Bio-Thermal Battery for ICDs

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1. Introduction

Implantable Cardioverter-Defibrillator (ICD) is an implantable device about the size of a pager that monitors a patient's heart rate. It uses batteries to send electric signals to a heart that's beating too slow, same as a pacemaker. It can also deliver an electric shock to help restore a normal heartbeat to a heart that's beating chaotically and much too fast. Cardiac defibrillation returns an abnormally fast or disorganized heartbeat to normal rhythm with an electric pulse. ICDs, since its advent in the early 80's, have been using Lithium Ion (Li-ion) batteries to power the device. The first ICD batteries lasted about two years before needing a replacement. Advances in the battery technology have made it possible for an ICD battery to have a life expectancy of about five to ten years, depending on how often it had to deliver power/energy and at what magnitude. The battery along with the circuitry of ICD is placed inside a leak proof casing in order to protect them from coming into direct contact with human visceral organs. As a result, when battery runs low on power, the whole unit has to be removed surgically and a new unit has to be installed in its place. The very nature of this replacement procedure is stressful for patients and carries the risk of post operative infection.

ICD battery must meet stringent requirements. The battery must be capable of delivering about 50 J of energy within about 5-10 seconds to charge the capacitors that deliver the defibrillation shock. A high-area electrode design is needed to meet this requirement. The battery must also deliver a continuous low current drain on the order of microamperes, and last for about 5-10 years. The performance of the battery must be highly predictable so that there is adequate warning before it is depleted [1]. Finally, the battery must be small enough so the ICD can be designed small and comfortable as possible.

While Li-ion batteries remain the battery of choice for ICDs for now, a new developments have taken a major step to ameliorate reliability issues of ICD batteries. Bio-thermal battery has the potential to become the ICD battery in future. At the root of this project lies thermoelectric material.

2. Discussion

The transfer of heat is normally from a high temperature object to a lower temperature object. Heat transfer changes the internal energy of both systems (objects). In a thermoelectric material (TM) there are free carriers which carry both electrical charge and thermal energy. In a thermoelectric material there are free carriers. These free carriers carry both charge and heat. If two objects maintained at different temperatures, are connected by means of a TM, the molecules (free carriers) at the high temperature end will diffuse farther than the molecules at the colder end causing a net build up of molecules (higher density) at the cold end. This density gradient causes the molecules to diffuse back to the hot end. At steady state, the density gradient counteracts the effect of the

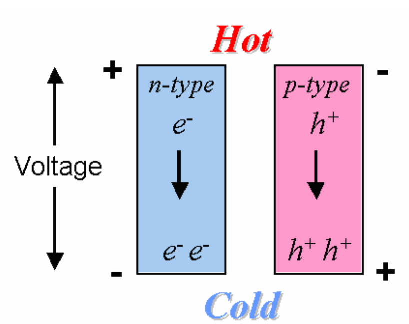
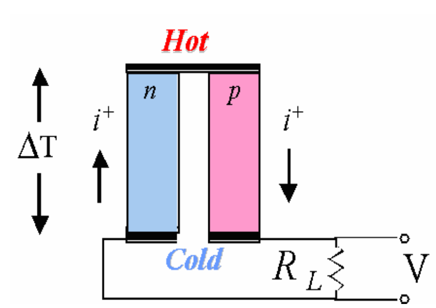


Fig 1: Schematic of positive/negative potentials [2].



temperature gradient to minimize the net flow of molecules. On the other hand, when the molecules are charged, the buildup of charge at the cold end produces a repulsive electrostatic force (and therefore an electric potential) to push the charges back to the hot end. For positive free charges, the material is called p-type and builds up positive charge on the cold end resulting in a positive potential. Similarly, for negative free charges, the material is called n-type and builds up negative charge on the cold end resulting in a negative potential.

If the hot ends of the n-type and p-type material are electrically connected, and a load connected across the cold ends, the voltage produced by the Seebeck effect causes the current to flow through the load, generating thermo-electrical power. Good thermoelectric materials are typically heavily doped semiconductors or semimetals. Also, a single type of carrier ensures optimization of thermoelectric power generation. Mixed n-type and p-type conduction also leads to an adverse effect and low thermo-power.

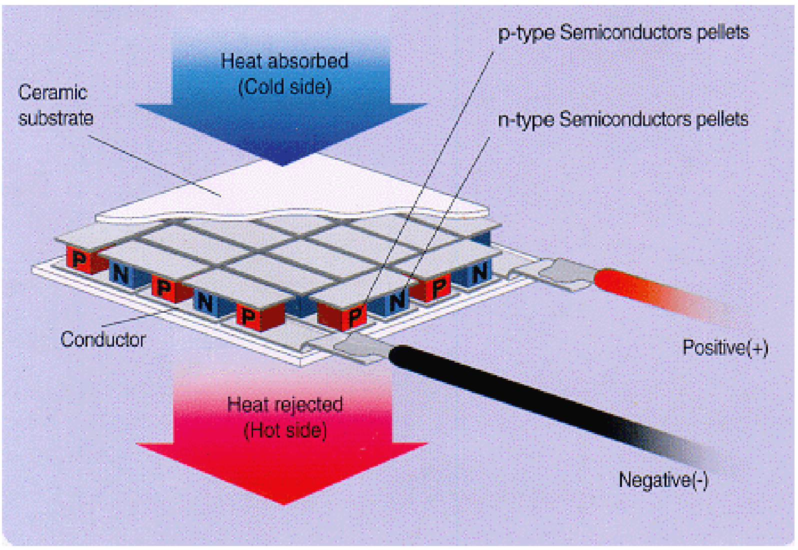


Fig 2: A sketch of a bio-thermal battery [3].

For the bio-thermal battery to work it needs a 2ºC temperature difference across it. But there are many parts of the body where a temperature difference of as much as 5ºC is available – typically within a few millimeters below the skin. The battery generators uses thermocouples made of the semiconductor bismuth telluride. The material is doped with impurities that give on side of the thermocouple an abundance of electrons – negative or n-type – while the other side contains impurities lacking electrons (positive, or p-type). The overall effect of this construction is to create a thermocouple with a much higher "figure of merit" than a metal-based one, generating higher voltages for a given temperature difference across the thermoelectric device.

3. Conclusion

The planned device has about 4,000 thermocouples in series, each generating a few microvolts for each 1ºC of temperature difference. A typical battery has an array 2.5 centimeters square (cm^2), total of about 6.0 cm^2 surface areas from all sides that generates 4 volts and delivers a power of 100 microwatts. The device aims to extend ICD and pacemaker battery life expectancy to more than three decades by continuously trickle-charging them [4]. It might even be able to power some low power pacemakers directly.

References

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[3] Duncan Graham-Rowe: Can implants run on body heat?. New Scientist, 12 June 2004; pg 23.
[4] Duncan Graham-Rowe: Power implant aims to run on body heat. New Scientist, June 04, 2004.