A rotating molecular ruler : determining nanometer-scale particle-particle distances in an optomagnetic cluster assay

Magnetic Field-Induced Rotaphoresis for Controlled Redistribution of Magnetic Particles over a Surface

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Magnetic particle-based assays in lab-on-chip devices require a high level of control over the behavior of the particles. By the application of magnetic fields, both the individual and the collective behavior of the particles can be manipulated. However, magnetic actuation is often accompanied by the aggregation of particles as well as the drift of particles toward magnet poles.

Here, we report a new method to manipulate large ensembles of magnetic particles in a highly controlled fashion, by so-called magnetic field-induced rotaphoresis: the conversion of rotational motion of particles near a surface into effective translational motion. Using experiments and numerical simulations, we show that particles can be moved along the surface at high velocities (several mm/s) by using an out-of-plane rotating magnetic field (Fig. 1). In addition, the particle clusters within the ensemble are completely disaggregated within a few seconds (Fig. 2) by controlling the field frequency and amplitude. Our experiments and simulatios show that rotaphoresis is an effective manipulation methodology for particles of various sizes and surface properties. As only externally generated magnetic fields are used, magnetic field-induced rotaphoresis is highly suited for stationary-fluidic lab-on-chip assays.

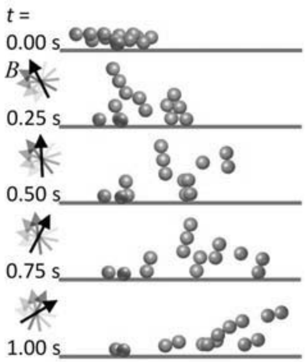

Figure 1 Concept of rotaphoresis. The figures correspond to a numerical Brownian dynamics simulation of the particle behavior.

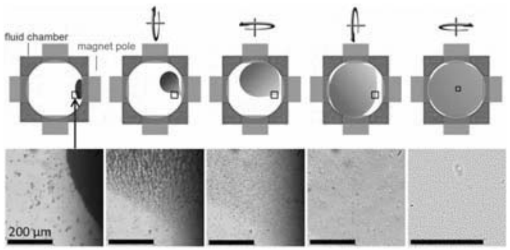

Figure 2 Experimental results showing that rotaphoresis, applied successively in different directions, can be used to evenly redistribute particles over a surface, within a time of 80 seconds.

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We investigate a fast and sensitive optomagnetic biomarker detection technology based on magnetic particles. Antibody-coated superparamagnetic particles capture biomarker molecules and form clusters with a biomarker molecule sandwiched between two particles. The particle clusters are actuated using a rotating magnetic field, which induces an oscillating light scattering cross-section (see Figs. 1a and 1b). Sub-picomolar biomarker concentrations can be resolved by the light scattering signals [Ranzoni et al, Nanoletters 2011; ACS Nano 2012].

In this paper we report a method to quantify inter-particle distances with nanometer resolution. The light scattering data show high-frequency signal components (see Fig. 1b). Simulations show that these high-frequency components hold detailed information about the geometry of the particle clusters, including a strong dependence on the inter-particle distance (see Fig. 1c). We will report the simulation results and experimental data of corresponding model cluster assays.

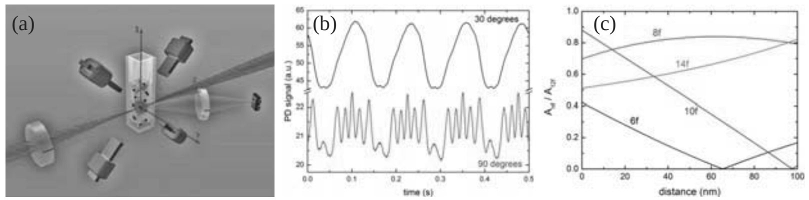

Figure 1 The particle-particle distance measurement technique. (a) Schematic representation of the light scattering setup. A quadrupole electromagnet creates a rotating magnetic field inside a cuvette. A laser beam is focused into the cuvette, the light scatters from the clusters and is collected at a photodiode. (b) Typical scattering signals at two different scattering angles. 30 degrees corresponds to the photodiode position displayed in figure 1a, 90 degrees corresponds to light scattering in the Y-direction. (c) Simulation of the Fourier amplitudes of the 90 degree scattering signal, normalised by the 12f amplitude, as a function of particle-particle distance.