Finite Element Evaluation of the Strength of Silicide-Based Thermoelectric Modules

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Abstract

One of the applications of thermoelectric materials is the production of electrical power from heat flow across a temperature gradient. In a module for power generation, thermoelectric couples of n-type and p-type semiconductors are electrically connected in series and thermally in parallel. Silicide-based thermoelectric modules provide a promising solution for thermoelectric power generation at mid-high temperatures. In particular, modules with Sb-doped Mg2Si n-type legs and Higher Manganese Silicide (HMS) p-type legs may operate with temperature gradients up to 600°C. With such temperature gradients, thermal stresses in materials with different coefficient of thermal expansion may undermine the mechanical stability of the system.

In this work, a finite element (FE) evaluation of the mechanical strength of a 16 legs thermoelectric module prototype (Figure 1) is presented. In the simulation, COMSOL Multiphysics® Thermoelectric Effect interface was used to calculate the temperature profile of module elements, which was then used as input in the Solid Mechanics interface for the evaluation of stress distribution [1,2]. Proper failure criteria for thermoelectric legs and Von Mises yield criterion for the connections were considered [3].

FE analysis has shown widespread damage in the module considering top aluminum nitride plate, even with low temperature gradient. Higher strength was reached replacing aluminum nitride with alumina. It was found that, for both solutions, cracks in the legs occur near the interfaces thermoelectric / conductor, mostly in Mg2Si chips (Figure 2). This was also experimentally observed during the test of the prototype: Infrared Thermography highlighted cracks occurring in the hot side of n-type legs of the tested 16 legs thermoelectric module (Figure 3) [4].
An evaluation of the strength of a 16 legs silicide-based thermoelectric module has been performed using COMSOL Solid Mechanics interface. FE analysis has shown that cracks are more likely to occur in Mg2Si legs, characterized by higher value of coefficient of thermal expansion, as observed also in the tested prototype. Simulation has furthermore indicated alumina as suitable choice for the ceramic plate on the hot side of the module.

Reference

[1] M. Jaegle, Simulating Thermoelectric Effects with Finite Elements Analysis using COMSOL, Proceedings of 5th ECT, Odessa (2007)
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[3] O.C. Zienkiewicz, R.L. Taylor, the Finite Element Methods (vol.2): Solid Mechanics, 5th ed. (2000)
[4] S. Boldrini et al., IR thermography for the assessment of the thermal conductivity of Thermoelectric Modules at intermediate temperature, Proceedings of SPIE 9861 (2016)

Figures used in the abstract

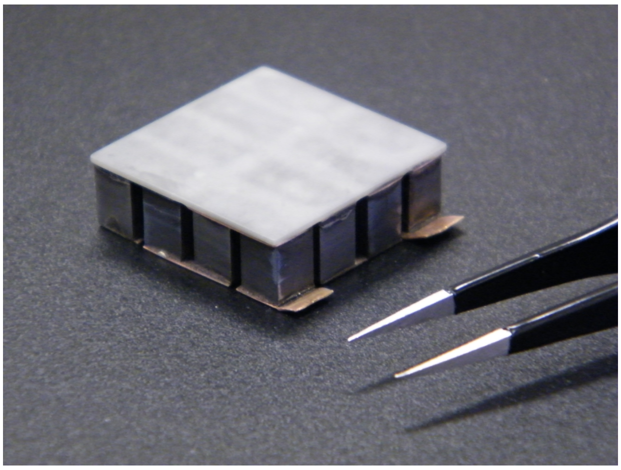

Figure 1: Prototype of the 16 legs thermoelectric module.

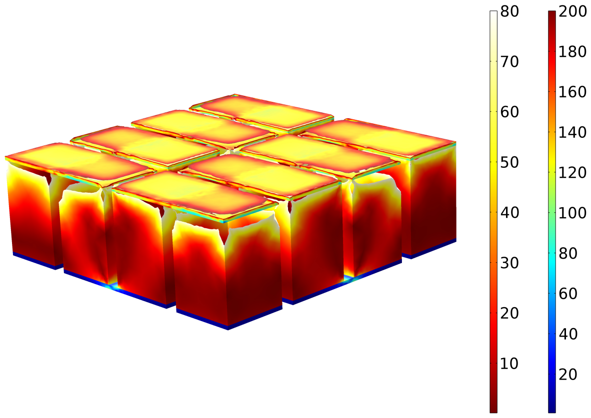

Figure 2: Maximum stress [MPa] in thermoelectric elements (Mohr – Coulomb, with stress cut-off, legend on the left) and metal connectors (Von Mises, legend on the right).

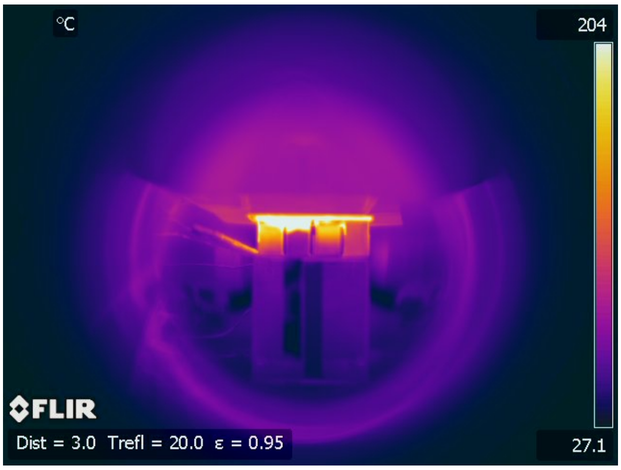

Figure 3: Cracks on Mg2Si legs highlighted with IR Thermography [4].