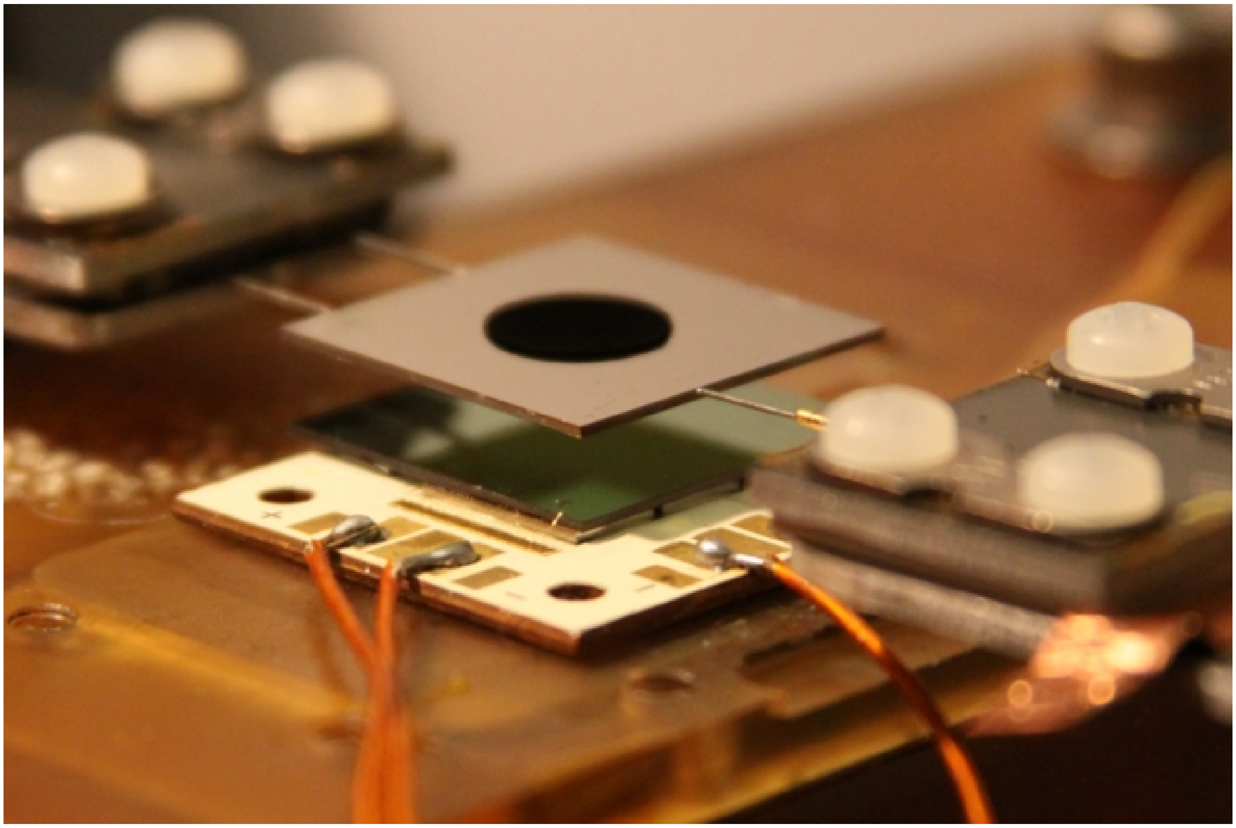
System converts solar heat into usable light, increasing solar cell's overall efficiency

May 24 2016, by David L. Chandler



While all research in traditional photovoltaics faces the same underlying theoretical limitations, MIT PhD student David Bierman says, “with solar thermal photovoltaics you have the possibility to exceed that.” In fact, theory predicts that in principle this method could more than double the theoretical limit of efficiency, potentially making it possible to deliver twice as much power from a given area of panels.

A team of MIT researchers has for the first time demonstrated a device based on a method that enables solar cells to break through a theoretically predicted ceiling on how much sunlight they can convert into electricity.

Ever since 1961 it has been known that there is an absolute theoretical limit, called the Shockley-Queisser Limit, to how efficient traditional solar cells can be in their energy conversion. For a single-layer cell made of silicon—the type used for the vast majority of today's solar panels—that upper limit is about 32 percent. But it has also been known that there are some possible avenues to increase that overall efficiency, such as by using multiple layers of cells, a method that is being widely studied, or by converting the sunlight first to heat before generating electrical power. It is the latter method, using devices known as solar thermophotovoltaics, or STPVs, that the team has now demonstrated.

The findings are reported this week in the journal *Nature Energy*, in a paper by MIT doctoral student David Bierman, professors Evelyn Wang and Marin Soljačić, and four others.

While all research in traditional photovoltaics faces the same underlying theoretical limitations, Bierman says, "with solar thermophotovoltaics you have the possibility to exceed that." In fact, theory predicts that in principle this method, which involves pairing conventional solar cells with added layers of high-tech materials, could more than double the theoretical limit of efficiency, potentially making it possible to deliver twice as much power from a given area of panels.

"We believe that this new work is an exciting advancement in the field," Wang says, "as we have demonstrated, for the first time, an STPV device that has a higher solar-to-electrical conversion efficiency compared to that of the underlying PV cell." In the demonstration, the team used a relatively low-efficiency PV cell, so the overall efficiency of the system was only 6.8 percent, but it clearly showed, in direct comparisons, the improvement enabled by the STPV system.

The basic principle is simple: Instead of dissipating unusable solar energy as heat in the solar cell, all of the energy and heat is first absorbed by an intermediate component, to temperatures that would allow that component to emit thermal radiation. By tuning the materials and configuration of these added layers, it's possible to emit that radiation in the form of just the right wavelengths of light for the solar cell to capture. This improves the efficiency and reduces the heat generated in the solar cell.

The key is using high-tech materials called nanophotonic crystals, which can be made to emit precisely determined wavelengths of light when heated. In this test, the nanophotonic crystals are integrated into a system with vertically aligned carbon nanotubes, and operate at a high temperature of 1,000 degrees Celsius. Once heated, the nanophotonic crystals continue to emit a narrow band of wavelengths of light that precisely matches the band that an adjacent photovoltaic cell can capture and convert to an electric current. "The carbon nanotubes are virtually a perfect absorber over the entire color spectrum," Bierman says, allowing it to capture the full solar spectrum. "All of the energy of the photons gets converted to heat." Then, that heat gets re-emitted as light but, thanks to the nanophotonic structure, is converted to just the colors that match the PV cell's peak efficiency.

In operation, this approach would use a conventional solar-concentrating system, with lenses or mirrors that focus the sunlight, to maintain the high temperature. An additional component, an advanced optical filter, lets through all the desired wavelengths of light to the PV cell, while reflecting back any unwanted wavelengths, since even this advanced material is not perfect in limiting its emissions. The reflected wavelengths then get re-absorbed, helping to maintain the heat of the photonic crystal.

Bierman says that such a system could offer a number of advantages over conventional photovoltaics, whether based on silicon or other materials. For one thing, the fact that the photonic device is producing emissions based on heat rather than light means it would be unaffected by brief changes in the environment, such as clouds passing in front of the sun. In fact, if coupled with a thermal storage system, it could in principle provide a way to make use of solar power on an around-the-clock basis. "For me, the biggest advantage is the promise of continuous on-demand power," he says.

In addition, because of the way the system harnesses energy that would otherwise be wasted as heat, it can reduce excessive heat generation that can damage some solar-concentrating systems.

To prove the method worked, the team ran tests using a photovoltaic cell with the STPV components, first under direct sunlight and then with the sun completely blocked so that only the secondary light emissions from the photonic crystal were illuminating the cell. The results showed that the actual performance matched the predicted improvements.

"A lot of the work thus far in this field has been proof-of-concept demonstrations," Bierman says. "This is the first time we've actually put something between the sun and the PV cell to prove the efficiency" of the thermal system. Even with this relatively simple early-stage demonstration, Bierman says, "we showed that just with our own unoptimized geometry, we in fact could break the Shockley-Queisser limit." In principle, such a system could reach efficiencies greater than that of an ideal solar cell.

The next steps include finding ways to make larger versions of the small, laboratory-scale experimental unit, and developing ways of manufacturing such systems economically.

This represents a "significant experimental advance," says Peter Bermel, an assistant professor of electrical and computer engineering at Purdue University, who was not associated with this work. "To the best of my knowledge, this is a new record for solar TPV, using a solar simulator, selective absorber, selective filter, and photovoltaic receiver, that reasonably represents actual performance that might be achievable outdoors." He adds, "It also shows that solar TPV can exceed PV output with a direct comparison of the same cells, for a sufficiently high input power density, lending this approach to applications using concentrated sunlight."

More information: David M. Bierman et al. Enhanced photovoltaic energy conversion using thermally based spectral shaping, *Nature Energy* (2016). DOI: 10.1038/nenergy.2016.68

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