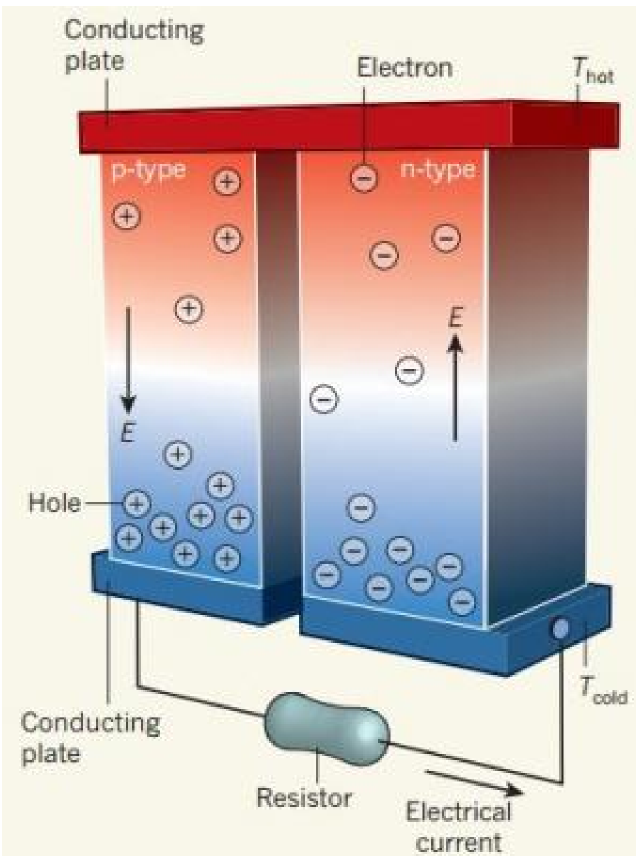
Researchers find tin selenide shows promise for efficiently converting waste heat into electrical energy

April 17 2014, by Bob Yirka

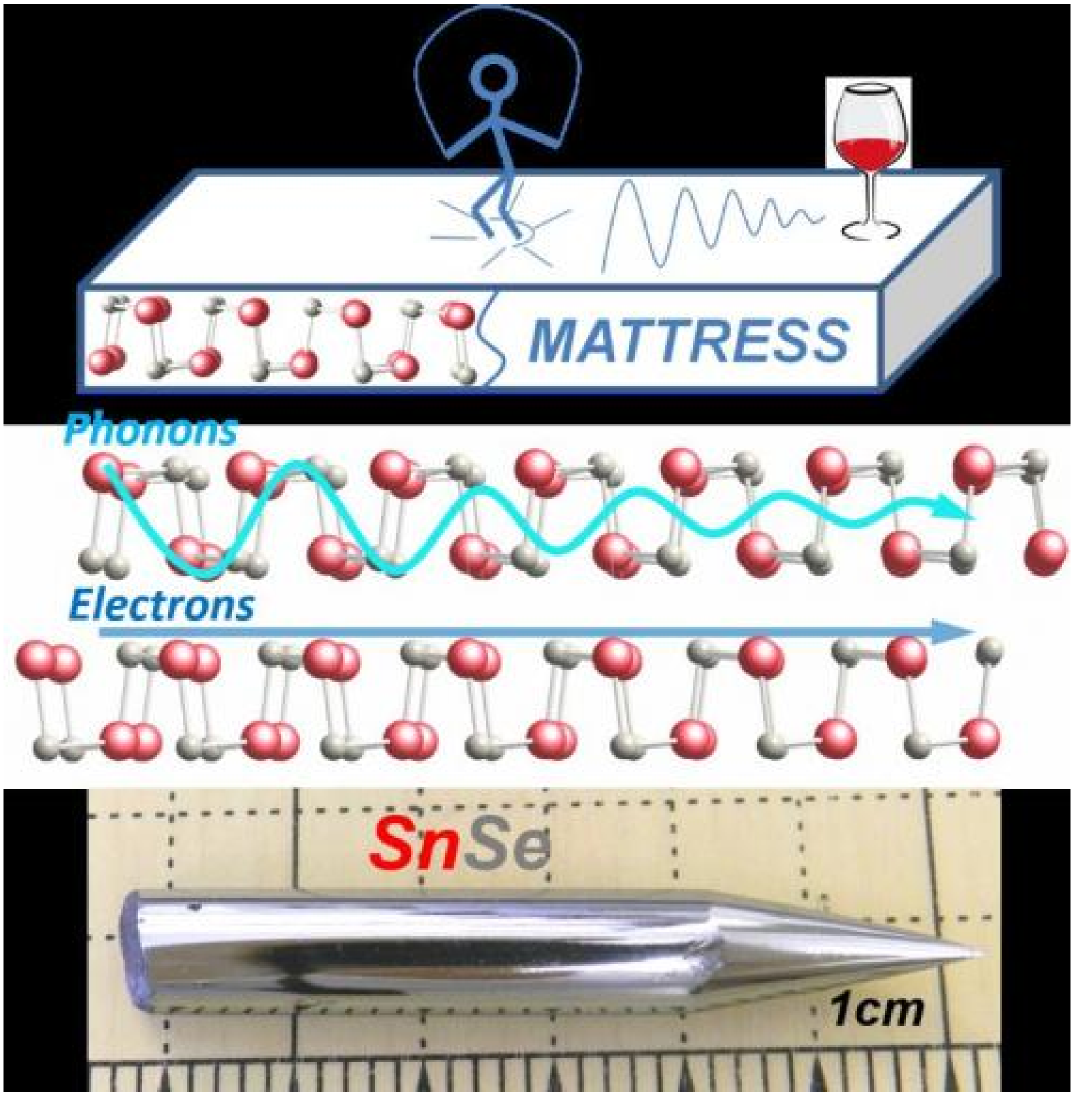


Working principle of a thermoelectric generator. Credit: (c) Nature, VOL 508, 327

(Phys.org) —A team of researchers working at Northwestern University has found that tin selenide (SnSe) has the highest Carnot efficiency for a thermoelectric cycle ever found, making it potentially a possible material for use in generating electricity from waste heat. In their paper published in the journal *Nature*, the team describes work they've conducted on SnSe and how their discovery might lead to even more efficient materials. Joseph Heremans gives a short history of thermoelectric research in a News & Views companion piece and offers some insights into why SnSe might be so efficient and how it might lead the way to the discovery of even better materials.

As the planet continues to experience the impact of global warming, scientists around the world frantically pursue alternate ways to produce electricity—one such possibility is to convert waste heat from industrial process into electricity. To make that happen, a thermoelectric generator must be constructed and used. Such generators operate by taking advantage of differences in temperature experienced by a single material. Two thermoelectric semiconductors are exposed to a temperature gradient and are connected together by conducting plates. Thus far, however, the process has not proved to be efficient enough to warrant the expense of building and using such generators, despite doubling in efficiency over just the past fifteen years—from zT 1 to 2.

The increase in efficiency has been due mostly to research work involving nanotechnology, and the materials used have generally been based on lead telluride. The difficulty in finding better materials has been stymied by the dual properties required: low thermal conductivity and high electrical conduction. SnSe has been used by scientists for a variety of purposes, but due to its stiff bonds and distorted lattice was not really considered as a possibility. But that was because others had not taken into account the compound's low anharmonicity. When the team at Northwestern tested it as a possible material for use in a thermoelectric generator they found it had the highest zT ever found, 2.6.



SnSe is the world's least thermally conductive crystalline material. Heat cannot travel well through this material because of its very "soft", accordion-like layered structure which does not transmit vibrations well. It reminds us of the TV commercial for posture-pedic mattress where one can jump up and down on one side of the mattress and a few feet away a glass of wine does not feel the vibrations. By analogy SnSe can get hot on one side and the other side remains cool. The cool side does not feel the vibrations (also known as phonons). In SnSe this means that all heat must go to the other side of the crystal "riding" on the electronic carriers, not lattice vibrations. Thus, the hot carriers can generate useful electricity during their transport. That is enabled by the high thermoelectric power of SnSe. The poor ability to carry heat through its lattice enables the resulting record high thermoelectric conversion efficiency. Credit: Lidong Zhao

The increase in efficiency is clearly welcome, but is still not enough to revolutionize the field—what might would be the discovery of another material with an even higher efficiency—something that might be similar to SnSe.

More information: Ultralow thermal conductivity and high thermoelectric figure of merit in SnSe crystals, *Nature* 508, 373–377 (17 April 2014) DOI: 10.1038/nature13184

Abstract
The thermoelectric effect enables direct and reversible conversion between thermal and electrical energy, and provides a viable route for power generation from waste heat. The efficiency of thermoelectric materials is dictated by the dimensionless figure of merit, ZT (where Z is the figure of merit and T is absolute temperature), which governs the Carnot efficiency for heat conversion. Enhancements above the generally high threshold value of 2.5 have important implications for commercial deployment1, 2, especially for compounds free of Pb and Te. Here we report an unprecedented ZT of 2.6 ± 0.3 at 923 K, realized in SnSe single crystals measured along the b axis of the room-temperature orthorhombic unit cell. This material also shows a high ZT of 2.3 ± 0.3 along the c axis but a significantly reduced ZT of 0.8 ± 0.2 along the a axis. We attribute the remarkably high ZT along the b axis to the intrinsically ultralow lattice thermal conductivity in SnSe. The layered structure of SnSe derives from a distorted rock-salt structure, and features anomalously high Grüneisen parameters, which reflect the anharmonic and anisotropic bonding. We attribute the exceptionally low lattice thermal conductivity (0.23 ± 0.03 W m^{-1} K^{-1} at 973 K) in SnSe

to the anharmonicity. These findings highlight alternative strategies to nanostructuring for achieving high thermoelectric performance.

Press release