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A high Reliability Module with Thermoelectric Device by Molding Technology for M2M Wireless Sensor Network

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Abstract. This paper presents the fabrication of a new energy harvesting module that used the thermoelectric device (TED) by using molding technology. The output voltage per heater temperature of the TED module at 20 °C ambient temperature is 8mV/K and similar to the result with the aluminium heat sink which is almost the same fin size as the TED module. The accelerated environmental tests are performed on damp heat test that is an aging test under high temperature and high humidity, cold test and highly accelerated temperature and humidity stress test (HAST) for the purpose of evaluating the electrical reliability in harsh environments. Every result of tests indicates that the TED and circuit board can be properly protected from harsh temperature and humidity by using molding technology, because the output voltage of after tested modules is reduced by less than 5%.This study presents a novel fabrication method for a high reliability TED-installed module appropriate for Machine to Machine wireless sensor networks

1. Introduction

Energy harvesting technology allows Machine to Machine (M2M) devices to operate indefinitely without any power source [1]. M2M devices must be mechanically robust and tolerant to an external environment. However the thermocouples of thermoelectric devices (TEDs) are usually exposed and mechanically fragile[2]. There is almost no energy harvesting module with TED which can be used in external environment. In this work, we fabricated a new energy harvesting module using the thermoelectric device (TED) as an energy harvesting device.

Figure 1 is a schematic of the designed light and durable TED module with a heat transfer sheet. In this study, the TED is built into a power generation module by using molding technology [3, 4]. Through molding technology, the TED and circuit board can be properly protected and a heat-radiating fin structure can be simultaneously constructed. This is because the exterior fin structure is covered by a graphite heat transfer sheet. Good thermal contact between this sheet and the TED by thermally conductive material ensures effective heat radiation from the fin. In this paper, the fabrication of the light and durable TED modulus by using molding technology and the reliability for M2M devices is presented.

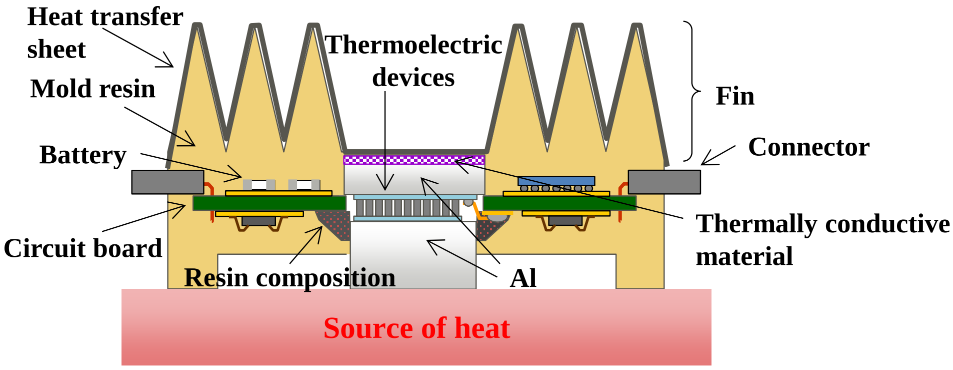


Figure 1. Schematic of TED Module with heat transfer sheet.

2. Fabrication

Figure 2 illustrates the fabrication process of the proposed TED module.

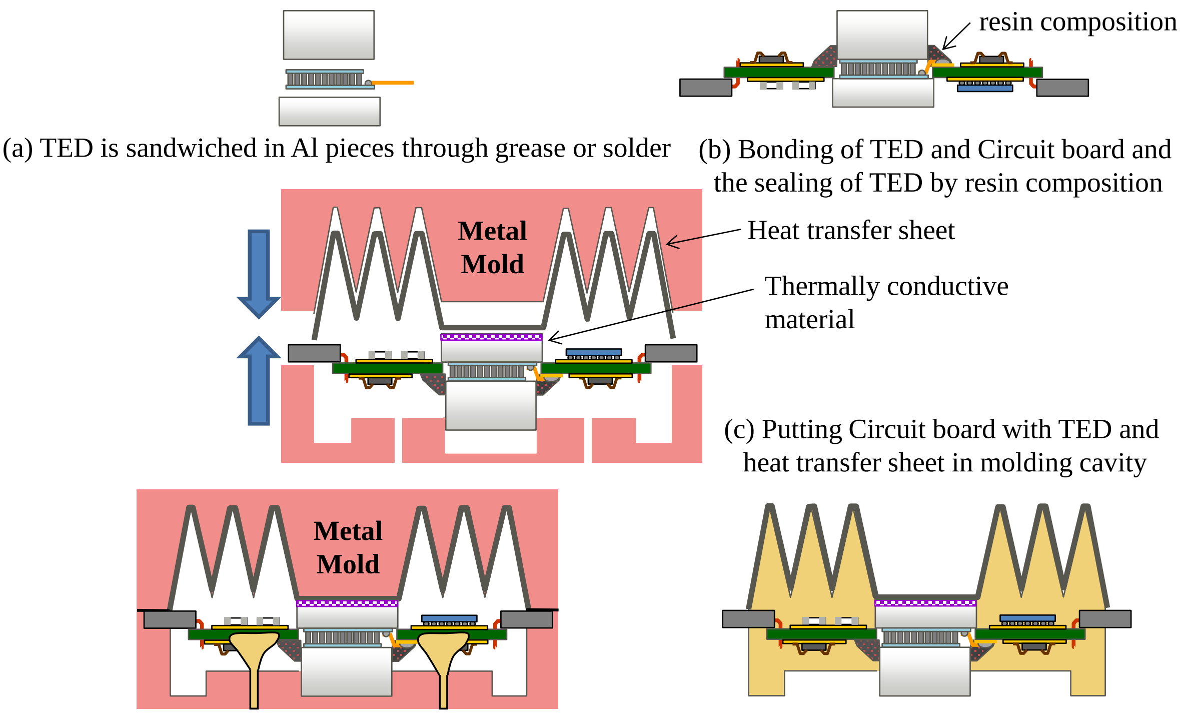


Figure 2. Fabrication process of TED module.

(a) The TED is sandwiched between Al pieces by using thermal grease or solder.(b) The TED interconnects are soldered onto the circuit board with connectors for the power supply of sensor devices and the TED is sealed by the resin composition in order to prevent of injection mold resin into the TED. (c) The circuit board installed with the TED and the heat transfer sheet are set into a metal mold. (d) The melted mold resin is injected. The injection pressure is 1.0 Pa, and the temperature of the melted resin is 230°C. After cooling, the TED module is released from a metal mold. The duration from setting parts to release of the module is a few minutes.

Molding is performed by a hotmelt process using solventless thermoplastic resin. Table 1 shows the properties of the mold resin (Henkel AG & Co. KGaA; Model OM652).

Table1 Material properties of mold resin

Operating Temperature Limits (℃)	Tg (℃)	CTE (ppm/K)	Young's Modulus (GPa) at 25℃	Thermal Conductivity (W/mK)	Flame Retardant
-40～100	-45	483	0.06	0.2	V-0

The TED is a commercial model (Model KTGS066A0: KELK Ltd.). Table2 shows the characteristics of TED.

Table 2 Characteristics of TED (KELK Ltd; Model KTGS066A00)

Demension Top side Bottom side (mm)	Thickness (mm)	Thermal Conductance (W/K) at R.T. in Dry Air	Electrical Resistamce (Ω) at 27℃	Open Circuit Voltage (V) at Th=32℃, Tc=22℃
7.16×6.57 7.57×7.16	1.32	0.035	7.11	0.26

3. Result and Discussion

Figure 3A shows the module attached to the heat transfer sheet. The module is 35 × 35 × 16.4 mm^3 in volume, and it weighs 17.5 g.

Figure 3B shows the tip point of the fin. The point angle is 3 degrees. The fin tip is filled without void with mold resin, which adheres well to the heat transfer sheet in spite of the sharp angle of the point of the fin. Through molding technology, a circuit board with the TED and a heat-radiating fin structure can be simultaneously constructed.

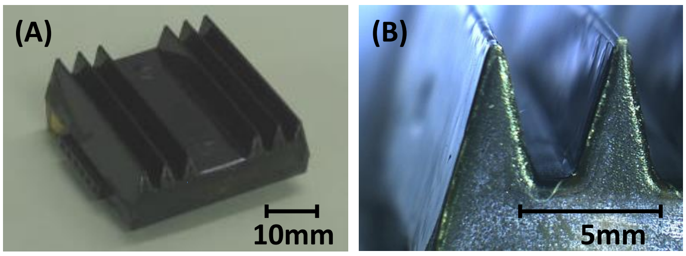


Figure 3. (A) Photograph of TED Module with heat transfer sheet. Size is 35 × 35 × 16.4 mm and weight is 17.5 g. (B) Microphotograph of fin.

Because the molding pressure of injection is more than one-hundred times smaller than conventional molding pressure, the devices on the circuit board are less damaged. In addition, because the solidification time in hotmelt molding is very short (several seconds), the turn-around time is at most only a few minutes. Therefore, the proposed fabrication process is very economical. The heat transfer sheet keeps in contact with the Al pieces with TED by molding.

Figure 4 plots the output voltage of the TED module as a function of heater temperature at 20 °C ambient temperature. For the purpose of comparison, the output voltage of the same TED with an aluminum heat sink (LPD35-7B Alpha Co. Ltd.) which is about the same fin size as the TED module is measured. The size of the heat sink is 35×35×7mm. The output voltage per heater temperature of module is 8mV/K and similar to the result with the heat sink. This result shows the fins with the graphite heat transfer sheet fabricated by molding technology have similar thermal radiation characteristics to the heat sink.

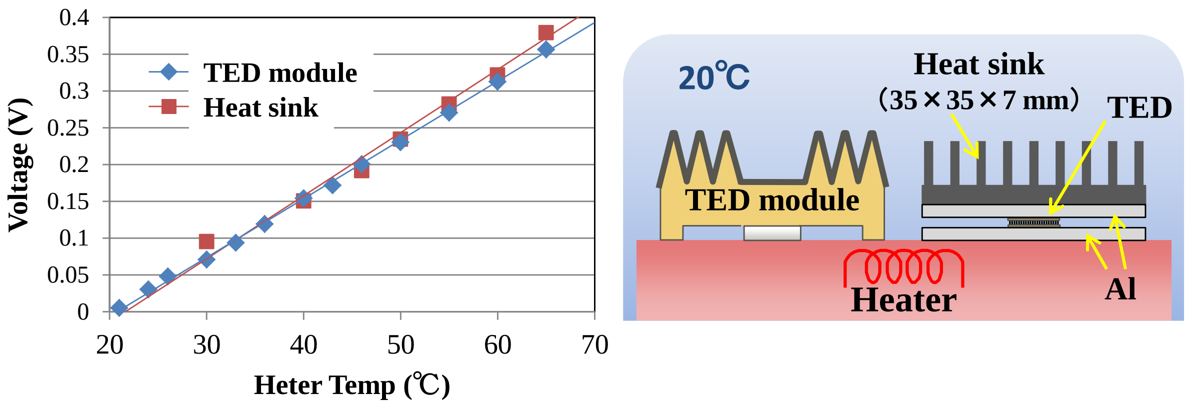
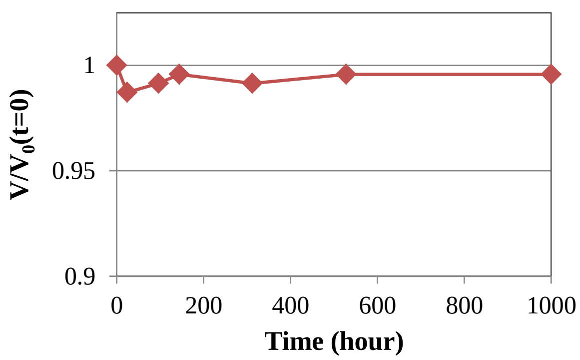


Figure 4. Output Voltage of TED Module vs. heater temperature at 20°C ambient temperature.

The accelerated environmental tests are performed on a damp heat test that is an aging test under high temperature and high humidity, a cold test and a highly accelerated temperature and humidity stress test (HAST) for the purpose of evaluating the electrical reliability in harsh environments. The damp heat test is performed in the conditions of 85 °C/85% RH/1000houers. The HAST is performed in the conditions of 110 °C/85% RH/1.2 Pa/408 h. Each result plots a ratio of the output voltage after each test V to the initial voltage V_0 (t=0), V/V_0. Figure 5 shows the damp heat test results. The damp heat test criterion is the voltage reduction within 8% (JIS C 8990). Because the output voltage of after tested modules is reduced by less than 5%, the voltage degradation is well within the pass standard. Figure 6 shows the cold test results and Figure 7 shows HAST results. Both results of the output voltage of all tested modules are reduced by less than 5%.

The thermal expansion or contraction of mold resin is a possible cause of the deterioration of power generation characteristics, because the TED is peeling off from Al pieces or the thermocouples are damaged. But the figure indicated that the power generation characteristics dose not deteriorate in hot or cold environments, because the flexibility of mold resin is considered to be retained by low Tg (glass transition temperature) -45°C.

The purpose of HAST is evaluation of the electrical reliability in humid environments. The results of HAST indicate that the cases made by hotmelt molding can protect the circuit board with TED from humid environments.



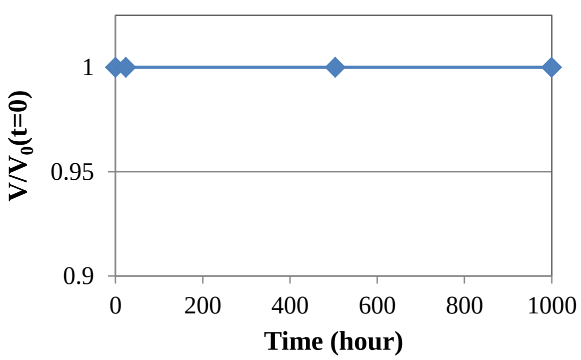


Figure 5. Result of damp heat test (85°C 85%RH1000h)**Figure 6.** Result of cold test (-45°C 1000h)

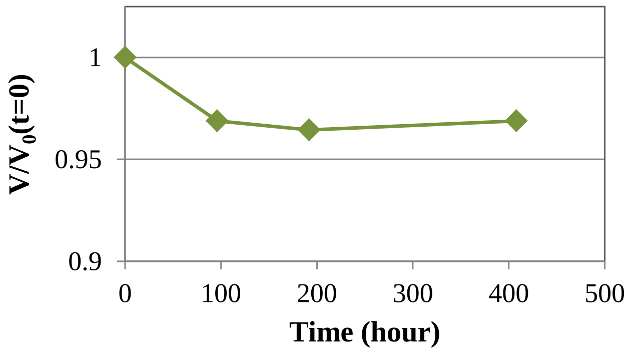


Figure 7. Result of Highly Accelerated temperature and humidity Stress test : HAST (110°C 85%RH1.2Pa408h)

Through molding technology, the TED and circuit board can be properly protected.

Considering our evaluation results described above, we conclude that the new energy harvesting module using TED as an Energy Harvesting Device by molding technology may be applicable to M2M sensor devices.

4. Conclusion

This paper presents the fabrication of a new energy harvesting module that used the thermoelectric device (TED) as an Energy Harvesting Device, for Machine to Machine (M2M) wireless sensor networks. M2M devices must be mechanically robust and tolerant to an external environment.

We propose the novel power generation module by using a molding technology enabled circuit board with the TED, the heat-radiating fin structure and heat transfer sheet to be simultaneously constructed. The light and robust power generation module with TED can be fabricated.

The output voltage per heater temperature of the TED module at 20 °C ambient temperature is 8mV/K and similar to the result with the aluminium heat sink which is about the same fin size as the TED module.

The accelerated environmental tests are performed on a damp heat test that is an aging test under high temperature and high humidity, a cold test and a highly accelerated temperature and humidity stress test (HAST) for the purpose of evaluating the electrical reliability in harsh environments. Every result of the tests indicates that the TED and circuit board can be properly protected from high and low temperature and humidity by using molding technology, because the output voltage of after tested modules is reduced by less than 5%.

We conclude that the new energy harvesting module using TED as an Energy Harvesting Device by molding technology may be applicable to M2M sensor devices.

References

[1] Tanaka T, Suzuki T and Kurihara K 2013 *FUJITSU 64,5, 557-563*
[2] Hiraishi K et al. 2009 *Jpn. J. Appl. Phys. 48 071501-1*
[3] Beaker B and Schoeneweiss A 2007 *Auto Technology 3 34-35*
[4] Yahata K 2008-09 *Materiak Stage 8(6) 14-18*