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Effects of Several Parameters on Thermoelectricity

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Abstract - Energy is an important part of basic needs. All living things on the earth need energy to survive. However, energy crisis and environmental damage due to pollution are becoming problems. That is the reason why the need for renewable energy is inevitable. There are many sources of renewable energy like wind energy and hydropower. Among several forms of renewable energy, energy from thermoelectricity is one of promising candidates because it does not generate noise and harmful gases. The thermoelectric materials convert waste heat into electricity based on Seebeck effect. This article describes a simple explanation about the introduction, theory and principle of thermoelectric devices. Several important parameters such as a figure of merit (ZT), thermal conductivity, electrical conductivity, Seebeck coefficient are related each other. This article also gives a brief calculation of several parameters of thermoelectric material and the results are shown in graphs so it will give better intuition for understanding thermoelectricity.

Keywords - thermoelectric, energy, temperature, renewable.

1. Introduction

The need for renewable energy increases as the world starts to run out fossil fuel formed million years ago (Panwar, Kaushik, & Kothari, 2011). The fossil fuels will be preserved if people uses renewable energy. Natural gas, coal and oil are the main fossil fuels. Oil is not environmentally friendly because it generates carbon dioxide and acid rain. Natural gas also can create problems such as being volatile, generating greenhouse emission and it is also dangerous if carelessly transported. The solution to reduce dependence on fossil fuels is to use renewable energy (Taşçıoğlu, Taşkın, & Vardar, 2016). There are plenty sources of renewable energy for example hydroelectricity, wind, solar and heat. Hydroelectricity has disadvantages such as being costly, needing expensive construction and disturbing ecosystem. Wind power can be noisy and disturb radio and television signal. Therefore, in comparison to other sources of renewable energy, thermoelectric energy can be very promising because it is silent, abundant, cheap and having no pollution. The energy from heat is converted into electrical energy so it can be used in many appliances. A thermoelectric generator (TEG) is an electronic device which convert heat into electricity through a phenomenon called the Seebeck effect. Thomas Johann Seebeck discovered that a conductor generates a voltage when applied to a temperature difference in 1821 (Anwar, Mishra, & Anwar, 2016). Thermoelectricity can be applied to harvest waste heat to produce electrical power (Aranguren, Astrain, Rodríguez, & Martínez, 2015). Thermoelectricity is a phenomenon where heat energy is converted into electricity and vice versa (Ginting et al., 2017).

2. Literature Review

A figure of merit ZT describes the thermoelectric conversion efficiency of a material (Xiao, Tan, Ye, Tang, & Ren, 2018). In order to achieve a high figure of merit, a material must have low thermal conductivity and high electrical conductivity (Pacchioni, 2017). One of the methods to increase figure of merit is to reduce the thermal conductivity of the thermoelectric material (Rabari, Mahmud, & Dutta, 2016). The definition of The Seebeck effect α is the voltage generated across a conducting or semiconducting material when a temperature difference is given (Salinas & Velasquez, 2019). In experiment, the Seebeck coefficient is defined as the ratio between the voltage difference and the temperature difference of two points in a sample (H. O. Lee & Sun, 2019). In concept, the Seebeck coefficient is the ratio of electromotive force generated to the applied temperature difference across the sample (Kumar, Patel, Singh, Kandasami, & Kanjilal, 2019). Seebeck coefficient can also be defined the ratio of voltage drop to temperature difference (Ogata & Fukuyama, 2019). The Seebeck coefficient can also be described as the electrical response because of the finite temperature difference T across the system (Mani & Benjamin, 2017). A lot of factors can affect the Seebeck coefficient. Material composition and carrier concentration strongly affect the Seebeck coefficient (J. Lee et al., 2008; Li, Yang, Huang, Li, & Zhang, 2006; Limmer et al., 2012; Mannam et al., 2009; Trahey, Becker, & Stacy, 2007). The Seebeck coefficient is also related to the electron concentration and mobility (Choi et al., 2018). There are many ways to increase the Seebeck coefficient. Band engineering has shown an effective way to improve Seebeck coefficient (Liu et al., 2018). Graphene can also increase the Seebeck coefficient and reduce the thermal conductivity (Tang et al., 2018). Filtering away low-energy charge carriers were proposed to increase Seebeck coefficient without disturbing electronic conductivity (Berland et al., 2016). Nanostructuring was carried out to increase Seebeck coefficient by quantum confinement (Hicks & Dresselhaus, 1993a, 1993b; Mahan & Sofo, 1996) . The Seebeck coefficient can be measured by bridging the sample between a heater and heat sink and testing the voltage difference between the hot and the cold sides (Guo, Ma, & Zheng, 2016). The static DC method is measurement of Seebeck coefficient (Okuyama et al., 2019). The thermal conductivity of a material is characteristic to conduct heat (Sankar, Reddy, & Prasad, 2016). The thermal conductivity is also described as a measure of ability to conduct heat (Abd-Elhady, Abd-Elkerim, Ahmed, Halim, & Okail, 2019). Many factors such as ceramic distribution and porosity in the composite material affect the thermal conductivity (Wu, Xiang, Liu, Ma, & Wang, 2018; Yuan, Li, Cao, Tang, & Zhang, 2019). The structure of the materials also has a strong relationship to the thermal conductivity (Zhu, Ren, & Bi, 2018). To decrease thermal conductivity, enhancing phonon scattering can also be conducted (Anufriev, Yanagisawa, & Nomura, 2017; Feng, Lindsay, & Ruan, 2017; Xing & Li, 2016). Nanostructuring is also one of many methods to reduce thermal conductivity (Dong et al., 2019). There are several ways to measure thermal conductivity such as transient hot wire method, transient plane source method, modified transient plane source (mtps) method, transient line source method, modified transient line source method, laser flash method, 3ω-method, freestanding sensor-based 3ω-method, time-domain thermoreflectance method, dyntim method.

3. Result and Discussion

Figure 1 (a) shows temperature dependence of ZT with varied from 50 μV/K to 250 μV/K. The horizontal axis represents temperature in kelvin while the horizontal axis represents the figure of merit which is dimensionless. Overall, ZT inreases with the temperature and Seebeck coefficient. At temperature of 0 K, the ZT is also 0 and increases gradually to around 2.8 at temperature 1000 K according to equation (1). **Figure 1**(b) gives information about the efficiency. The efficiency is 0% at 0 K and rises to around 15% at 1000 K for ZT = 0.5. If ZT is increased to 2.5, the efficiency rises to about 55% percent at 1000 K according to equation (2). **Figure 1** (c) describes about area dependence of resistance R. Wider thermoelectric elements have a greater cross-sectional area which can contribute to lower electrical resistance. **Figure 1** (d) shows the length dependence of thermal conductance. It shows that longer elements give lower thermal conductance. Low thermal conductivity is very important to keep one side hot and the side cold to generate a large voltage.

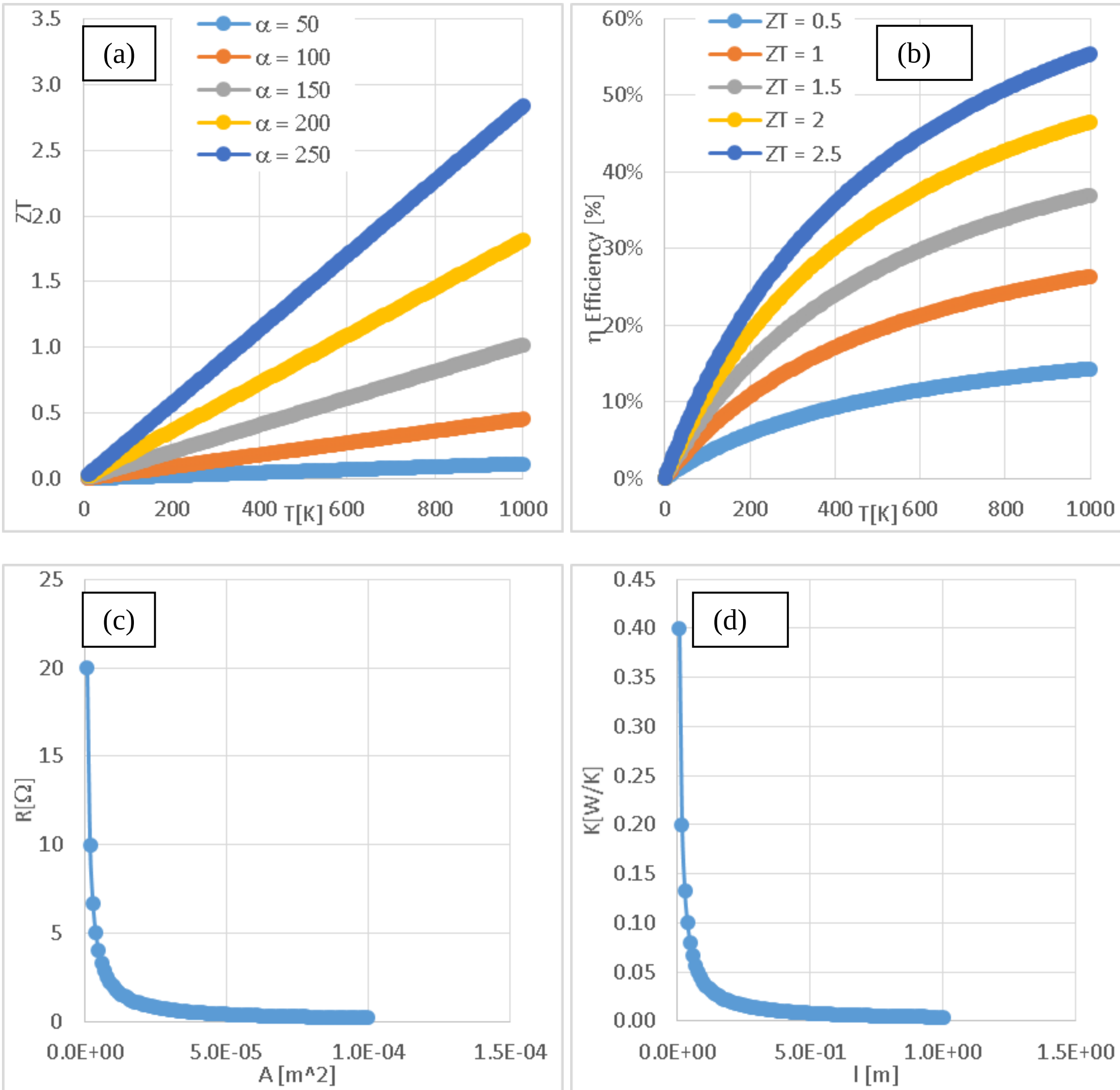

Figure 1. (a) Area dependence of R and (b) length dependence of K.

Figure 2 shows the compatibility factor. Thermoelectric device will not work if the difference of compatibility factor between one segment and the other segment is more than a factor of about two. The compatibility factor change slightly when the temperature increases. **Figure 3** gives information about relative current density dependence of reduced efficiency ηr with varied κ and α. The relative current density is ratio of electric current density to heat flux. The reduced efficiency ηr is the ratio of electrical power output to the thermal energy applied.

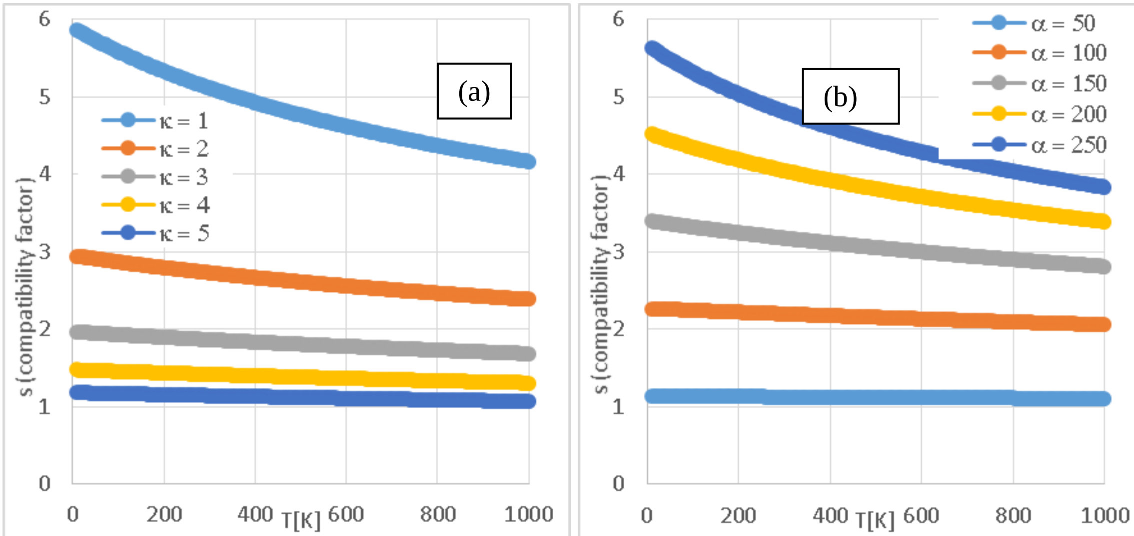

Figure 2. Temperature dependence of compatibility factor with (a) varied κ and (b)varied α.

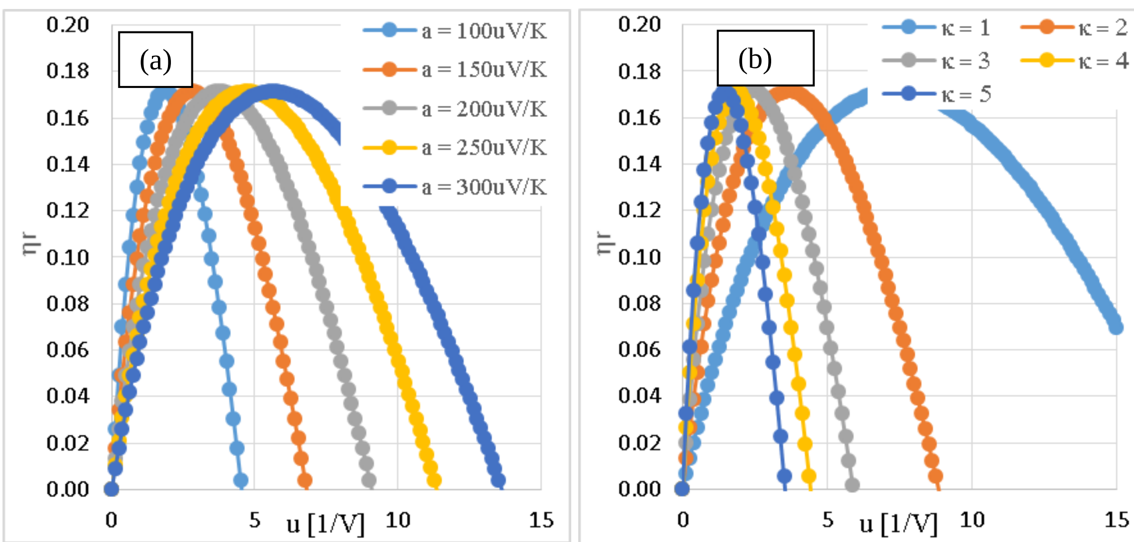

Figure 3. Relative current density dependence of reduced efficiency ηr with (a) varied κ and (b)varied α.

4. Conclusion

In conclusion, a simple analysis on mechanism, principle and application of thermoelectric generator has been presented. Materials with improved ZT, high electrical conductivity, high Seebeck coefficient and low thermal conductivity are required to fabricate thermoelectric generator with high efficiency.

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