Power Supplies from Environmental Heat are On Track

With a helping hand from the National Science Foundation, we have pushed along a technology for direct conversion of environmental heat directly to electricity. We have found that semiconductors under specific conditions can have two different temperatures at the same location, one for the lattice and one for carriers. Using this, we have engineered a heat engine (Peltier Effect), which exploits the temperature difference.

The broad impact of this work will be the availability of low-cost energy without environmental damage. This technology could prove to be viable for energy production at costs well below those of even solar and wind energy, which are globally now the lowest levelized cost ways to produce electricity. Longer life power supplies for mobile communications and other electronic devices, remote energy production and power for low cost water desalination are among the best use cases for the proposed technology. Low-cost energy will:

- Reduce the disparity and consequent conflict between rich and poor by increasing the minimum resources available to everyone.
- Eliminate confrontation over energy sources.
- Drive down CO_2 emissions and other pollutants.

We call the engine an Ambient Thermal Electric Converter (ATEC). The implications of the ATEC are exciting. And so is what we have learned about the underlying physics.

The ATEC is a structure that makes use of quantum-mechanical behavior of electrons in semiconductor materials of differing composition. Prototypes of mercury cadmium telluride show persistent voltages across themselves. Models show that small ATEC units (sub-millimeter) will convert watts of environmental heat to electricity. ATEC units can be assembled into power supplies for many applications, including billions of IoT devices (Figure 1).

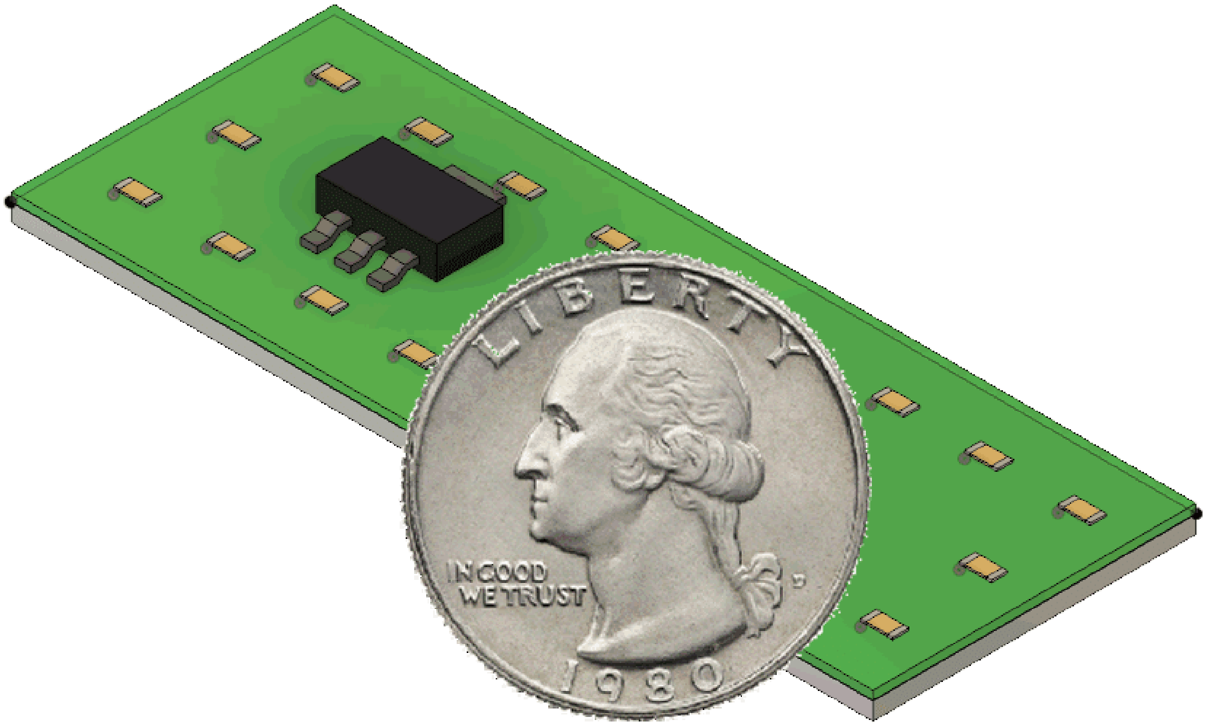
Figure 2 shows the key result from our study of a common semiconductor structure - the LED. It shows the startling result that electrons within an LED have a much higher temperature than the bulk material. This confirms a basic model for semiconductor behavior which underlies the ATEC design.

A complementary part of our work is to expand the conceptual models for LED behavior to explain the measurements made of LED outputs, such as in Figure 3. Our experiments indicate that the populations of electrons do not necessarily line up exactly, resulting in a significant temperature rise for the electrons on the left side.

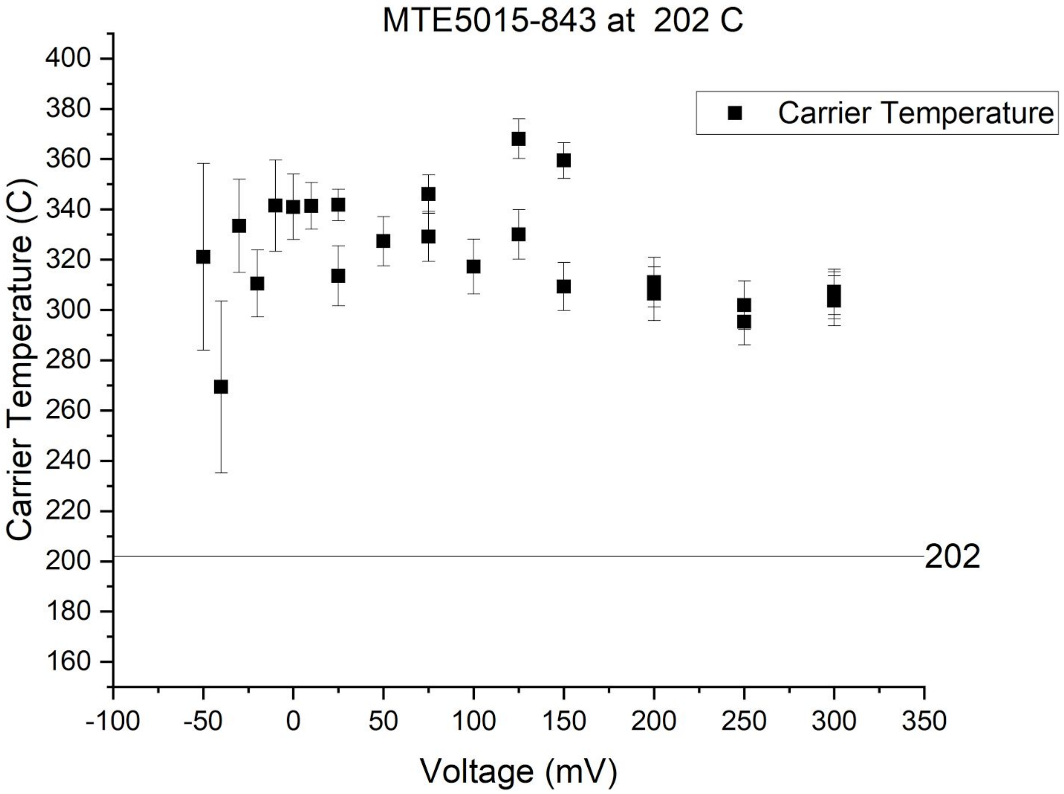
LED physics connects to ATEC physics at the “hot electrons” that have at least enough energy - known as work function - to break free of bulk materials and diffuse across material junctions, as shown (Figure 4). The difference in work functions in different materials produce a net voltage and therefore net current that can be tapped as useful electricity.

Our original prototype devices, of aluminum gallium arsenide, were subjected to a voltage sweep while net voltage across them was measured, first in forward and then in reverse orientation. The two orientations showed differing net voltages. The difference between these nets was (twice the) contribution made by the device. Similar measurements on resistors showed no such contribution (Figure 5).

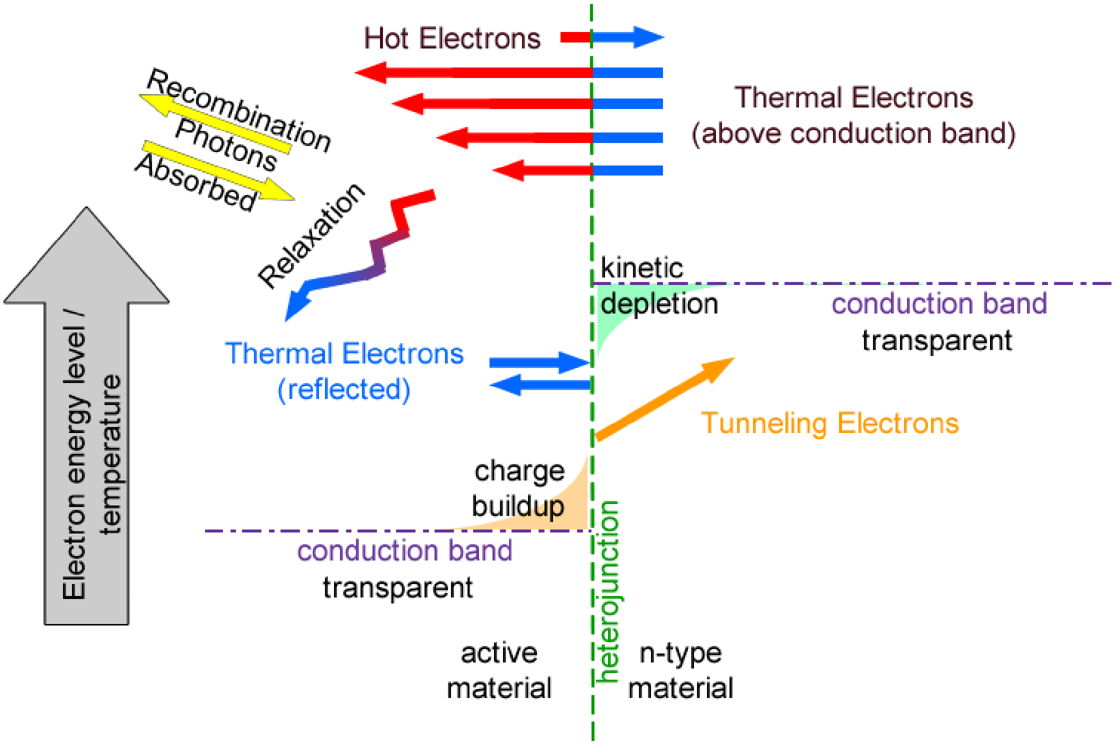
Voltage measurements across prototype ATECs of mercury cadmium telluride fabricated to our specifications showed persistent results, with significant variation among the units (likely due to variation in leakage currents, to be mitigated on the next prototypes). Future work will reduce the current leakage down the mesa side and will redesign the contacts to be more manufacturable (Figure 6).



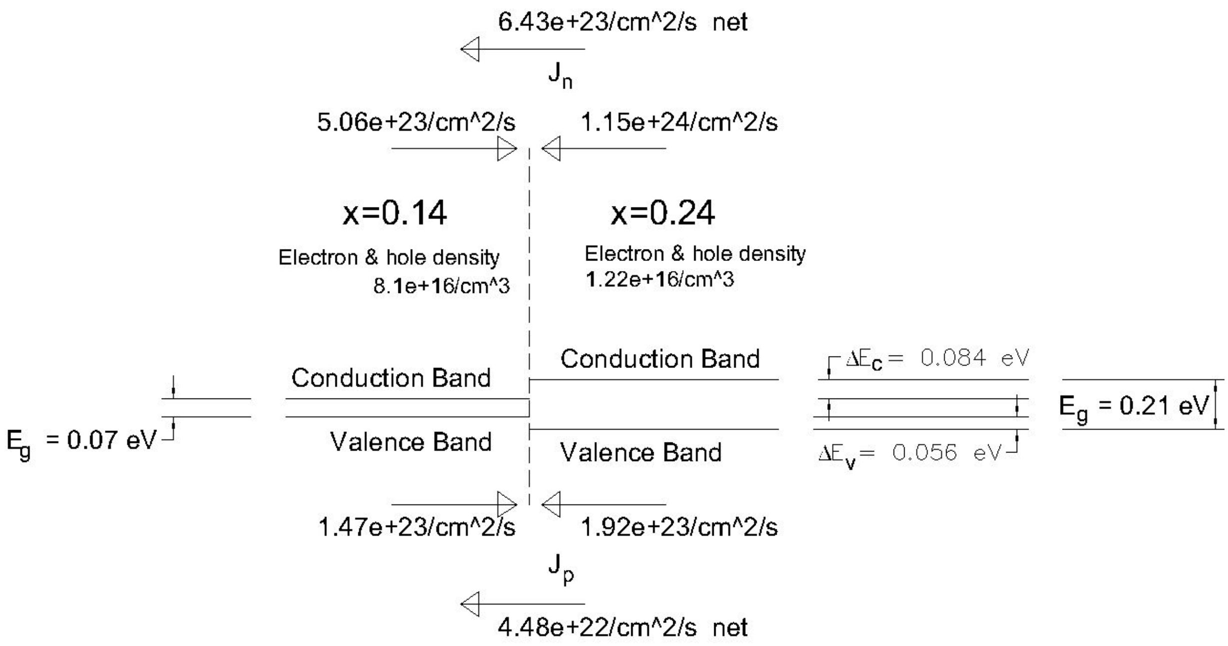
1: ATEC units are easily incorporated in IoT power supplies, with: multiple 0603-form units to aid heat conduction (yellow), mechanical/conduction base (gray), mounting board (green), voltage regulator (black). Units of sufficient area for current are connected in series to develop required voltage.



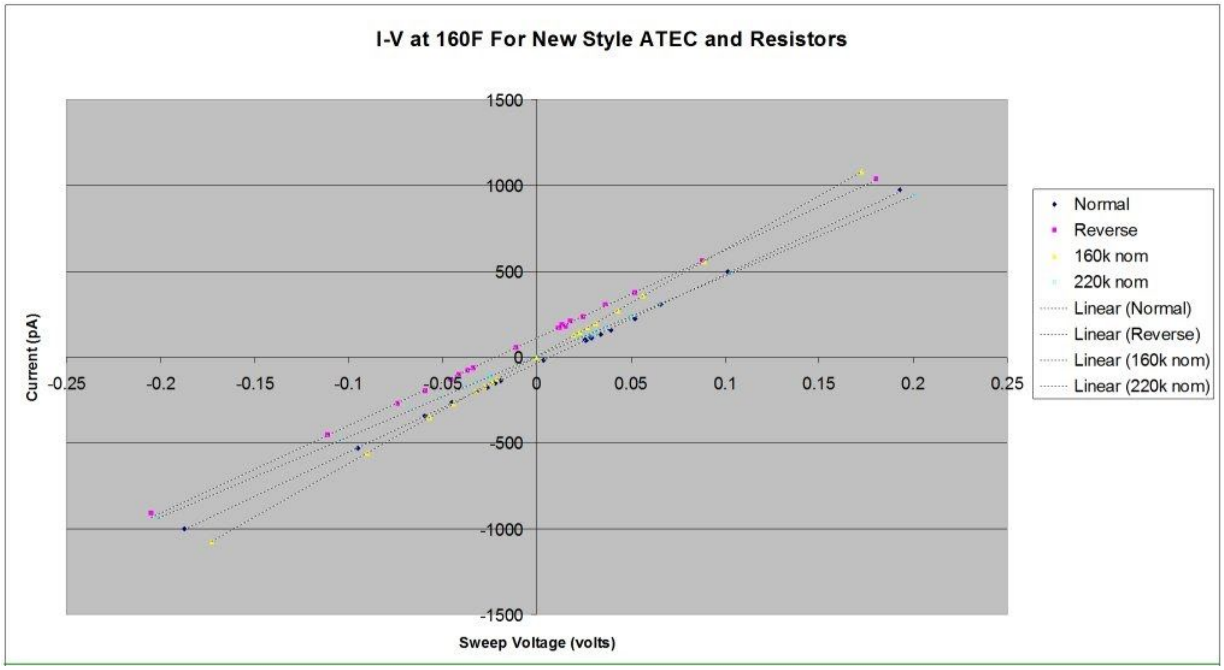
2: Electron temperature against applied voltage at 202°C. Data appear to preclude a uniform temperature within the device, even at zero bias.



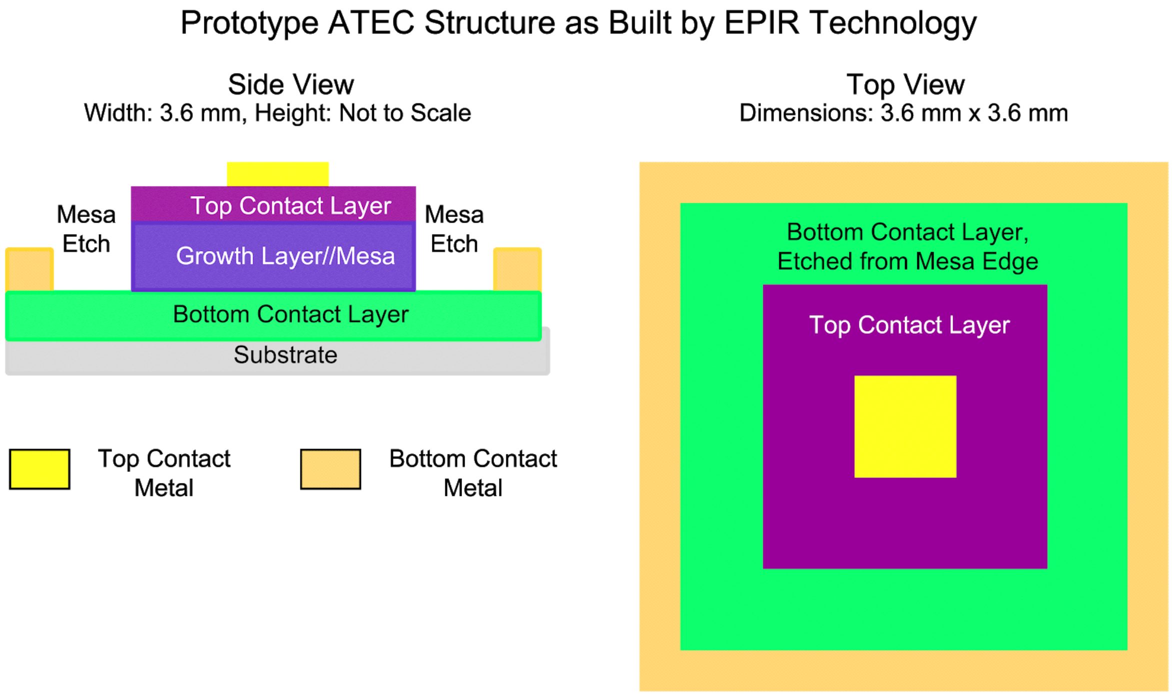
3: Conceptual view (expanded) of electron flow around the n-type heterojunction of a LED. Electrons which are just above the conduction band on the right are far above the band on the left side - in other words, ‘hot’.



4: ATEC makes use of quantum-mechanical behavior of electrons in semiconductors between materials of differing composition. Thin layers (“mesa”) of selected semiconductor materials generate persistent voltages across themselves, driven by differences in band gap.



5: Measured net voltage of AlGaAs prototype in forward and reverse orientation, subjected to voltage sweep. ATEC contributed to net voltage, while resistors did not.



6: Side and top view of prototypes metallization to make contacts (side view not to scale). Periphery of ATEC structure in the mesa of semiconductor material is etched out chemically to separate top and bottom contacts.