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Thermal radiation in dipolar many-body systems

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Abstract. The framework of fluctuational electrodynamics for dipolar many-body systems is one of the working horse for theoretical studies of thermal radiation at the nanoscale which includes dissipation and retardation in a naturally way. Based on this framework I will discuss near-field thermal radiation in non-reciprocal and topological many-body systems. The appearance of the Hall and non-reciprocal diode effect for thermal radiation illustrates nicely the interesting physics in such systems as well as the edge mode dominated heat transfer in topological Su-Schrieffer-Heeger chains and a honeycomb lattices of plasmonic nanoparticles. In the latter, the theory allows for quantifying the efficiency of the edge-mode dominated heat transfer as function of the dissipation. Finally, I will present how the theoretical framework can be generalized to study far-field thermal emission of many-body systems close to an environment like a substrate, for instance. This theory might be particularly interesting for modelling thermal imaging microscopes.

1 Introduction

The theory for near-field thermal radation in dipolar many-body systems has been established more than ten years ago [1]. Since then it has been extended and due to its simplicity applied by many theoretical groups to study a great number of near-field effects as summarized in the review [2]. Here, I want to review some of our recent results in non-reciprocal and topological systems and finally show how the dipole approach can be applied for treating far-field thermal emissions of a nanoparticle assembly in a given environment.

2 Non-reciprocity

Magneto-optical or more generally non-reciprocal materials show interesting effects due to their non-reciprocal properties like the thermal radiative Hall effect [3], persistent currents [4], giant magneto-resistance [5, 6],and circular heat fluxes [7] as well as persistent angular momentum and spin of thermal radiation [7] have been highlighted. We review some of the recent developments in this direction [8] and discuss in some detail the possibility to rectify nanoscale radiative heat fluxes by means of non-reciprocal surface waves and propose a nanoscale heat flux rectifier or diode which can be controlled actively by means of externally applied fields [9]. We furthermore, reveal the spin coupling mechanism behind the observed heat flux rectification [10] as depicted in Fig. 1.

3 Topology

The fluctuational electrodynamics framework can also be applied to topological nanoparticle assemblies where near-field energy densities [11, 12] and heat fluxes [13] can be studied in the topological phase including retardation and dissipation. We discuss these properties for a Su-Schrieffer-Heeger chain as well as a honeycomb lattice of nanoparticles as depicted in Fig. 2. We show the impact of the edge mode dominated heat transfer with an emphasis on the impact of dissipation.

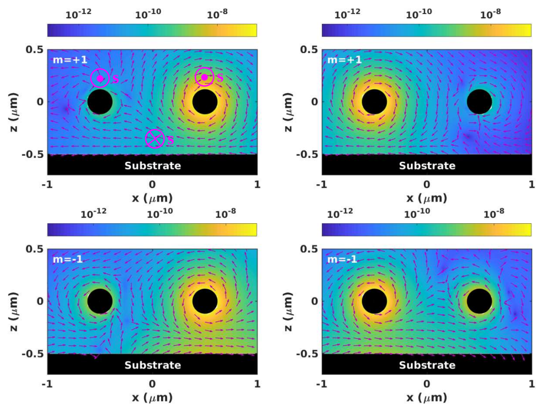

Figure 1. Directional spectral heat flux in forward and backward direction due to the coupling of the $m = \pm 1$ resonances with the spin-momentum locked non-reciprocal surface modes for InSb.

4 Far-field emission

Finally, a theory based on the fluctuational electrodynamics formalism is presented in order to treat thermal emission of dipolar objects close to an arbitrary environment which can be a substrate. This approach generalizes the single particle theory in Ref. [14] to the many-body case where the temperatures of the particles and environment

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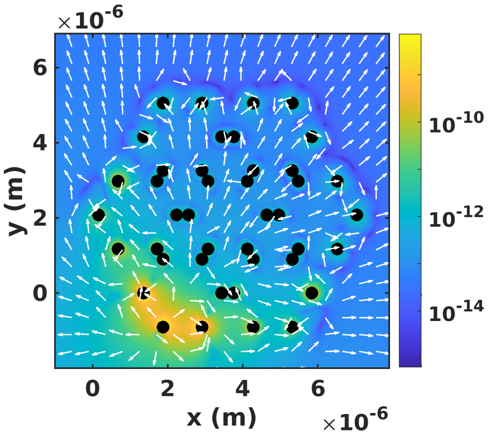

Figure 2. Spectral mean Poynting vector at the edge mode frequency in a honeycomb lattice of InSb nanoparticles where the particle at the lower left is heated with respect to the other particles.

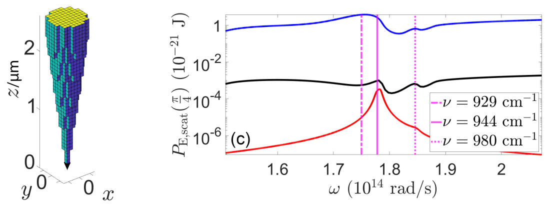

Figure 3. Far-field spectrum of a Si scattering tip (black curve) 10nm above a planar SiC substrate compared to the result of a single dipole model (small: red curve, large: black curve). The tip is treated within a discrete dipole approximation as in Ref. [16].

can be fixed separately. The versatility of the theory is demonstrated by discussing thermal emission spectra of nanoparticle assemblies and macroscopic objects within a discrete dipole approximation in close proximity to a planar substrate [15]. The latter can be used for modelling signals of scattering type near-field thermal microscopes as shown in Fig. 3.

References

[1] P. Ben-Abdallah, S.-A. Biehs, and K. Joulain, "Many-body radiative heat transfer theory," Phys. Rev. Lett. **107**, 114301 (2011).

[2] S.-A. Biehs, R. Messina, P. S. Venkataram, A. W. Rodriguez, J. C. Cuevas, and P. Ben-Abdallah, "Near-field radiative heat transfer in many-body systems," Rev. Mod. Phys. **93**, 025009 (2021).

[3] P. Ben-Abdallah, "Photon Thermal Hall Effect," Phys. Rev. Lett. **116**, 084301, (2016).

[4] L. Zhu and S. Fan, "Persistent Directional Current at Equilibrium in Nonreciprocal Many-Body Near Field Electromagnetic Heat Transfer," Phys. Rev. Lett. **117**, 134303 (2016).

[5] I. Latella and P. Ben-Abdallah, "Giant Thermal Magnetoresistance in Plasmonic Structures," Phys. Rev. Lett. **118**, 173902, (2017).

[6] R. M. Abraham Ekeroth, P. Ben-Abdallah, J.C. Cuevas, and A. Garcia Martin, "Anisotropic Thermal Magnetoresistance for an Active Control of Radiative Heat Transfer," ACS Photonics **5**, 705 (2017).

[7] A. Ott, P. Ben-Abdallah, and S.-A. Biehs, "Circular heat and momentum flux radiated by magneto-optical nanoparticles," Phys. Rev. B **97**, 205414 (2018).

[8] A. Ott, R. Messina, P. Ben-Abdallah, S.-A. Biehs, "Magnetothermoplasmonics: from theory to applications," J. Photon. Energy **9**, 032711 (2019).

[9] A. Ott, R. Messina, P. Ben-Abdallah, S.-A. Biehs, "Radiative thermal diode driven by nonreciprocal surface waves," Appl. Phys. Lett. **114**, 163105 (2019).

[10] A. Ott and S.-A. Biehs, "Thermal rectification and spin-spin coupling of non-reciprocal localized and surface modes," Phys. Rev. B **101**, 155428 (2020).

[11] A. Ott and S.-A. Biehs, "Radiative heat flux through a topological Su-Schrieffer-Heeger chain of plasmonic nanoparticles," Phys. Rev. B **102**, 115417 (2020).

[12] A. Ott, Z. An, A. Kittel, and S.-A. Biehs, "Thermal near-field energy density and local density of states in topological one-dimensional Su-Schrieffer-Heeger chains and two-dimensional Su-Schrieffer-Heeger lattices of plasmonic nanoparticles," Phys. Rev. B **104**, 165407(2021).

[13] A. Ott and S.-A. Biehs, "Topological near-field heat flow in a honeycomb lattice," Int. J. Heat Mass Transf. **190**, 122796(2022).

[14] K. Joulain, P. Ben-Abdallah, P.-O. Chapuis, Y. De Wilde, A. Babuty, and C. Henkel, "Strong tip sample coupling in thermal radiation scanning tunneling microscopy," J. Quant. Spectr. Rad. Transf. **136**, 1 (2014).

[15] F. Herz and S.-A. Biehs, "Generalized coupled dipole method for thermal far-field radiation," arXiv:2112.12016.

[16] S. Edalatpour, V. Hatamipour, and M. Francoeur, "Spectral redshift of the thermal near field scattered by a probe," Phys. Rev. B **99**, 165401 (2019).