Thermoelectric Effects for IoT: Future Energy Harvesting

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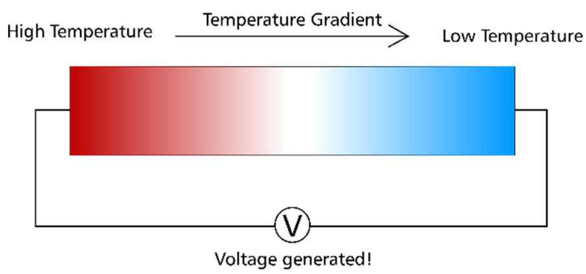
In the future, more and more objects will be part of the Internet of Things (IoT), i.e., they will be connected to the Internet and correlated with each other, and this will be of great benefit to human society. However, securing power sources for the exponentially increasing number of IoT devices is becoming an inevitable problem, given the rapid spread of the IoT. One potential answer is the concept of Energy Harvesting (EH), extracting energy from the omnipresent environment, in contrast to conventional energy supplies where power is obtained on a large scale by consuming fossil fuels. Thermoelectric effects are some of the most promising candidates for EH.

The thermoelectric effects have been known for a long time since the 19th century. The thermoelectric effects are phenomena in which electrical and thermal phenomena interact with each other. Let me give an example. If you heat one side of a conductor and cool the other side, there will be a voltage in the conductor. This voltage generation is the Seebeck effect, one of the thermoelectric effects, and Seebeck discovered it in 1821. The meaning of this phenomenon is that if there is a temperature gradient, there is a voltage. There are temperature differences all around us, and anything could be a source of electric power generation by the Seebeck effect. The Peltier effect is also one of the thermoelectric effects and works as the principle for cooling elements because electric current induces heat flow, which is just the inverse process of the Seebeck effect. It is the Seebeck effect that we will utilize for EH.



In principle, the energy generation by the Seebeck effect does not require any moving parts, and thermoelectric materials can generate electricity independently, namely, without any material supply, which is very compatible with the IoT's concept of connecting various things via the Internet. There are also many concrete advantages. For example, we will not need wires any more to supply electricity by virtue of independence. Moreover, we can reduce the environmental impact caused by batteries, such as lithium batteries, which we have used for independent devices.

Although the thermoelectric effects have been known for a long time and can potentially contribute to various problems we face today, we do not widely use the Seebeck effect as a source of energy because thermoelectric materials have not had enough performance for EH. Moreover, it has been difficult to make thermoelectric materials at a low cost. However, with the development of today's material design technology, the performance of thermoelectricity has been improving. We can expect thermoelectric materials to contribute to making IoT popular in our society. To make thermoelectric materials to be widely used in the market, they should have the following properties.

- High thermoelectric conversion performance worthy of practical use
- Easy and inexpensive to produce
- Easy to process to be used in a variety of situations

The importance of the first two goes without saying. The techniques to produce materials with better performance at a lower cost are essential for their widespread use. We can measure thermoelectric conversion performance by a number called the dimensionless figure of merit, often written as ZT. Materials with a high ZT are said to have good thermoelectric conversion performance, that is to say, have good thermal efficiency as a thermal cycle. In research fields, it is of the main interest to obtain thermoelectric materials with a higher ZT, specifically larger than ZT = 1, which is the threshold for practical use. In addition, materials will need to have a low environmental impact given today's growing environmental problems. The ease of processing means that human society can use thermoelectric materials as an energy source in wide applications. For instance, if we can develop a soft and thin thermoelectric material that can generate electricity for a perpendicular temperature gradient, the material will be used as a power source for wearable devices. Further, this development will motivate the development of innovative devices.

The thermoelectric effects are not only promising in terms of applications but also interesting as natural phenomena. We must consider situations in which the systems have temperature unevenness and flow to study thermoelectric effects. People call this situation non-equilibrium states in a physics term. Studies of non-equilibrium systems are a place where many unanswered questions remain. The developments of better thermoelectric materials from the standpoint of the applications to human society give better knowledge and understanding of non-equilibrium phenomena. The reverse is also true. A fundamental understanding of non-equilibrium phenomena can serve as a guideline for designing materials that meet the demands. For example, in situations where non-equilibrium conditions are strong, it is expected that a physical situation unique to non-equilibrium will appear, which does not appear when the effects of non-equilibrium are weak. The studies of thermoelectricity in non-equilibrium are interesting as a fundamental physics problem and provide hints for obtaining large ZT materials. These attempts broaden the scope of material exploration.

As we have seen, the thermoelectric effects have been known since the 19th century and will play an essential role in the spread of IoT. Further development will continue in this field, in which people with various interests make a concerted effort.