# ON CHIP THERMOELECTRIC MICROCOOLERS

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***Abstract*** *— The present work reports the fabrication and characterization of a planar Peltier microcooler on a flexible substrate. The microcooler was fabricated on flexible Kapton© polyimide substrate, 12 µm in thickness, using* $Bi_2Te_3$ *and* $Sb_2Te_3$ *thermoelectric elements deposited by thermal co-evaporation. The cold area of the device is cooled using four pairs of thermoelectric elements, connected in series with aluminum/nickel contacts. Flexible substrates add uncommon mechanical properties to the composite film-substrate and enable their integration with many novel types of electronic devices. Films were deposited by co-evaporation of Bismuth and Tellurium or Antimony and Tellurium to obtain* $Bi_2Te_3$ *or* $Sb_2Te_3$ *compounds, respectively. The performance of Peltier microcooler is analyzed by infrared image microscopy, on still-air and under vacuum conditions, and the temperature difference between the cold side and the hot side of the device is recorded and it's comparable with literature available for Peltier microcoolers on rigid substrates.*

***Key Words****: Thermoelectric, Peltier microcooler,* $Bi_2Te_3$*,* $Sb_2Te_3$*.*

## I INTRODUCTION

Microcoolers with efficient cooling capacity, small area (down to parts of a millimeter) and short response time, are in high demand on the telecommunication markets. Since Peltier devices are reversible, they can also be used as electrical generators, converting thermal into electrical energy [1]. Micro-thermoelectric generators can be used in a lot of small low-power devices such as hearing aids or wrist watches. This has been shown recently by Seiko and Citizen with their commercialized thermoelectrically driven low-power wrist watches. Nevertheless, only few approaches to manufacture thermoelectric devices in small dimensions, which make them suitable for applications mentioned above, are known up to now [2] [3] [4].

Thermoelectric cooling is widely employed in electronics to stabilize the temperature of devices, decrease noise levels and increase operation speed. Conventional Peltier devices (with cross-sectional heat flow) are commercialized for a long time, with thermoelectric elements made on tellurium compounds. In theory, this configuration could be reduced for micro-device fabrication, but the conventional fabrication processes are not scalable to the micrometer range. Using a lateral (in-plane) configuration, thin-film techniques can be used to scale down the thermoelectric coolers and generators to micro-device dimensions [5]. In the present work, planar thin-film technology will be addressed to fabricate such devices.

A microcooler is fabricated on flexible polyimide Kapton© substrate, which adds uncommon mechanical properties to the composite film-substrate and enable their integration with many novel types of devices (Fig.1).

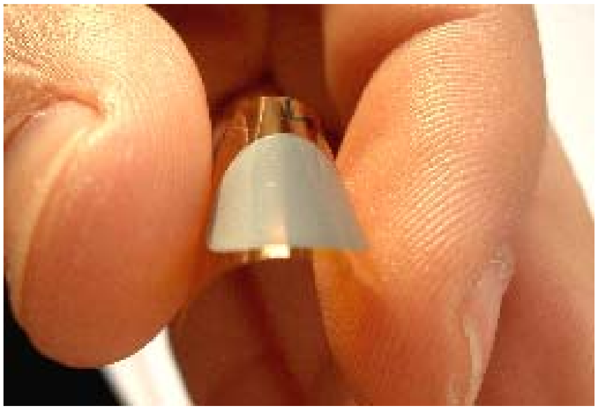

**Figure 1: Flexible thermoelectric film.**

## II DEVICE FABRICATION

The thermoelectric performance of thermoelectric materials is characterized by the dimensionless parameter figure of merit (ZT):

$$ZT = \frac{\alpha^2}{\rho\lambda} T \qquad (1)$$

where $\alpha$ is the Seebeck coefficient, $\rho$ the electrical resistivity, $\lambda$ the thermal conductivity and T the temperature [5].

Thermoelectric p-type and n-type thin films with high figures of merit, were obtained by thermal co-evaporation method [6], in a high-vacuum chamber, with thickness up to 10 μm. (Fig. 2). The substrate temperature and evaporation rates were controlled during all the deposition process in order to obtain the desired properties. These thermoelectric properties obtained (Seebeck coefficient of -220μV/ºC and +190 μV/ºC in n-type and p-type respectively and electrical resistivities in the range 10-20 μΩ.m make this materials suitable for the fabrication of lateral Peltier coolers and thermal micro-generators. Table 1 summarizes the thermoelectric properties, namely the Seebeck coefficient, the resistivity and the figure of merit at 300 K.

**Table 1: Summary of the thermoelectric properties of $Bi_2Te_3$ and $Sb_2Te_3$.**

| Film | Te | Bi or Sb | Seebeck (μV/ºC) | Resistivity (μΩ.m) | Fig. merit (300 K)* |
|---|---|---|---|---|---|
| $Bi_2Te_3$ | 62% | 38% | -248 | 12.6 | 0.86 |
| $Sb_2Te_3$ | 73% | 27% | 188 | 12.6 | 0.49 |

*Thermal conductivity of 1.7 $Wm^{-1}K^{-1}$ was assumed on calculations

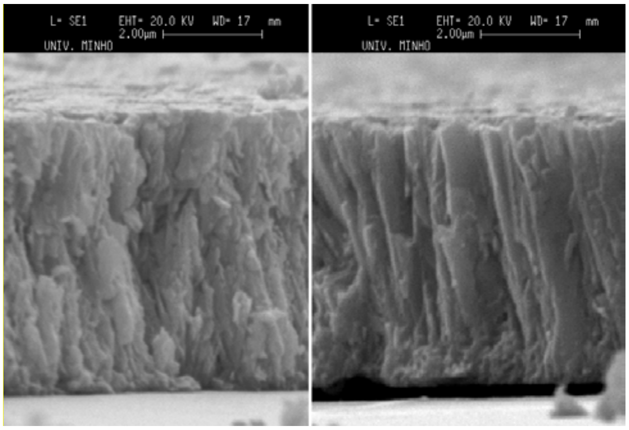

**Fig 2: SEM photos of 5μm $Sb_2Te_3$ and $Bi_2Te_3$ films.**

The thermoelectric elements are connected in series with metal contacts, which are fabricated on the substrate by deposition of a 800 nm layer of aluminum covered with a thin layer of Nickel (20 nm).. Thermoelectric films were deposited on top of contacts. (Fig. 3).

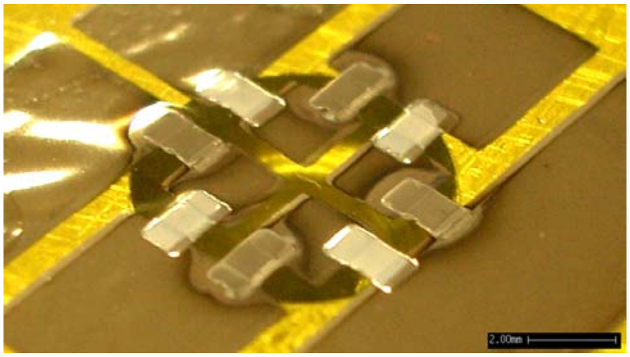

**Fig 3: Microcooler device fabricated on flexible substrate.**

These films were patterned during the evaporation process using shadow masks, and a thermoelectric device with four pairs of thermoelectric elements was fabricated. Polyimide was chosen as substrate because of its low thermal conductivity (0.16 $W.m^{-1}.K^{-1}$), thus allowing for higher performance of cooler devices, even with higher values of substrate thickness (12 μm foil was used).

An alternative way to fabricate the devices, which allow smaller dimensions is being tested and uses SU-8 photoresist.

This epoxy-based material offers good properties, such as high mechanical strength, good substrate adhesion and very low sidewall roughness [7]. The SU-8 based fabrication is a low-cost process, UV lithography semiconductor compatible and does not require expensive masks. It can be processed with a spin-coater, an UV light source and a hot-plate.

The negative mask used for patterning the microcooler is fabricated from a regular transparency sheet. The chosen SU-8 photoresist is the SU-8 2150, which has a high viscosity and it is the most appropriate for the required structure height. The fabrication starts with spinning of SU-8 photoresist on the substrate. The pre-expose bake is performed by soft bake at 90 ºC for 2 hours in the hot-plate. After that, the substrate with the SU-8 is exposed to an UV light of 80 $mW/cm^2$. Then, the substrate is placed again in the hot-plate and the temperature is ramped up to 90 ºC for 20 minutes and ramped down again. The result of this step is shown on Fig. 4.

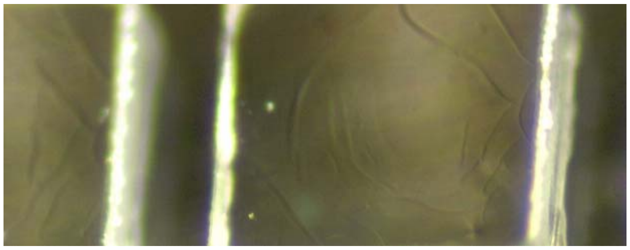

Fig 4: Patterned contact pad in SU-8.

The next step is to deposit the metal by PVD (Physical Vapor Deposition), which form the electrical contacts, over the SU-8 (Fig. 5 and 6).

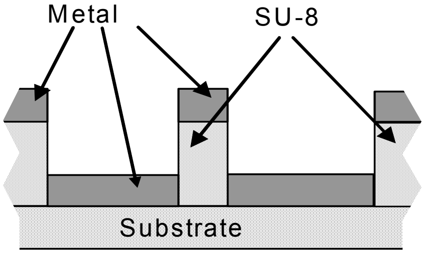

Fig 5: Process used to pattern metals and thermoelectric elements.

Fig 6: Metal pads before removal of SU-8 sacrificial layer.

Then, the SU-8 columns are removed and therefore the aluminum on top of those columns.

The same approach is used to place the thermoelectric $Bi_2Te_3$ and $Sb_2Te_3$ elements.

## III EXPERIMENTAL RESULTS

The performance of the microcooler was analyzed by use of a thermal image map generated with a infrared microscope. An image was obtained with the device excited with a 4 mA current [Fig 7] and cold side and hot side are clearly identified. A temperature difference of 5 ºC was measured between the hot and the cold side of the micro cooler.

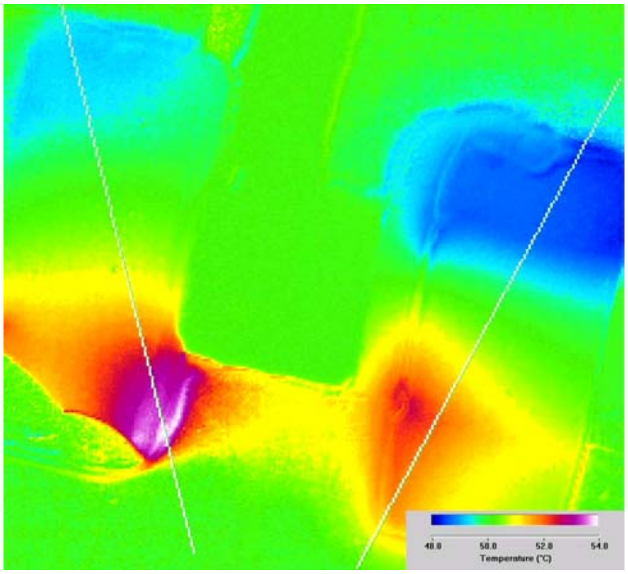

Fig. 7: Temperature map of the microcooler.

From the thermal image it's possible to conclude that thermal contact between the thermoelectric elements and the metal pads has undesirable low thermal conductivity value, since the thermal gradient on this region is quite high, compared with gradient along metals or along thermoelectric elements. This thermal resistance will be lowered in future designs by use of other metals on contact.

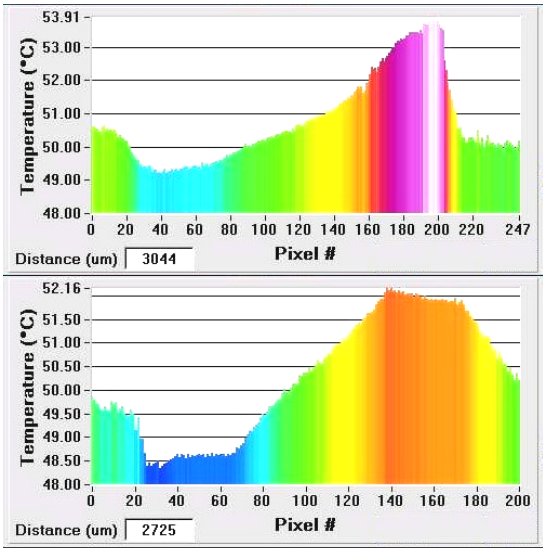

Fig. 8: Temperature profile on p-type and n-type thermoelectric legs (top and bottom graph respectively)

The hot-cold side temperature difference obtained (Fig. 8) was lower than the expected value obtained from simulation results (10 ºC). This difference was due to contact resistance, which is much higher than expected. Contact resistance on this device (with Al+Ni contacts) was of the same magnitude of thermoelectric elements (2 Ω). Fig. 9 shows the evolution of resistance measured on a two different metal-element junction, from contact pad until thermoelectric element. The position along the device is plotted on x-axis and the resistance on y-axis. The slope of the two straight lines represents the resistivity of metal pad and thermoelectric element respectively. The distance between the two lines is the electrical contact resistance. A small barrier voltage (less than 80 μV) was also measured on some contacts.

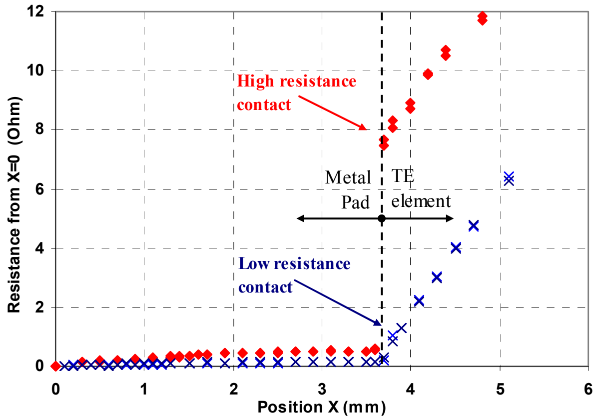

**Fig 9: Different materials on contact pads result in different contact resistances between metallic pads and thermoelectric elements.**

## IV CONCLUSIONS

State of the art n-type and p-type thermoelectric materials were fabricated, in form of thin film, with Seebeck coefficients of -248 μV/ºC and +188 μV/ºC respectively and resistivity of 12.6 μΩ.m. Electrical contact resistance between metal pads and thermoelectric elements was characterized on pads deposited with different metals.

A microcooler, based on Peltier effect, suitable to integration with microelectronic systems was presented and the corresponding MEMS fabrication process was described. A functional device was characterized on vacuum and still air environment, and a temperature difference of 5 ºC was achieved between the hot side and cold side of the device.

The flexible concept was demonstrated by the use of a 12 μm thickness polyimide substrate. Future work will persecute lower electrical and thermal contact resistance and lower dimension elements patterned on top of a silicon nitride membrane, KOH etched from a silicon substrate wafer.

## V ACKNOWLEDGMENTS

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