Development of High-Power Large-Sized Peltier Module

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ABSTRACT With the progress of electronic and communications equipment in recent years toward higher mounting density and higher speed, greater importance has been attached to countermeasures against the heat generated in the equipment. Peltier device, an electronic cooling device, has expanded applications in the market taking advantage of its active, spot cooling capability. However, it was difficult conventionally to realize a large-sized Peltier module because of its inferior resistance against thermal stress. The authors have recently developed a 70-mm-square Peltier module provided with superior stress resistance, which is aimed at solving the problem of the limited size of conventional modules and thereby responding to the needs for high-power, large-sized Peltier modules. In the future, the authors intend to develop its applied products as well as to expand applications in the market.

1. INTRODUCTION

Recent years have seen IT revolution of modern society, where implementation of Internet systems such as ADSL and FTTH (fiber to the home) is progressing rapidly. This brings about the development and the speed and capacity increase in network equipment such as servers and routers, communications equipment for office buildings and personal computers, accompanied by heat generation in the CPUs. Device cooling technologies are required, in view of society maturation and environment consciousness, to be diversified beyond the compressor-based cooling technology thus expanding new applications, but conventionally, with respect to Peltier device, only high-precision but compact and small-capacity devices of several tens watts have been available to respond to such requirements. In this paper a large-sized Peltier module with a capacity in excess of 100 W is presented.

2. LARGE-SIZED THERMOELECTRIC MODULE

2.1 Peltier Module

Prior to describing the large-sized thermoelectric module we have developed, let us briefly explain about Peltier element which is generally called thermoelectric element. A Peltier element consists of, as illustrated in Figure 1, a pair of p- and n-type semiconductor elements bonded with a metal electrode. An electric current flows from the n-type to the p-type semiconductor when a DC voltage is applied in the direction shown in the Figure, whereby for the p-type semiconductor heat transfers in the direction reverse to the current, while for the n-type in the forward direction, thereby the heat is absorbed at the upper electrode where the current flows from the n-type to the p-type, making the metal electrode a heat absorber.

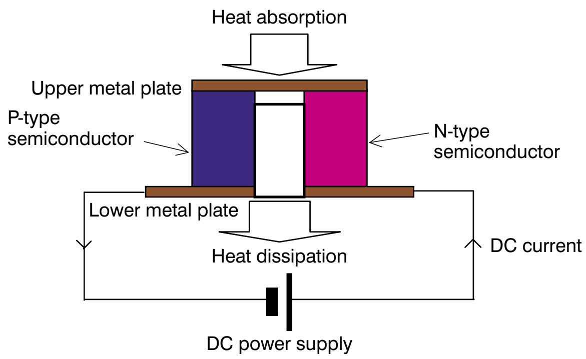

Figure 1 Structure of Peltier element.

This process is a kind of heat pump, and can constitute a very effective cooling system in case the heat-dissipating side (i.e. high-temperature side) can sufficiently dissipate the heat. Note, however, the heat dissipation rate at the high-temperature side normally includes the absorption heat and the Joule heat generated in the semiconductors due to the conduction current, both added together.

The heat absorption rate Q can be expressed as shown below, taking I as the conduction current, T_h as the temperature of the heat-dissipating surface, T_c as the temperature of the heat-absorbing surface, and N as the number of semiconductor element pairs. The first, second and third terms of the Equation represent the ones due to Peltier effect, heat conduction and Joule heat, respectively.

$$
\begin{aligned}
Q &= N[(\alpha_p-\alpha_n)IT_c-K(T_h-T_c)-\frac{1}{2}IR^2] \\
R &= \rho_p(L/A)+\rho_n(L/A) \\
K &= \lambda_p(A/L)+\lambda_n(A/L) \qquad (1)
\end{aligned}
$$

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Since the input voltage V can be expressed as $V = N[(\alpha_p - \alpha_n)\, I\, (T_h - T_c) + IR]$, the power consumption W can be represented as follows.

$$W = VI = NI[(\alpha_p - \alpha_n)\, I\, (T_h - T_c) + IR] \qquad (2)$$

where: A is the cross-sectional area of the semiconductor element; L is its length; α_p and α_n are Seebeck coefficients of the p- and n-type semiconductor elements respectively; ρ_p and ρ_n are their electric resistivity; and λ_p and λ_n are their thermal conductivity.

2.2 Module Structure

Figure 2 shows the common structure of a Peltier module, in which plural pairs of p- and n-type semiconductors such as BiTe doped with Se and the like are arranged on two electric insulating substrates made of alumina, aluminum nitride or the like provided with an electrode on its one surface. The use of ceramic substrate is aimed at ensuring good thermal contacts with the electrically conductive heatsink made of aluminum or copper, while maintaining electrical insulation. The electrode is normally a copper sheet of several tens μm in thickness, and it is bonded with the thermoelectric semiconductors using solder like Sn-Pb solder and Au-Sn solder.

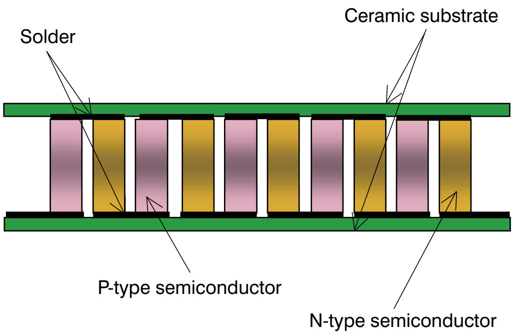

Figure 2 Structure of ordinary Peltier module.

What should be noted here is that, as illustrated in Figure 3, these ceramic substrate-based Peltier modules generate, since the upper and lower ceramic substrates and the multiple semiconductor elements are bonded together using solder, a shearing stress at the fixed portion of the semiconductors due to the fact that in operation the heat-dissipating side is heated to expand, while the heat-absorbing side is cooled to contract. This stress can result in fractures of the module and generation of fatigue cracks at the solder-bonded portion when repeatedly used for a long period under a large temperature difference. These fractures and cracks are remarkable at the ends of the module, posing a serious problem in the case of large-sized modules.

Thus it has been difficult to manufacture large-sized Peltier modules, so that the maximum size commercially available was limited to 40~50 mm square at most, and these products have been supplied to the market targeting mainly at such applications where high-precision temperature control is needed for small- to medium-capacity cooling, e.g. CCD cameras with extended definition and

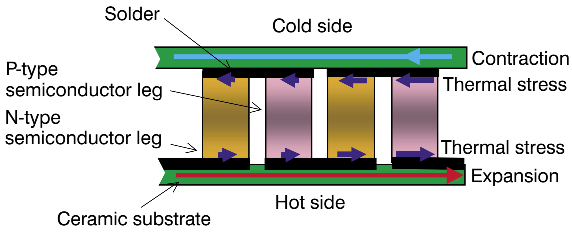

Figure 3 Thermal stress on P/N semiconductor legs.

sensors. In cases where cooling by heat absorption in excess of 100 W is desired, plural modules connected either in series or in parallel were used, but the modules have to be strictly controlled individually in terms of the height to improve the thermal conductivity between the heatsink and module, and in addition, they have to undergo selection to provide an even level of heat absorption rate or temperature difference.

2.3 Product Concept

We have carried out the development, as described above, based on a product concept aimed at solving the problem of the limited size of conventional modules and thereby responding to the needs for high-power, large-sized Peltier modules.

2.3.1. Basic Structure and Materials for Thermoelectric Module

Figure 4 shows the basic structure of the thermoelectric module developed here, and Photo 1 its appearance.

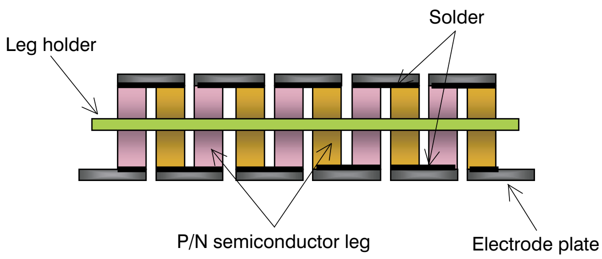

Figure 4 Structure of developed large-sized Peltier module.

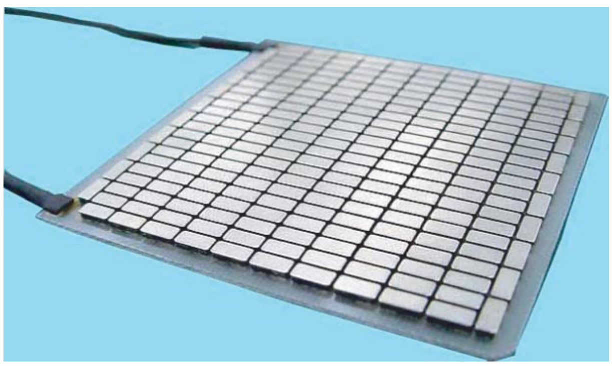

Photo 1 Large-sized Peltier module.

Structural features of the developed thermoelectric module are summarized into three items as follows:

(1) Semiconductor elements are fixed using an insulator at the center for mechanical connection, while their upper and lower ends are not fixed.

(2) Semiconductor elements are connected at their upper and lower ends using a small nickel-plated copper electrode to form thermoelectric pairs, for electrical connection.
(3) The element and the electrode are fixed using solder.

Table 1 shows the structure and materials.

Table 1 Structure and materials of large-sized Peltier module.

Item	Dimensions	Materials
Electrode	2.3 × 5.0 × 0.4 mm	Nickel-plated oxygen-free copper
Semiconductor element	2 × 2 × 2.3 mm 248 pairs	Bismuth telluride
Solder	—	Tin-Lead solder
Separator	71 × 72 × 0.5 mm	Heat-resistant reinforced resin
Module size	71 × 72 × 3.2 mm	—

2.3.2. Structural Advantages

In this module, the p- and n-type semiconductor elements are fixed at the center using a heat-resistant epoxy resin insulator, while their upper and lower ends are bonded with electrodes to form a pair using solder. The paired elements are less susceptible to the shearing force due to thermal expansion than the conventional module where all pairs are integrally structured using a ceramic substrate, thereby resulting in a higher degree of reliability against thermal stress as well as ease of size enlargement. This large-sized Peltier module is fully applicable to those purposes in particular where rapid heating- and cooling-operations are required—a major advantage of Peltier effects—because of its excellent resistance against thermal strains.

2.3.3. Products Lineup

The standard shell shown in Figure 5 and the hard shell shown in Figure 6 have been developed to be incorporated with the 70×70-mm, large-sized Peltier module, constituting the products lineup. Their external views are shown in Photos 1 through 3.

These two types of shells are intended to adapt the 70×70-mm, large-sized Peltier module to specific applications, and they provide sealing to enable applications in the dew-condensing environments. The standard shell has a low profile of 4.1 mm in thickness, so that it is suitable for such applications where installation space is limited, while the hard shell has a robust structure with superior shock resistance, so that it is suitable for a wide range of applications.

The standard shell has a structure such that two 0.5-mm thick aluminum plates with an insulating layer on the inner side are used, with the aim of temperature stabilization and homogenization, to sandwich the 70×70-mm, large-sized Peltier module from both the heat-absorbing and heat-dissipating sides, and an elastic adhesive is used to seal and fix the sides overall.

The hard shell has a structure more robust than the standard shell, consisting of two aluminum plates on the heat-absorbing and heat-dissipating sides in addition to a

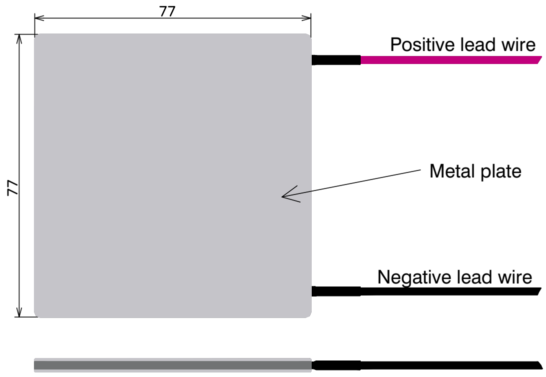

Figure 5 Standard shell incorporated with 70x70-mm Peltier module.

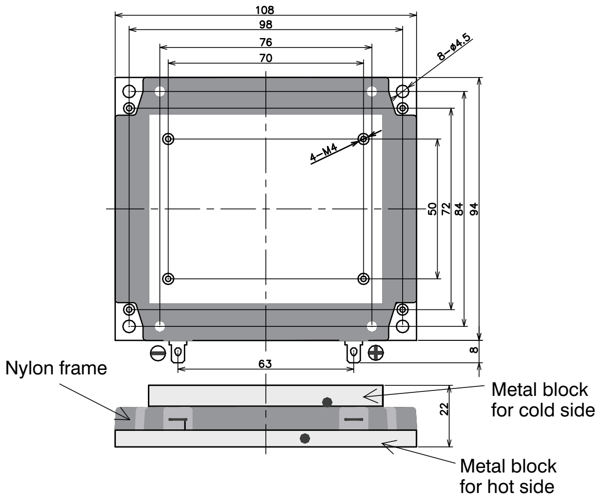

Figure 6 Hard shell incorporated with 70x70-mm Peltier module.

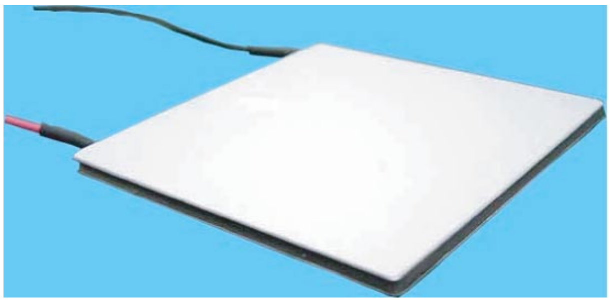

Photo 2 External view of standard shell.

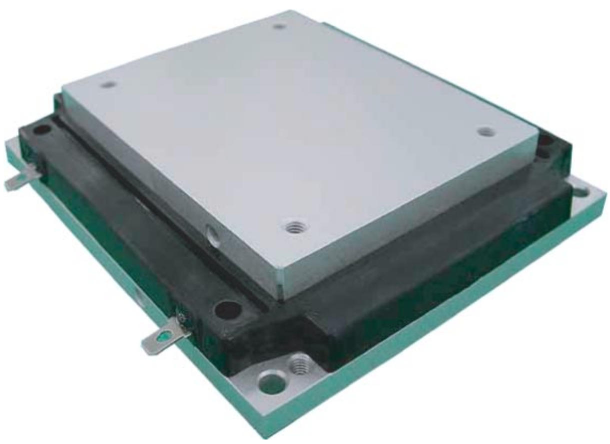

Photo 3 External view of hard shell.

nylon frame for fixing the plates. The module and the aluminum plates are electrically insulated, as in the case of the standard shell, by an insulating layer on the inner side of the aluminum plates, providing an electrical insulation rating of DC 500 V for both the standard and hard shells.

Table 2 shows specifications for the standard and hard shells.

Table 2 Specifications of standard and hard shells.

Item	Specification	
	Hard shell	Standard shell
Model name	OKT-7070-H	OKT-7070-S
Max. current (A)	6	
Max. voltage (V)	27	
Max. temperature difference (°C)	65	67
Max. heat absorption rate (W) (ΔT=0°C)	120	120
Internal resistance (Ω) (measured at T_h=50°C)	3.2±10%	
Number of pairs	P/N 241 pairs	
Connection for power supply	Terminal type	Lead wire (Red: positive, Black: negative)
Outer dimensions (mm) (L×W×H)	94×108×22	77×77×4.1
Mass (g)	520	90
Retention strength of lead wire (kg)	2	

3. MAJOR CHARACTERISTICS

3.1 Thermoelectric Characteristics

Figure 7 shows the thermoelectric characteristics of the standard shell (model name: OKT-7070-S) using a large-sized Peltier module, where the heat absorption rate Q versus temperature difference ΔT_g characteristics and the supply power W versus temperature difference ΔT_g characteristics are plotted, taking the module current as a parameter.

As can be seen from the heat absorption rate Q versus temperature difference ΔT_g characteristics in Figure 7, under the condition of constant input current, the higher the difference ΔT_g the smaller becomes the heat absorption rate Q. That is to say, the maximum heat absorption rate Q_{max} is obtained when ΔT_g=0, i.e. when the heat-dissipating surface temperature is equal to that of heat-absorbing surface. Thus maximum heat absorption rate is defined under the condition of ΔT_g=0, and as can be seen from the Figure, it is 130 W for the standard shell.

Furthermore, the temperature difference ΔT_g reaches at its maximum when the heat absorption rate is zero, and as can be seen from the same Figure, it is about 68°C at the maximum current rating of 6 A.

3.2 Heat Cycle Resistance

Conventional Peltier modules suffer from the disadvantage of an extreme weakness against thermal strains caused by rapid heating- and cooling-operations, in addition to insufficient long-term reliability when operated under on-off temperature control.

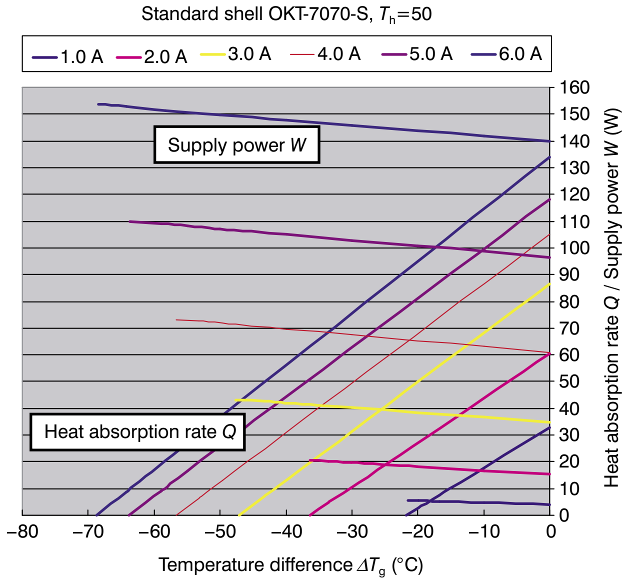

Figure 7 Thermoelectric characteristics of standard shell. (at T_h=50°C)

Since the developed large-sized Peltier module adopts a skeleton-based structure where the semiconductor elements are fixed at their center using a heat-resistant epoxy resin insulator, the module is less susceptible to the shearing force due to thermal expansion than the conventional module where all pairs are integrally structured using a ceramic substrate, thereby resulting in a higher degree of reliability against thermal strains. Durability of the 70×70-mm, large-sized Peltier module (model name: OKT-7070-S) has been tested to evaluate its reliability against thermal strains using the method shown in Figure 8.

The test results are shown in Figure 9, where the changes in the resistance of a module over time and the number of heat cycles are plotted with the cycle on the X-axis and the resistance on the Y-axis. It can be seen that the resistance is stable up to 50,000 cycles, sufficient durability against thermal strains.

Figure 10 shows the test results of durability against thermal strains for the hard shell (model name: OKT-7070-H). The heat cycles were applied by reversing the polarity of the module current to obtain a temperature cycles of from −15°C to +110°C at the heat-absorbing surface of the module. Stabilized durability of more than 10,000 cycles has been achieved.

4. APPLICATION FIELDS

Since the Peltier module developed here is large-sized and high-powered as well as provided with sufficient durability against rapid cooling- and heating-operations besides on-off control, it is applicable to a wide range of applications. It is expected that the module will expand its application fields taking advantage of such features. Table 3 shows the projected application fields at the present time.

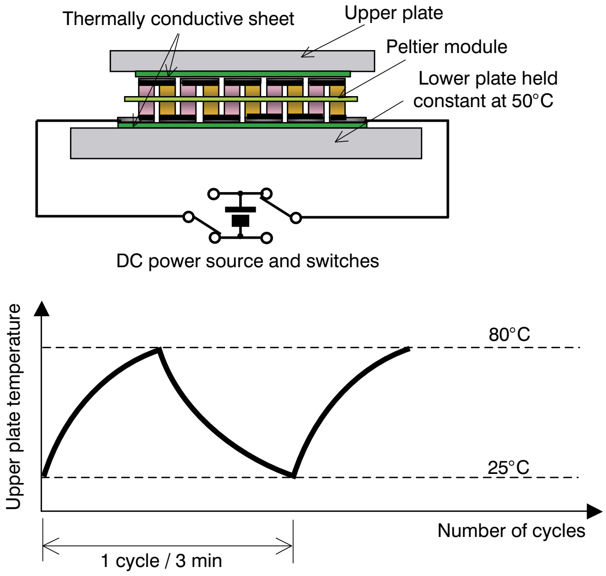

Figure 8 Durability test against thermal strains.

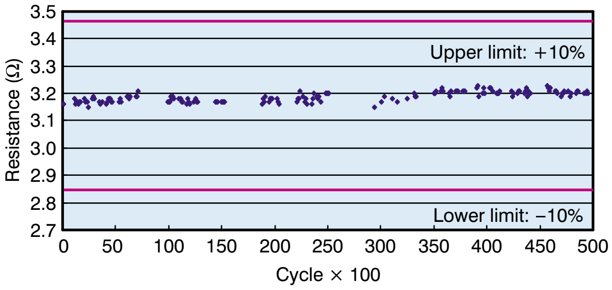

Figure 9 Heat cycle test results for standard shell. (Heat cycle: −25°C∼+80°C)

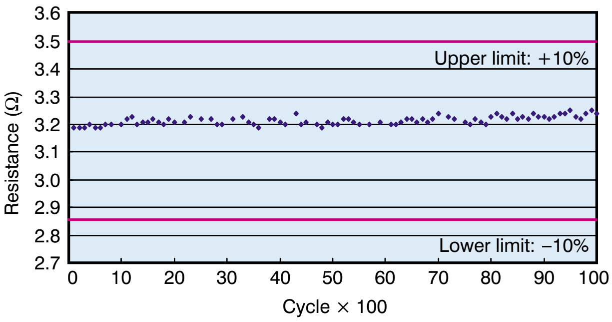

Figure 10 Heat cycle test results for hard shell. (Heat cycle: −15°C∼+110°C)

5. CONCLUSION

This paper has presented a general description of the 70×70-mm, large-sized Peltier module and its applications developed here. The module has been developed based on the skeleton structure where the semiconductor elements are held at the center. The advantages of this module are that regardless of its large size it has sufficient durability against thermal strains as well as a high heat-absorption rate, which is unattainable for conventional structures. Durability test against thermal strains proved its highly stabilized performance.

Hereinafter, it is expected that the product will find a wide range of applications taking advantage of its beneficial features, and we plan to expand its applications in the market as well as to develop many applied products.

In closing, we would like to extend our thanks to those at the Ecology and Energy Laboratory of Furukawa Electric for their valuable advice.

Table 3 Application fields of large-sized Peltier module.

Market and field	Applicable equipment	Objective
Semiconductor	Liquid circulating cooling equipment; Wafer prober; Rapid cooling equipment after wafer baking	High-precision, rapid cooling
Medical care, biotechnology	Icing equipment; DNA amplification equipment	Streamlining of test equipment; Automation of test; Noise reduction
Electronics	Test equipment for laser diode; Parts test equipment; Compact temperature-controlled oven	Downsizing; Precision improvement
Industry	Refrigerator; Test equipment; Manufacturing equipment Temperature control for controlling unit; Cooling of laser machining equipment	Downsizing
Vehicle	Cooling box	Downsizing