Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Engineering 25 (2011) 1201 – 1204

Procedia Engineering

www.elsevier.com/locate/procedia

Proc. Eurosensors XXV, September 4-7, 2011, Athens, Greece

A magnetic particle micro-trap for large trapping surfaces

Chinthaka P. Gooneratne[a*], Cai Liang[a], Ioanna Giouroudi[b], Jürgen Kosel[a]

[a]*Division of Physical Sciences and Engineering, King Abdullah Universiy of Science and Technology, Thuwal 23955, Kingdom of Saudi Arabia*

[b]*Institute of Sensor and Actuator Systems, Vienna University of Technoloy, Gusshausstrasse 27-29/366-ISS, Vienna, 1040, Austria*

Abstract

Manipulation of micron-size magnetic particles of the superparamagnetic type contributes significantly in many applications like controlling the antibody/antigen binding process in immunoassays. Specifically, more target biomolecules can be attached/tagged and analyzed since the three dimensional structure of the magnetic particles increases the surface to volume ratio. Additionally, such biomolecular-tagged magnetic particles can be easily manipulated by an external magnetic field due to their superparamagnetic behavior. Therefore, magnetic particle-based immunoassays are extensively applied in micro-flow cytometry. The design of a square-loop micro-trap as a magnetic particle manipulator as well as numerical and experimental analysis is presented. Experimental results showed that the micro-trap could successfully trap and concentrate magnetic particles from a large to a small area with a high spatial range.

Keywords: magnetic particle, micro-trap, magnetic force, cytometry

1. Introduction

Micron-size magnetic particles of the superparamagnetic type behave as magnetic particles only in the presence of an external magnetic field [1]. They can therefore be turned "on" or "off" by simply applying or removing an external magnetic field, which also prevents agglomeration of the particles. Several micro-devices have been developed for manipulating magnetic particles utilizing micro permanent magnets and/or electromagnets [2,3]. However, these micro-devices do not allow their precise manipulation, resulting in low trapping rates. The trapping rate of biomolecular tagged magnetic particles is crucial since it directly influences the accuracy and reliability of disease diagnostics. The micro-trap which is proposed in this research consists of current carrying square micro-loops as shown in Fig. 1. The magnetic particles are attracted to and trapped at the outermost loop at the start of the manipulation process and are

* Corresponding author. Tel.: +966-50-158-2953 ; fax: +966-2-802-0140 .
E-mail address: chinthaka.gooneratne@kaust.edu.sa.

doi:10.1016/j.proeng.2011.12.296

transported towards the innermost loop by applying current sequentially to the loop sets. Furthermore, the unique design of micro-loops sets (red: innermost, blue: middle or gold: outermost in Fig .1) ensures that the magnetic particles which were not attracted before are re-attracted, thus increasing the trapping rate. The number of loops in the micro-device can be customized according to the micro-channel area from which the magnetic particles need to be attracted, trapped and transported without the need to increase the number of switches. The micro-device allows local control of magnetic particles and it ensures that a very high percentage of magnetic particles reaches the smaller target area, hence increasing the trapping rate.

2. Method for Trapping Magnetic Particles

2.1. Magnetic force calculations

The dominant force for the manipulation of magnetic particles is the magnetic force. The force exerted on a superparamagnetic type particle which is constrained in the linear susceptibility regime, can be expressed as [4],

$$F_m = ((v/\mu_0)\times(\chi_m - \chi_s))\times(B\cdot\nabla B) \quad (1)$$

where B is the magnetic field in Tesla, v is the volume of the magnetic particle, μ_0 is the permeability of free space, χ_m is the susceptibility of the magnetic bead and χ_s is the susceptibility of the surrounding medium.

It can be seen from Eq. 1 that both the magnetic field and its gradient are directly proportional to the magnetic force, since while the magnitude of the magnetic field gives rise to a torque the gradient of the field is required to exert a translational force. The surrounding medium of the magnetic particles also play a key role in the magnetic force exerted on the particle. In most applications that involve magnetic particle manipulation the surrounding medium is a liquid such as water, which has a susceptibility much less than the magnetic particles. Hence, χ_s can be neglected and only χ_m can be taken into account.

2.2. Numerical Analysis

Numerical analysis was performed with COMSOL® on a 2-D symmetric square loop model as shown in Fig. 2. The cross-sectional area of the wires was set to 10 μm×0.5 μm. The innermost square loop was 30 μm from the center of the micro-trap while the rest of the loops were 10 μm apart. A current of 100 mA was applied to the cross-section of the loops in a sequential pattern. It can be seen from the contour lines in Fig. 2 that the magnetic field is high in the locality of the loops but reduces drastically moving away from them. It must be noted that even though a superparamagnetic type particle can be controlled by an external magnetic field the magnitude of the field should be considered for successful manipulation. Magnetic particles have small volumes and low susceptibility values so the force exerted by external magnetic fields are often low. Fig. 3 (a) shows that the edges of the loops have magnetic fields in the mT range but drops almost ten-fold a few μm from the edges. The corresponding force calculations shown in Fig. 3 (b) also show that the force drops to nearly 0 a few μm from the loop edges. Hence, in order to trap and move magnetic beads it is necessary to apply current sequentially to the loop sets.

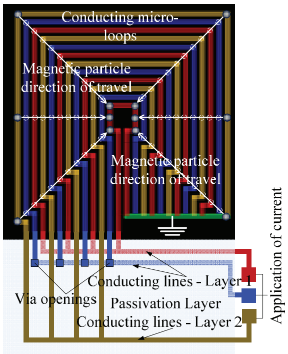

Fig. 1. Proposed micro-trap to manipulate magnetic particles

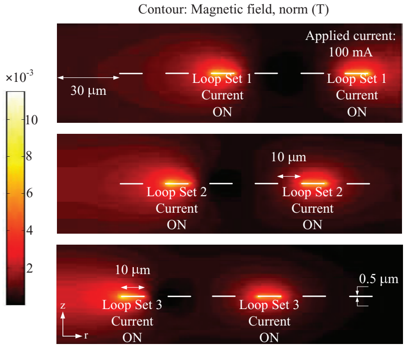

Fig. 2. Numerical analysis

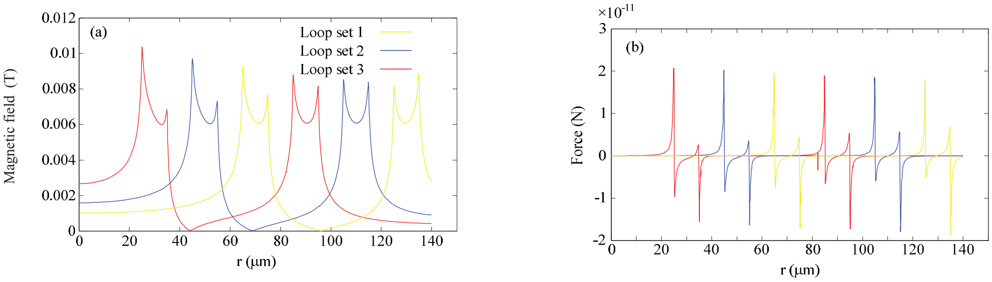

Fig. 3. (a) Magnetic field produced by the square loop sets; (b) Magnetic force exerted on a 2 μm magnetic particle

3. Experimental Results

3.1. Experimental Analysis

The concept of attracting, trapping and transporting magnetic particles with sequential application of current to the loops was proved by experiments which were carried out with a three square-loop micro-trap. Magnetic particles of 2 μm diameter were injected on the surface of the micro-trap and the trapping efficiency was observed for two cycles, where one cycle consisted of applying current to all three loop sets. As shown in Fig. 4 (a) the particles floated around randomly when no current was applied. Current was then initially applied to the outermost loop set and it can be seen from Fig. 4 (b) that the particles were attracted to the square loops in this set. When current was applied to the middle loop set the magnetic particles moved to the square loops contained in this set (Fig. 4 (c)). Finally, when the current was applied to the innermost loop set the magnetic particles moved to the square loops in this set (Fig. 4 (d)). This procedure was repeated (cycle 2) in order to increase the trapping rate (see Fig. 4 (e)-(g). The increase in trapping rate is apparent if we consider the density of magnetic particles trapped at the innermost loop of the micro-trap. At the end of cycle 1 it can be seen how the density of magnetic particles trapped at the innermost square loop increased compared to the situation when the magnetic particles were first injected on the surface of the micro-trap. At the end of the second cycle there is a significant increase in the number of magnetic particles trapped at the innermost loop in comparison to the end of the first cycle. This shows that by continuous switching of current between the loop sets the trapping rate of magnetic particles can be increased. Furthermore, once trapped and concentrated to a target area a magnetic sensor can be integrated to the micro-trap in order to detect the concentration of the

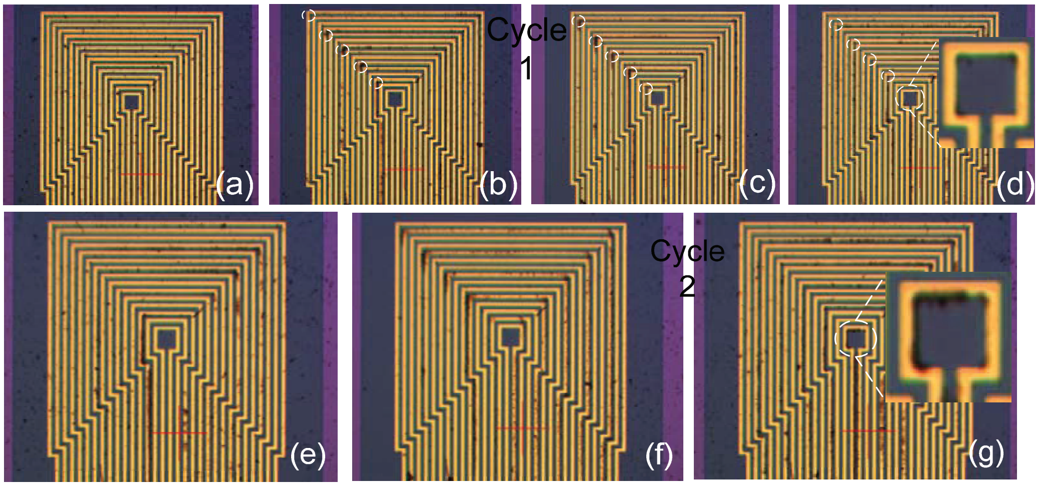

Fig. 4. (a) No current; Current applied to (b),(e) outermost set of loops; (c),(f) middle set of loops; (d),(g) innermost set of loops

magnetic particles. Hence, the proposed micro-device and method of manipulation have the potential to reduce the complexity of an on-chip diagnostic device and increase the sensitivity at the same time.

4. Conclusion

Recent research trends suggest magnetic particles can be used as biomolecular tags to sort, separate and purify cells of interest in immunoassays leading to disease diagnostics. In this research we have shown an effective way to increase the trapping rate of magnetic particles thus leading to more accurate diagnosis of diseases. Numerical analysis was employed to optimize the design and experiments were done to prove the concept. A micro-magnetic sensor can also be integrated to the suggested micro-trap hence enabling the study towards a cost-effective, flexible, low power and portable on-chip disease diagnostic device.

Acknowledgements

The authors would like to thank Mr. Basil Chew, Dr. Ren Jian, Mr. Xiang Yu and the cleanroom staff for their help in micro-fabrication. The authors would also like to thank Mr. Guodong Li for his help with electronic circuitry.

References

[1] N. Pamme. Magnetism and Microfuidics. *Lab Chip* 2006; **6**:24-38.

[2] N.T. Nguyen, K.M. Ng, and X. Huang. Manipulation of Ferro Fluid Droplets Using Planar Coils. *Appl Phys Lett* 2006; **89**:052509.

[3] R. Rong, J.W. Choi, and C.H. Ahn. An on-chip magnetic bead separator for biocell sorting. *J Micromech Microeng* 2006;**16**: 2783-2790.

[4] C. Liu, T. Stakenborg, S. Peeters, and L. Lagae. Cell manipulation with magnetic particles toward microfluidic cytometry. *J Appl Phy* 2009;**105**:102014.