Near Field Radiation Heat Transfer Measurement

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Abstract

The following research project involves preparing a method to measure near field radiative (NFR) heat transfer between two surfaces, and then extracting real data measurements of such heat transfer. This will be done through a system in which the deflection of a silica sphere tipped bi-material cantilever will be tracked as it transfers heat to a plate at a distance less than 10 µm from it.

Background

Based on the thermodynamic control volume in figure 1, the steady state energy balance tells us that $Q_{abs} = Q_{conduct} + Q_{NFR}$ and without a plate within 10 µm for near field thermal radiation to activate, the energy balance becomes: $Q_{abs} = Q_{conduct}$ where Q_{abs} is the heat absorbed from a laser, and $Q_{conduct}$ is the heat conducted through the AFM probe. It is this project's interest to reduce the heat conducted within the probe to maximize the heat radiated quantified as Q_{NFR}. Alternating the AFM probe for one with a less thermally conductive base material will allow for greater quantities of heat to thermally radiate. The thermal conductance of a probe can be characterized by its 'G' value where $Q_{conduct} = G(T_{tip} - T_\infty)$. T_{tip} is the temperature of the probe tip where the laser is concentrated and T_∞ is the ambient temperature. The lower the thermal conductance characterized as G, the higher the near field heat radiation will be. Previously, a silicon-based probe has successfully been used and now a pyrex-based (borosilicate glass) probe is of interest. Its predicted that a pyrex-based probe will have a smaller G value thus resulting in a higher amount of thermal radiation. These simulations will help to clarify whether the difference is significant.

Method

Steady state thermal simulations were performed on Ansys. The probe geometry and a small chunk of the base were re-created with relative accuracy in Design modeler. A 50 µm dimeter silica sphere is attached to the 420 nm thick Si3Ni4 side of the probe to better simulate the experimental setup and to compare G values with other literature. The laser heat input is simulated as a heat flux through a 15 µm diameter circle at the tip of the 70nm thick gold side of the probe. The base chunk is represented as a 200 µm half circle extruded 10 µm. The back-edge of the base will have a temperature boundary condition of 24.5 ºC. By alternating the material of the base, a comparison can be drawn between Pyrex and silicon. A study is performed varying the thermal conductivity of gold and varying the heat input from the laser.

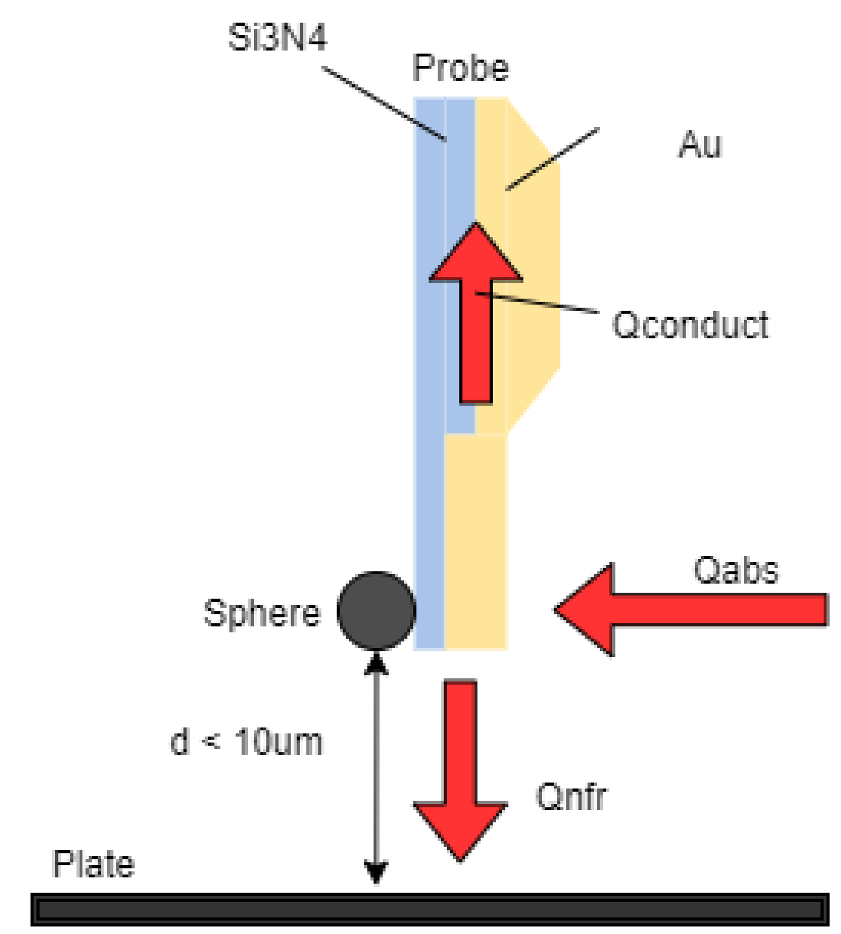

Figure 1: Heat Transfer Model of Probe and Plate within range of NFR

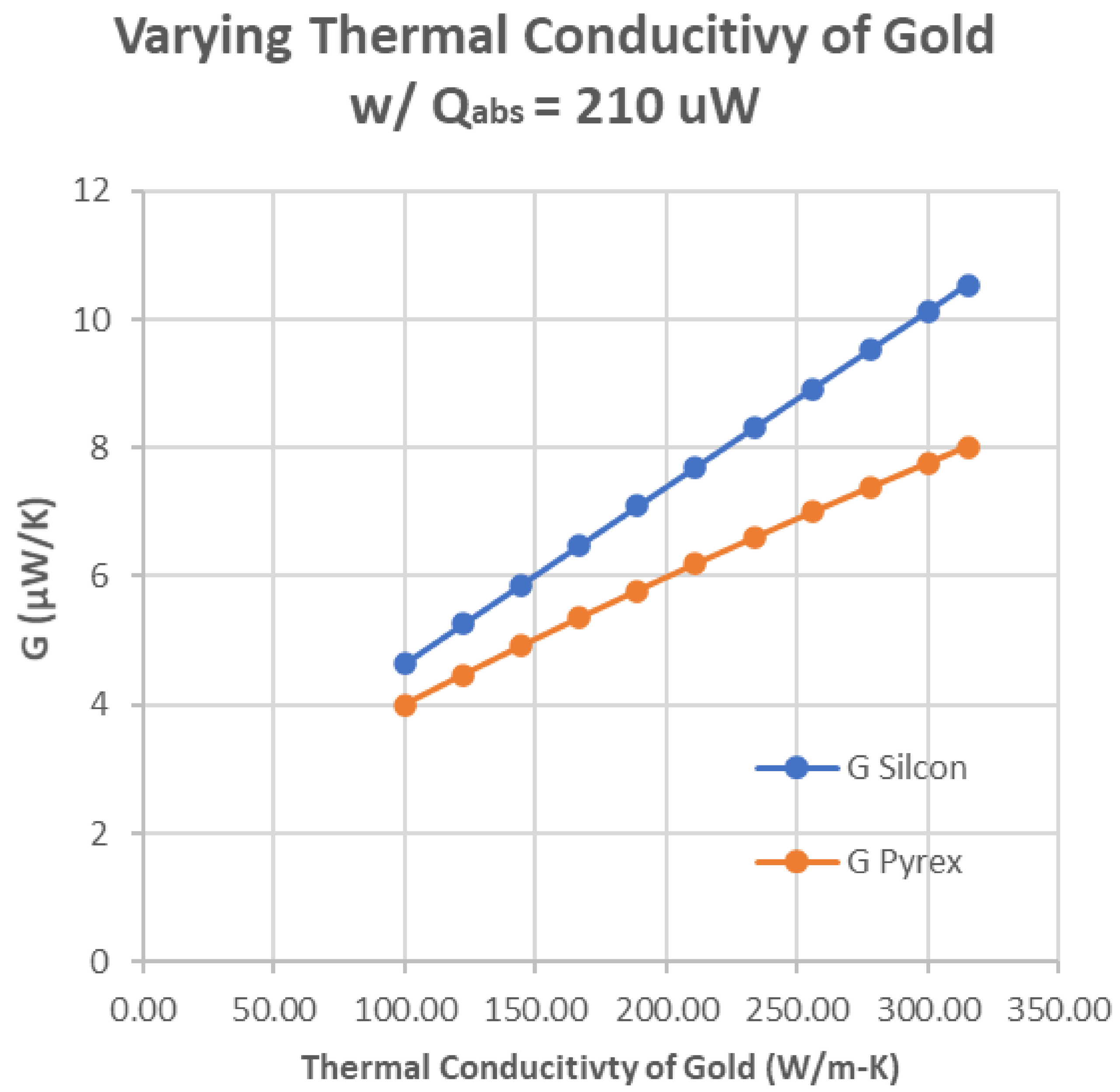

Figure 2: G Value of Pyrex and Silicon against k_{Au}

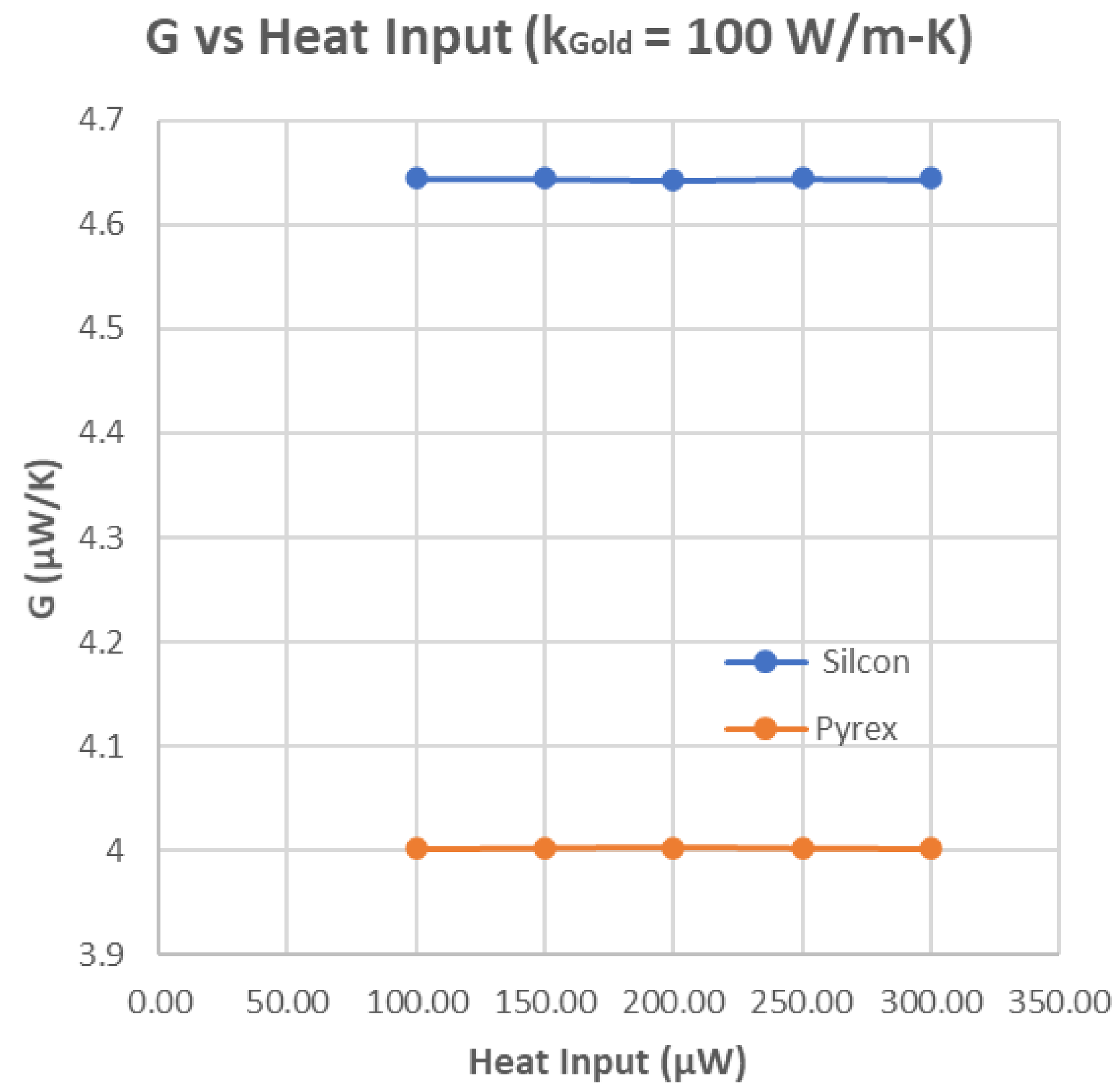

Figure 3: G Value of Pyrex and Silicon against Q_{abs}

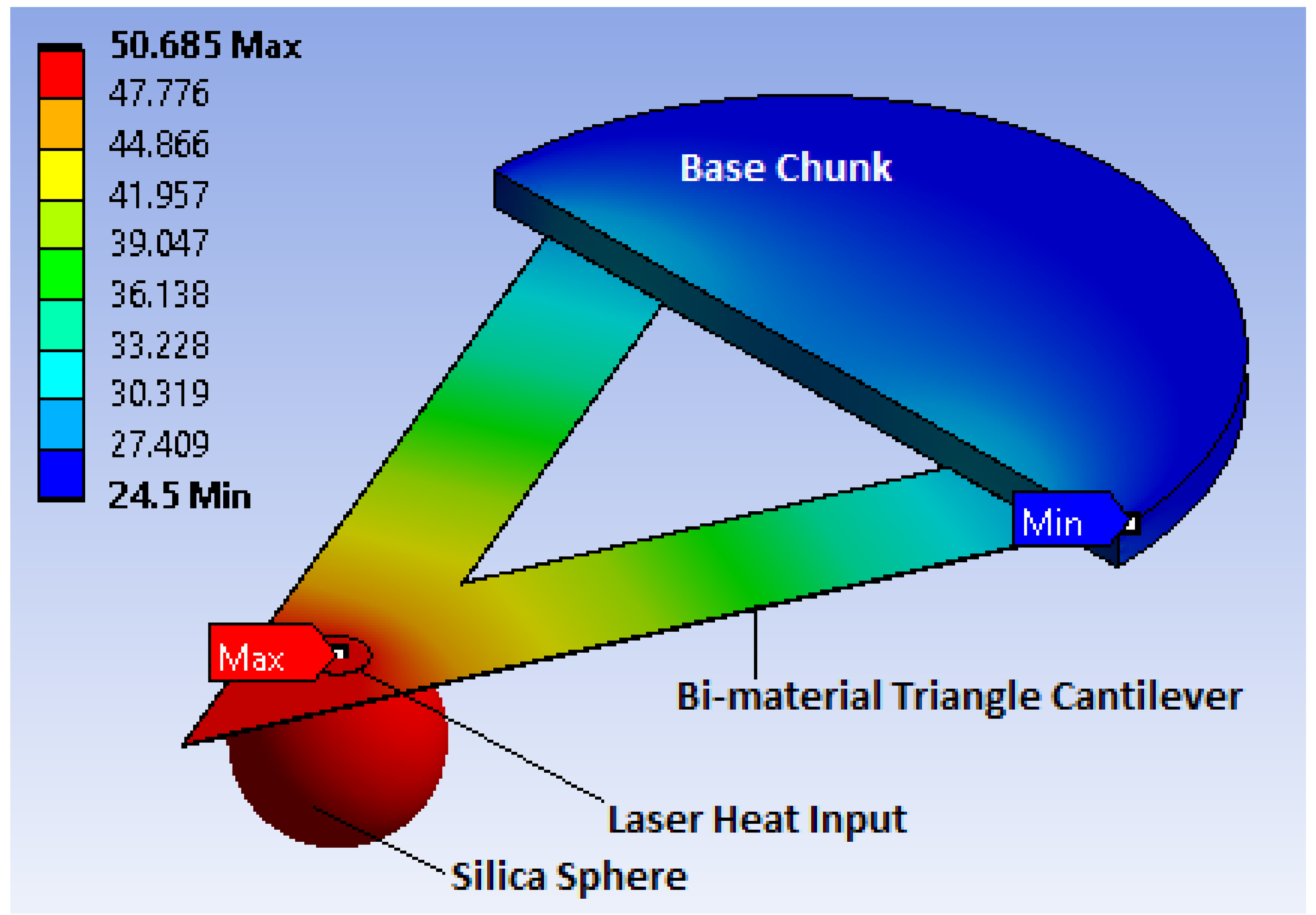

Figure 4: Example Thermal Model from Ansys with Temperature Contours

Conclusion

Sheng S. and Gang C. from MIT conducted his experiment using a silicon-based probe. He had a resulting G value of 4.52 µW/K. From the simulations, the thermal conductivity of Gold in his case was about 100 W/m-K, a significant reduction from the more typical bulk value of around 300 W/m-K. The graphs show that the G value with Pyrex-based probe is lower than the silicon-based. As expected, the G value does not vary with the laser heat input as seen in figure 3. The thermal conductances of the silicon and Pyrex probes with a gold thermal conductivity of 100 W/m-K are 4.64 and 4.00 µW/K which is a 14.8 % difference.

References

[1] Kondakindi, Ramteja Reddy. 2019. AFM Bi-material Cantilever Based Near-field Radiation Heat Transfer Measurement
[2] Sheng S, Gang C. 2008. Near-field radiative heat transfer between sphere and a substrate