Fatigue Life and Degradation Properties of a Thermoelectric Device Under Thermal Cycling

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1. Introduction

Thermoelectric (TE) devices can convert electric energy into thermal energy (the Peltier effect) and vice-versa (the Seebeck effect). The Peltier effect is usually used for cooling and the Seebeck effect is used for power generation. Worldwide, TE devices have received attention as potential sources of renewable and sustainable energy. TE devices have many merits; for example, they are eco-friendly, generate no noise, are compact in size, do not require a compressor for cooling, can generate power via waste heat, and can be employed in extreme environments. Numerous studies have aimed to enhance the performance of TE devices, but there are few papers on their reliability. Reliability assessments are essential for commercialization. Thus, in this study, our first objective is to assess the fatigue life of TE devices under thermal cycling, which is a type of thermal fatigue. Our second objective is to assess the degradation properties of TE devices, including power generation and figure of merit (ZT) under thermal cycling. The hypothesis is that when exposed to thermal cycling, TE devices will fail due to differences in the thermal expansion coefficient among materials. [1]

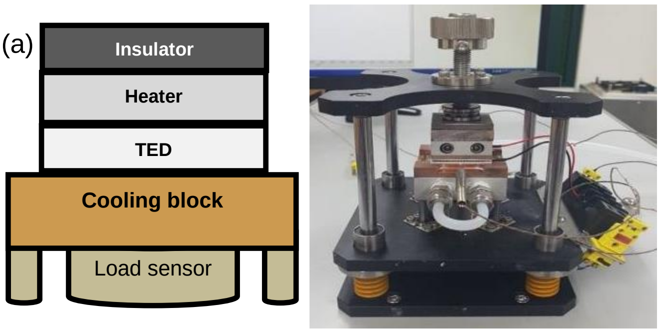
2. Experiments

In this study, a TE generating module (TGM-199-1.4-0.8; Kroytherm) was used. A reliability testing system was devised to assess the fatigue life and degradation properties (Fig. 1). The fatigue life and degradation properties of the TE device were assessed using this system. The first step in the experiments was assessment of the fatigue life. The TE device was subjected to thermal cycling, as shown in Fig. 2, using the Peltier effect and a cooling block. The resistance of the TE device was measured at the end of every cycle. Increased resistance leads to the formation of cracks in the device. The reliability testing system was stopped when current resistance approached the set maximum resistance. Experiments investigating the temperature difference (ΔT) between the upper and lower sides of the TE device were also conducted using the same procedure. These experiments generated a ΔT-N curve (where N is the number of cycles). The ΔT-N curve was subjected to TE and thermal stress analysis. Second, the power output and degradation properties were assessed. The maximum power output was measured by a variable resistor. ZT was then assessed using the Harman method for TE device, and was calculated by Eq. (1), where s is the Seebeck coefficient, σ is electrical conductivity, T is temperature and k is thermal conductivity. Properties associated with ZT were calculated using Eq. (2), where V_T is the TE component of voltage, V_E is the electrical component of voltage, ΔT is the temperature difference, A_{TE} is the cross-sectional area of the element, I is the electrical current, L is the length of the element and T is the mean temperature. [1]

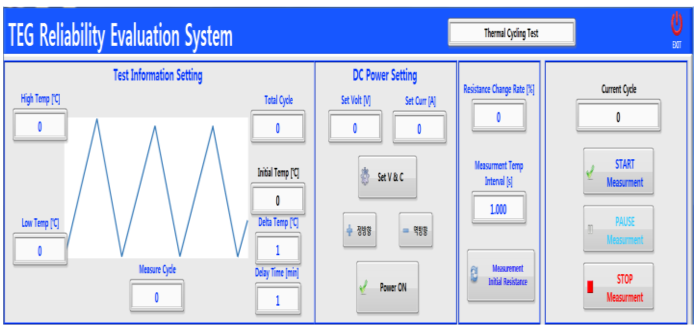
$$ZT = \frac{S^2 \cdot \sigma \cdot T}{k} \quad (1)$$

$$ZT = \frac{V_T}{V_E},\ S = \frac{V_T}{\Delta T},\ \sigma = \frac{V_E \cdot A_{TE}}{IL},\ k = \frac{S \cdot I \cdot T \cdot L}{\Delta T \cdot A_{TE}} \quad (2)$$

(a)



(b)



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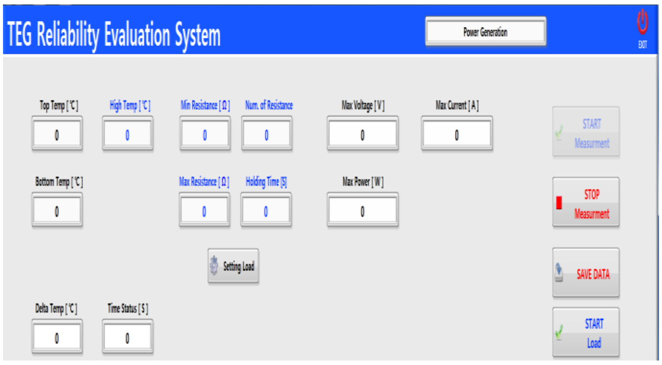

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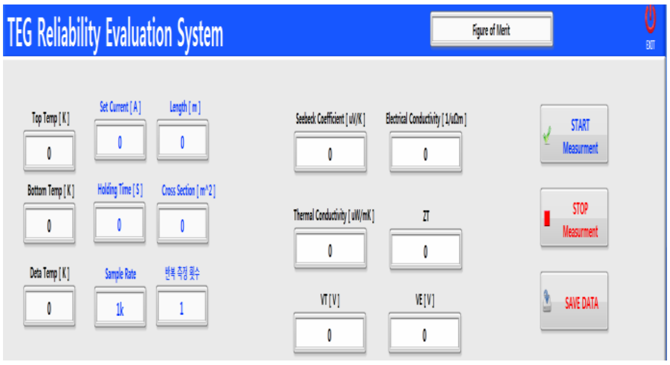


Fig. 1 Reliability testing system.

(a) shows a simple schematic and photograph of the hardware, (b) is a screenshot of the software used to analyze fatigue life, (c) is a screenshot of the power generation software, and (d) is a screenshot of the software used to analyze the figure of merit (ZT).

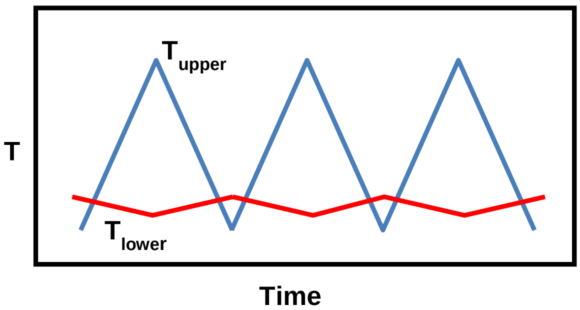
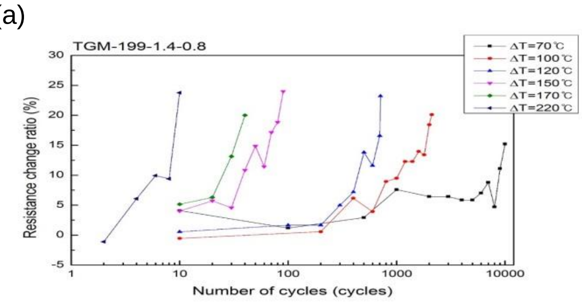


Fig. 2 Temperature of the thermoelectric (TE) device during thermal cycling. T_{upper} and T_{lower} represent the temperature of the upper and lower sides of the TE device, respectively.

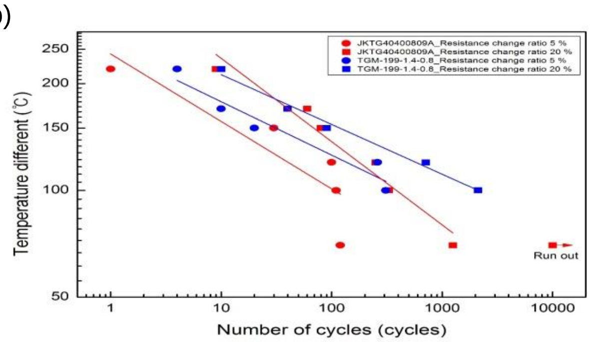
3. Results

Reliability information is shown in Fig. 3.

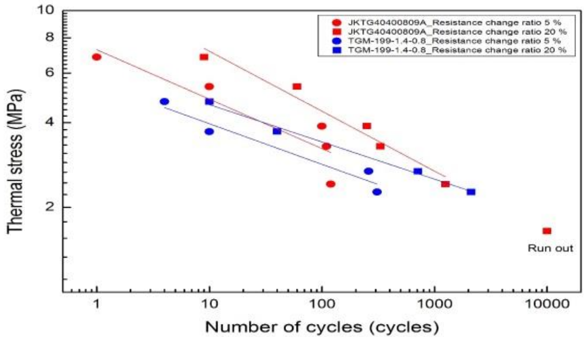
(a)



(b)



(c)



(d)

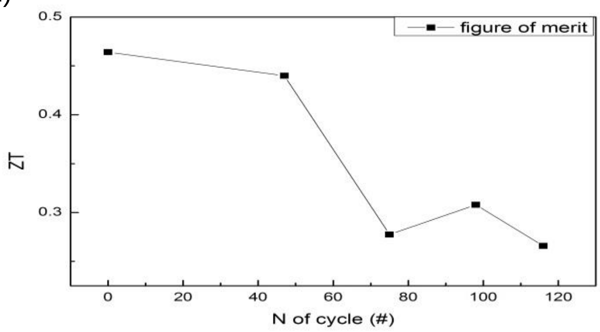


Fig. 3 Reliability of the TE device.

(a) shows the change in resistance according to the number of thermal cycles, (b) shows the temperature difference (ΔT) between the upper and lower side of the TE device according to the number of thermal cycles, (c) shows σ_T (thermal stress) according to the number of cycles, and (d) shows ZT according to the number of thermal cycles.

References

[1] M. T, Barako, W. Park, M. Marconnet, M. Asheghi and K. E. Goodson, Thermal Cycling, Mechanical Degradation, and the Effective Figure of Merit of a Thermoelectric Module, Journal of Electronic Materials, 42(3) (2013) 372-381.