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 radiative 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 been 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