NANOCRYSTAL MANUFACTURING MAY REVOLUTIONIZE THERMOELECTRICS

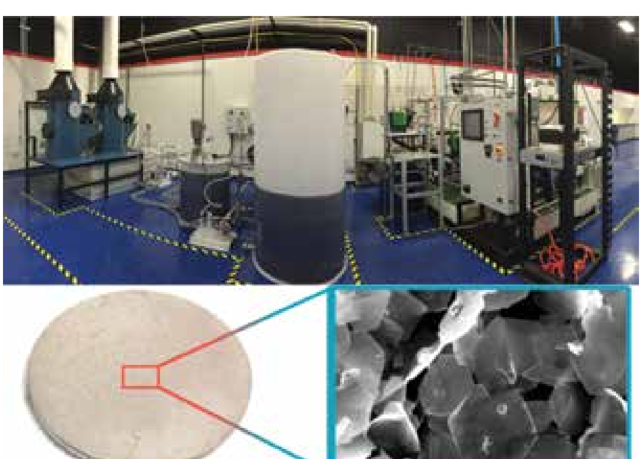
Thermoelectric materials can convert heat into electricity, or use electricity to produce cooling. They hold promise as a means to recover waste heat from automobile exhaust, power plants, and many industrial processes. From just 7% of U.S. waste heat, and at 5% efficiency, thermoelectric materials could harvest as much clean electricity as it takes to power about three million American homes every year.

The thermoelectric industry currently relies on bismuth telluride alloys. Unfortunately, the low efficiency characteristic of these alloys limits their use in thermoelectric applications. Thermoelectric efficiency is proportional to the thermoelectric figure of merit (ZT). The figure of merit for bismuth telluride alloys has hovered around $ZT \sim 1$ for decades.

Thermoelectric materials with double today's energy-conversion efficiencies (*i.e.,* $ZT > 2$) could facilitate development of new technologies, such as solid-state thermoelectric heat pumps, self-powered sensors, and industrial heat-to-electricity capture of more than 500 GWh/yr. Creating materials with high ZT values is challenging, because it requires the simultaneous control of three unfavorably coupled properties: electrical conductivity (σ), thermal conductivity (κ), and the Seebeck coefficient (α), a key parameter that measures the electric voltage produced per unit temperature difference.

To harness thermoelectric materials in commercial applications, low-cost, high-volume production methods are essential. The most promising idea to improve thermoelectric materials is nanostructuring, but this approach has been difficult to scale up and recreate outside of academic laboratories.

To address this manufacturing challenge, researchers at Rensselaer Polytechnic Institute (RPI) in Troy, NY, recently developed a microwave-stimulated approach that combines nanostructuring, compositional control, and ppm-level impurity doping. ThermoAura, Inc., a start-up company co-founded by the researchers, has translated this lab-scale concept to the tons-scale — manufacturing high-performance thermoelectrics with tunable properties.



▲ **Top:** Panorama of the continuous microwave process line for tons-scale nanocrystal production. **Bottom:** High-ZT nanostructured bismuth telluride wafer made by heat-pressing nanocrystals.

ThermoAura developed a first-of-its-kind continuous microwave process to fabricate bismuth telluride alloy nanocrystals. This method produces more than 15 kg of nanocrystals per hour with control over composition, shape, size, and doping, at temperatures below 120°C and with yields near 100%. The resulting thermoelectric materials have an energy conversion efficiency approximately 25% higher ($ZT = 1.2$–1.3) than conventional materials, and have the potential to achieve an increase of more than 50% ($ZT > 1.5$). Thermoelectric alloys from the ThermoAura process have higher ZT values, because nanostructuring yields a combination of high σ, low κ, and high α — a difficult blend to achieve otherwise. The company opened a manufacturing plant in Colonie, NY, in Dec. 2014, and can now produce up to 55 ton/yr of high-ZT bismuth telluride alloy nanocrystals.

The main innovation of the bottom-up process is the rapid seeding of nanocrystals using microwave activation of simple precursors to generate nanoparticles of any composition and controlled size. ThermoAura's process is more cost-efficient than traditional, non-nanostructured manufacturing, because the energy and purity demands are significantly lower. These advantages stem from the microwave chemistry and the simplicity of the low-footprint reactor design that allows automated continuous synthesis. "Contrast our bottom-up paradigm with the top-down melting-casting-crushing approach of legacy manufacturing," says Rutvik Mehta, president and co-founder of ThermoAura. The bottom-up approach enables the use of advanced manufacturing technologies — a pathway not accessible to traditional methods — for producing novel thermoelectric devices. For example, tiny thermoelectric cells could be created to power electronics using only body or ambient heat.

According to Ganpati Ramanath, co-founder of ThermoAura and professor of materials science at RPI, the technology is a springboard for industrial-scale manufacturing of nanomaterials for applications beyond thermoelectrics. Besides ramping up production of the flagship bismuth telluride alloy nanocrystals, ThermoAura is exploring high-volume production of heat-pressed wafers from the nanocrystals to expand into thermoelectric device manufacture. The company expects to ship the first commercial products — thermoelectric materials to power next-generation refrigeration devices — this year.

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