Optical Detection of the Nanometric Dynamics of a Colloidal Particle Adjacent to an Electrode Passing Alternating Current

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Electrophoretic deposition is often used to bring colloidal particles to a surface.[1] Many investigators have observed lateral aggregative motion of particles in addition to motion normal to the electrode for both AC and DC electric fields.[2-8] It is important to clarify the underlying mechanisms of the lateral motion because the ability to control lateral particle motion at an electrode is industrially significant in novel display technologies among other applications. Two distinct theories for the cause of lateral motion during electrophoresis have emerged: the electrokinetic model (EK), and the electrohydrodynamic model (EH).[9] Experiments designed to complement the theory were the subject of this work.

Previous research has focused on lateral motion of particles under ac electric fields as a test for the suggested mechanisms; to date no one has examined particle motion in the direction normal to the electrode. This contribution optically explores the longitudinal motion of particles near an electrode as a possible indicator of the mechanisms responsible for the aggregation or dispersion of particles. The measurements of the colloidal particle's motion, a comparison with the motion expected from electrokinetic theory and a comparison with quantitative electrohydrodynamic model form the body of this work.

The experiments employed total internal reflection microscopy (TIRM) as described by Prieve.[10] TIRM is an optical technique for linear nanometric distance measurement. It relies on the scattering of an evanescent wave that exists adjacent to an interface when light is brought to a less optically dense medium from a more optically dense medium at an angle greater than a critical angle. 6.2-micron nominal diameter sulfonated polystyrene particles were suspended in 0.13 millimolar concentrations of potassium hydroxide or sodium bicarbonate. The solution of particles was then injected via syringe into a fluid flow cell comprised of two indium tin oxide coated glass slides and a 1.34mm polycarbonate spacer. The fluid cell rested on a glass prism, and was optically connected to the prism using optical matching fluid.

One counts photons to determine the particle height in static TIRM measurements. In dynamic TIRM, however, measuring the intensity by digital photon counting is not necessarily an accurate measurement of the particle height. With digital sampling the amount of light collected between each measurement interval, Δt, is the sum of the differential amounts of light scattered at every instantaneous height within that time interval. If a particle is moving at a high enough velocity, $U(t)$, such that $U(t)*\Delta t*\beta$ is not small (where β is a correction factor for motion near a wall) then the averaging nature of digital sampling causes the measured height of the particle calculated to be distinguishably lower than the true height. In practice, this limitation is only a significant concern for combinations of low frequencies and strong appliedf ields.

A typical ac electric field experiment consisted of three parts. First, the field was applied for two minutes for the particle to reach a stationary but oscillating behavior where the particle oscillates with an amplitude of tens of nanometers about an average height of about 100 nm. The intensity was measured at 1ms intervals for between 100 to 500 seconds, and finally the field was disconnected for at least three minutes between trials. The down time between experiments was maintained to allow the system to return to equilibrium behavior and to allow any heat generated via ohmic heating to dissipate. During all experiments, the room temperature was monitored for changes at the start of each run and the average temperature maintained within ±1 .

In this manner the nanometric-scale motion of a single levitated colloidal particle, immersed in an aqueous solution, located near an electrode, and subjected to an alternating electric field was recorded. The particle motion varied with the electric field strength; it was sinusoidal above the particle's average height while flattened and skewed below its average height. Furthermore, the average height itself depended on the frequency, electric field strength, and the electrolyte. The average height exhibited minima in its frequency and voltage dependences in potassium hydroxide, but increased monotonically in sodium bicarbonate. The observed behavior is consistent with electrohydrodynamic theory.

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