Applications: Thermoelectrics

Quantum dots breathes life back into Thermoelectrics

Shortcomings of Traditional Thermoelectric devices

Thermoelectrics is the science and technology associated with turning temperature gradients into electrical current and vice versa. Thermoelectrics can be put towards one of two fundamentally useful tasks- it can exploit an existing temperature difference to generate usable electricity or it can exploit an existing electrical current to induce a temperature gradient. In effect, thermoelectrics lets one swap heat and electricity, given the right materials and conditions.

These thermal circuits have a variety of advantages, including no moving parts, long life, low maintenance, and no emissions- making them an ideal device for a diverse set of applications in the medical, military, space, and especially the silicon chip industries, where excess heat generation from ever-shrinking computer chips threatens to stall the entire industry's growth within a decade. However, the positive aspects of this technology have been traditionally overshadowed by efficiency limitations that stem from shortcomings of materials used to construct thermoelectric devices. These inefficiencies lead to prohibitively high costs for thermoelectric devices. As a consequence, the field has been dormant since the 1950's owing to inadequate materials. Evident Technologies has a plan to reawaken it.

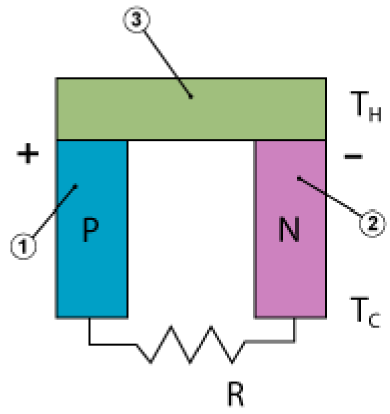
Quantum Dots - Reawakening the Thermoelectric Industry

Discoveries in nanotechnology and quantum dots have sparked interest in a thermoelectric comeback. Evident Technologies is at the forefront of this research effort, and our quantum dot product line shows great promise in vastly improving the efficiency of thermoelectric devices. This promise is due to our expertise in designing specialty low-dimensional systems composed of our custom tailored quantum dots. These quantum dot systems have unique qualities allowing them to improve performance by increasing devices' electrical conduction while reducing thermal conduction that leads to inefficient waste heat. By working on the nanometer scale, Evident's quantum dots and low dimensional systems exploit the quantum properties of materials, helping to overcome the limitations of traditional thermoelectric devices.

The Thermoelectric Process and its Limitations

Physics of Thermoelectric Devices

The field of thermoelectrics has its origins in Seebeck's 1822 discovery of the effect that bears his name. Seebeck discovered that in an open circuit composed of two different conductors with a temperature difference between the ends, a voltage is created. This voltage is proportional to the temperature difference by a factor called the Seebeck coefficient - the larger the temperature difference, the larger the induced voltage.



Engineering of Traditional Thermoelectric Devices

A closely related phenomenon is the Peltier effect, discovered in 1834, which can be roughly understood as similar to the Seebeck effect, but in reverse. The Peltier effect states that when an electrical current is passed through a circuit of two different conductors, the junction of the two conductors will either absorb or release heat, depending on the current direction. The amount of heat generated is proportional to the current flowing in the conductors by a factor called the Peltier coefficient - the larger the current flowing, the larger the induced heat flow.

Above is an illustration of a thermoelectric device designed to turn temperature gradient into an electric current. Sections 1 and 2 are semiconductor slabs, owing to the fact that semiconductors possess higher Seebeck coefficients then metals. The P and N labels are semiconductor designations describing that section 1 is "hungrier" for moving electrons (the basis of electricity) then section 2. Making the semiconductors dissimilar in this manner ensures that electricity will flow in the device. The "R" is resistance, and represents a useful application of the electricity the devise creates, for example a motor or light bulb. Section 3 is a metallic bridge that completes the circuit, allowing electricity to flow. The two Temperatures, TH and TC represent the greater and smaller temperature; the difference between them determines the induced voltage, and therefore, the induced current in the circuit.

These devices produce no emissions and contain no moving parts, making them ideal for situations where machines cannot be easily or readily fixed, such as on the battlefield or in deep space. Additionally, the temperature differentials necessary to power thermoelectric devices are abundant in our world of machinery.

Factors Controlling Efficiency

It is established that the efficiency of thermoelectric devices is controlled by a factor termed the Figure of Merit, denoted as "ZT." ZT is described in the following relationship as:

$$ZT = \frac{a^2}{\kappa\rho}T$$

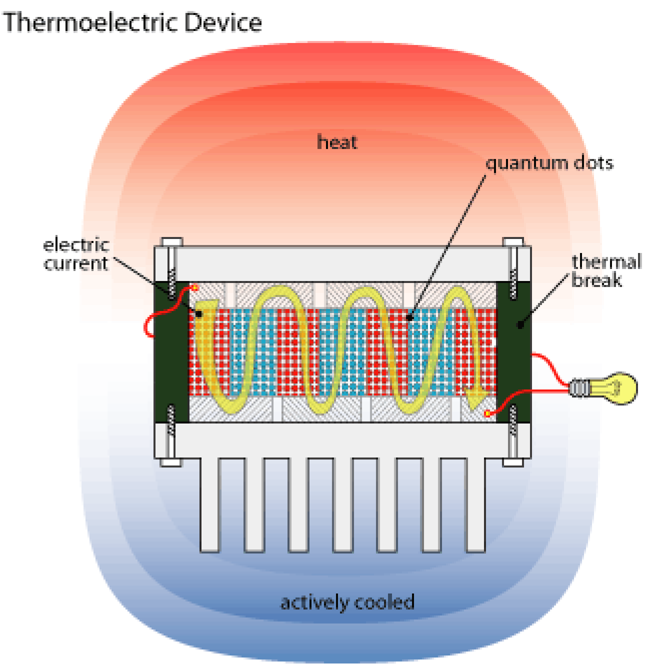
T is simply the temperature difference between TH and TC, which is user specified. The three remaining factors are the Seebeck coefficient a, the thermal conductivity κ, and the resistivity ρ. Since high Figures of Merit correspond to more efficient devices, it would be ideal to develop a device with a large Seebeck coefficient, a small thermal conductivity, and a high electrical conductivity (corresponding to a low resistivity). Unfortunately, these three factors are related to one another in such a way that improving the performance of one factor tends to subtract from the performance of another. In traditional materials, the upper ZT limit is acknowledged to be about 1 and unlikely to change. This upper limit is the reason for the historical relegation of thermoelectrics to a narrow band of applications and to the extreme slowdown in thermoelectric interest after the 1950's.

Quantum Dots - All New Possibilities in Thermoelectric Devices

Quantum Dots and the Engineering of Low Dimensional Thermoelectric Devices

Quantum Dots or EviDots, are novel semiconductors. Quantum dots resemble bulk semiconductors in composition, but have diameters on the order of 2-10 nanometers. At these small sizes, the electrical and thermal properties of materials diverge from those of bulk materials, as established by quantum mechanics. The "low dimensionality" designation comes from the fact that while bulk objects are three dimensional, quantum dots are so small in each of the three dimensions as to be effectively zero dimensional- each dot is to an extent isolated from every other dot, with important repercussions on thermal and electric conduction.

The schematic for a low dimensional thermoelectric device would look identical to a traditional one, with the exception that the N and P semiconductor material would no longer be a solid slab. Instead, it would be a solid composed of vast networks of zero dimensional quantum dots. The vast matrix of dots would be held together by molecular bonding between the thin "shells" (composed of a few atomic layers) that surround EviDots.



"Low dimensionality" systems provide a number of possible levers that may be applied to the enhancement of the thermoelectric Figure of Merit. Firstly, research has established that the electron energy of quantum dots biases the Seebeck coefficient "a" towards a higher magnitude, increasing Figure of Merit.

Secondly, the thermal conductivity of a "low dimensionality" solid is reduced, owing to the fact that vibrations face greater difficulty propagating across a large number of quantum dots than they do propagating through one continuous solid. By way of analogy, it is best to think of a pile of contiguous jello like that from a mold, versus a pile of jello cubes. If single, molded jello were to be flicked, the entire structure would wobble, illustrating the ease with which thermal waste heat is created in a traditional semiconductor. However, if the same jello is cut up into small cubes with approximately the same overall shape, sending one cube into motion will do little to affect the cubes on the other side of the pile, because most of the vibration will die out before it penetrates too far into the pile, simulating an array of quantum dots. In this fashion, thermal conductivity "κ" is reduced, increasing the Figure of Merit.

Quantum Dots as New Life for Thermoelectrics

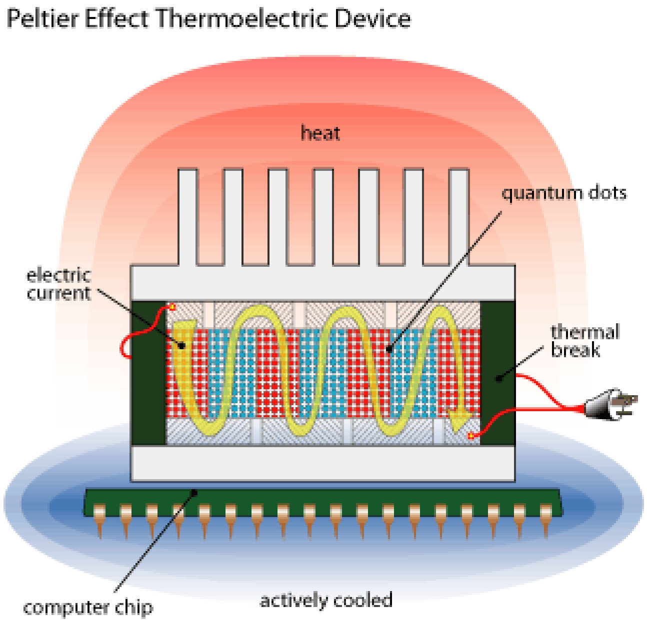
Research to date has established that Figures of Merit of 2.0 are possible, and that ZT's of 4 and even higher are conceivable. This more than doubles the current efficiency limit of thermoelectric devices, and suggests that a whole new generation of applications may be possible. The immense advantages of thermoelectrics, from low cost to cleanliness to the ability to operate in demanding environments; combined with Evident Technologies' technical acuity put Evident in a strong position to help lead in the coming wave of innovation.

Quantum Dot Opportunities in the Silicon Chip Industry

Quantum dot thermoelectric devices would be of particular use to the silicon chip industry, which is just beginning to face the so-called "power problem" which threatens to strangle growth in the chip business. Everything from the cell phones to the computers we use everyday make use of silicon chips. In large part, the financial health and technical progress of this industry (which includes such names as Intel and IBM) depends on the ability of manufacturers to fabricate each new chip model smaller than the last. The long economic expansion of the 1990's was in part due to the explosive growth of computer sales within the United States and abroad, all fueled by smaller and smaller generations of chips.

However, chip manufacturers are beginning to run up against fundamental restrictions on further miniaturizing their products that arise from the ever increasing amounts of heat that such small chips produce. It is believed that without eventual technological breakthroughs that reduce damaging heat production in chips, industry will meet engineering limits that will produce disastrous technological growth slowdown as well as financial hardship. With the application of our unique quantum dot technology, this future is not necessary.

Quantum dot thermoelectric devices manufactured to exploit the Peltier effect could be used to electrically cool silicon chips, ensuring that the silicon chip industry can continue to develop better and better computer products.



For More Information:

- Quantum Dot Nanomaterials
- Quantum Dot Composites
- Quantum Dots Overview & Introduction