Cheaper, improved solar cell fabrication

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Using light as a source of heat in a reflecting cavity distributes energy precisely for making higher-performance photovoltaics.

The photovoltaic industry routinely uses infrared furnaces to make solar cells from a thin wafer of silicon. Although modern furnaces can handle high throughput, they are typically not energy efficient. Generally, they produce a uniform energy flux over the wafers, but the wafer edges radiate more heat than their centers, and so the resulting temperature is not uniform throughout the wafer. This results in compromised performance: for example, a large-area solar cell’s edges will have poor electrical performance and degrade its overall output power.

To rectify this, we have developed an optical cavity furnace as a single-wafer processing system, akin to a rapid thermal processing system. It uses unique geometry and multiple reflections to efficiently produce an energy distribution on the wafer that exactly compensates for the heat loss at the edges. The result is a highly uniform temperature distribution across the wafer. With this furnace, we have also established that an uncooled system can be run in a steady state to minimize energy loss. In addition, new processes that take advantage of photonic effects can enhance the cell efficiency. The furnace takes advantage of changes in the optical properties of semiconductor-metal interfaces—for instance, between silicon and aluminum—due to interdiffusion and alloying. We are confident that the principles of our single-wafer processor can easily be scaled to a high-throughput system (e.g., 2000 wafers per hour) using conveyor-belt technology.

The optical cavity furnace uses banks of lights, segmented into different lateral zones and heights, and dispersed inside an insulating ceramic cavity (see Figure 1). The geometry of the cavity reflects the visible and infrared light directly onto the solar cells. Ports for insertion of wafers and exhaust perturb the radiation flux very little. This design reduces unnecessary heating of the furnace chamber, saving energy and shortening the energy payback time (the amount of time a device must be in operation to recover the energy used in its own construction). This arrangement also results in reproducible temperature uniformity of ±1°C across a 156mm × 156mm cell. The design of the optical furnace is based on detailed computer modeling of optical absorbance calculated using the National Renewable Energy Laboratory’s (NREL’s) PV Optics software. The inside surface of the cavity is made up of high-temperature ceramic, and so only the lamp ends need to be cooled. In this way, it reduces the volume of coolant used. The highly reliable optical cavity furnace combines the advantages of photonics with tightly controlled engineering to maximize efficiency and minimize heating, cooling, and ownership costs.

NREL has developed several applications for the optical cavity furnace. Various configurations of the furnace can be used to screen wafers for defects, using light to thermally stress the material, then identify and remove weak, crack-containing wafers.

Continued on next page
before they enter the production line. A different configuration can be used for several other applications. The furnace can facilitate growth of high-quality wet/dry oxide on silicon wafers; such oxides are typically used for surface passivation of wafers for minority-carrier lifetime studies and passivation of solar cells. It can also create n- and p-type junctions in silicon wafers, apply silver or aluminum contacts to the front and back surfaces of wafer/thin-film silicon solar cells, and improve the light-trapping properties of solar cells by modifying the firing profile to create shiny or diffuse semiconductor-metal interfaces. The optical cavity furnace’s even, controlled application of light is also useful for annealing and for vacancy injection gettering, which is used to remove harmful impurities such as iron from silicon solar cells.

All processing is done inside a clean quartz muffle within the cavity, which keeps the device free of any contamination. The process cycles for each of the steps include photonic effects that favorably influence interdiffusion of impurities to form a junction at lower temperature and shorter time duration, silicon diffusion to form a uniform metal-Si alloy layer, and diffusion of transition metals for strong impurity gettering. Careful control of photonic effects can also change the point defect concentration in the material and inject vacancies into silicon from a silicon-aluminum interface. Defect clusters limit the performance of multicrystalline silicon solar cells and also act as sites for impurity precipitation. Precipitated impurities cannot be gettered by conventional processes, which limits the performance of existing multicrystalline silicon solar cells to below 17%. However, using optical excitation in our furnace to inject vacancies, we are able to dissolve these precipitates and getter them at lower temperatures (compared to the melting point of the precipitated impurities).

The manufacturing costs of solar cells using our clean furnace are only one-quarter to one-half those of a standard industrial thermal or infrared furnace. The furnace also consumes 40% less electrical power during wafer processing, and we calculate that it could increase the conversion efficiency of solar cells by 3% to 4%. In its present form, the optical cavity furnace is a bench-top, single-wafer processing furnace. We are currently negotiating to license the furnace for commercial manufacturing and our future work will increase the furnace’s capacity handle to commercial, high-throughput manufacturing processes.

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Bhushan Sopori is a principal engineer. His current research interests include defect engineering for advanced device fabrication, development of instrumentation for material growth and device fabrication, wafer strength, and development of new processing techniques. Sopori has developed several instruments and solar cell fabrication methods that are either licensed or under negotiation for licensing to industry for commercial production. Three of these instruments, including the optical cavity furnace discussed in this article, have won prestigious R&D 100 awards.

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References