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MICROFABRICATED ARRAYS OF PELTIER COOLERS FOR HIGHLY LOCALISED TEMPRATURES AT CELLULAR LEVEL

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ABSTRACT

This work is a part of an on-going research effort to develop an array of micro thermoelectric coolers (TECs) for highly localized control of temperature at the cellular level (micrometers). The prototype device will be fabricated using multi-step LIGA (Lithographie, Galvanoformung and Abformung) technique which would enable production of high density wiring essential for such a device [Figure 1]. The organization of the device will consist of an array of 100 TECs that will be formed by electrodeposition of the proper materials (bismuth, Bi and telluride, Te). Within the array, the coolers will be interspersed to enable each one to be individually addressable and with each individual TEC having an n-type and p-type leg elements. These arrays of TECs will be embedded in polymethylmethacrylate (PMMA) matrix to improve insulation and will be situated under the tissue system to be cooled. PMMA sheet will provide an interface between the cooler and the embedded cells.

Prior the fabrication of a thermoelectric device using MEMS technique have been reported [1-2], but there is no available data about the material optimization, the relationship among the deposition conditions, composition, electrical performance of the films and their performance as a device. This project aims at providing all these missing links and optimizing the required parameters which will eventually result in the unique capability of temperature manipulation and control on cellular scales.

To establish the relation between the cooling parameters and the TEC structure a system design methodology involving finite element analysis (FEA) was adopted [3]. Initially, an analytical model was developed following Yamanashi's approach [4], wherein the design parameters and conditions were varied to obtain a range for the expected cooling power. A closed form solution was also obtained to describe the transient temperature distribution within the device. The FEA model developed using MatLab, describes the thermal dynamics through all the intermediate stages and layers, including ceramics and soldering. Certain assumptions were made in this model. Firstly, because of the symmetric design of the TEC, analysis was done considering a single thermoelectric element sandwiched between two substrates. Based on the size of the region that requires localized temperature control in a typical tissue system (~10 µm) we chose to restrict the width of the TE leg element to 10 µm. As a further simplification of the device analysis, we neglected the temperature distribution along the width of the TE leg element. This model has been verified with the characteristic data available for commercial TECs and the preliminary results show that with our constraints we can achieve a drop of around 10°C provided the current is maintained between 1-10mA and the heat released from the cell is in milli-Watts range. Further work is being done to eliminate the assumptions made and incorporate as many as real-world technical details as possible.

For the fabrication of the device it is essential to get the p-type and n-type branches of the TE actuators. To achieve this, doped alloys of Bismuth-telluride (Bi-Te) need to be electrodeposited. The p-type Bi-Te alloy is bismuth rich whereas the n-type is tellurium rich [1]. It was found that the lower the pH, the less time the tellurium took to dissolve in solution. This result was further corroborated by an analysis of the Pourbaix diagram [5] which showed that a pH 0.25 was optimal for the electrodeposition of Bi_2O_3 (at a concentration of ~70%). The compositions of the deposits were analyzed using an Energy Dispersive X-Ray Fluorescence (ED-XRF) Spectrometer (Kevex Omicron).

To determine the electrodeposition characteristics of Bi-Te the current densities ranging from 0.2 to 13.88 mA/cm^2 were studied [6]. It was observed that at the lower values of these current densities the growth rate of the deposit was slow, whereas at the higher values in spite of having a good growth rate the material had black colored grit formation and did not adhere to the electrode. The deposited films displayed desirable characteristics of metallic, regular pearl-gray deposition for current densities in the range of 0.3 to 7.5 mA/cm^2 with corresponding growth rates of 0.34 to 3.9 µm per half hour.

Figure 2 shows the final deposition characteristics observed from the analysis obtained data, using which the specific range of potential values to fabricate p-type or n-type can be determined. Bi-Te with the stoichiometric composition ratio Bi_2Te_3 (Bi% - 52.2%, Te% - 47.8%) is electronically neutral. In Figure 2 as the potential decreases, the percent composition of bismuth increases, indicating a progression from n-type to p-type. It also indicates that p-type material would be obtained for values of $E < 0.23V$ and n-type for values of $E>0.23V$. Further testing is under way to supplement these results.

The n-type and p-type leg element deposition can be achieved by varying the cathodic potential while maintaining the same bath composition. Hence the material deposition development can focus on a singe material system, which will yield both n-type, and p-type pellets of TEC. The deposition of bismuth-telluride with the proper doping is being studied experimentally. Flat plate experiments are underway which would establish the relationship between the electrical and thermal properties of the films with the composition and deposition conditions.

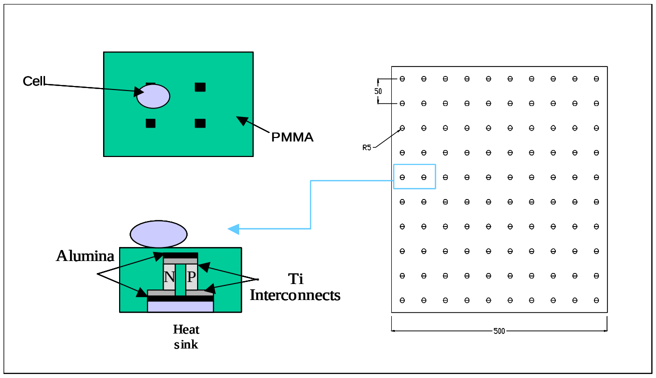

Figure 1: Device Schematic. The TECs will be staggered as shown, with spacing between the like devices of 50 microns. The entire device will be an array of 10x10 coolers.

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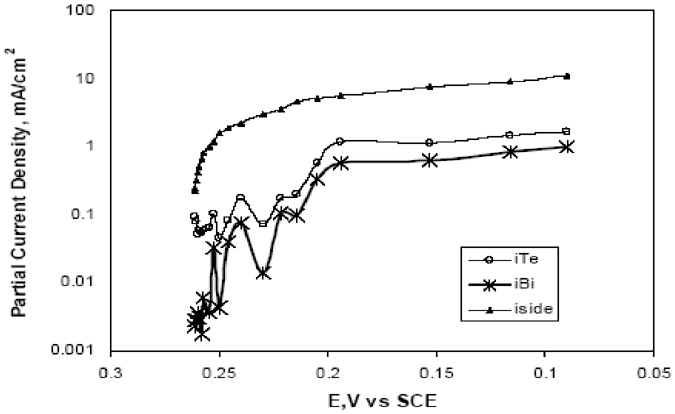

Figure 2: Partial currents for the Bi-Te deposition along with side reactions, rotation rate of 450 rpm, and avg. current density of 2.9mA

REFERENCES

1. Huang, L., Wang, W., Murphy, M.C., "Microfabrication of high aspect ratio Bi-Te alloy microposts and applications in micro-sized cooling probes", *Microsystems Technologies*, 6, 1-5 (1999).
2. Snyder, G.J., Lim, J.R., Huang, C., Fleurial, J., "Thermoelectric microdevice fabrication a MEMS-like electrochemical process", *Nature Materials*, 2, 528-531 (2003).
3. Rowe D.M., CRC Handbook of Thermoelectrics, CRC press, Boca Raton, Florida, USA (1999).
4. Yamanashi M., "A new approach to optimum design in thermoelectric cooling systems", *J. Appl. Phys*., 80, 6368-6369 (1996).
5. Prentice, G., "Electrical Engineering Principles", Prentice Hall, Englewood Cliffs, NJ, 277 (1991).
6. Prabhakar, A., Podhala-Murphy E.J., Murphy, M.C., Devireddy, R.V., "Electrodeposition characteristics of Bismuth-Telluride Films", *Nanoscale Materials Science in Biology and Medicine*, edited by Laurencin, C.T., Botchwey, E.A., Mater. Res. Soc. Symp. Proc., 845, Warrendale, PA. Paper #AA5.25 (2004).