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Preparation of Ring-Shaped Thermoelectric Legs from PbTe Powders for Tubular Thermoelectric Modules

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Waste heat recovery—for example, in automotive applications—is a major field for thermoelectric research and future application. Commercially available thermoelectric modules are based on planar structures, whereas tubular modules may have advantages for integration and performance in the field of automotive waste heat recovery. One major drawback of tubular generator designs is the necessity for ring-shaped legs made from thermoelectric material. Cutting these geometries from sintered tablets leads to considerable loss of thermoelectric material and therefore high cost. Direct sintering of ring-shaped legs or tubes of thermoelectric material is a solution to this problem. However, sintering such rings with high homogeneity and density faces some difficulties related to the mechanical properties of typical thermoelectric materials such as lead telluride (PbTe)—particularly brittleness and high coefficient of thermal expansion. This work shows a process for production of thermoelectric rings made of *p*- and *n*-doped PbTe. Long tubes of PbTe have been sintered in a current-assisted sintering process with specially designed sintering molds, coated with a diffusion barrier, and finally cut into ring-shaped slices. To demonstrate the technology, a tubular thermoelectric module has been assembled using these PbTe rings.

Key words: Thermoelectric generator, TEG, waste heat recovery, sintering, lead telluride, thermoelectric module, tubular module, lead telluride rings, SPS

INTRODUCTION

In automotive combustion engines over 50% of the fuel's energy is lost as waste heat. Thermoelectric generators (TEGs) have the potential to recover some of this waste heat when installed in the engine exhaust pipe or exhaust gas recirculation cooler (EGR) and thus increase the car's fuel economy.[1,2] In recent years there have been several research projects demonstrating integration of TEGs into cars, using hot exhaust gas as the heat source on the hot side and a liquid-based cooling system on the cold side. Most of the generators used in these projects were based on modules using the conventional planar layout of *p*- and *n*-legs.[3,4] To minimize the temperature drop between the exhaust gas and the thermoelectric (TE) material within the module, good contacts between the exhaust pipe and TE module are necessary. This usually requires pressing the modules against the gas conducting pipe with high forces, which in turn makes the whole generator design very heavy.

The design of a tubular TE module as demonstrated in this work is shown in Fig. 1a. In this design, ring-shaped legs of *p*- and *n*-type thermoelectric material are arranged alternately along the tube's axis with insulating rings in between to prevent electrical shortcut. The TE legs are alternately connected by short metallic tubes at the inner and outer diameter of the TE rings. Note the difference in this design compared with the design proposed by Gao Min in which the connecting bridges are arranged between the TE rings as illustrated in Fig. 1b.[5–7] To prevent contamination of the module by exhaust gas or cooling liquid, a coating or an additional tube at the

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