Running on waste heat

Gang Chen ' s thermoelectric devices turn waste heat into electricity for vehicles and other machines.

Rob Matheson | MIT News Office
August 8, 2014

Press Inquiries

It ' s estimated that more than half of U.S. energy — from vehicles and heavy equipment, for instance — is wasted as heat. Mostly, this waste heat simply escapes into the air. But that ' s beginning to change, thanks to thermoelectric innovators such as MIT ' s Gang Chen.

Thermoelectric materials convert temperature differences into electric voltage. About a decade ago, Chen, the Carl Richard Soderberg Professor of Power Engineering and head of MIT ' s Department of Mechanical Engineering, used nanotechnology to restructure and dramatically boost the efficiency of one such material, paving the way for more cost-effective thermoelectric devices.

Using this method, GMZ Energy, a company co-founded by Chen and collaborator Zhifeng Ren of the University of Houston, has now created a thermoelectric generator (TEG) — a one-square-inch, quarter-inch-thick

RELATED
GMZ Energy
Gang Chen
Mildred Dresselhaus
Department of Mechanical Engineering
School of Engineering

ARCHIVES

module — that turns waste heat emitted by vehicles into electricity to lend those vehicles added power.

“Everybody recognizes the great potential of waste heat, but the challenge has always been that not many think seriously about systems that can turn that heat into power,” Chen says. “It’s not just waste heat, it’s wasted potential to do useful work.”

In a TEG, electricity is generated when heat enters the top of the module, and then moves through the semiconductor material — packed into the TEG — to the cooler side. The resulting motion of electrons in the semiconductor under this temperature difference creates a voltage that’s extracted as electricity.

However, in many TEGs, atomic vibrations in the material can also leak heat from the hot to the cold side. GMZ’s method essentially slows the heat leakage, leading to a 30 to 60 percent increase in performance across many thermoelectric materials.

The company’s TEG can withstand temperatures of roughly 600 degrees Celsius on its hot side (top surface), while maintaining a temperature of 100 C on its cold side (bottom surface). With this gradient of 500 C, a module that’s 4 centimeters squared can produce 7.2 watts of power. Installed near a car’s exhaust pipe, for instance, this converted electricity could power the car’s electrical components, essentially reducing the load on the vehicle’s alternator, reducing fuel costs and overall emissions.

In June, GMZ successfully generated 200 watts from a larger TEG as part of $1.5 million program supported by the U.S. Department of Energy (DOE). The goal is to eventually integrate multiple 200-watt TEGs into the Bradley Fighting Vehicle, a U.S. military tank, to produce 1,000 watts, helping save on fuel consumed on the battlefield, which can cost $40 per gallon.

GMZ is also working under another $9 million DOE grant as part of a program to improve fuel economy in passenger vehicles by 25 percent. GMZ has plans to soon apply its TEGs to cars, with aims of improving efficiency by 5 percent.

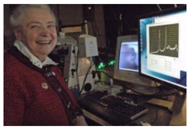
Decades in the making

The concept of thermoelectrics dates back to 1821. Initially called the Seebeck effect, after its discoverer Thomas Seebeck, it derives from heating one end of a conductive material — a semiconductor, for example — to cause electrons to move to the cooler end, producing an electric current. Applying a current to the material, in turn, carries heat from the hot to the cool end.

Thermoelectric technologies picked up steam in the 1950s, as companies and research labs started funding projects to bring the technology to real-world applications. Although these efforts led to niche applications in refrigeration


Boston College, MIT researchers achieve dramatic increase in thermoelectric efficiency


Nanotech gives thermoelectricity a new glow


Thermoelectric materials are one key to energy savings


Explained: Thermoelectricity

and sensors, large-scale applications did not materialize, because thermoelectric materials are notoriously inefficient: While these materials conduct electricity well, they also conduct heat well, so they’d equalize temperature quickly, leading to a low efficiency.

The field remained stagnant for decades. Then, in the 1990s, researchers — including Institute Professor Emeritus Mildred Dresselhaus at MIT — began using nanotechnology to restructure thermoelectric materials for greater efficiency.

Chen arrived at MIT in 2001 after researching thin films and nanowire-based thermoelectrics for four years at the University of California at Los Angeles, including a long-distance collaboration with Dresselhaus. At MIT, he continued his collaboration with Dresselhaus and brought in Ren, a materials expert, to develop new materials.

Then, in 2008, Chen, Ren, and Dresselhaus met another milestone: They realized a 40 percent increase in the efficiency of bismuth antimony telluride — materials used in thermoelectric coolers — using an inexpensive process.

As described in a *Science* paper that year, Chen and his team crushed the material into a nanoscopic dust and reconstituted it in bulk form — with grains and irregularities that dramatically slowed the passage of phonons through the material. (Phonons, a quantum mode of vibration, are primary means of heat conduction.) This reined in the heat leakage, while allowing for the free flow of electrons.

Using a cost-effective and safe alloy in bulk form meant the material could be applied to a variety of applications. And Chen saw that the method — “now widely used around the world,” he says — was ripe for commercialization. “With thermoelectrics, you’re always doing research for potential application,” he says. “Once the material was good, it was time to move.”

The world “needs a device”

To branch out into a startup, Chen found inspiration from MIT’s entrepreneurial ecosystem. “You sort of feel it,” he says. “You hear and see what other people are doing and you get inspired.” (Now, he says, he’s become part of that ecosystem, “guiding students who want to start a company.”)

After their discovery, Chen and Ren launched GMZ out of a garage in Waltham, Mass., with the broad goal of developing and commercializing their materials.

“But we were a little naive,” Chen says. “It turns out that because the thermoelectric market is small, there ’ s no big buyer. We realized the materials world wasn ’ t just about materials. It needs a device. ”

Three years later, they had tangible products to pitch to investors: a device that could draw electricity from solar hot-water collectors and an early version of the current TEG module. They managed to raise $7 million in their first funding round and $18 million a few months later.

But challenges persisted. Because there was no similar product on the market, they went through years of trial and error; deciding on materials, for example, is challenging, because in thermoelectric applications there are many types of materials to use and a variety of heat sources. “ The [efficiency] of a material depends on temperature you ’ re facing, ” Chen explains. “ So you have to look at what ’ s the heat source temperature, and what material matches that temperature range. ”

For their commercial TEG modules, which the company started producing around 2011, GMZ settled on half-Heusler materials, an alloy with a strong crystal structure that allows great stability at high temperatures. But the company has future plans for other materials: bismuth telluride, lead telluride, the mineral skutterudites, and silicon germanium.

Apart from giving the company a boost, the development of TEGs was a means of helping the whole market evolve, Chen says: “ Thermoelectrics isn ’ t something you can see. It ’ s not as recognized as a battery or photovoltaic cell. The whole field needs successful products on the market to sustain, inspire, and stimulate innovation. That ’ s really a mission for people working on this. ”

Ultimately, Chen sees GMZ as a big step toward his goal of helping create a more energy-efficient world. “ Most of my research at MIT is about energy, ” he says. “ The motivation for me is really taking this basic research into the real world. I take great pride in that. ”

Topics: Innovation and Entrepreneurship (I&E) Startups Energy Faculty Thermoelectricity Materials science Nanoscience and nanotechnology Research Mechanical engineering School of Engineering

Comments

View the discussion thread.

About This Website

This Website is maintained by the MIT News Office.

About the MIT News Office
MIT News Press Center
Press Inquries
Filming Guidelines
Contact Us
Terms of Use

RSS
Twitter
Facebook
Google+
Instagram
Flickr
YouTube

MIT Homepage
MIT Video
MIT Connect
MIT Resources
Events Calendar

About MIT
Admissions
Alumni
Education
Labs and Centers

Resources

Submit Campus News
Pitch a Story
Sign Up for Newsletter
Subscribe to Press Releases
Terms of Use

MIT News Office • Building 11-400
Massachusetts Institute of Technology • Cambridge, MA 02139-4307

GIVE TO MIT