

# Simple Method Quantifies Recombination Pathways in Solar Cells

Highlights in  
Research & Development

NREL's analytic equation uses open-circuit voltage data to determine how much recombination occurs via different channels in a solar cell.

Shockley-Reed-Hall recombination plays an important role in determining the performance of solar cells that are limited by defects. Critical regions with problematic defect recombination can include the space-charge region (SCR), quasi-neutral region (QNR), base-emitter interface, and surfaces.

The dominant recombination mechanism in a solar cell can be identified experimentally by measuring open-circuit voltage ( $V_{oc}$ ) as a function of temperature and light intensity. But existing analytical formulas for  $V_{oc}$  are currently derived for a single mechanism—and they do not permit separate determination of the magnitude of recombination in each region.

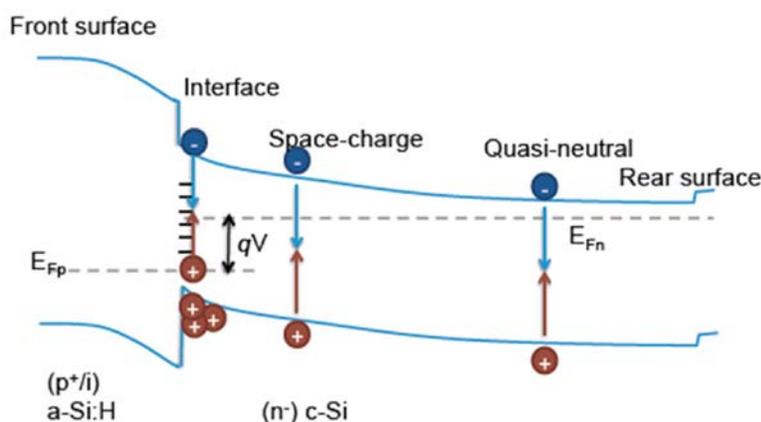
Scientists at the National Renewable Energy Laboratory (NREL), however, have developed a straightforward characterization approach to analyze recombination occurring via different pathways in a solar cell. The overall recombination in different regions of a cell is equated to the total generation rate, and the resulting excess carrier concentration is related to  $V_{oc}$ . The scientists thereby obtain an equation for  $V_{oc}$  that depends on the light intensity, temperature, and strength of recombination in the SCR, QNR, and junction-interface regions.

The new formula can be applied to accurately model performance variation with respect to defect parameters, light intensity, and temperature. As an application, NREL researchers used their new method with experimental data on polycrystalline CuInGaSe solar cells. By determining recombination fractions in each region, they have gained a better understanding of possible device modifications to improve overall performance.

**Technical Contact:** Sachit Grover, [sachit.grover@nrel.gov](mailto:sachit.grover@nrel.gov)

**References:** Grover, S.; Li, J.V.; Young, D.L.; Stradins, P.; Branz, H.M. (2013). "New Analysis of Suns- $V_{oc}$  and  $V_{oc}(T)$ : A Simple Method to Identify Recombination Channels in Solar Cells." *39th IEEE Photovoltaic Specialists Conference*; June 16–21, 2013, Tampa, Florida.

Grover, S.; Li, J.V.; Young, D.L.; Stradins, P.; Branz, H.M. (2013). "Reformulation of Solar Cell Physics to Facilitate Experimental Separation of Recombination Pathways." *Applied Physics Letters* (103: 9); pp. 093502–093502-5. DOI: 10.1063/1.4819728.



Heterojunction band-diagram for amorphous/crystalline silicon (a-Si/c-Si) solar cell. The labeled regions of potential recombination are the front and rear surfaces, interface, space-charge region, and quasi-neutral region.

## Key Research Results

### Achievement

NREL developed a characterization approach to analyze recombination occurring via different channels in a solar cell.

### Key Result

NREL researchers obtained an equation for open-circuit voltage that depends on light intensity, temperature, and strength of recombination in different regions of a solar cell.

### Potential Impact

Applying the new formula allows accurate modeling of changes in performance due to defect parameters, light intensity, and temperature.

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.

15013 Denver West Parkway  
Golden, CO 80401  
303-275-3000 | [www.nrel.gov](http://www.nrel.gov)

NREL/FS-5200-59207 | September 2013

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 10% post consumer waste.