

Thin-Film Thermoelectric Devices with High Room-Temperature Figures of Merit

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All electronic devices produce heat that must be dissipated to prevent overheating and malfunction. Thermoelectric technology can be used not only for this type of cooling, but also for producing electric power from heat sources.

RTI developed a superlattice thermoelectric material that is more than twice as efficient and 23,000 times faster than bulk technology, the existing state of the art. In addition, RTI's material has 100 times the cooling intensity of existing technology. Such solid state devices can be used for power conversion, heating, cooling, and precise temperature control. When fully developed, the materials developments reported in this paper can enable numerous applications—such as cooling computer chips and laser communication devices, enabling green refrigeration, providing power for pacemakers and bio-implants, and achieving improved fuel efficiency in automobiles and for other uses.



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In this paper, we reported the first breakthrough in thermoelectrics in over 40 years—the first significant enhancement in figure of merit (ZT), where Z is a measure of a material's thermoelectric properties and T is the absolute temperature. RTI's superlattice materials achieved a ZT of 2.4 in thermoelectric device elements near room temperature. As noted in Cronin Vining's accompanying commentary to this publication in *Nature* (413:577-578, 11 Oct 2001), “even skeptics and dispassionate observers can safely be encouraged. The material properties, as measured by the figure of merit ZT , are 2.5 times better than the current state of the art, have been verified by more than one method, and are useful at room temperature. It has been a long time in coming, but any conjecture about a thermoelectric barrier of $ZT=1$ seems to have been safely put to rest.”

Since our breakthrough, others in the field have reported enhanced ZT in similar nanoscale materials and have adopted similar strategies to improve performance. The ability to fine-tune the transport of heat-carrying phonons and/or charge-carriers appears to be important in achieving the significantly improved ZT in superlattices. Our work established the basis for increasing ZT by reducing lattice thermal conductivity in nanoscale semiconductor material systems.

In addition to enhanced ZT at the material level, we demonstrated that thin-film thermoelectric devices can achieve very high cooling power densities and very fast cooling. Such thin-film devices can remove heat flux levels in the range of 700 watts/cm² and that localized cooling and heating occurs about 23,000 times faster than in bulk thermoelectric devices. In addition, these thin-film devices, only about 5 microns thick, were shown to enable controlled cooling of micro-scale regions, which had never been demonstrated previously.