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Stack-type thermoelectric power generating module with flexible section and using phase changes of low-boiling-point medium

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ABSTRACT

In order to realize reliable electrical connections in a stack-type thermoelectric power generating module, flexible sections were installed between lower-temperature-sides of thermoelectric elements. These sections were expected to play three important roles of interpolating different thermal expansions of the module components, enlarging heat removal area and penetration of any media through themselves. Then, a low-boiling-point medium was also applied for a high-speed direct heat removal via its phase change from the lower-temperature-sides of the thermoelectric elements in the proposing stack-type thermoelectric power generating module.

No electrical disconnections inside the proposing stack-type thermoelectric power generating module were observed for more than 7 years of use, confirming the module stability. The power generating density from the proposing stack-type thermoelectric power generating module with the flexible sections and the low-boiling-point medium was improved about two thousands fold, compared to that without flexible sections and with water instead.

1. Introduction

Contemporary society is facing many critical problems such as global warming, loss of biodiversity and exhaustion of fossil fuels. Among these issues, the exhaustion of fossil fuels is considered the most urgent threat, and needs to be solved in order to ensure the survival of mankind. To accomplish energy sustainability, technologies and demands listed in Tables 1a and 1b are required in the coming decades [1–3]. Especially, low-temperature-waste-heats are of particular interest because of their enormous quantity, ubiquity and heretofore limited actual usefulness such as hot water supply, space heating and dehydration in adsorption and absorption heat pumps [4,5]. We have focused on power generators based on thermoelectric, piezoelectric and liquid turbine driven by low-temperature-heats below 373 K in the aim of contributing to energy sustainability [6–8]. Among them, the thermoelectric power generator (TEG) has been world-widely developed via material engineering. TEG modules with bismuth-tellurium compounds are suitable for harvesting electric power from low-temperature-heats below 573 K. This compounds have been improved by surface modifications, coatings, doping, replacements of tellurium with its cognate light atoms, etc., approaching to an optimized thermoelectric element [9,10].

Some issues still remain with traditional π-type TEG modules such as a long current pass, low heat transfer rates through adiabatic supporting ceramic plates and sudden zero output due to disconnection of the components with different thermal expansion coefficients. Then, stack-type TEG module was proposed to solve the former two issues [11]. Concerning the last issue, relaxation edges for the TEG components' thermal stresses and functionally graded materials at the junctions of each TEG component were applied, assuring all the components were in contact electrically [12,13]. However, there are still quite a limited number of investigations to overcome the issues described-above.

In this study, two ideas were applied to the stack-type TEG module for highly reliable electrical connections of the module components with different thermal expansion coefficients and high-speed direct heat removal from lower-temperature-sides of thermoelectric elements (i.e. higher power generating density). Concretely, one idea was the installation of flexible sections, and another idea was the utilization of a low-boiling-point medium.

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Table 1a
Technologies for energy sustainability.

Technologies	Examples	This study
Nuclear fusion	ITER in France	
Practical power generation from renewable energies	Solar, wind, geothermal, hydraulic, tidal, biomass, etc.	
Energy harvesting from low-temperature-waste-heats	Thermoelectric power generation, binary power generation, etc.	Relevant

Table 1b
Demands for future energy.

Demands	Event, strategy or candidates	This study
Safety	Fukushima Daiichi nuclear accident	Relevant
Assurance	Power generator independent of any lifelines	Relevant
Conservation	Heat storage, co-generation, etc.	Relevant

This paper firstly introduces our historical tracks to a new stack-type TEG module with the two ideas described-above, specifying the backgrounds reaching to probative materials of copper wools installed into flexible sections between the lower-temperature-sides of the thermoelectric elements and Novec merchandised by 3M Japan Ltd. [14] as a low-boiling-point medium. Secondary, a pathway to Novec/water biphasic medium is described, and its significances in the proposing stack-type TEG module are explained together with anticipated heat transfer and hydrodynamic phenomena. Thirdly, experimental proofs indicating effectivities of the two ideas with a preliminary testing apparatus are shown. Fourthly, experimental data from a prototype stack-type TEG module are discussed in details, and effects of parameters deeply related to the two ideas on the power generating density are clearly pointed out. Finally, future strategies for further improvement of the proposing stack-type TEG module with the flexible sections and using phase changes of the low-boiling-point medium are declared.

2. History to new stack-type TEG module with flexible sections and low-boiling-point medium

Fig. 1 shows schematics of unit segments from the existing to a proposing stack-type TEG module with two ideas of the installation of flexible sections and the utilization of a low-boiling-point medium. It can be seen that the existing stack-type TEG module has no flexible parts, and it is fragile for variations in heating fluxes as well as temperatures of a high-grade heating source and a low-grade heat releasing target. It should be appreciated that all heats are transferred by conductions, i.e., a low temperature-difference between one side and another of each thermoelectric element, which is well-known directly proportional to a figure of merit in TEG module [9,10,15], and the outputs must be reduced.

To upgrade resistance characteristics of the stack-type TEG module towards thermal variations in heating fluxes and temperatures, interpolation of different thermal expansions of the module components by installation of flexible sections between the lower-temperature-sides of the thermoelectric elements had been originated. Then, we could reach a bundle of copper wools as a probative flexible material in this study because of its availability, low cost and high thermal conductivity. Other potential candidates of the flexible materials are shown in a closing stage of this paper. The flexible sections, where copper wools were installed into, were expected to play additional two roles of enlarging heat removal area and penetration of any media through themselves, enabling high-speed direct heat removal via phase change of a low-boiling-point medium. Therefore, a larger-temperature-difference between one side and another of each thermoelectric element (i.e. higher outputs) can be expectable as synergistic effect of the flexible copper wools' sections and the low-boiling-point medium.

Favorable properties of the low-boiling-point medium for the proposing stack-type TEG module are its lower specific heat and latent heat of vaporization for vigorous flow fields and corresponding heat interchanging rate enhancement by the medium, resulting to Novec merchandised by 3M Japan Ltd. [14] with indispensable properties as shown in Table 2.

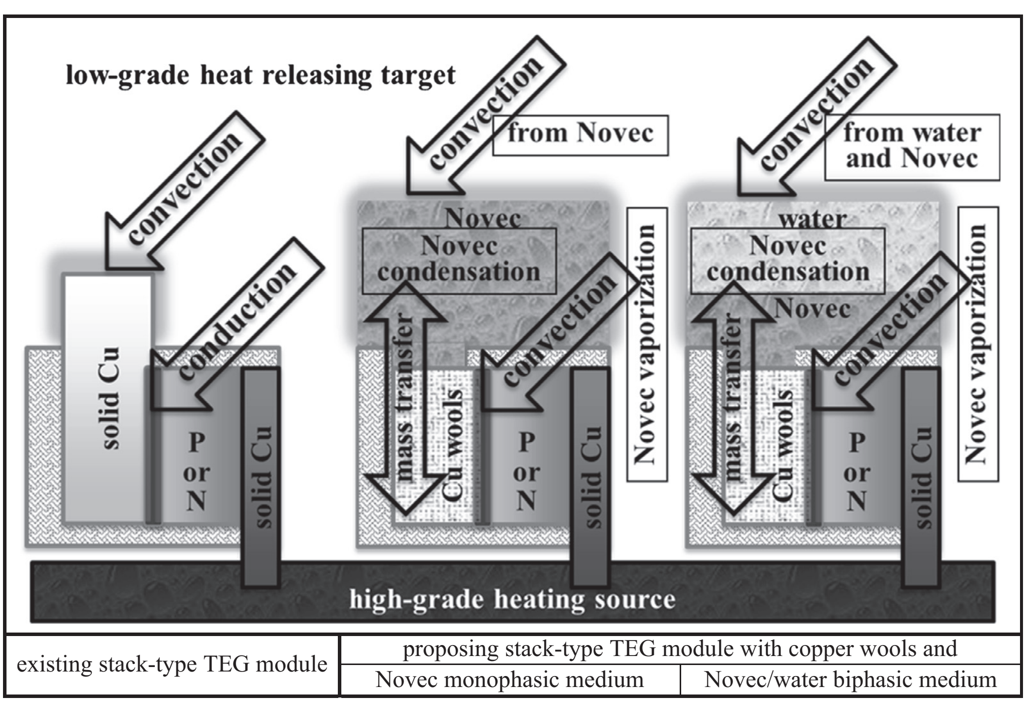

Fig. 1. Schematic drawings from existing to proposing stack-type TEG modules.