Plasmonic Brownian Ratchet

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Abstract

The motion of nanoscopic objects in a liquid is generally dominated by thermal noise: the random collisions with the solvent molecules result in Brownian motion of the objects [1]. In agreement with the second law of thermodynamics, this temperature-governed fluctuating forces originate no net motion in the large scale at equilibrium. However, by driving an anisotropic system out of thermodynamic equilibrium, work can be performed out of thermal noise even in the absence of large scale thermal gradients. This is the working principle of the so-called Brownian ratchets [2, 3].

In this work, we present a proof of principles demonstration of a light-driven nanoscale Brownian motor based on plasmonic interactions (see Fig. 1). This Brownian ratchet makes use of plasmonic-based optical forces [4], that first enable the trapping of nanoscopic particles and then drives them a long distance displacement in a single device at room temperature. By means of an array of optical antennas with broken spatial symmetry, we generate an anisotropic trapping potential for an ensemble of dielectric beads (see Fig. 2). This trapping potential can be repeatedly excited by turning on and off a laser field, thus taking the system out of equilibrium and yielding a directed drift of the particles into one direction. We demonstrate the ratchet mechanism by means of a Molecular Dynamics simulation, showing the rectified Brownian motion of a sub-micrometer bead in the absence of any external bias (see Fig. 3).

References

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Figures

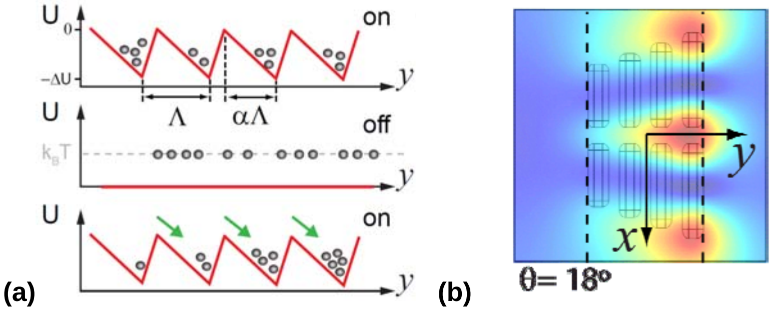

Figure 1. (a) Ratchet concept: by periodically turning on and off an external potential the brownian diffusion of an ensemble of particles is biased into one direction. (b) The norm of the electric field generated by the plasmonic structure when illuminated at λ = 1.5μm is plotted at z = 90nm.

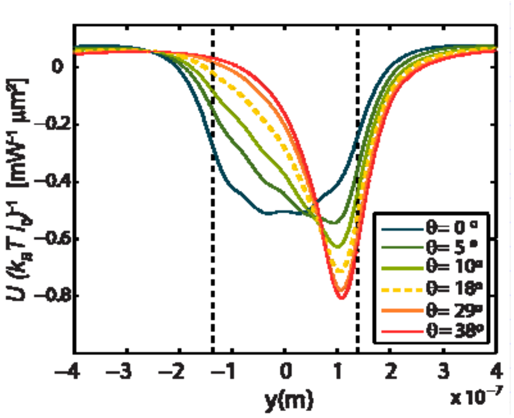

Figure 2. Variation of the anisotropic trapping potential experienced by the PS bead for several values of the geometrical asymmetry.

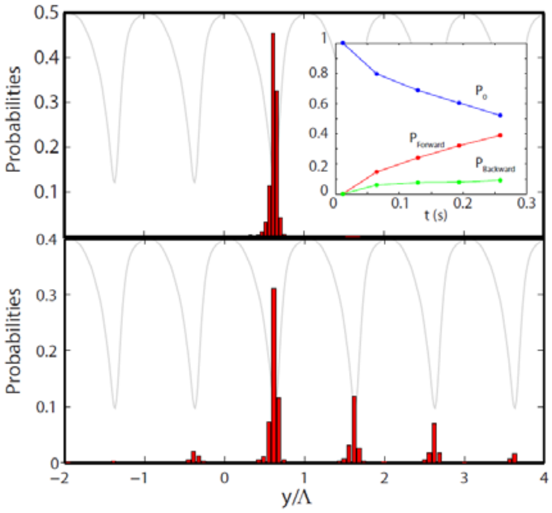

Figure 3. Dynamics for a Plasmonic Brownian Motor for N = 4000 realizations of the system. One PS bead (radius 50 nm, density 1050 kg/m^3) is solved in water (viscous coeffcient 10^{-3} kg/(m s)) at room temperature (T = 300 K). (a) Initial situation: the particle probability distribution is centered at the trapping position of the nanotweezer. Inset panel: time evolution of the probabilities for the particles to move forward (PF), backward (PB) or to remain in the initial unit cell (P0). (b) Final situation: after 16 on-off cycles, the probability for the particle to show a directed motion in the forward direction is 40%. The black gray line represents the plasmonic potential in arbitrary units.