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New analytical tool to clarify the role of optical loss in the near field heat transfer for materials

ICFO researchers present a new general and fully analytical framework that improves the study of near field radiative heat transfer in plasmonic and polar materials.

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The interest in studying near-field radiative heat transfer (NFRHT) and heat transfer between objects separated by sub-micrometric vacuum gaps, has increased considerably in the last years. NFRHT exhibits high-thermal densities and, in theory, this process can enable better thermodynamic efficiencies, it can potentially have a significant impact as well as drastically improve the performance of several applications, from energy harvesting with thermophotovoltaics systems to heat-assisted nano-lithography systems.

According to the current theories, evanescent electromagnetic modes, manifested in the form of polaritons, in the near field have a key contribution in the process of optimally transferring heat between two separated bodies. Polaritons, which are considered to be hybrid particles made up of a photon strongly coupled to an electric dipole and that can occur in plasmonic and polar materials, are excitations that exhibit a maximum intensity at the interface between two media and decay exponentially away from it.

These evanescent modes can originate in two ways: in metals, they can be generated from surface plasmon-polaritons (the resonance is here caused by the oscillation of electrons when interacting with light), while in the case of the polar dielectric, such resonant modes occur in the form of phonon-polaritons (originating from the coupling of collective oscillations of atomic displacements with light).

Among the features of the resonance behind these evanescent modes, its bandwidth plays a key role in the heat transfer in near field. In fact, the resonance bandwidth is linked to the optical loss in the material, which is known to enable thermal emission in the first place, as well as absorption in any structure illuminated by light. To quantitatively characterize this feature, the authors rely on the material quality factor (Q factor) of the polariton resonance. This parameter is inversely related to resonance bandwidth, and therefore to the optical loss: the higher the Q factor, the sharper the resonance.

Until now studies had shown that the optical loss, the temperature, and other dielectric properties were mathematically intertwined with one another, creating a complex analytical tool or formalism that hindered a deep understanding of the fundamentals of the NFHRT process.

Now, ICFO researchers **Mariano Pascale** and ICFO **Prof. Georgia T. Papadakis,** have described in a recent paper published in **Physical Review Applied** a new analytical framework for NFRHT in polaritonic materials that uses evanescent modes in a planar configuration (two almost infinitely extending planes separated by a nanometric vacuum gap) to explain the process in a more thorough way.

The researchers developed a new formalism that disentangles for the first time the role of the optical loss from other dispersion characteristics of the materials as well as the temperature. They show that the Q factor alone is not sufficient to accurately describe NFRHT. In contrast, to complete the NFRHT analytical framework, they introduce the material residue parameter B, a loss independent quantity that encompasses critical properties in polaritonic materials, i.e., the resonance frequency and the spectral width of the Reststrahlen band.

As a result, they obtained a universal expression linking the optimal Q factor to the material residue B, therefore identifying the optimal interplay between the optical loss and the resonance frequency for maximal near-field heat transfer. With this new formalism, the researchers were also able to set upper bounds (the maximum achievable thermal conductance) for each analyzed media.

According to the first author of the study, Mariano Pascale, this new formalism "clarifies the role of various material dispersion characteristics such as optical loss and material quality factor for near field heat transfer".

As the authors highlight, ï¿½the decoupling of the temperature, the material's quality factor and the material's residue (..) allow for a quantitative classification of different materials as candidates for tailoring NFRHT ".

With the analysis and further descriptive formalism described in the present work, it is possible to identify the optimal characteristic of different materials, independent of the temperature, that maximizes NFRHT and see how this process changes with optical loss.

The study includes the analysis and classification of several polaritonic emitters on one hand, such as Silicon Carbide (SiC), hexagonal Boron Nitride (h-BN) and doped semiconductors such as Gallium Arsenide (GaAs) or Indium Arsenide (InAs), as well as plasmonic materials, on the other hand, such as noble metals like Gold (Au) and Silver (Ag).

"By removing the dependence from optical loss from the equation, we are able to systematically and quantitatively classify a wide range of relevant plasmonic and polar materials for near-field radiative heat transfer", said Mariano Pascale.

The new formalism "offers a compact and robust description of this effect and is in excellent agreement with fluctuational electrodynamicsï¿½, concludes the ICFO researche

Original paper

Pascale, M. Papadakis, G. (2023) Tight bounds and the role of optical loss in

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