DIAMAGNETIC REPULSION - A VERSATILE MEANS FOR THE MANIPULATION OF OBJECTS IN MICROFLUIDIC DEVICES

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ABSTRACT

We demonstrate the selective, label-free manipulation of polymer microparticles, including trapping, focussing and continuous flow deflection, within microfluidic devices using diamagnetic repulsion forces.

KEYWORDS: Diamagnetic repulsion, microparticles, focussing, diamagnetophoresis.

INTRODUCTION

Diamagnetic materials such as polymers, wood and glass are repelled from areas of high magnetic field gradient, a phenonomen known as diamagnetic repulsion. The effect is weak but can be enhanced by suspending the material in a paramagnetic buffer. Previously, we demonstrated the use of superconducting magnets to deflect diamagnetic particles in paramagnetic buffer [1]. However, such magnets are expensive and only available in specialist laboratories. So far, conventional magnets have been used to trap objects, or to facilite the separation of large diamagnetic particles [2, 3]. Here, using small permanent magnets, we explore the versatility of diamagnetic repulsion as a tool for the manipulation of polymer particles (trapping, focussing and deflecting) for three example applications (plug based assays, preconcentration and separation) (fig. 1).

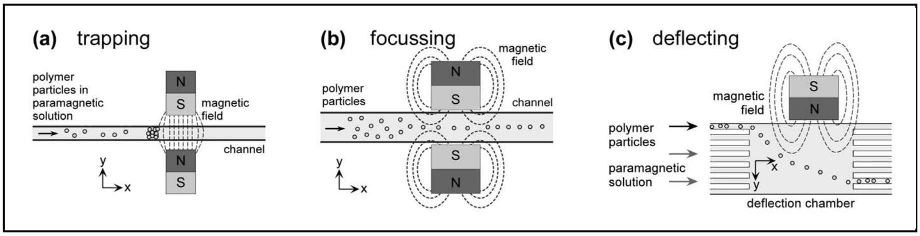

Figure 1: Diamagnetic repulsive forces for (a) trapping (b) focussing and (c) deflecting.

THEORY

The magnetic force ($\mathbf{F_{mag}}$) acting on a particle (eqn. 1) depends on the difference in magnetic susceptibility of the particle (χ_p) and of the medium (χ_m), the volume of the particle (V_p) and the field strength and gradient of the magnetic field ($(\mathbf{B}\cdot\nabla)\mathbf{B}$).

$$\mathbf{F_{mag}} = \frac{(\chi_p - \chi_m)V_p}{\mu_0}(\mathbf{B}\cdot\nabla)\mathbf{B} \qquad \text{Equation (1)}$$

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For a diamagnetic particle ($\chi_p < 0$) suspended in a paramagnetic medium ($\chi_m > 0$) the difference in suspecitibilities is negative and the particle is repelled from a region of high magnetic field towards a field minimum. Thus, diamagnetic repulsive forces can be used to focus, trap or repel diamagnetic particles, as shown in fig. 1.

EXPERIMENTAL

Particle trapping and particle focussing experiments were performed in fused silica capillaries, 100 μm and 150 μm i.d., respectively (Polymicro Technologies, USA). Suspensions of 10 μm diameter polystyrene particles (Polysciences and Micromod, Germany) in paramagnetic $MnCl_2$ solution (10% w/v), were pumped through the capillaries under negative pressure. For deflection experiments, a microchip featuring a 6 mm x 6 mm separation chamber with multiple outlets was used. Mixed particle suspensions of 5 μm and 10 μm particles suspended in $MnCl_2$, were pumped via the particle inlet and a disc magnet placed on top of the chip, to the side of the chamber.

RESULTS AND DISCUSSION

Trapping: a plug of polystyrene particles was formed by placing a pair of magnets across the capillary and pumping through a particle suspension. A second plug of streptavidin coated particles was formed with a second magnet pair upstream from the first. A flow velocity of 250 μm s^{-1} was used to achieve 100% trapping efficiency. After flushing the particle plugs with fluorescently labelled biotin, the biotin selectively bound to the streptavidin-functionalised plug, which fluoresced green in comparison to the control plug (figure 2).

Focussing: by fixing a pair of magnets across a capillary with like poles facing, a magnetic field minimum was created in the centre of the capillary. 10 μm polystyrene particles were pumped through the capillary at a flowrate of 670 μm s^{-1} and were observed to focus into the centre.

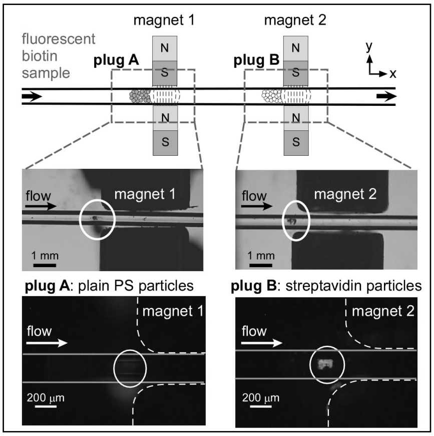

Figure 2: Diamagnetic trapping of particles to form plugs for a particle based assay.

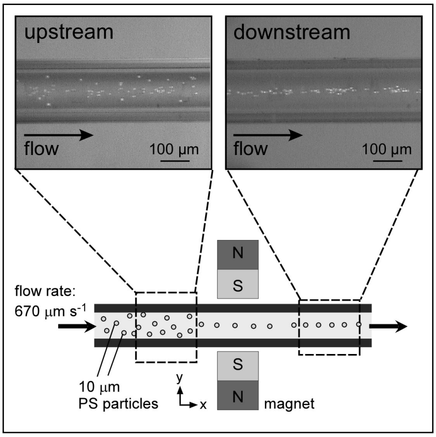

Figure 3: Diamagnetic focussing of particles to within ± 20 μm of the centre line of a 150 μm capillary.

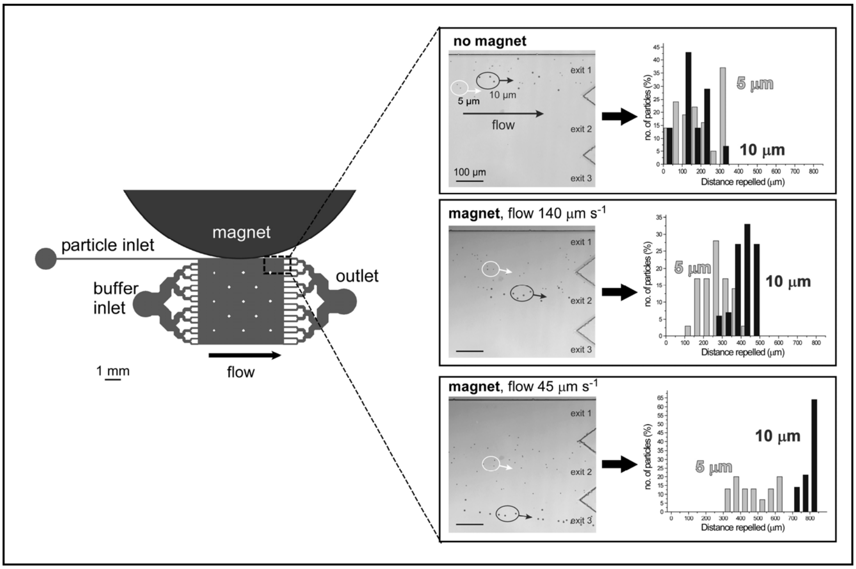

Figure 4: Diamagnetophoresis - continuous flow separation of 5 µm and 10 µm particles based on diamagnetic repulsion forces.

Upstream from the magnets, particles were spread out across the full width of the channel, yet downstream the particles were confined within approximately ± 20 µm of the centre line (figure 3).

Deflection: A suspension of 5 µm and 10 µm polystyrene particles was pumped into the separation chamber at a flow velocity of 140 µm s^{-1}. In the absence of a magnetic field, both particle populations exited the chamber via exit 1. In the presence of the magnetic field, both particle populations were deflected from laminar flow. The 10 µm particles, having the largest volume, were deflected further by the magnetic field. At a flow velocity of 45 µm s^{-1}, the two particle populations were separated from one another by size-selective diamagnetophoresis (figure 4).

CONCLUSIONS

We have demonstrated diamagnetic repulsion forces for the contactless, label-free manipulation of polystyrene particles for a range of particle handling applications. Using a simple magnetic set-up particles can be easily trapped, focussed and separated inside microfluidic devices.

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