Optimization of on-chip magnets for directional control of biomoleculer carrier translocation

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1. Introduction

In magnetic nano-biotechnology for biomolecular translocation, separation and sensing application, manipulation of magnetic bead carriers in the microfluidic channels using electromagnets and soft magnetic structures has been reported in the literature [1-7]. While the designs using electromagnets generally produce small magnetic fields in the microfluidic channels, the designs of passive soft magnetic structures generally provide larger fields and gradients in the channels.

However, it is crucial in the selective hybridization of biomolecules to precisely control the magnetic beads in the forward and backward directions. In the literature [8], there is a new microsystem using lithographically patterned soft magnetic semi-elliptical Ni80Fe20 pathways for the directional control of magnetic beads that can carry certain chemical or biological entities toward a particular sensing site using translational forces on superparamagnetic beads. But there is no report on the driving forces of carriers as functions of on-chip magnet shape and field.

Here, we present an optimization of on-chip magnets for biomoleculer translocation using calculation and simulation, which can assist researchers in designing this kind of soft magnetic structure in microsystem.

2. Experimental Methods

We used Ni80Fe20 soft magnetic thin film with a thickness of 100 nm as the on-chip magnets, and commercially available Dynabed® M-280 superparamagnetic beads with a diameter of 2.8 um and the susceptibility of 0.65 (SI). In the calculation and simulation, the force of the magnetic bead aroud on-chip magnets was calculated and simulated under an applied field of 50 Oe. To simulation we used Maxwell3D software (Version 12.2, Ansoft) for obtaining gradients of magnetic field around on-chip magnets.

3. Results and Discussion

Translocation of magnetic beads is due to functional field and its gradients around on-chip magnet in the channels, as following.

$$\vec{F} = \frac{\chi_{bead} V}{\mu_0} \nabla (\vec{B} \cdot \vec{B}) \quad (1)$$

Here V is the volume of the bead(m^3), χ_{bead} is the magnetic susceptibility of the bead, $\mu_0 = 4\pi \times 10^{-7} (N/A^2)$ is the permeability of vacuum, and $\vec{B}$ is the applied magnetic field (T).

When the on-chip magnet radius of full disk is changed under a applied field of 50 Oe, the radial force and the rotational force on the magnetic beads of different size are calculated as following. The radial force is maximum at the on-chip magnet radius near 3 um when the bead radius is 1.4 um. To the same bead radius, the rotational force is maximum at the on-chip magnet radius near 2 um. Hence, it is best to get the maximum magnetic force when the on-chip magnet radius is twice of the bead radius. When the on-chip magnet radius continue to be increased, the force on the bead is to be reduced slowly. Therefore using the on-chip magnet radius of 5 um, the large force could still be obtained. In the next calculation and simulation, this size of on-chip magnet was used.

To full disk, when the the angle of bead position is ±90° along the direction of the applied field, the magnetic flux density is minimum. Hence, the radius force and the rotational force are minimum values. To half disk, the curving and flat edges produce different magnetic flux density, thereby causing asymmetric forces on the magnetic beads. The rotational force at the curving edge side has a maximum near 25 pN. However the rotational force at the flat edge side has a maximum value near 5 pN. The rotational force at the curving edges is five times larger than the force at the flat edges. Therefore the magnetic beads can be controlled in one directional along the curving edge of the pathway.

4. Conclusion

In summary, we optimized the on-chip magnet size and explained the reason why using half disk the magnetic beads can be controlled in one directional along the curving edge of the pathway. When the on-chip magnet radius is twice of the bead radius, the magnetic force is maximum. The asymmetry in translational forces at the curving and flat edges allowed directional control of the magnetic beads along the curving edge of the pathway.

5. References

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