Radiative heat transfer through nanometer-size gaps

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One of the central open problems in nanoscience is the study of the heat transport in nanoscale devices, which has remained largely unexplored due to experimental challenges. In this context, a key issue is the understanding of the heat transfer via thermal radiation between systems separated by nanometer-size gaps. In this extreme regime, the electromagnetic near-field is expected to give rise to a dramatic enhancement of the radiative heat transfer, something that has only be quantitatively verified for gaps on the order of 20-30 nm [1]. In this work, we present a combined experimental and theoretical study of the radiative heat transfer in the extreme near-field regime (gaps of 1-10 nm). From the experimental side, we performed systematic studies using AFM-based scanning probes with integrated nanoscale thermocouples [2], which were coated with dielectrics (SiO_2 or SiN_x). Our experiments of heat transport between the scanning probes and a flat substrate coated with dielectrics, performed in an ultra-high vacuum environment, confirm that heat transport is dramatically enhanced in the near-field. To understand our experimental results, we investigated these near-field enhancements within the framework of the theory of fluctuational electrodynamics [3]. To be precise, we performed extensive numerical simulations making use of a combination of a fluctuating-surface-current formulation of radiative heat transfer with the boundary element method [4,5]. Such a combination allows us describing realistic geometries for our tip-sample setups. Our theoretical results are in good agreement with the measured heat flows between both dielectric and metallic surfaces, which establishes the validity of fluctuational electrodynamics in modeling near-field heat transport all the way to nanometer-size separations.

References

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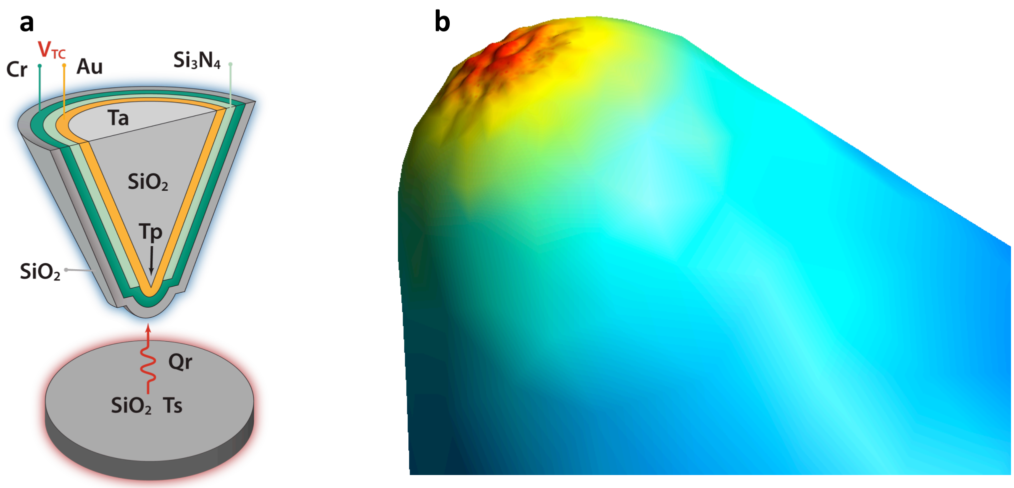

a Schematic diagram of the experimental setup. The AFM probes incorporate a thermocouple, made by a spherical Au/Cr junction with a diameter of 200 nm. **b** Numerical simulation of the spatially resolved heat transfer between a tip and a plate made of silica and separated by a distance of 1 nm. The radius of the tip is 225 nm. The color scale is logarithmic, showing the radiative heat transfer enhancement in the extreme near-field.