The Progress and Future of Near-Field Radiative Heat Transfer

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As a fundamental method of heat transfer, thermal radiation spontaneously occurs for any material with nonzero kelvin temperature. The radiative heat transfer corresponds to the energy transfer between objects through thermal radiation. So far, the radiative heat transfer is mainly divided into two categories, which are determined by the relative size of the characteristic geometric dimension of objects and the dominant wavelength of thermal radiation determined from Wien’s displacement law. For example, when the dominant wavelength of thermal radiation is much smaller than the distance between the heat source and heat sink, the radiative heat transfer is called far-field radiative heat transfer (FHRHT). The corresponding radiative heat flux is limited by the well-known Stefan-Boltzmann law.1 This is because that the radiative heat transfer channel (i.e., wave vector \( k \)) is limited in the propagating modes \((k < \omega/c)\), where \(\omega\) is the angular frequency and \(c\) is the light speed in the vacuum.1,2 Instead, when the dominant wavelength of thermal radiation is comparable to or even larger than the distance between the heat source and heat sink, the radiative heat transfer is called near-field radiative heat transfer (NFRHT). The corresponding radiative heat flux can break through the well-known Stefan-Boltzmann law and exceed the radiative heat flux predicted by the well-known Stefan-Boltzmann law even several orders of magnitude.1,2,3 This is because that the radiative heat transfer channel \((k)\) can extend from the propagating modes to the evanescent modes \((k > \omega/c)\).1,2,3 Meanwhile, the radiative heat flux can be further enhanced due to near-field effects, such as excitation of surface waves including surface phonon polaritons (SPhPs) and surface plasmon polaritons (SPPs), which can effectively enhance the transmission factor for evanescent modes.1,4,6 During the past few decades, this feature of NFRHT has attracted a lot of attention, including theoretical and experimental research. Especially in the past decade, the theoretical and experimental research of NFRHT has made continuous breakthroughs, and the theoretical research of NFRHT has been verified by much experimental research, attracting more and more scholars to join the research of this field.1,2,4 With the development of new materials and structures in NFRHT field, the physical mechanism and potential application of the NFRHT have been greatly enriched. Therefore, in this editorial article, we would like to give a brief overview of NFRHT.

Conventional isotropic polar materials, semiconductor materials, and metal materials may be welcomed and studied by researchers earlier. The SPhPs supported by polar materials and the SPPs supported by semiconductor materials and metal materials can result in the transmission factor keeping high value to large wave vector \( k \) for evanescent waves in a narrow angular frequency band.1,2,3 This can greatly enhance the radiative heat flux and make it monochromatic (i.e., sharp peak in the spectral radiative heat flux),1,2,6 and thus is very important in enhancing and regulating NFRHT. However, these materials are usually nonmagnetic, and thus the SPhPs and SPPs are mainly excited in the \( p \)-polarization, limiting their way to enhance and regulate the NFRHT. Due to supporting the surface waves in the \( s \)-polarization, metamaterials have been involved to further enhance and regulate NFRHT.9,10 Accordingly, it can be seen that the NFRHT can be significantly affected by the excitation of surface waves. Consequently, due to the adjustable SPPs from terahertz to mid-infrared, graphene exhibits great potential in the enhancement and regulation of NFRHT, which has been confirmed by many subsequent studies.11-13 Graphene is a representative two-dimensional material, and its great progress in the field of NFRHT has also inspired scholars to explore the effect of other two-dimensional materials such as molybdenum disulfide (MoS\(_2\)) materials and black phosphorus sheets on NFRHT.14,16 In addition to extending nonmagnetic materials to metamaterials, researchers also extend isotropic materials to various anisotropic materials, along with different physical mechanisms which can...
The development of the calculation methods of NFRHT is still backward. Finally, we inferred that there would be more possible new physical mechanisms significantly affecting NFRHT to be developed. Another important development for the structure of NFRHT is the enhancement and regulation of NFRHT, or opening up some new potential applications of NFRHT. Therefore, we should actively develop more unique structures cooperating with conventional or specific materials in NFRHT, analyze the possible new physical mechanism, and explore the new potential applications. We believe that through the unceasing efforts of scholars, NFRHT would play an important role in the applications of thermal management, energy conversion system, scanning thermal microscope, and so on.

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