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Sandia National Laboratories

In-House Manufacturing of New-Generation Multijunction Thermal Converters at Sandia National Laboratories

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Introduction/Motivation

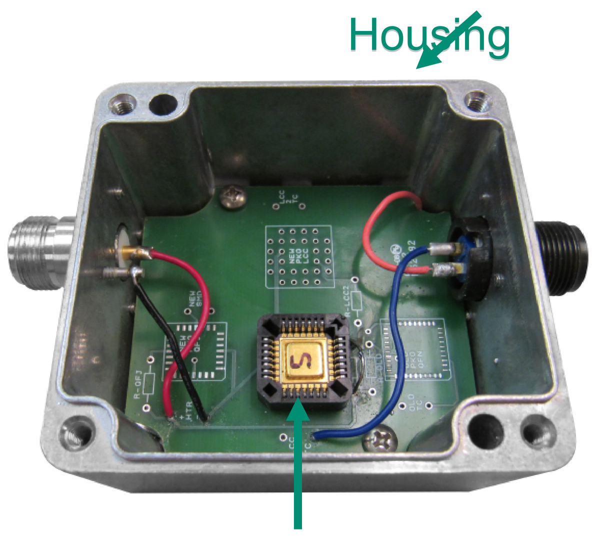
Overview: Multijunction thermal converters (MJTCs) are used as a transfer standard for alternating voltage metrology.

Problem: A new housing system was needed to begin using previously fabricated Sandia MJTC die (silicon chips) as alternating voltage standards.

Goal: Design and build a new housing for MJTC die and assess the AC-DC difference with the eventual goal of reestablishing a complete MJTC manufacturing process at Sandia.

Experimental Methods

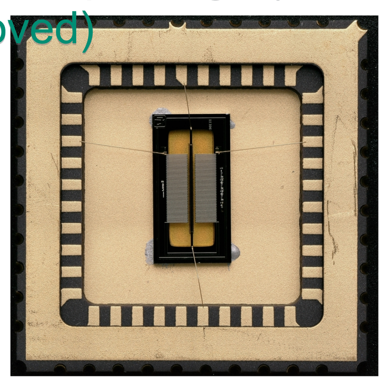
- MJTC devices were produced at Sandia on standard silicon wafers typically used for semiconductor electronics.
- The die were then placed into vacuum-sealed surface mount and J-leaded chip packages. Small gold leads are used to make the connection between the die and package pins.
- The package was attached to the printed circuit board (PCB) using a "chip carrier" that allows packages to be easily swapped between metal housings.
- A new metal housing was constructed to hold MJTC packages while allowing for more operation modes in the future.
- AC-DC measurements were made at Sandia using a Fluke Calibration model 57630A High Performance Multifunction Calibrator as a voltage source. Two Keithley model 2182A Nanovoltmeter were used to measure the thermocouple output of a calibrated reference MJTC and the device under test.



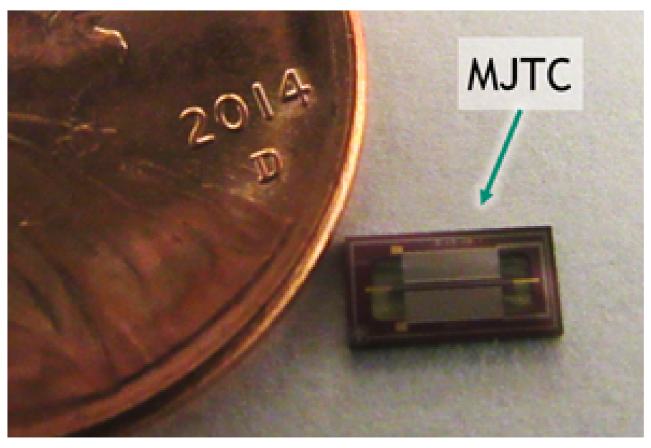
Background

- In typical MJTC devices, ~100 thermocouples are connected in series around the resistive heater element. The AC and DC signals are applied to the heater, the heater heats up, and the thermocouples detect the change in temperature via the thermoelectric effect.
- A strip of silicon substrate directly under the heater – referred to as the obelisk – is used to provide thermal stability at low frequency. However, this results in capacitive coupling and current flow through the obelisk at high frequency. To reduce the capacitive coupling, Sandia and other national metrology institutes have investigated a high-resistivity substrate.
- Sandia is working to reestablish a manufacturing process for MJTC devices – including both normal silicon substrates and high-resistivity silicon substrates.

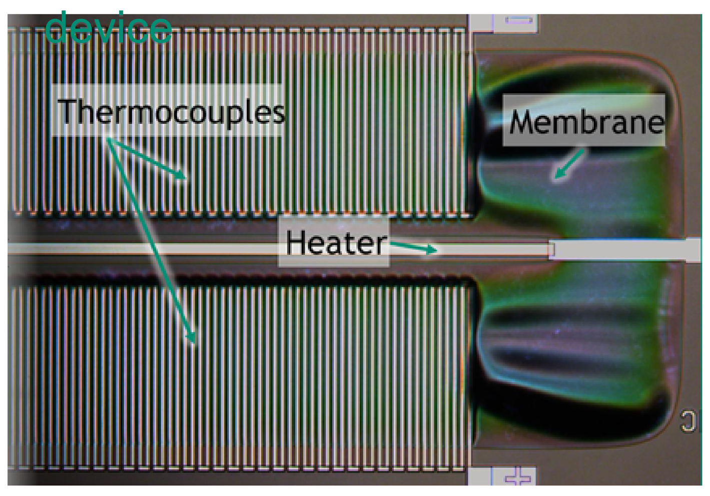
MJTC in package (lid removed)



One MJTC device

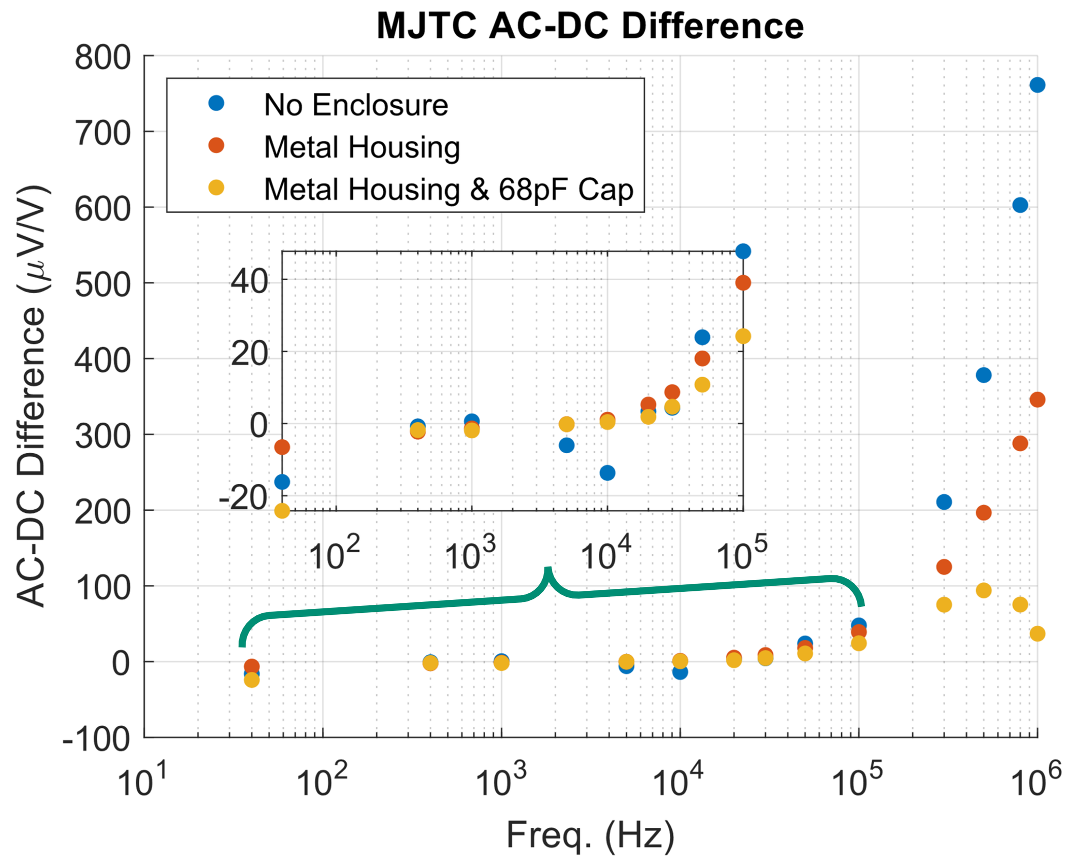


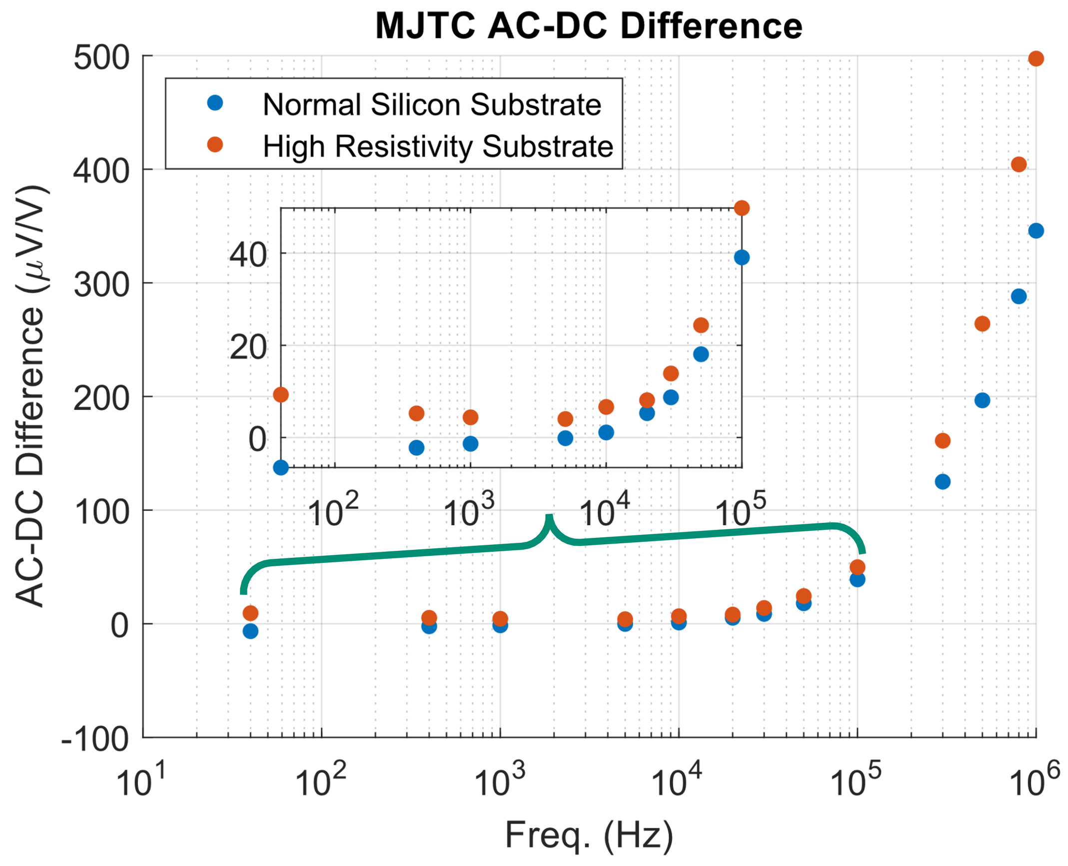
Zoomed-in image of MJTC device



Results

- A new prototype metal housing and PCB were successfully designed, and two units were built for testing.
- The new PCB allows for compatibility with both types of chip package, parallel operation, and the use of range resistors in series with the heater.
- This generation of MJTC has an AC-DC difference that trends positive with frequency (more AC voltage is needed to match the thermocouple output generated by the equivalent DC voltage). This trend is more significant than other similar coaxial MJTC [3].
- The new metal housing causes a significant reduction in AC-DC difference. It was initially suspected that this was due to capacitive coupling between the heater and the housing, although recent measurements show almost no capacitance at the heater input terminals.
- A separate small ceramic capacitor (~68 pF) in parallel with the heater reduces the positive AC-DC difference to less than 100 μV/V at high frequency. This configuration may not be ideal because the capacitor is also in parallel with the heater of the standard MJTC.
- A small amount of positive AC-DC difference could be attributed to skin effect. Measurements of AC resistance across the heater show an increase of roughly 7 milliohms from DC to 1 MHz.
- High-resistivity substrates increase AC-DC difference [2], supporting Wunsch's assessment that the heater is capacitively coupled to the obelisk [1].
- AC-DC difference measurements were performed to compare the effect of the housing, additional parallel capacitance, and substrate type.





Acknowledgement

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References

1. T. Wunsch, "Microfabricated multijunction thermal converters," *Ph.D. dissertation, Univ. New Mexico, Albuquerque, NM,* 2001.
2. R. Johnson-Wilke, A. Meyrick, J. Dominguez, K. Lukes, J. Stanford, S. Cular and E. O'Brien, "New Generation Multijunction Thermal Converters at Sandia National Laboratories," in *Conference on Precision Electromagnetic Measurements*, Denver, 2020.
3. L. Scarioni, M. Klonz and E. Kebler, "Explanation for the AC_DC Voltage Transfer Differences in Thin-Film Multijunction Thermal Converters on Silicon Chips at High Frequencies," IEEE Transactions on Instrumentation and Measurement, vol. 56, pp. 567-570, 2007.

Conclusions

- A new housing design, PCB, and package have been prototyped and are nearly ready for production.
- The metal housing helps to reduce the AC-DC difference at high frequencies; however, the mechanism behind this reduction is still under investigation.
- Contrary to other similar MJTC designs, these Sandia made MJTC have a positive AC-DC difference at high frequency.
- Although multiple reasons for this trend were investigated, at this time, no single factor or set of factors has been identified that can account for an AC -DC difference of this magnitude.

Future Work

- The positive AC-DC difference at high frequencies will be investigated further.
- A new batch of MJTC devices will be fabricated with the aim of reducing the AC-DC difference at high frequencies.

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