Focusing of near-field heat flux radiated between a tip and a substrate for heat-assisted magnetic recording applications

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The development of fluctuational electrodynamics and the discovery that radiative heat flux can be strongly amplified in the near field have paved the way to several applications including heat-assisted magnetic recording (HAMR). In HAMR, a small surface area of a magnetic material is heated to raise its temperature close to the Curie temperature, where its magnetic coercivity is weak. Then by applying a magnetic field a new magnetic state can be recorded inside the material. Achieving high information densities requires the confinement of heat to nanoscale regions, ideally approaching the superparamagnetic limit of tens of nanometers.

In this work we address the spatially resolved near-field radiative heat transfer between a nanoparticle (simulating a tip) and a substrate in the fluctuational-electrodynamics framework within the dipolar approximation and explore two strategies both to enhance heat transfer and to spatially focus it.

In the first part, we consider the radiative heat transfer between a magneto-optical particle (whose optical properties can be manipulated by applying a magnetic field) and a substrate. We study the maximum of the Poynting vector below the nanoemitter and its Full Width Half Maximum (FWHM) as a function of the applied magnetic field for different radii of the nanoparticle. The results highlight a non-monotonic behavior, according to which the maximum Poynting vector (FWHM) first increases (decreases) as a function of the applied field, then decreases (increases), by reaching values even below (above) the reference one for vanishing field. This highlights the existence of an optimal scenario for which not only is the local heat flux quantitatively increased, but it is also more focused on the surface of the substrate. These results are interpreted by an analysis of the flux spectral properties and frequencies of resonant surface modes in the nanoparticle-substrate system.

In the second part, we consider the configuration of a tip made of a polar material and address the role played by a thin film of polar material placed on the underlying substrate. We show that this can also lead to a substantial enhancement and spatial focusing of the radiative heat flux. The influence of the probe–substrate separation, film thickness and substrate permittivity is analyzed, revealing that the effect originates from near-field interactions governed by the interplay between film-induced modifications of electromagnetic mode dispersion and the distance-dependent coupling strength. Our results highlight a viable route toward the active control of local radiative heat transfer at the nanoscale.