Serpentine Heater Lines

CNF Project Number: 3016-22
Principal Investigator(s): Andrea Pickel
User(s): Benjamin Harrington, Kyle VanDelden, Jay VanDelden

Affiliation(s): Department of Mechanical Engineering, Materials Science Program, University of Rochester; EigenPhase Techologies

Primary Source(s) of Research Funding: National Science Foundation

Contact: apickel@ur.rochester.edu, bharrin9@ur.rochester.edu, kylevandelden@gmail.com, jvd@eigenphase.com
Website(s): https://labsites.rochester.edu/pickel/

Primary CNF Tools Used: Wire bonder, mask writer, ion mill, stepper, evaporator

Abstract:

Testing the performance of new nanoscale thermometry tools requires test structures that produce steep nanoscale temperature gradients. To achieve this outcome, we designed and fabricated Nichrome serpentine heater lines on crystalline quartz substrates that allow for four-point probe electrical measurements. When the serpentine lines are Joule heated, the current density concentrates at the inner corners of the heater lines. This results in a higher temperature rise at the inner corners than the outer corners, a geometric effect known as "current crowding" [1]. The low thermal conductivity of the Nichrome alloy helps maintain the temperature gradient between the inner and outer corners of the serpentines, while the use of the crystalline quartz substrate (factor of ~ 10 higher thermal conductivity than amorphous quartz) maintains the overall temperature rise at a reasonable level.

Summary of Research:

After first making a mask, the serpentine heater lines were then fabricated using a stepper lithography process. Individual chips containing an array of serpentine heater lines were created by dicing the crystalline quartz wafers on which the serpentine lines were fabricated (Figure 1).

Ultrasonic wire bonding was performed on the Westbond 7400A wire bonder at the Cornell NanoScale Facility. The goal was to electrically connect contacts on a printed circuit board (PCB) to the serpentine heater line chip. Over the course of the project, around 50 serpentine heater lines were attached to PCBs through silver epoxy at the University of Rochester (U of R) and brought to Cornell to be wire bonded. For each sample, four 1.25 mil aluminum wedge-to-wedge wire bonds were placed, corresponding to each of the gold contact pads on the PCB leading to the Nichrome pads on the serpentine heater line chip.

Once wire bonded, the heater line/PCB samples were brought back to the U of R to measure the resistance of serpentine heater line section only by means of a four-point probe resistance measurement. The sample was placed atop a hot plate and its resistance was monitored as the temperature increased. A temperature vs. resistance plot with an expected positive linear relationship was generated, and a temperature coefficient of resistance (TCR) value was calculated for the serpentine heater lines (Figure 2). The TCR value will serve as a calibration basis for later experiments, where the heater line will need to be held at a specific temperature via Joule heating.

Conclusions and Future Steps:

Nichrome serpentine heater lines on crystalline quartz substrates were successfully fabricated and the TCR value was calibrated. Major next steps are to measure the temperature rise as a function of the input Joule heating current and to subsequently use the Joule-heated serpentine lines to demonstrate nanoscale temperature mapping.

References:

[1] Q. Weng, et al., "Near-Field Radiative Nanothermal Imaging of Nonuniform Joule Heating in Narrow Metal Wires," Nano Letters 18, 7, 4220-4225 (2018).

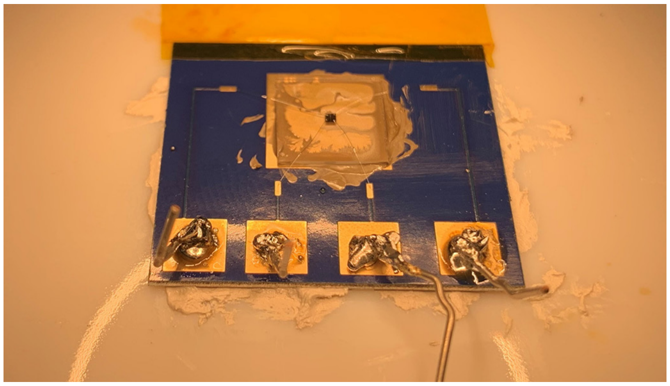

Figure 1: Wire bonded serpentine heater line and PCB sample. Wires soldered onto contact pads of the PCB are used for four-point probe measurements. Wire bonds connect the PCB to the serpentine heater line; in this setup the heater line chip has a single serpentine heater line. The bottom of the PCB is coated with thermal paste and is placed atop a hot plate.

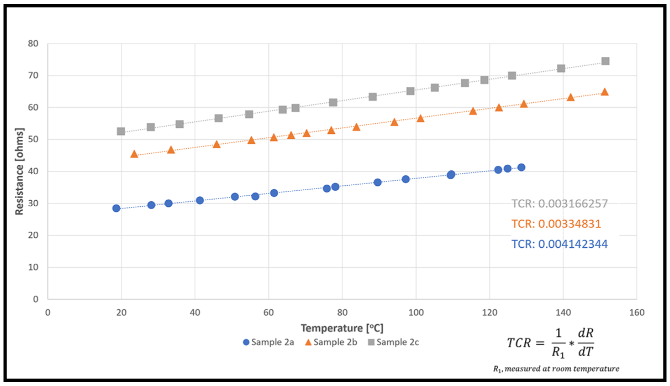

Figure 2: Temperature vs. resistance plot for Nichrome serpentine heater lines. Calculated temperature coefficient of resistance (TCR) values using the formula shown in the figure are also displayed for each respective sample.