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Development of the High Performance Thermoelectric Modules for High Temperature Heat Sources

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Abstract

From a viewpoint of heat stress at high temperatures and contact thermal resistance, it is confirmed that the optimal structure is the skeleton structure using Cu substrate on the cooling side, which has excellent heat conductivity and the optimal installation method is to adopt a carbon sheet and a mica sheet to the high temperature side, where Si grease is applied to the low temperature side, under pressurized condition. The power of the developed modules indicated 0.5W in an $FeSi_2$ *module and 3.8 W with a SiGe module at 823K, respectively.*

Keywords: thermoelectric element, thermoelectric module, structure of module

1. Introduction

Recently, utilizing waste heat energy in factories effectively is noticed as important technology [1]. The waste heat from sintering furnaces is a direct concern for powder metal manufacturers. In particular, the thermal energy during the cooling phase of the production process after sintering is not utilized yet.

Meanwhile, thermoelectric technology which can convert the thermal energy to electrical energy directly is attractive as an effective exhaust-heat recovery technology [2]. However, thermoelectric technology has only been applied for low temperature use in wrist watches; there has been no experience to apply it in high temperatures [3]. Thus, the thermoelectric technology needs to solve the concerns of the diffusion on the connecting interface and the thermal stress, which is generated between the module components, etc., in order to be applicable.

Research has therefore been conducted into developing a highly efficient thermoelectric system for use in effectively using the waste heat from incinerators, PM sintering furnaces and other electric furnaces.

2. Experimental and Results

Trial Production Modules

Table 1 shows the specifications of the manufactured modules. Module 1 used the conventional peltier module structure [4]. Module 2 is a skeleton structure for the purpose of reducing the thermal stress on the high temperature side. Since Cu of the substrate needed to be insulated with an electrode, a resin was used for the connecting process.

Module 3 is a structure, which enables high performance of a thermoelectric element and a thinner electrode, based on Module 2. The thermoelectric element used was SiGe and the electrode used was a Mo board. 20 pairs of each module were prepared. Ag solder was used to connect the thermoelectric elements, the electrode, and alumina substrates.

Table 1. Specifications of Manufactured Modules

		Module 1	Module 2	Module 3
Thermoelectric element		$FeSi_2$	$FeSi_2$	SiGe
Size of thermoelectric element [mm]		3.7x3.7x5.1^t	3.7x3.7x5.1^t	3.7x3.7x4^t
Electrode		Cu	Cu	Mo
Size of electrode [mm]		4.5x10x5^t	4.5x10x5^t	4.5x10x1^t
Substrate	hot side	Al_2O_3	-	-
	cold Side	Al_2O_3	Cu	Cu
Size of substrate [mm]		35x40x1^t	35x40x2^t	35x40x4^t

Power-generation Examination

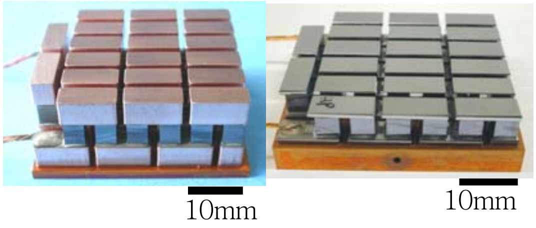
The module was installed between a heating duct equipped with heater and water-cooled duct, and subjected to various different temperatures. In the case of the installation method (a) a mica sheet with a thickness of 0.1mm and a carbon sheet with a thickness of 0.2mm were inserted between the module and the heating duct, and silicone grease was applied between the cold duct and the module, which was pressurized at 0.07MPa. The carbon sheet was used as a means of reducing the contact thermal resistance, and the mica sheet was used as a means of insulation between the electrode and the heating duct.

The installation method (b) had an alumina board with a thickness of 1mm between the heating duct and the module, and was pressurized at 0.02MPa.

The thermal cycling test heated the hot duct to 823K in a N_2 gas, and was then immediately cooled to 473K, this pattern was repeated 30 times. It had a load of 5Ω for the external resistance using an electronic load apparatus, electromotive force and electric current was measured and the power was calculated.

Trial Production of Modules

At the time of brazing, the connection of the alumina substrate and a Cu electrode was damaged and Module 1 was not able to be produced. On the other hand, breakage at the time of brazing was not seen in Module 2 and 3. Fig. 4 shows the arrangement of Module 2 and 3.



[a] Module 2 **[b] Module 3**

Fig. 4. Arrangement of Module 2 and 3

Relation between the Installation Method and the Power of the Module

Fig.5 shows the power of the module 2 according to the installation method for each temperature. In the case of installation method (a), the power of the module was 0.5W and, in the case of installation method (b), the power of the module was 0.07W. Since the power of the module was proportional to the 2nd power of the temperature, installation method (a) is presumed to be about 2.6 times the temperature of the installation method (b). Since the highest temperature of the Cu substrate of the module showed 423K by the installation method (b) and 373K by the installation method (a), it was concluded that the difference in temperature of the modules is greatly influenced by the difference in the installation method.

The heat cycle test of Module 2 was performed using the installation method (a) where high power was obtained. No decrease in the power was observed even after 30 times of testing.

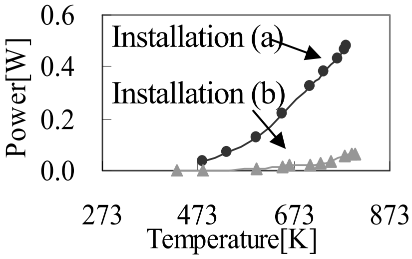


Fig. 5. Power of the module according to the installation method for each temperature

Performance of Highly Efficient Module (Module 3)

When the hot duct side temperature was 823K, the power was 3.8W, about 8 times the power of Module 2's 0.5W. The reason for this difference is in the performance difference of the thermoelectric element, the thermal resistance of the joining interface, etc..

3. Conclusion

The following were clarified in the development of a thermoelectric module for high temperature conditions. (1) The module using the skeleton structure is effective in reducing the thermal stress. (2) The installation method of the module where a carbon sheet and mica sheet are applied to the skeleton side, silicon grease applied on the substrate side, and pressurized, is effective in reducing the contact thermal resistance. (3) The power of the module using $FeSi_2$ was shown to be about 0.5W and SiGe was shown to be about 3.8W.

Acknowledgement

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4. References

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