Tapping into waste heat for electricity by nanostructuring thermoelectric materials

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Thermoelectric materials will let us produce useful electricity from the enormous amounts of waste heat generated continuously in industrial processes. Credit: Wirestock on Freepik

In our ongoing struggle to reduce the usage of fossil fuel, technology to directly convert the world's waste heat into electricity stands out as very promising. Thermoelectric materials, which carry out this energy conversion process, have, thus, recently become the focus of intense research worldwide. Of the various potential candidates applicable at a broad range of temperatures, between 30 and 630 °C, lead telluride (PbTe) offers the best thermoelectric performance. Unfortunately, the outstanding qualities of PbTe are eclipsed by the toxic nature of lead, driving researchers to look into safer thermoelectric semiconductors.

Tin telluride (SnTe) could be an alternative. But it does not perform nearly as well as PbTe, and various methods to improve its thermoelectric performance are actively being studied. There are two main problems with SnTe that lower its figure of merit (ZT): its high thermal conductivity and its low Seebeck coefficient, which determines how large the generated thermoelectric voltage is as a function of temperature. Although researchers have managed to improve these parameters separately, it has proven difficult to do so for both simultaneously in the case of SnTe.

In a recent study published in *Chemical Engineering Journal*, a pair of scientists from Chung-Ang University, Korea—Dr. Jooheon Kim and Hyun Ju—came up with an effective strategy to solve this problem. Their approach is based on nanostructuring—producing a material with desired structural properties at the nanometer scale. In this particular case, the scientists produced porous SnTe nanosheets. However, making nanosheets out of SnTe is remarkably complex using standard procedures, which prompted the scientists to devise an innovative synthesis strategy.

They took advantage of another semiconductor: tin selenide (SnSe). This material bears a layered structure that is relatively easy to exfoliate to produce SnSe nanosheets. The researchers submerged these nanosheets in a solution of tartaric acid ($C_4H_6O_6$) and pure Te under a nitrogen atmosphere to prevent oxidation. What $C_4H_6O_6$ does is extract Sn-Se pairs from the SnSe nanosheets, thereby allowing for the dissolved Te^- s to naturally replace the Se^- anion in the extracted pairs. Then, the Sn-Te pairs rejoin the original nanosheet in a slightly 'imperfect' way, creating pores and grain boundaries in the material. The result of this whole process is anion-exchanged porous SnTe nanosheets.

The scientists investigated the reaction mechanisms that made these SnTe nanosheets possible and carefully searched for the synthesis conditions that produced the optimal nanoscale morphology. "We found that the nanostructure of the optimal anion-exchanged porous SnTe nanosheets, composed of nanoparticles of only 3 nm in size with defective shapes, led to a substantial reduction in thermal conductivity and a higher Seebeck coefficient compared to conventional bulk SnTe," remarks Kim. "This is a direct result of the introduced nanointerfaces, pores, and defects, which help to 'dissipate' otherwise uniform vibrations in SnTe known as phonons, which compromise thermoelectric properties," he adds. The ZT of the best-performing SnTe nanosheets was 1.1 at a temperature of 650 °C; that is almost three times higher than that of bulk SnTe.

The overall results of the study are very promising in the field of high-performance thermoelectric materials, which is bound to find applications not only in energy generation, but also refrigeration, air conditioning, transportation, and even biomedical devices. Equally important, however, is the insight gained by exploring a new synthesis strategy, as Kim explains: "The unconventional method we employed to obtain porous SnTe nanosheets could be relevant for other thermoelectric semiconductors, as well as in the fabrication and research of porous and nanostructured materials for other purposes."

Most importantly, with thermal energy harvesting being the most sought-after application of thermoelectric materials, this study could help industrial processes become more efficient. Thermoelectric semiconductors will let us tap into the large amounts of waste heat produced daily and yield useful electrical energy, and further research in this field will hopefully pave the way to a more ecofriendly society.

More information: Hyun Ju et al, Anion-exchanged porous SnTe nanosheets for ultra-low thermal conductivity and high-performance thermoelectrics, *Chemical Engineering Journal* (2020). DOI: 10.1016/j.cej.2020.126274

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