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Computational modeling of near surface magnetic microparticle transport for potential biosensing applications

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Precise control of magnetic microparticle motion in microfluidic environments is essential for Lab-on-a-chip biosensing technologies. We present a simulation framework that predicts 3D trajectories of superparamagnetic microparticles moving close to a polymer-covered magnetic bilayer system under dynamically changing magnetic field landscapes [1]. The model combines analytic magnetostatic field descriptions, lattice Boltzmann fluid dynamics and surface-dependent Derjaguin–Landau–Verwey–Overbeek (DLVO) interactions.

A parallel-stripe magnetic domain pattern generates a periodically repeated magnetic stray field landscape. Particle motion is driven by superposing this field with a time-varying external magnetic field, inducing characteristic jump motions between neighboring domain interfaces. In the simulations, particle dynamics result from interacting magnetic gradient forces, electrostatic repulsion, hydrodynamic drag, and minor gravitational and van-der-Waals contributions.

We evaluate the sensitivity of jump height, jump duration, and equilibrium particle–substrate distance with respect to key parameters, including polymer thickness, magnetic particle properties, external field amplitudes and surface potentials. The most influential parameters are those that modify the magnetic gradient force. Electrostatic interactions predominantly affect the equilibrium distance but only weakly influence the jump itself.

Comparison with experimentally recorded 3D trajectories [2] confirms that the model captures the characteristic features of magnetic particle jumps. The simulation framework thus provides a powerful tool for predicting and tuning close-to-surface magnetic particle transport and offers a basis for future analyte-sensitive biosensing concepts relying on changes in surface charges of particles and substrate.

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References

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