Scientists debut most efficient 'optical rectennas,' devices that harvest power from heat

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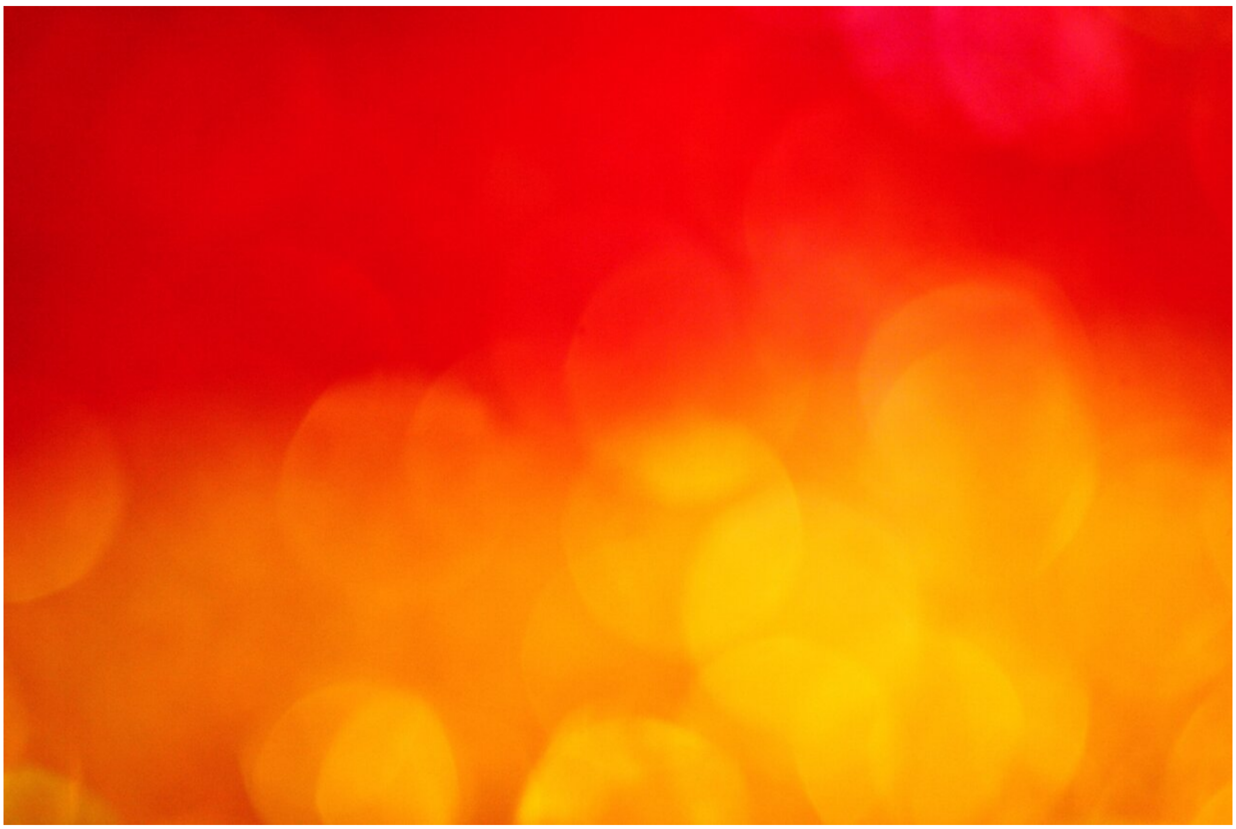

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Scientists at the University of Colorado Boulder have tapped into a poltergeist-like property of electrons to design devices that can capture excess heat from their environment—and turn it into usable electricity.

The researchers have described their new "optical rectennas" in a paper published today in the journal *Nature Communications*. These devices, which are too small to see with the naked eye, are roughly 100 times more efficient than similar tools used for energy harvesting. And they achieve that feat through a mysterious process called "resonant tunneling"—in which electrons pass through solid matter without spending any energy.

"They go in like ghosts," said lead author Amina Belkadi, who recently earned her Ph.D. from the Department of Electrical, Computer and Energy Engineering (ECEE).

Rectennas (short for "rectifying antennas"), she explained, work a bit like car radio antennas. But instead of picking up radio waves and turning them into tunes, optical rectennas absorb light and heat and convert it into power.

They're also potential game changers in the world of renewable energy. Working rectennas could, theoretically, harvest the heat coming from factory smokestacks or bakery ovens that would otherwise go to waste. Some scientists have even proposed mounting these devices on airships that would fly high above the planet's surface to capture the energy radiating from Earth to outer space.

But, so far, rectennas haven't been able to reach the efficiencies needed to meet those goals. Until now, perhaps. In the new study, Belkadi and her colleagues have designed the first-ever rectennas that are capable of generating power.

"We demonstrate for the first time electrons undergoing resonant tunneling in an energy-harvesting optical rectenna," she said. "Until now, it was only a theoretical possibility."

Study coauthor Garret Moddel, professor of ECEE, said that the study is a major advance for this technology.

"This innovation makes a significant step toward making rectennas more practical," he said. "Right now, the efficiency is really low, but it's going to increase."

An unbeatable problem

It's a development that Moddel, who has literally written the book on these devices, has been looking forward to for a long time. Rectennas have been around since 1964 when an engineer named William C. Brown used microwaves to power a small helicopter. They're relatively simple tools, made up of an antenna, which absorbs radiation, and a diode, which converts that energy into DC currents.

"It's like a radio receiver that picks up light in the form of electromagnetic waves," he said.

The problem, however, is that to capture thermal radiation and not just microwaves, rectennas need to be incredibly small—many times thinner than a human hair. And that can cause a range of problems. The smaller an electrical device is, for example, the higher its resistance becomes, which can shrink the power output of a rectenna.

"You need this device to have very low resistance, but it also needs to be really responsive to light," Belkadi said. "Anything you do to make the device better in one way would make the other worse."

For decades, in other words, optical rectennas seemed like a no-win scenario. That is until Belkadi and her colleagues, who include postdoctoral researcher Ayendra Weerakkody, landed on a solution: Why not sidestep that obstacle entirely?

A ghostly solution

The team's approach relies on a strange property of the quantum realm.

Belkadi explained that in a traditional rectenna, electrons must pass through an insulator in order to generate power. These insulators add a lot of resistance to the devices, reducing the amount of electricity that engineers can get out.

In the latest study, however, the researchers decided to add two insulators to their devices, not just one. That addition had the counterintuitive effect of creating an energetic phenomenon called a quantum "well." If electrons hit this well with just the right energy, they can use it to tunnel through the two insulators—experiencing no resistance in the process. It's not unlike a ghost drifting through a wall unperturbed. A graduate student in Moddel's research group had previously theorized that such spectral behavior could be possible in optical rectennas, but, until now, no one had been able to prove it.

"If you choose your materials right and get them at the right thickness, then it creates this sort of energy level where electrons see no resistance," Belkadi said. "They just go zooming through."

And that means more power. To test the spooky effect, Belkadi and her colleagues arrayed a network of about 250,000 rectennas, which are shaped like tiny bowties, onto a hot plate in the lab. Then they cranked up the heat.

The devices were able to capture less than 1% of the heat produced by the hot plate. But Belkadi thinks that those numbers are only going to go up.

"If we use different materials or change our insulators, then we may be able to make that well deeper," she said. "The deeper the well is, the more electrons can pass all the way through."

Moddel is looking forward to the day when rectennas sit on top of everything from solar panels on the ground to lighter-than-air vehicles in the air: "If you can capture heat radiating into deep space, then you can get power anytime, anywhere."

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