Exploring Screen Printing Technology On Thermoelectric Energy Harvesting With Printing Copper-Nickel And Bismuth-Antimony Thermocouples

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Introduction

Thermoelectric generators (TEGs) can generate electrical energy for autonomous microsystems from a thermal gradient present in the environment. This poster reports the fabrication and testing of copper (Cu) – nickel (Ni) and bismuth (Bi) – antimony (Sb) based thermocouples fabricated using screen printing technology. Copper and nickel have been used to explore the function of various screen printed designs and geometries for their low cost, while bismuth and antimony films are investigated achieve greater performance because they have a higher theoretic Seebeck coefficient [1]. The transport properties of the printed thermoelectric material were measured in room temperature while the Seebeck voltage and power output of the printed thermocouples were tested under a variety temperature gradient. Initial thermoelectric materials have been integrated in inks and then deposited on substrate by the simple, low-cost and low-temperature operation screen printing technology. For single thermocouple, the generated voltage is about 1.5 mV, higher that a single thermocouple in the same size from other researchers [2].

Printed Thick-film Devices Fabrication

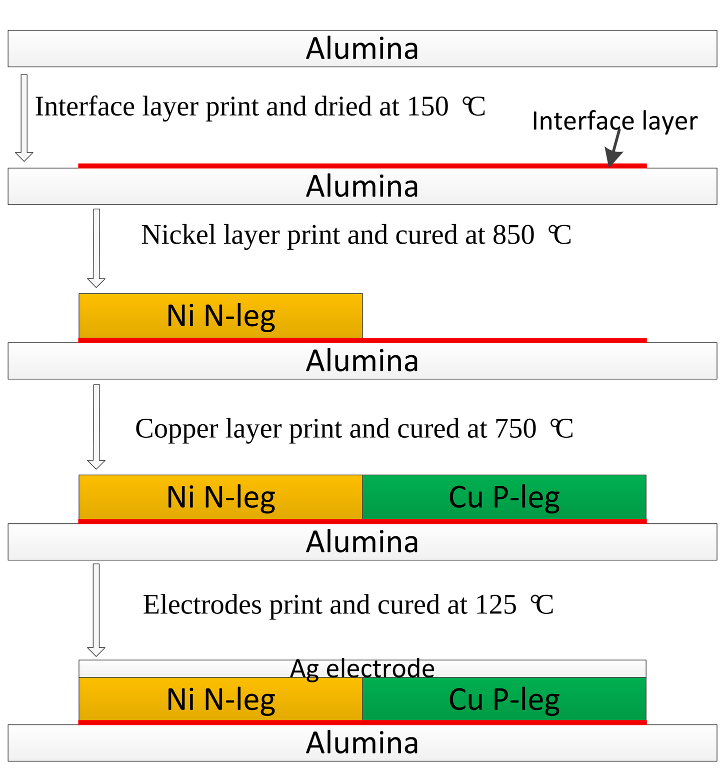

***Figure 1**: Fabrication process of screen printed TEGs*

- An interface layer was added to solve the adhesion issue between nickel thick-film and alumina layer.
- For Bi-Sb thermocouples, there was no adhesion problem between the active thermoelectric material layer and the alumina substrate.
- The low melting point of Bi and Sb requires a curing temperature of 250 °C [1].
- A polish process needed for Bi-Sb thermocouples (SEM images before and after polishing shown in figure 2).

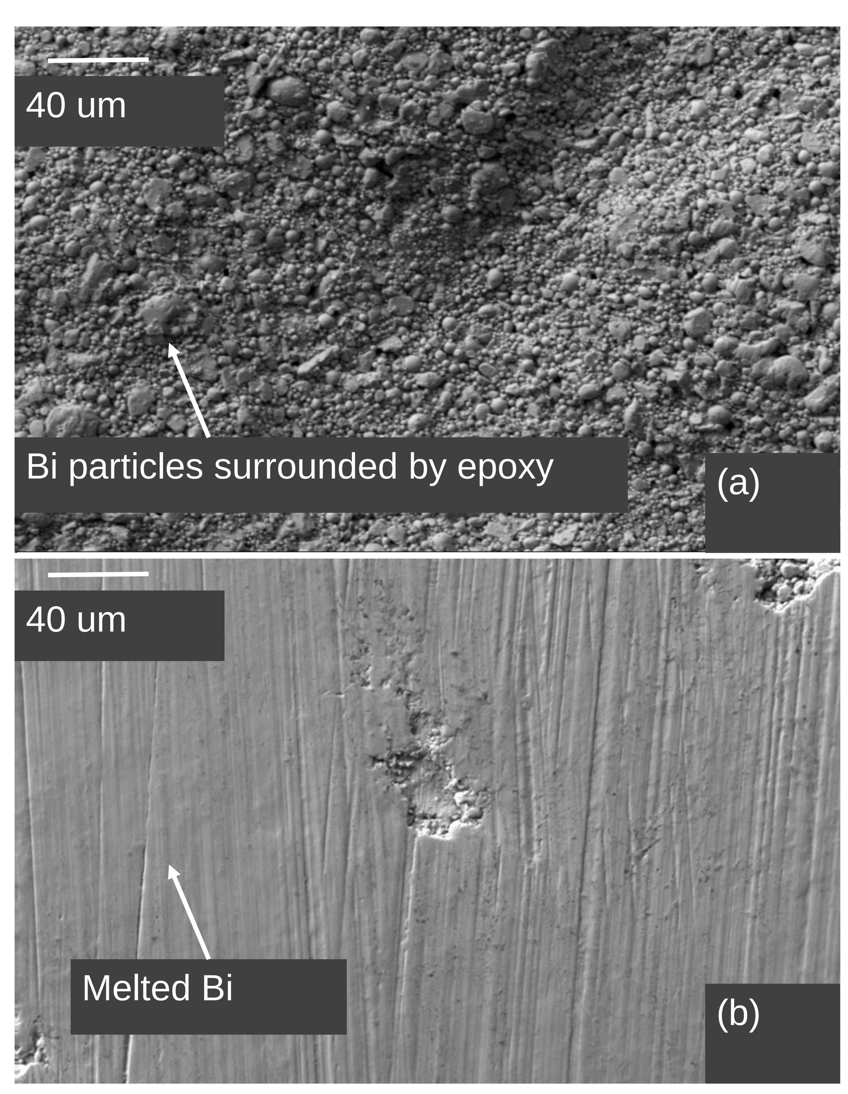

***Figure 2:** Scanning electron microscope images of (a) Bi/epoxy composite film before polish and (b) Bi/epoxy composite film before polish.*

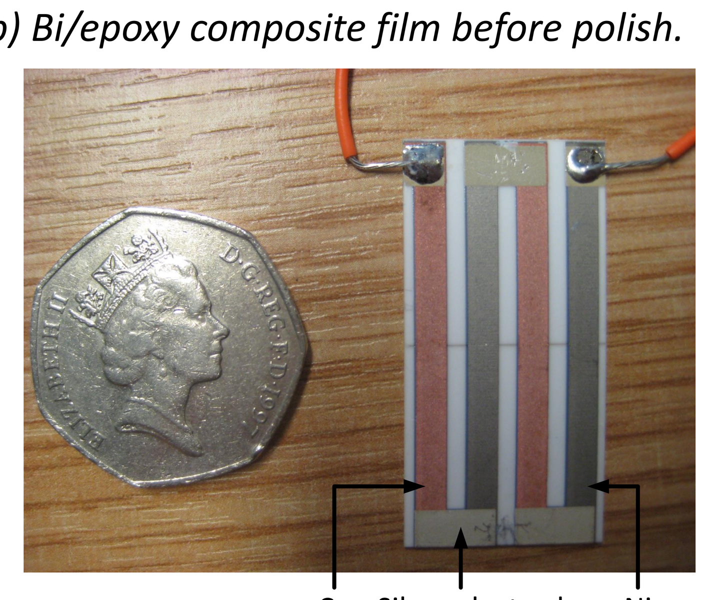

***Figure 3**: Images of printed thermocouples on alumina substrate*

Device Characterization

- The efficiency of a TEG depends on the figure of merit Z of the materials ($Z=\alpha2/(\rho\cdot\lambda)$, where α is the Seebeck coefficient, ρ is the electrical resistivity, and λ is the thermal conductivity) [3].
- Hall effect measurement: HMS 3000 from Ecopia.
- The Seebeck coefficients of printed copper and nickel samples were measured using custom-made equipment to determine the voltage output of the material for a given temperature difference (ΔT).
- Seebeck voltage measurement: applying various temperature differences across the tested sample while monitoring this temperature difference of two ends. (Figure 3).

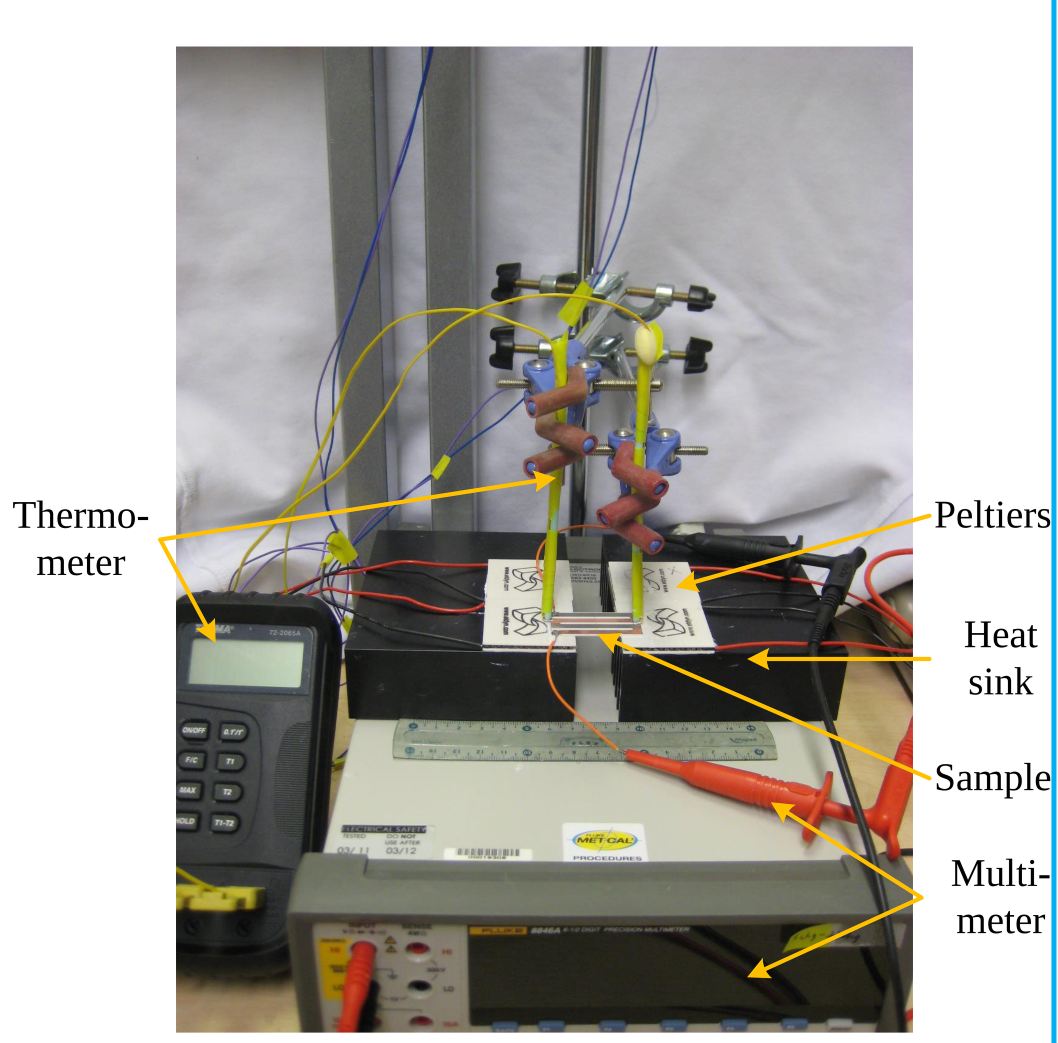

***Figure 4**: Seebeck voltage measurement setup*

Thermoelectric properties of printed thick-films

	Cu	Ni	Bi	Sb
ρ (Ω·cm)	6.4×10^{-5}	4.86×10^{-4}	7.26×10^{-2}	1.24×10^{-3}
Bulk ρ (Ω·cm)	1.71×10^{-6}	7.12×10^{-6}	1.07×10^{-4}	3.9×10^{-5}
α (μV/K)	3	-13 ~ -17	-57~ -60	23 ~ 25
Bulk α (μV/K)	1.83	-19.5	-70	40

***Table 1**: Transport properties and Seebeck coefficient of Cu, Ni, Bi and Sb*

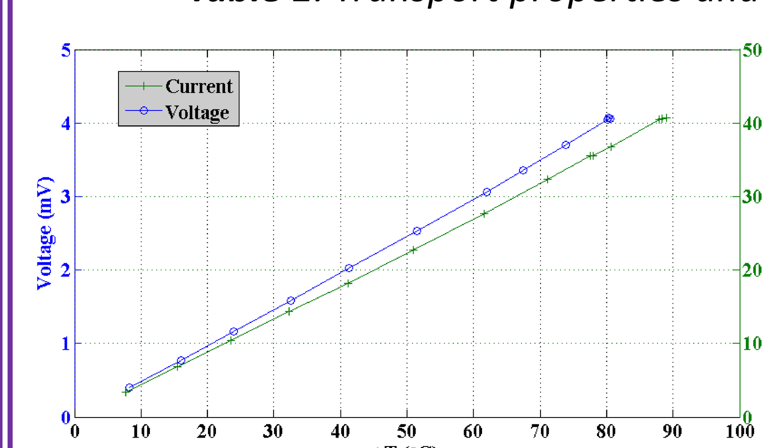

***Figure 5**: Generated Seebeck voltage of two printed Cu-Ni thermocouples*

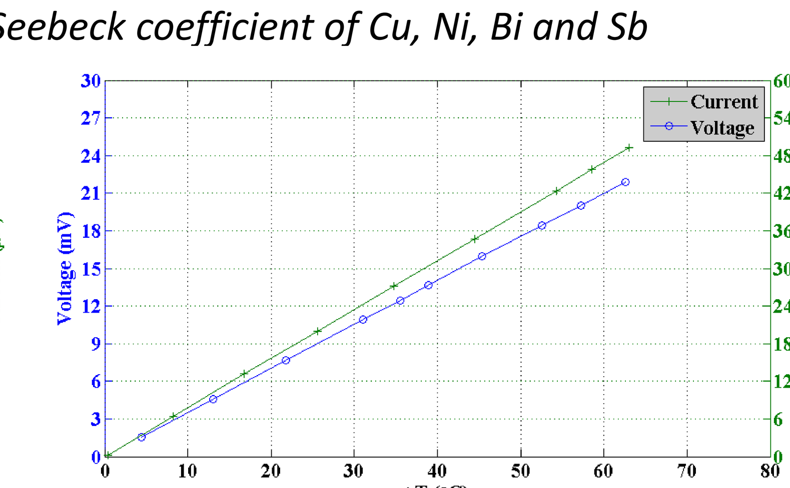

***Figure 6**: Generated Seebeck voltage of 4 printed Bi-Sb thermocouples*

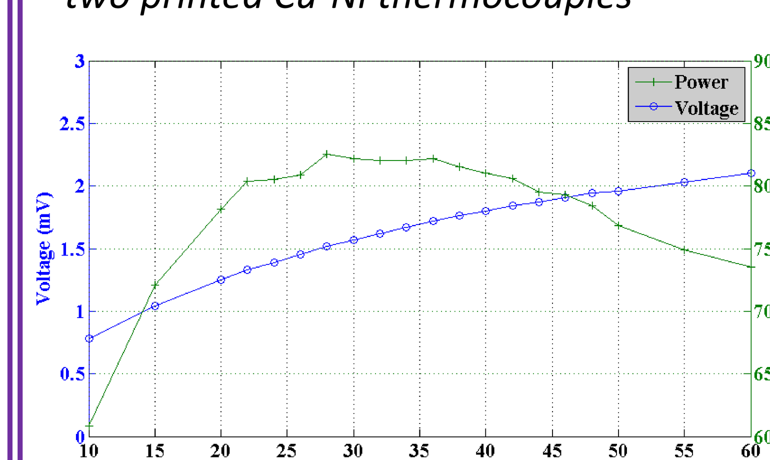

***Figure 7**: Power output and voltage of the 8 Cu-Ni thermocouples as a function of load resistance at a 20K temperature difference*

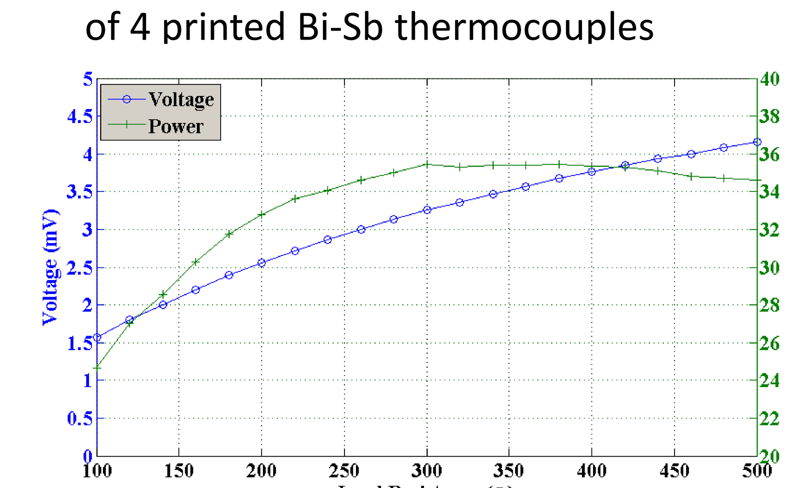

***Figure 8**: Power output and voltage of the 4 Bi-Sb thermocouples as a function of load resistance at a 20K temperature difference*

Discussion and Conclusions

- Screen printing technology can be applied on fabrication of large area TEGs
- At a temperature difference of 60°C, For single thermocouple, the generated voltage is about 1.5 mV.
- The power output of Bi-Sb thermocouples is limited by the resistivity for the easily oxidization during printing process.
- optimize the device design, fabrication and materials processing will improve the overall device electric impedance
- Bi_2Te_3 and Sb_2Te_3 based thermoelectric active materials can be applied into making screen printable inks for their higher figure of merit in room temperature

Acknowledgements

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Reference

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[2]: S. Duby, B. Ramsey, D. Harrison, and G. Hay, "Printed thermocouple devices," in *Sensors, 2004. Proceedings of IEEE*, ed: IEEE, 2004, pp. 1098-1101.

[3]: S. Beeby and N. White, *Energy Harvesting for Autonomous Systems*: Artech House, 2010.