Nanothermocouple Characterization Platform: Simulation and Experiment

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INTRODUCTION

We study the heat distribution by simulations in nanoscale structures for nanothermocouple (NTC) characterization. The relative Seebeck coefficient (RSC) of NTCs is reduced compared to the bulk values [1]. Direct measurement of the RSC of NTCs requires an accurate measurement of the temperature difference between the hot and cold junctions. An accurate measurement of the temperature at the hot junction is determined from the resistance of the thermometer, assuming that it is at the same temperature as the hot junction. Therefore, we have designed, simulated, and fabricated a characterization platform that allows the simultaneous measurement of the temperature at the hot junction and the induced open-circuit voltage of the NTC. A spatially confined heat source is used to raise the temperature of only the hot junction, while the cold junction remains at the ambient temperature. Here we discuss the simulation of the characterization platform to optimize it for accurate temperature measurements.

SIMULATIONS

The characterization platform is constructed from a heater, a resistive thermometer, and an NTC (Fig. 1a). The layout of the platform was simulated using the electric currents and the heat transfer module of COMSOL to investigate the temperature increase in the thermometer and the hot junction. Simulations predict that placing the hot junction and the thermometer equidistant on either side of the heater wire does not guarantee their equal temperature increase. Figure 1a shows the simulated temperature increase at the surface for the initial design of the characterization platform. Fig. 2a shows the temperature increase along the thermometer and at the hot junction. Note that the temperature increase on the thermometer is not uniform. The temperature is greatest at the center of the thermometer and decreases towards the terminals. The thermometer measures the average temperature between its terminals, which is indicated by the dashed line. Although the thermometer and the hot junction are located equidistant from the heater in this initial design, their simulated increases in temperature are, unfortunately, not the same. The difference in temperature increases above ambient between the hot junction and the thermometer is 45%.

The design of the platform was modified to compensate for this temperature difference. The improved layout features symmetric geometries of the hot junction and the thermometer. Fig. 1b shows the simulated temperature increase on the surface of the improved characterization platform, and Fig. 2b shows its simulated temperatures. The difference between the average temperature on the thermometer and the temperature of the hot junction is now reduced to 2%. However, the error is geometry-dependent, which limits the accuracy for single-metal NTCs [2].

For accurate RSC measurement of single-metal NTCs, the design was further optimized to eliminate the geometry-dependent error (Fig. 3) by placing the hot junction on top of the heater. Figs. 4 and 5 show the simulated surface temperature, temperature distribution, and hot junction temperature. The difference between the average temperature of the thermometer and the temperature of the hot junction is reduced to 0.5%. The difference is independent of the dimensions of the wire widths between 50 nm and 300 nm. Fig. 6 shows that the simulated and measured temperatures are in excellent agreement.

REFERENCES

[1] S. Sadat, A. Tan, Y. J. Chua, and P. Reddy, *Nanoscale Thermometry Using Point Contact Thermocouples*, Nano Lett., **10**, 2613 (2010).

[2] G. P. Szakmany, A. O. Orlov, G. H. Bernstein, and W. Porod, *Single-Metal Nanoscale Thermocouples*, IEEE Trans. Nanotechnol., **13,** 1234 (2014).

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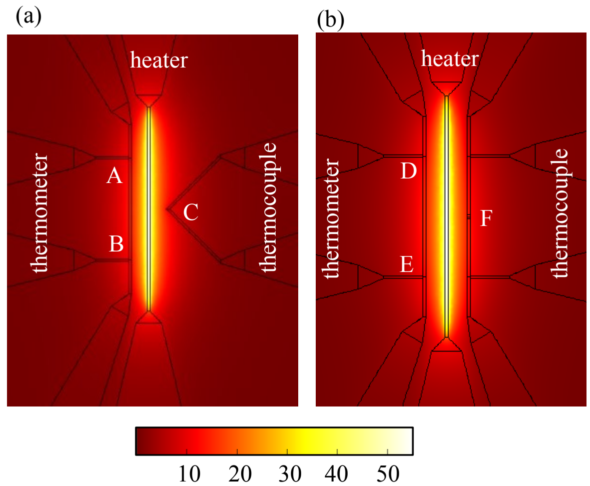

Fig. 1. Simulated surface temperatures of (a) asymmetric and (b) symmetric designs.

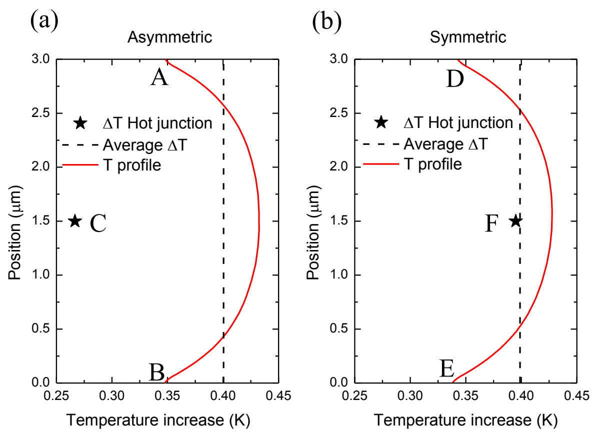

Fig. 2. Simulated temperature increase along the thermometer (between points A-B, and D-E) and the temperature at the hot junction (points C and F), when 300 µA flows through the heater. The average temperature of the thermometer is indicated by the dashed line.

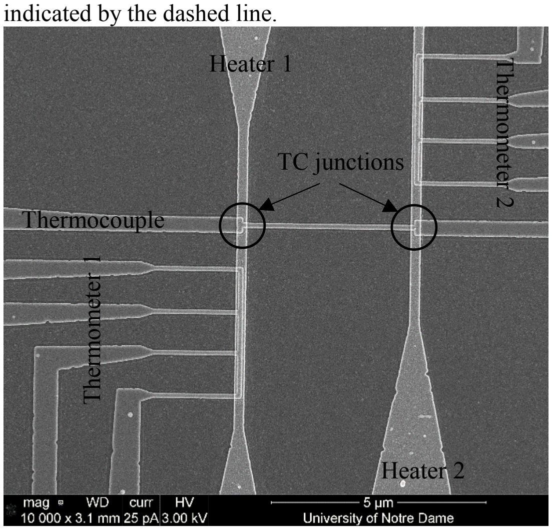

Fig. 3. Scanning electron micrograph of the finalized structure. The heater is electrically insulated from the TC and the thermometers by a 20-nm-thick AL_2O_3 layer.

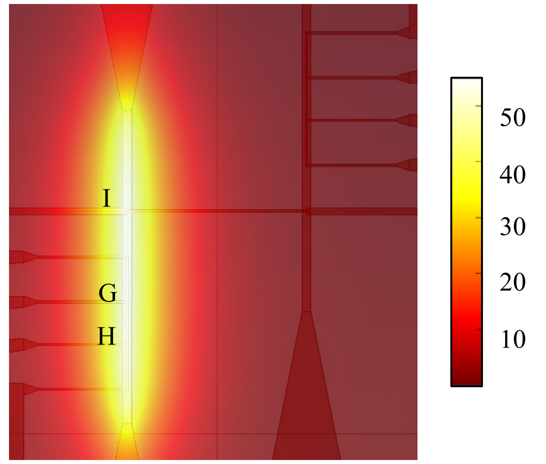

Fig. 4. Simulated surface temperature of the finalized design.

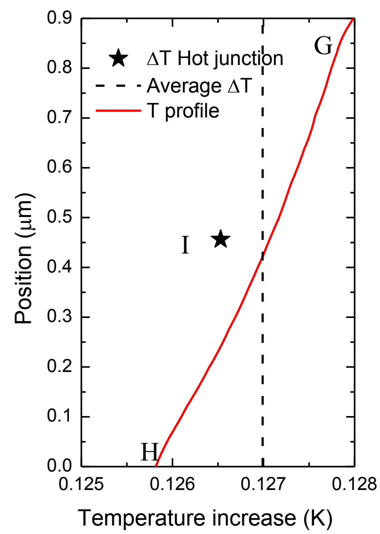

Fig. 5. Simulated temperature increase along the thermometer and hot junction when 300 µA flows through the heater.

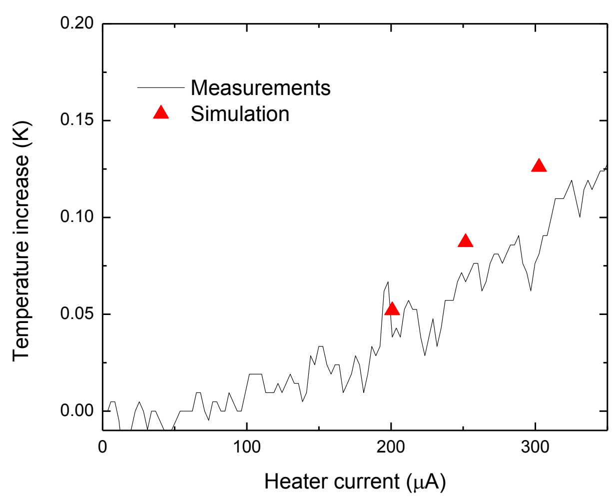

Fig. 6. Comparison of the simulated and measured temperature increase as a function of heater current.