FINITE ELEMENT ANALYSIS OF A THIN-FILM THERMOELECTRIC MODULE FOR THERMAL MANAGEMENT IN MICRO ELECTRONICS

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Abstract: The performance of a micro thermoelectric cooler (μ-TEC) for micro electronics chip was simulated using finite element methods (FEM). The μ-TEC is composed of multiple couples of P-type and N-type semiconductor columns electrically connected serially and thermally in parallel. The μ-TEC module has 100 thermoelectric couples on an area of 10 mm^2 (3.3 by 3.3 mm). In this work, a single couple of thermoelectric column with a cross-sectional area of 0.06 mm^2 was modeled for the evaluation. Three major factors affecting cooling performance were chosen, which are: (1) the aspect ratio (width / depth), (2) the thickness of thermoelectric columns and (3) the thickness of electrodes. The range of the aspect ratio was varied from 0.5 (200 μm / 431 μm) through 5.8 (800 μm / 137 μm), while the cross-sectional area of the thermoelectric columns was same. The investigation range of the thermoelectric film thickness was changed from 12 μm through 32 μm, the metal electrode, from 0.2 μm through 10 μm, respectively. Under the consideration of micro fabrication processes, the obtained design value of the aspect ratio was 3.6, the thermoelectric column thickness, 25 μm and the electrode, 2 μm, respectively, with the predicted cooling ability of 65.8 mW.

Keywords: Micro thermoelectric cooler (μ-TEC); Finite element methods (FEM); Electronics chip cooling

INTRODUCTION

The cooling of microprocessors and electric components has become crucial issue as the chips are integrated highly for better performances and the heat dissipation rate increases dramatically [1, 2]. Past efforts have been made on the development of effective cooling methods which have high heat removal rates while having decreased volumes and weights. Recently, a micro thermoelectric cooler (μ-TEC) has received an increasing interest, because it does not require any physical movement in cooling mechanisms and can be easily installed on the microelectronic chips [3, 4]. In addition, this micro electro-mechanical system (MEMS) based device can be fully manufactured with current semiconductor surface micromachining technologies.

In this work, the performance of the μ-TEC for micro electronics chip is simulated using finite element methods (FEM). The evaluation processes with a single couple of thermoelectric column are explained in detail. Major factors affecting cooling performance are selected and their effects on the cooling performance are investigated. Considering the micro fabrication processes, the preferred geometries are suggested and its cooling ability is predicted.

μ -TEC MODULE

Structure of the μ-TEC module

The μ-TEC cools down the chips placed directly on them. When electric current is supplied, the thermoelectric cooling starts, while they heats on the other side by the Peltier effect [5]. The overall size of the proposed μ-TEC is 3.3 by 3.3 mm and 100 thermoelectric couples of P-type and N-type semiconductor films are integrated on the area of 10 mm^2. All the thermocouples are connected electrically in series and thermally in parallel.

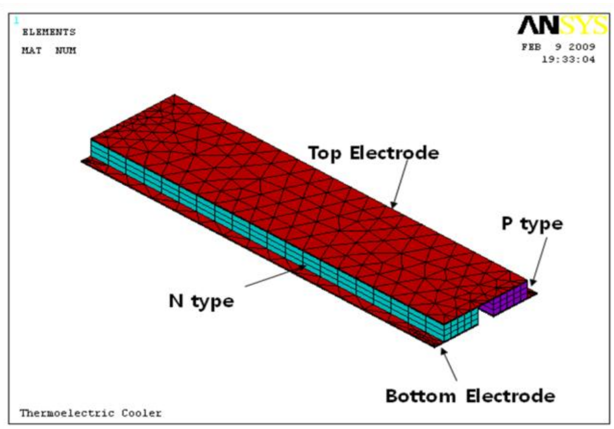

Fig. 1: Structure of the meshed μ-TEC analysis model.

When operating, the heat flows through all of the elements from the bottom substrate to the top plate. Consequently, the hot spot can be cooled down below a critical temperature so that their performance can be reliable.

Simulation plan

For the evaluation, a single couple of thermoelectric column with a cross-sectional area of 0.06 mm^2 was modeled using the Ansys FEM software, as shown in Fig. 1. It is composed of a couple of P-type and N-type thermoelectric columns, which substrate area is 0.1 mm^2. Both columns are electrically connected each other with the top gold (Au) electrode and each column is contacted on a bottom electrode line which leads to a neighboring thermocouples.

The cooling performance of the μ-TEC can be affected by the dimensions of thermoelectric films and electrodes. Among them, three major factors were selected, which are: (1) the aspect ratio (width / depth), (2) the thickness of thermoelectric columns and (3) the thickness of electrodes. The range of the aspect ratio was varied from 0.5 (200 μm / 431 μm) through 5.8 (800 μm / 137 μm) with the same cross-sectional area of the thermoelectric columns. The investigation range of the thermoelectric film thickness was changed from 12 μm through 32 μm and the metal electrode, from 0.2 μm through 10 μm. Material properties for the analysis are listed in Table 1. Based on this analysis plan, the effects of the geometries of thermoelectric columns and the thicknesses of connecting electrodes on the absorbed heat were investigated.

Table 1: Material properties for the analysis [3].

	Seebeck Coefficient, A (μV/K)	Resistivity, ρ (μΩm)	Thermal Conductivity, W/(m·K)
N type Bi_2Te_3	-210	9.0	1.5
P type Sb_2Te_3	110	3.5	1.5
Au Electrode		2.4	316

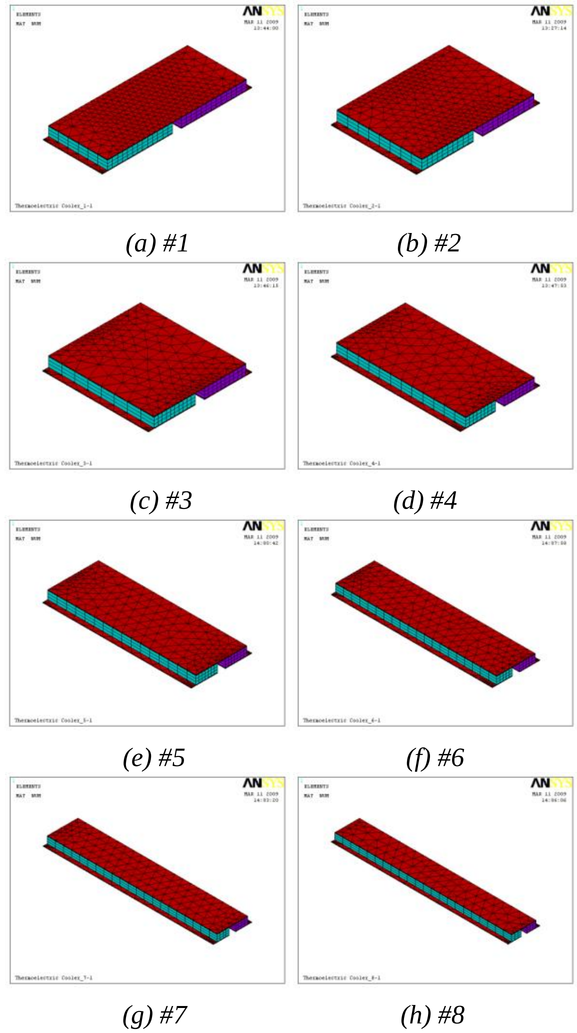

Fig. 2: Meshed models for the geometry analysis.

PERFORMANCE ANALYSIS

The aspect ratio analysis

To investigate the effect of the aspect ratio, eight μ-TEC modules were modeled as shown in Fig. 2. The smallest aspect ratio of the #1 model was 0.5 (200 μm / 431 μm) and the largest value of #8 model, 5.8 (800 μm / 137 μm), while the cross-sectional thermoelectric column area of each model was fixed to be 0.06 mm^2 as explained in Table 2. The simulation results are plotted in Fig. 3. It explains the heat absorbed at the cold side (Q_c) versus aspect ratios for the eight models. Q_c increases rapidly until aspect ratio reaches 3.0 and it converges slowly after that point. Considering micro-fabrication processes, aspect ratio of 3.6 (600 μm / 167 μm, #6 model) would be proper value, which has Q_c of 65.8 mW. The temperature profile of the #6 model is shown in Fig. 4. The maximum value was observed at the top of the column, which was 70.0˚C and the minimum at the bottom with a value of 55.0˚C, respectively.

The thermoelectric column thickness analysis

The thickness of the thermoelectric column is another important factor and seven models of different thicknesses were analyzed from 12 μm through 32 μm. The curve of simulation results of Q_c versus thicknesses was similar with the graph of the aspect ratio results and it is plotted in Fig. 5. Q_c also increased continuously up to the thickness of 30 μm but the inclination of the curve decreased slightly. This interprets that the thicker films would have better system performance. But 25 μm thick films were selected because conventional micro-fabrication technology has difficulties in the deposition of more than 25 μm thick films.

Table 2: Dimensions of the analysis models.

Model Number	w (μm)	d (μm)	w/d	Module area (mm^2)	Cross-sectional area of columns (mm^2)
1	200	431	0.5	0.09	0.06
2	260	333	0.8	0.09	0.06
3	315	279	1.1	0.09	0.06
4	400	227	1.8	0.09	0.06
5	500	191	2.6	0.10	0.06
6	600	167	3.6	0.10	0.06
7	700	151	4.6	0.11	0.06
8	800	137	5.8	0.11	0.06

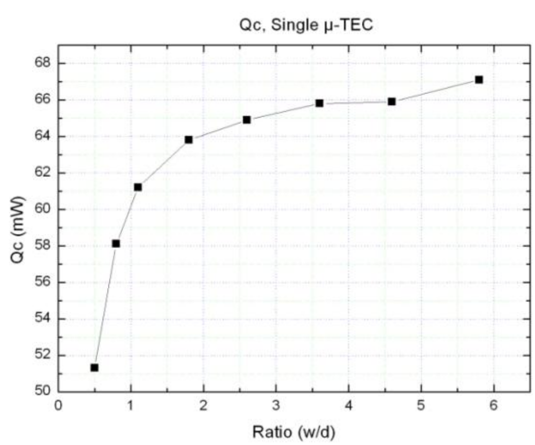

Fig. 3: The heat absorbed at the cold side, Qc versus the width to depth ratio (width / depth).

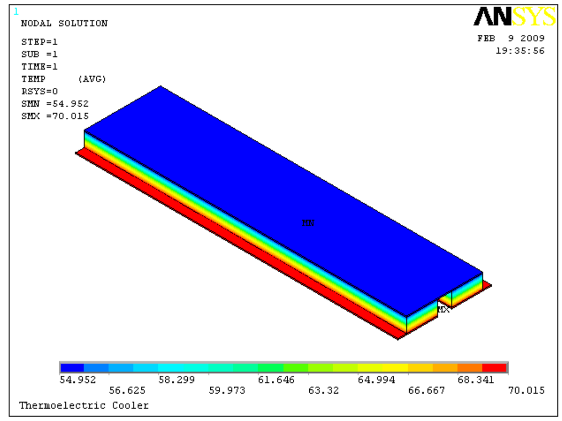

Fig. 4: The temperature profile of the #2 model.

The electrode thickness analysis

The last factor was the thicknesses of the electrodes, which were changed from 0.2 μm through 10 μm. This simulation result graph also resembled the previous two curves, as shown in Fig. 6. This implies that the thicker electrodes would have less electrical resistant, which causes less joule heating at the electrodes and better cooling performances. Q_c reached the top of the curve when the thickness of the electrode became 2 μm, which was chosen as a design value. The inclination of this graph was steeper than previous two graphs, so the electrode thickness is thought to be the most sensitive factor to the value of Q_c.

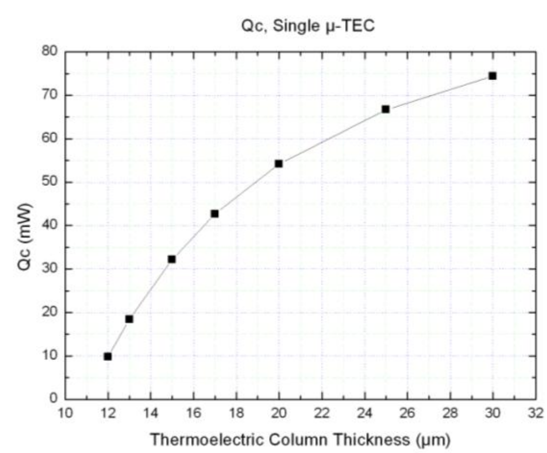

Fig. 5: The heat absorbed at the cold side versus the thermoelectric column thickness.

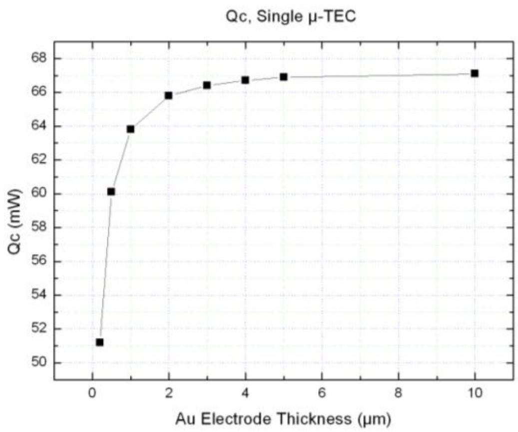

Fig. 6: The heat absorbed at the cold side versus the gold electrode thickness.

RESULTS AND DISCUSSION

From previous simulation results, the design values of the aspect ratio was 3.6, thickness of the thermoelectric column, 25 μm and the electrode, 2 μm, respectively. The recommended μ-TEC module using these dimensions was modeled and the cooling performance was calculated by FEM. The cooling ability of the μ-TEC module was predicted to be 65.8 mW and the whole module containing 100 couples, 6.58 W (65.8 W/cm^2), respectively.

CONCLUSION

The performance of the μ-TEC for micro electronics chips was simulated using FEM. The μ-TEC is composed of multiple couples of P-type and N-type semiconductor columns electrically connected serially and thermally in parallel. In this work, a single couple of thermoelectric column with a cross-sectional area of 0.06 mm^2 was modeled for the evaluation. The aspect ratio, the thickness of thermoelectric columns and the thickness of electrodes were thought to influence the system performance and the effects of them were investigated. The range of the aspect ratio was from 0.5 (200 μm / 431 μm) through 5.8 (800 μm / 137 μm) with the cross-sectional area of the thermoelectric columns fixed. Additionally, the thermoelectric film thickness was changed from 12 μm through 32 μm and the electrode, from 0.2 μm through 10 μm. The selected aspect ratio was 3.6, the thicknesses of the thermoelectric column, 25 μm and the electrode, 2 μm, respectively. The predicted cooling performance was 65.8 mW, which interprets that the whole module containing 100 couples would remove the heat flux of 6.58 W (65.8 W/cm^2). .

ACKNOWLEDGEMENT

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