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PII: S0022-4073(18)30541-7
DOI: https://doi.org/10.1016/j.jqsrt.2018.10.005
Reference: JQSRT 6242

To appear in: *Journal of Quantitative Spectroscopy & Radiative Transfer*

Received date: 25 July 2018
Revised date: 2 October 2018
Accepted date: 3 October 2018

Please cite this article as: Moladad Nikbakht, Radiative heat transfer between core-shell nanoparticles, *Journal of Quantitative Spectroscopy & Radiative Transfer* (2018), doi: https://doi.org/10.1016/j.jqsrt.2018.10.005

Radiative heat transfer between core-shell nanoparticles

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Abstract

Radiative heat transfer in systems with core-shell nanoparticles may exhibit not only a combination of disparate physical properties of its components but also further enhanced properties that arise from the synergistic properties of the core and shell components. We study the thermal conductance between two core-shell nanoparticles (CSNPs). The contribution of electric and magnetic dipole moments to the thermal conductance depend sensitively on the core and shell materials, and adjustable by core size and shell thickness. We predict that the radiative heat transfer in a dimer of Au@SiO_2 CSNPs (i.e., silica-coated gold nanoparticles) could be enhanced several order of magnitude compared to bare Au nanoparticles. However, the reduction of several orders of magnitude in the heat transfer is possible between SiO_2@Au CSNPs (i.e., silica as a core and gold as a shell) than that of uncoated SiO_2 nanoparticles.

Keywords: core-shell nanoparticles; radiative heat transfer; surface modes; thermal conductance

1. Introduction

Radiative heat transfer between objects is sensitively dependent upon their separation distance. If the separation is too small compared to the thermal wavelength, then energy transfer exceeds the well-known classical Planck's law of the black-body radiation [1]. Several studies have shown that the radiative heat transfer between objects with planar geometry depends on the materials and could be manipulated by using anisotropic materials, layered materials, and covering objects with different material composition [2, 3, 4, 5, 6, 7]. In addition to the separation distance, the radiative heat transfer in a dimer of nanoparticles depends on various properties of the constituent nanoparticles, including material composition [8, 9], size [10], surface structure [11], shape [12, 13, 14], and relative orientation [15, 16, 17]. From these studies, it can be concluded that, in addition to the dielectric constant of the host material, the radiative heat transfer strongly depends on the optical properties of objects in the system. Since the optical properties of particles strongly depend on their characteristics, the shape, size, and material composition of particles have a decisive role in heat transfer, which have been the subjects of majority of studies in past years. The proper choice of each of these quantities depends on the desired application which could include reducing, increasing or rectifying the radiative heat transfer.

Material selection is of great importance in thermal management and among materials, those that can support surface phonon modes in the infrared (e.g., polar dielectrics SiC and SiO_2) are generally used to enhance near-field heat transfer. On the contrary, metallic nanoparticles which have resonances only in the visible or the UV range, do not perform as well as polar dielectrics for near-field heat transfer applications. The reason is the negligible contribution of plasmon modes to thermal transport, since according to Wien displacement law, the peak wavelength for thermal emission at room temperature, is much longer than the surface plasmon wavelengths of most conventional metals. However, the search for methods that can

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