3D-Model of Asymmetric Thermo-Electric Generator Modules for High Temperature Applications

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Abstract

Thermo-electric generators (TEG) offer a high potential for waste heat utilization and as a robust power supply for standalone systems. While current commercial TE-materials (Bi2TE3) are restricted to temperatures below 400°C, recently developed ceramic materials allow operation in a range from 500°C up to > 1000°C. In a thermo-electric generator module (TEM) alternating pairs of legs from conjugate materials with different TE-type have to be combined for optimal operation. Conventional TE materials are semiconductors can be manufactured as p- and n-type doped sub-type varieties with conjugate TE properties. A common TEM-design therefore has a symmetric twin geometry for p- and n legs. In case of the investigated high temperature materials thermoelectric p- or n-type behavior is currently available only with different base materials (p: B7C, n: TiB2), that have very different thermo-physical properties. An optimum TE-performance for an corresponding TE-Module can be obtained for a design with an asymmetric geometry of the paired p- and n-type legs, with different base area (figure 1). In order to assist the practical development of TE-Modules on basis of B7C and TiB2 TE-material a 3D-Finite element model of the TE-Module design in full geometrical detail (legs, substrate, electrode layers, …) has been set up in COMSOL Multiphysics® (figure 2). To implement the physical thermo-electric coupling with Seebeck- and Thomson-Effects a corresponding user defined physical interface was implemented for the electric (figure 3) and thermal (figure 4) behavior using the PDE-mode and taking advantage of the flexible multiphysics options of the COMSOL Multiphysics® code. The model has been used to analyse different geometry variants to find a optimum design that fits the scheduled specifications as well as to verify simpler, 1D and 0D model approaches and to quantify additional loss mechanisms for instance due to electrode resistances and parasitic thermal bridges. An optimized design proposal has been derived from the model and a sufficient validity of the simpler models could be confirmed. As a future prospect the model may be extended to thermo-mechanical behavior, evaluating the deformations and mechanical stresses resulting from manufacturing and operation. Next step in the development process of a complete thermoelectric generator will be the thermal power adjustment between TEM and a heat exchanger component (HEX). For this task the multiphysics capabilities (CFD, Heat Transfer) of COMSOL Multiphysics® will allow to give further assistance by analysis and optimization of the fluid-solid heat transfer in the HEX and its interaction with the TE-Modules, representing another possible prospect of the modeling activities.

Reference

W. Seifert, M. Ueltzen, Eckhard Müller, One-dimensional modelling of thermoelectric cooling, Physica Status Solidi (a), 1(194):277 – 290, 2002
H.-P. Martin, I. Kinski, J. Schilm, Thermoelectric generators based on Ceramic Technologies, Annual Report Fraunhofer IKTS 2010, Dresden, 18-19

Figures used in the abstract

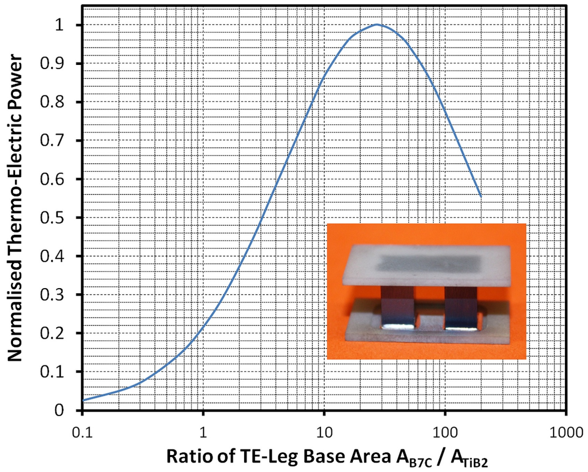
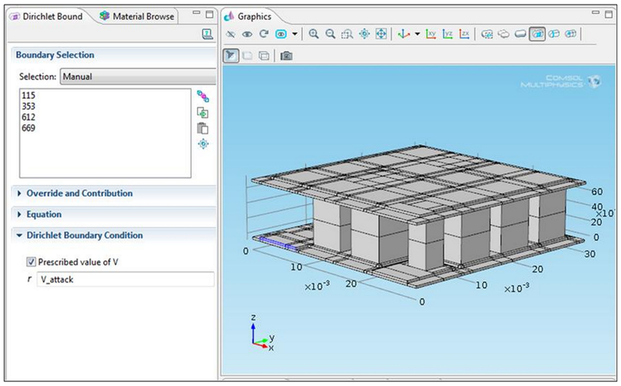


Figure 1: Results for the normalized output of electrical power of a asymmetric TEM under variation of the ratio between the base area of p- type (B7C) and n-type (TiB2) leg. Total thermal resistance of the TEM is kept constant (adapting overall coverage with TE-material) to achieve comparable thermal adjustment.



Selection: Manual

115
353
612
669

☑ Prescribed value of V

r V_attack

Figure 2: COMSOL model for TE-Module geometry variant.

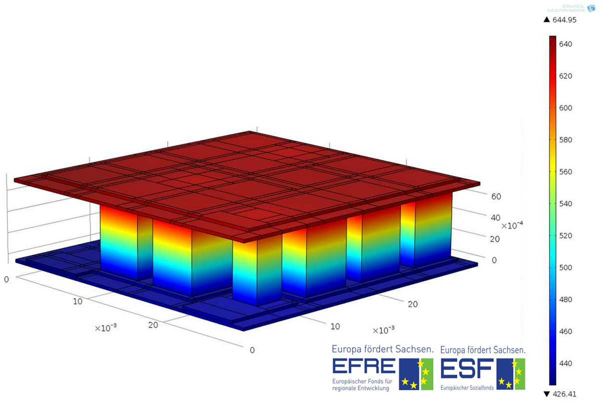


Figure 3: Result for temperature distribution under thermoelectric load (T1= 648 K, T0= 423 K; I= 0.17 A)

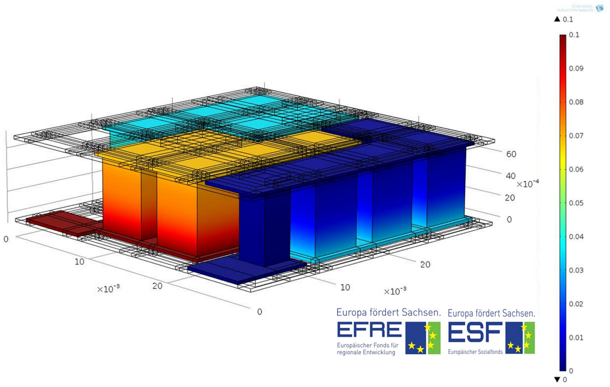


Figure 4: Result for voltage distribution under thermoelectric load (T1= 648 K, T0= 423 K; I= 0.17 A)