustrations are not to scale. Illustration by Ryan France, NREL

The figure at right illustrates the materials and design of the NREL cell. First, lattice-matched high-bandgap gallium indium phosphide (GaInP, 1.8-eV bandgap) and gallium arsenide (GaAs, 1.4-eV bandgap) subcells are grown on a GaAs substrate. Then, compositionally graded $Ga_xIn_{1-x}P$ buffer layers transition the lattice spacing to two gallium indium arsenide (InGaAs) subcells.

These metamorphic InGaAs subcells are used to tailor the bottom two bandgaps of the four-junction solar cell, allowing a multijunction bandgap combination engineered to a given spectrum. The graded buffers have led to 1.0-eV and 0.7-eV metamorphic InGaAs subcells with very high material quality.

The density of dislocations in the mismatched subcells is kept low by using an optimized structure and growth conditions in the graded buffers. The collection of charge carriers in these mismatched subcells is nearly perfect, and voltages are also excellent across a wide bandgap range.

NREL researchers have also made other improvements in the device compared to previous designs, including: a broadband four-layer antireflection coating, a novel metamorphic tunnel junction interconnect, and unprecedented performance from the GaInP top layer.

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References: (1) R.M. France et al., Quadruple-junction inverted metamorphic concentrator devices, IEEE J. Photovoltaics 5(1), 432–437 (2015). DOI: 10.1109/jphotov.2014.2364132. (2) R.M. France et al., Design flexibility of ultra-high efficiency four-junction inverted metamorphic solar cells, IEEE PV Specialists Conference, June 14–19, 2015, New Orleans, LA. (3) M.W. Wanlass et al., Lattice-mismatched approaches for high-performance, III-V photovoltaic energy converters, IEEE PV Specialists Conference, Jan. 3–7, 2005, Lake Buena Vista, FL.

Key Research Results

Achievement

NREL scientists can confine dislocations in metamorphic materials to inactive regions of multijunction solar devices.

Key Result

Even highly mismatched materials can now be considered to create highly efficient multijunction cells.

Nonconcentrating devices reached 37.8% efficiency; concentrating devices reached 45.6% efficiency under 690 suns.

Potential Impact

With NREL's new design, multijunction devices can achieve extremely high efficiency using lattice-mismatched subcells.

Metamorphic buffers allow great flexibility in designing a device fine-tuned to different spectra.

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.

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