NREL's Optical Cavity Furnace Brings Together a Myriad of Advances for Processing Solar Cells

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

An innovative furnace uses light and unique light-induced effects to make higher-efficiency solar cells at lower cost.

Turn on the Lights

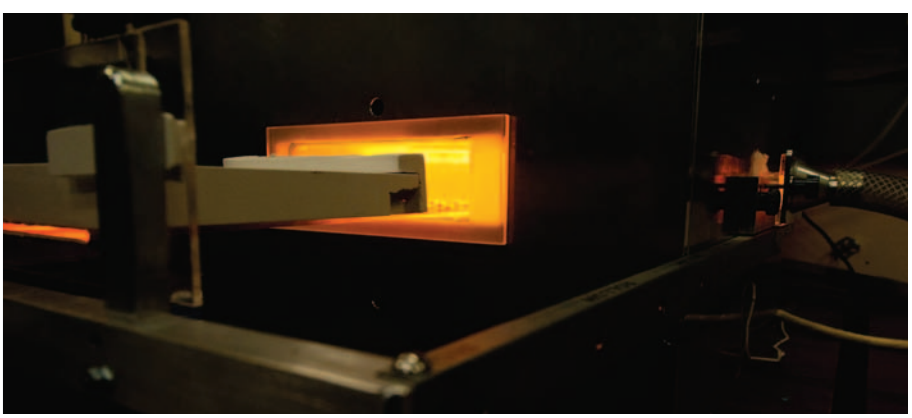
Billions of solar cells are manufactured each year, and each one must be heated several times in a furnace as part of the fabrication process. But heating by conventional means can waste a considerable amount of energy if it is not focused specifically on the cells. And uneven temperature profiles across a cell can create a final solar device having sub-par performance.

To rectify this situation, scientists at the National Renewable Energy Laboratory (NREL) have turned to light as a source of heat. Lights from a specially designed array illuminate a thin wafer of silicon within a furnace known as an Optical Cavity Furnace. The furnace virtually eliminates energy loss by lining the cavity walls, which have an optimal geometric design, with ceramic materials of high reflectance and thermal insulation. The operational temperature of the cell ranges up to 1,200°C, with almost all the energy being delivered to the wafer rather than being wasted heating the space between the lights and wafer.

Cell Processing, Step by Step

NREL has developed several applications for the optical processing of silicon wafers. One furnace configuration allows wafer screening, and a second handles four other process steps. These various applications are described below.

- **Wafer screening**. NREL's furnace provides mechanical testing of the wafer integrity immediately following wafer sawing and before any further processing. Conventional screening methods require physical twisting to apply this load, whereas the NREL furnace screening is a non-contact technique that uses light to thermally stress the material, then identify and remove weak, crack-containing wafers upstream from the processing line. Optical furnace screening has low power requirements and potentially leads to higher throughput and lower cost.
- **Junction formation by diffusion or low-temperature epitaxy**. The basis of a silicon solar cell is the *p-n* junction diode, typically formed by diffusing a phosphorus dopant into a *p*-type semiconductor at high temperature. The so-called photonic or light-induced effects enabled by the Optical Cavity Furnace enhance interdiffusion of some impurities, allowing junction formation at a lower temperature and in a shorter time. These effects also promote epitaxial growth—similarly oriented crystal structures—of amorphous silicon over crystalline silicon, enabling a new low-cost method for junction formation.
- **Annealing**. This heat treatment alters the microstructure of the wafer (or other polycrystalline thin films), causing property changes such as increased grain size, altered composition, and lower stress. Compared to a conventional furnace, the Optical Cavity Furnace offers more efficient heating and uniform spatial temperature to produce better diffusion of dopants. It can be used for a variety of annealing applications that can change the grain structure, defects, and composition to more favorable conditions for higher cell efficiency.



A special component of the Optical Cavity Furnace—a quartz muffle—diffuses and controls the intensity of the optical flux to provide a homogenous temperature profile across a 6-inch by 6-inch wafer. In addition, it provides a very clean process environment, which improves device quality and performance.
Photo by Dennis Schroeder, NREL/PIX 19517

The commercial version of the Optical Cavity Furnace, which provides exact flux control and uniform heating by using 26 lamps configured into three zones.
Photo by Bhushan Sopori, NREL/PIX 19519

- **Metallization**. Silicon cells can have silver front-contacts and an aluminum back-contact that can be formed ("fired") simultaneously during cell fabrication. The Optical Cavity Furnace achieves better control of the firing process that results in a stronger back-surface field and improved cell performance. The furnace selectively heats the silicon and metal interface to localize the melt in a very stable process. The furnace is also highly effective in gettering, which is a high-temperature process that removes crystal defects in the material and improves cell performance.
- **Oxidation**. In this processing step, a thin layer of silicon dioxide is formed on the wafer surface to improve the electronic properties through "surface passivation," where fewer light-generated electronic carriers are lost at the surface. Furnace designs have been developed for dry and wet oxidations. The furnace can also create a texturing of the back-contact silicon/aluminum interface to produce a highly reflective surface that reflects light back into the cell. This processing can increase the cell's conversion efficiency.

Faster, Cheaper, More Versatile

The Optical Cavity Furnace can help the solar cell manufacturing industry in the United States by producing solar cells with higher quality and efficiency at a fraction of the cost of conventional thermal furnaces. This clean furnace could increase the relative conversion efficiency of solar cells by 3% to 4%, and it is only one-quarter to one-half the cost of a standard industrial thermal or infrared furnace. It also consumes 40% less electrical power during wafer processing.

AOS Solar, Inc., is currently working with NREL under a cooperative research and development agreement and has built the first commercial Optical Cavity Furnace. Further design work is focusing on expanding the capabilities of the furnace to handle additional oxidation and diffusion processes. Furthermore, multiple process steps can be done within the same furnace, which saves time in not having to move cells from one furnace to another.

Lower power consumption. Simpler operations. Smaller equipment footprint. Expanded capabilities in processing steps. When it comes to solar cell processing, the Optical Cavity Furnace is using light and NREL's innovation to provide a strong alternative to today's conventional industry furnaces.

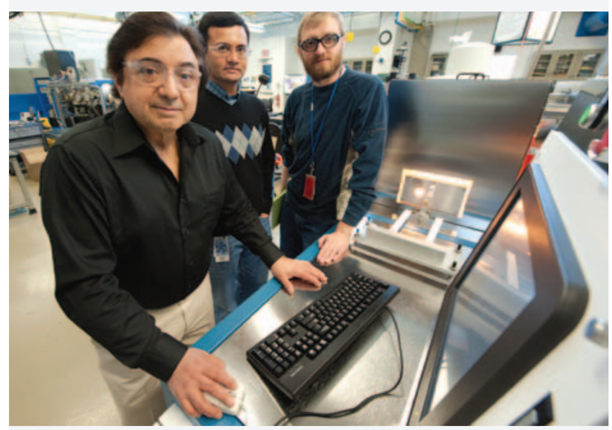
A 20-Year Pursuit

The Optical Cavity Furnace is the culmination of two decades of NREL research on optical processing technologies. The tenacity in pursuing this furnace design is underscored by the 12 patents that relate in some way to its development.

This intellectual property has covered a range of topics—starting with the overall concept of an optical furnace, and adding the details of specific components of the furnace, such as the quartz muffle and diffuser plate, or considering specific applications of the furnace, such as screening wafers, growing silicon dioxide layers, gettering impurities, and improving device contacts.

Furthermore, the design of the optical furnace is based on detailed computer modeling of thermal absorbance calculated using PV Optics software, a previous R&D 100 award winner.

The furnace's throughput is currently a single wafer at a time, but high throughput is the solar industry's primary focus for reducing costs. So NREL has continued to develop such capabilities for the furnace, working on a design for a conveyor system that could raise throughput to an industrial-compatible rate of 2,000 wafers an hour.



Dr. Bhushan Sopori (left) has been at the center of the fundamental and focused research needed to develop the Optical Cavity Furnace. Other scientists, including Vishal Mehta and Peter Rupnowski (background), have contributed significantly to the success of this project.
Photo by Dennis Schroeder, NREL/PIX 19518

For More Information

NREL: Bhushan Sopori
303-384-6683
bhushan.sopori@nrel.gov

AOS Solar: Anikara Rangappan
310-995-4277
arangappan@aossolar.com

National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, Colorado 80401
303-275-3000 · www.nrel.gov

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

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/FS-2000-52216 • August 2011