AFM Based 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 complex system in which the deflection of a sphere tipped bi-material cantilever will be tracked as it transfers heat to a plate at a very close distance from it.

Background

Planck's blackbody is a theoretical surface which absorbs all radiant energy which falls upon it and is also a perfect emitter. It is called a blackbody because all visible light would be absorbed and not reflected which will make the surface appear black. Ideally, since it is the perfect emitter, no surface should be able to emit more radiation than a blackbody. However, recent experiments show that when two surfaces are close enough, the radiation far exceeds that predicted of the blackbody's. At distances this close, the radiation is classified as near-field radiation (NFR) in which, as mentioned above, the distance between the two surfaces is smaller than the characteristic wavelength of the radiation. Two types of waves are emitted for radiative heat transfer. The first is the propagating wave and the second is the evanescent wave. At far distances, where far field radiation occurs, prorogating waves dominate the evanescent waves and vice versa for near field heat transfer. The domination of evanescent waves in NFR is what causes the great increase in thermal radiation.

Method

The experimental setup is aimed to measure the NFR heat transfer between an atomic force microscopy (AFM) bi-material cantilever with a sphere attached to its tip and a glass plate. The plate is brought to a distance of less than 10 micrometers from the sphere, which is the theorized distance in which a substantial amount of NFR heat transfer will take place. To ensure no convective heat transfer takes place, the entire setup is placed inside a vacuum chamber. A laser is focused on the cantilever tip to heat up the cantilever. The temperature difference between tip and plate causes both heat transfer, and a change in cantilever temperature. Due to the bi-material construction, the cantilever deflects as both metals of the bi-material cantilever exhibit different thermal coefficients of expansion. The deflection of the cantilever is recorded with a PSD tracking the reflected laser beam. The recorded deflections are associated with the cantilever temperature which is now measurable and from the temperature data, the amount of heat transferred to the plate can be calculated. The 4 parameters affecting the NFR heat transfer are absorbed heat from the laser (Q_{abs}), heat conducted through the probe (Q_c). Temperature of the sphere (T_{sp}), and distance between sphere and plate (d).

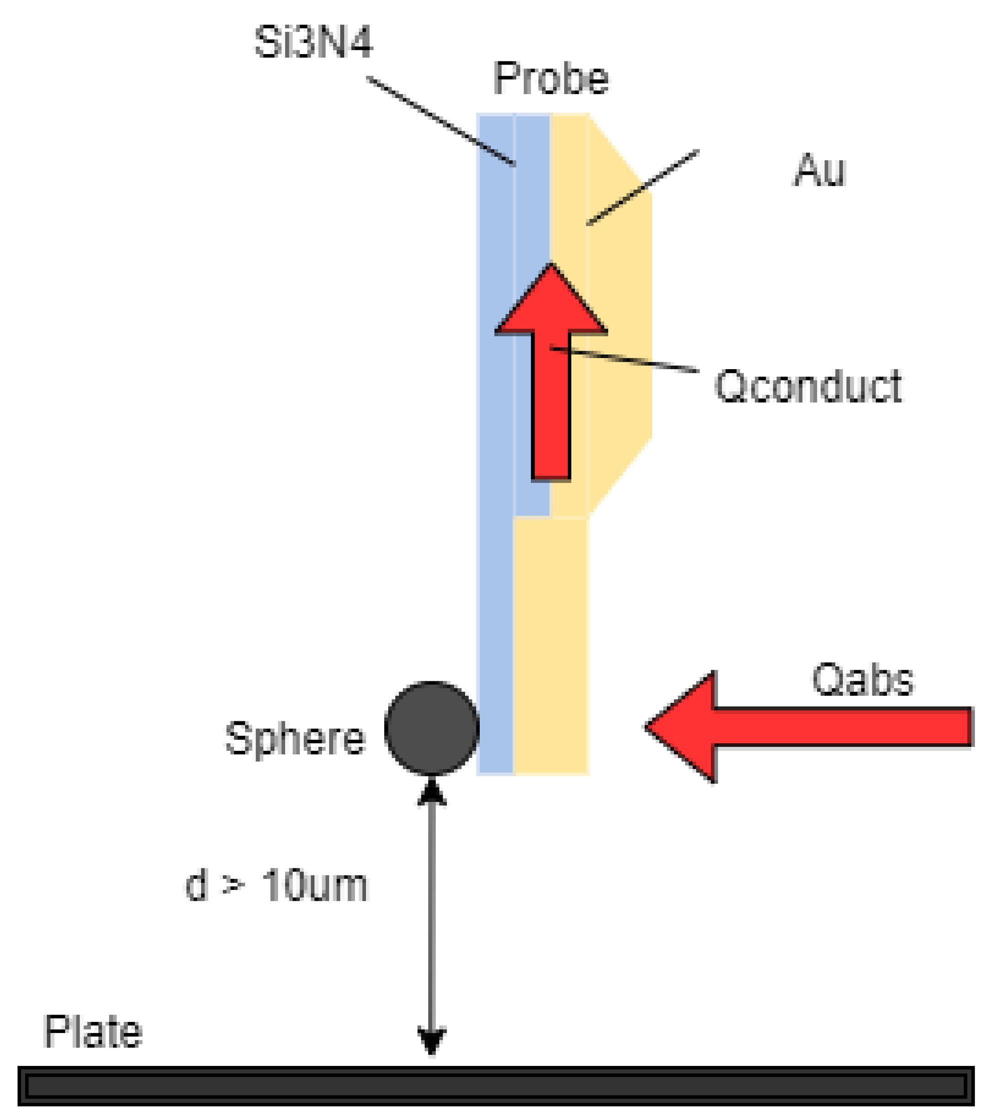

Figure 1: Heat Transfer Model of Probe and Plate out of effective range of NFR

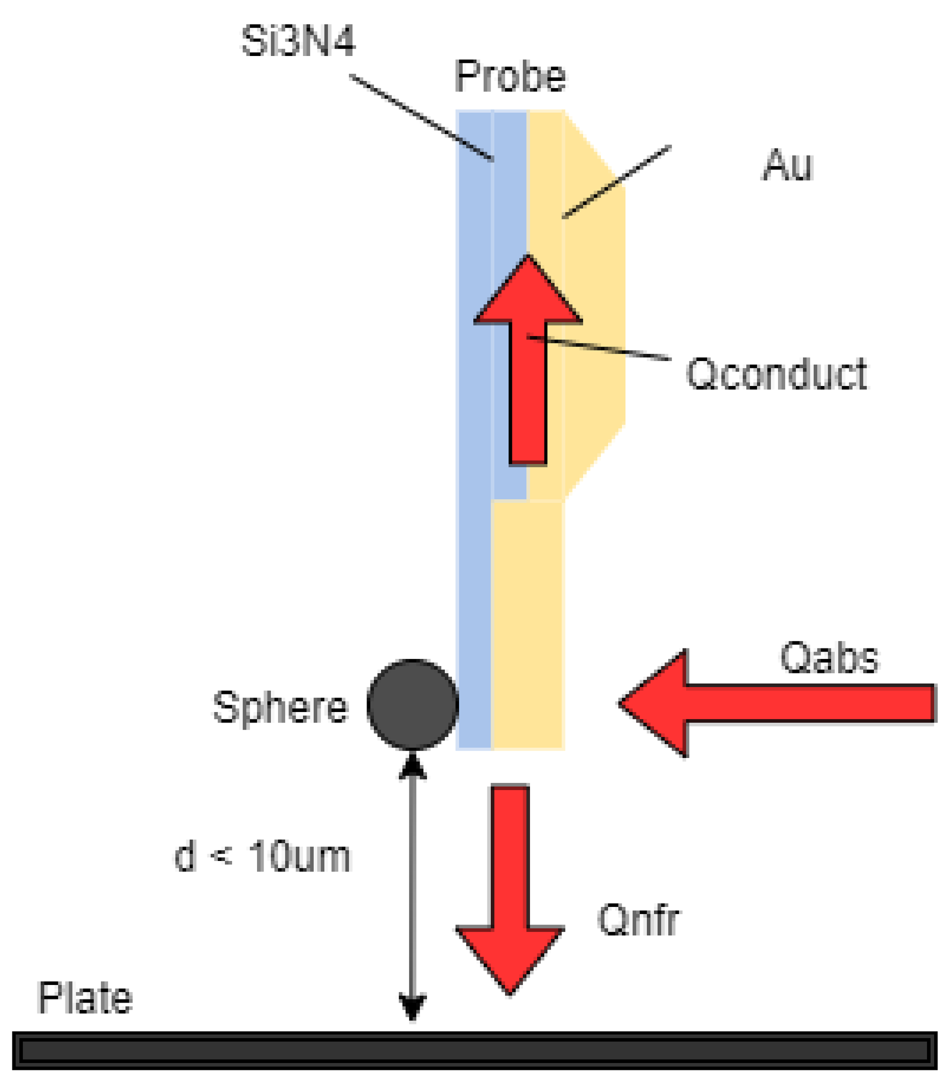

Figure 2: Heat Transfer Model of Probe and Plate within range of NFR

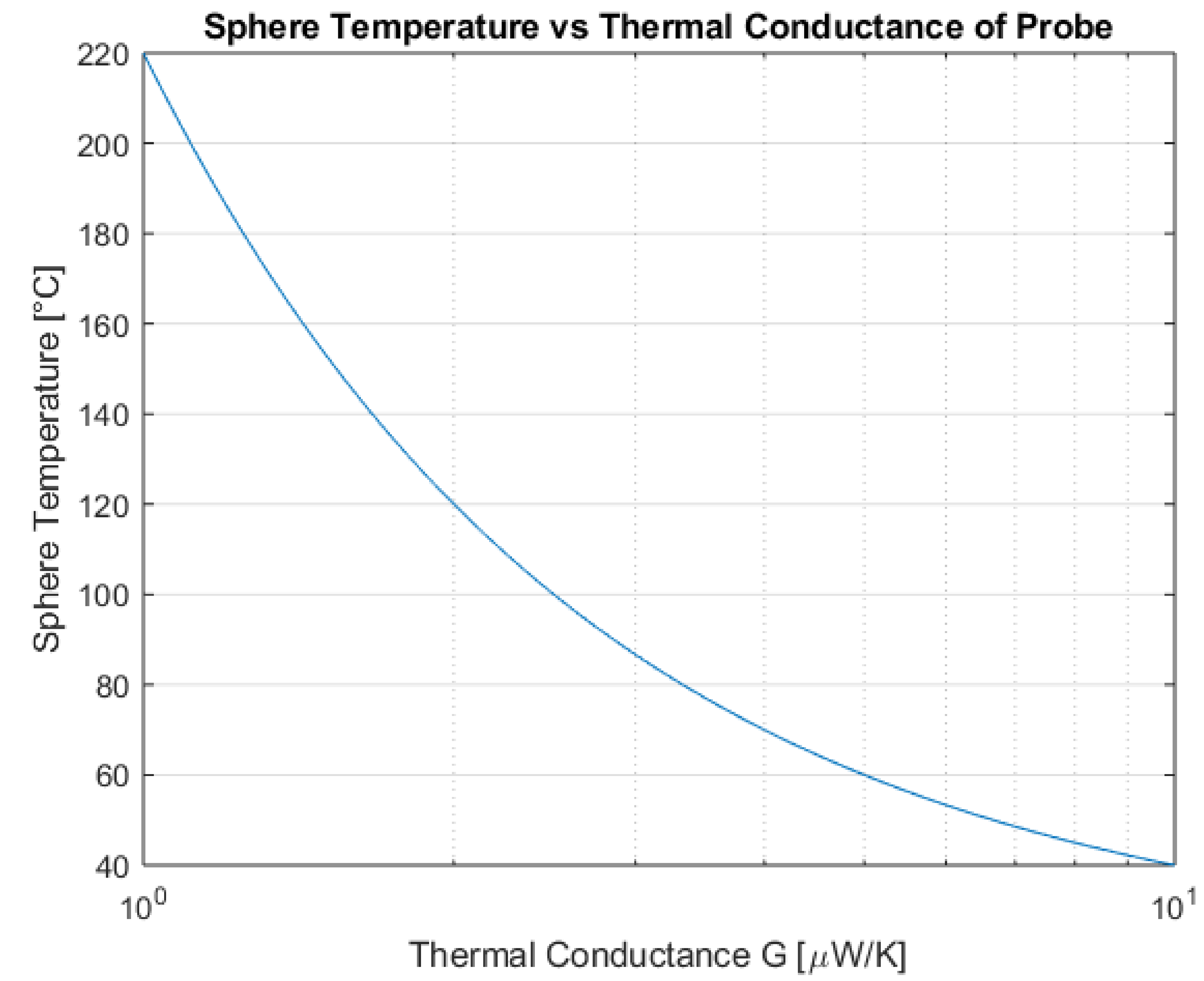

Figure 3: Theoretical Plot of Sphere Temp vs Thermal Conductance of AFM Probe; No NFR Heat Transfer

Conclusion

The goal is to maximize the possible measurable NFR heat transfer. One way to do this is to use a probe with less thermal conductivity. Lower thermal conductivity allows for a higher temperature at the tip of the cantilever. The sphere is assumed to have the same temperature as the tip. As shown in figure 2, a higher sphere temperature results in a larger temperature difference between plate and higher temperature differences result in greater quantities of heat transfer. Figure 3 presents a curve showcasing this conclusion.

References

[1] Kondakindi, Ramteja Reddy. 2019. AFM Bi-material Cantilever Based Near-field Radiation Heat Transfer Measurement

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