Nanoscale Thermoelectrics for Energy Conversion

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The demand for alternative methods of electricity production has increased in recent years due to instability in various fossil fuel markets, concerns for the environment, and small-scale applications which require off-grid electricity. Recent developments in thermoelectrics materials science have allowed thermoelectric generators to become a viable energy technology. Specifically, our research group has made strides in materials modeling, materials development, and device construction.

Thermoelectric materials are devices that convert heat directly into electricity. This arises from the Seebeck effect, where a temperature gradient imposed on a material causes a voltage difference which can be used to drive a current. The dimensionless figure of merit for thermoelectric materials is $zT=S^2\sigma T/\kappa$, where S is the Seebeck coefficient, σ the electrical conductivity, and κ the thermal conductivity. If materials have nanometer-sized grains, the lattice thermal conductivity of the material can be decreased, thus increasing the dimensionless figure of merit. This nanostructuring is accomplished by ball milling the thermoelectric material until the particles are nanometer-sized, then quickly hot-pressing these particles so that they sinter together to form a pellet. This is a nanotechnology synthesis technique, yet it is accomplished at a bulk scale.

We use these nanostructured thermoelectric materials to demonstrate that solar energy converion can be accomplished with thermoelectrics. Our recent work has shown that solar thermoelectric generators can convert sunlight to electricity with an efficiency of nearly 5%, which is 8 times the previous highest-reported efficiency for such a device. This breakthrough is due to four factors: nanostructured thermoelectric materials, wavelength-selective solar absorbers, vacuum technology, and proper device optimization.

Recent modeling has also shown promise for high-temperature thermoelectric applications, such as concentrating solar thermoelectric generators and automotive applications. For these generators, multiple thermoelectric materials must be used in series, for example skutterudites for the hottest part and bismuth telluride below that. With such multi-material systems, we predict that concentrating solar thermoelectric generators can achieve solar-to-electric energy efficiencies exceeding 10%. Experimental progress towards achieving this potential will be reported.