POLITECNICO DI TORINO

ABSTRACT

DEPARTMENT OF APPLIED SCIENCE AND TECHNOLOGY

Thesis for the degree of Doctor of Philosophy

MODELLING AND CONSTRUCTING DEVICES INCLUDING INNOVATIVE JOINING OF HIGH TEMPERATURE THERMOELECTRIC MODULES

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Thermoelectric generators (TEGs) are devices that convert a heat flow into electricity. The efficiency of a thermoelectric generator depends on the thermoelectric properties of the material, the temperature difference across the device, and is often limited by the thermal and electrical losses at contacting interfaces. The vast majority of the thermoelectric research literature focuses on improving the properties of the thermoelectric material. However, the reliability and thermal stability challenges of incorporating thermoelectric materials into high-performance devices still represent a key bottleneck. In this work, fabrication methods for robust, medium-high temperature regime thermoelectric modules are proposed. To achieve this, different metallization layers, their deposition routes and several joining techniques that utilized commercial and novel bonding materials were developed.

Two thermoelectric module assembly approaches were explored. The first one involved testing conventional, high temperature brazing using materials that works in the desirable and narrow brazing window temperature range. Although mechanically strong contacts were formed, extensive growth of the reaction layer at the interconnect – thermoelectric interface and metallization layer delamination were observed that could presumably cause a device failure at higher service temperatures. The second approach involved assembly studies using low-temperature bonding materials and novel metallization

layers that minimized reaction layer formation and resulted in low electrical contact resistance performance. This work also demonstrates an implementation of the Solid-Liquid Interdiffusion (SLID) bonding technique using a novel aluminium-nickel multilayer system and extensive investigation into the electrical, mechanical and microstructural properties of contacting interfaces.

Three module prototypes were fabricated using off-the-shelf $Mm_y(Fe,Co)_4Sb_{12}$ *p-type* (*Mm* - Mischmetal) and $(Ni,Co)Sb_3$ *n-type* thermoelectric materials with average zT ($\overline{zT}$) of 0.12 and 0.27 respectively, measured between 50 ºC and 450 ºC. The high-temperature thermoelectric performance of device prototypes was fully characterized using in-house developed module test system and related to simulation results from finite element analysis using COMSOL Multiphysics ® software. The highest performing 7-couple thermoelectric module developed in this research was featured with P_{MAX} of 608 mW and power density of 695 mW/cm^2 measured at ΔT = 450 ºC in open air.