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Review

The thermal near-field: Coherence, spectroscopy, heat-transfer, and optical forces

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ABSTRACT

One of the most universal physical processes shared by all matter at finite temperature is the emission of thermal radiation. The experimental characterization and theoretical description of far-field black-body radiation was a cornerstone in the development of modern physics with the groundbreaking contributions from Gustav Kirchhoff and Max Planck. With its origin in thermally driven fluctuations of the charge carriers, thermal radiation reflects the resonant and non-resonant dielectric properties of media, which is the basis for far-field thermal emission spectroscopy. However, associated with the underlying fluctuating optical source polarization are fundamentally distinct spectral, spatial, resonant, and coherence properties of the evanescent thermal near-field. These properties have been recently predicted theoretically and characterized experimentally for systems with thermally excited molecular, surface plasmon polariton (SPP), and surface phonon polariton (SPhP) resonances.

We review, starting with the early historical developments, the emergence of theoretical models, and the description of the thermal near-field based on the fluctuation–dissipation theory and in terms of the electromagnetic local density of states (EM-LDOS). We discuss the optical and spectroscopic characterization of distance dependence, magnitude, spectral distribution, and coherence of evanescent thermal fields. Scattering scanning near-field microscopy proved instrumental as an enabling technique for the investigations of several of these fundamental thermal near-field properties. We then discuss the role of thermal fields in nano-scale

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heat transfer and optical forces, and the correlation to the van der Waals, Casimir, and Casimir–Polder forces. We conclude with an outlook on the possibility of intrinsic and extrinsic resonant manipulation of optical forces, control of nano-scale radiative heat transfer with optical antennas and metamaterials, and the use of thermal infrared near-field spectroscopy (TINS) for broadband chemical nano-spectroscopic imaging, where the thermally driven vibrational optical dipoles provide their own intrinsic light source.

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1. Introduction

In this review we will discuss recent advances in the investigation, understanding, and application of the distinct spectral, spatial, and coherence properties of the thermal near-field compared to far-field thermal radiation. In particular, the special resonant enhancement of the near-field electromagnetic