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Current Perspectives

Particles Sorting in Micro Channel Using Designed Micro Electromagnets of Magnetic Field Gradient

Yung-Chiang Chung, Chen-Ming Wu, Shih-Hao Lin

Department of Mechanical Engineering, Ming Chi University of Technology, New Taipei, Taiwan, R.O.C

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A B S T R A C T

In this study, microelectromagnet, microchannel, syringe pump, and controlling devices were integrated to form a particle sorting system. A simple, two-dimensional, relatively quick fabricating and easily operating microelectromagnet was designed. Polystyrene particles and magnetic beads were pumped into the microchannel with the syringe pump, and it was observed that the magnetic beads were attracted to one of two outlets by the microelectromagnet, which features a gradually changing magnetic field. The polystyrene particles would move to another outlet because of different-width micro channel, and it completed the separation of the particles. Based on experimental results, the magnetic flux density of the microelectromagnet was 2.3 Gauss for a 12.5-μm average distance between electrodes at 1.0-μm increments, and the magnetic force was 0.22 pN for 2.8-μm magnetic beads. The separating rate was greater for larger distance increment and smaller average distance between the electrodes. The separating rate of the magnetic beads increased as the electric current increased and flow velocity decreased. When the flow velocity was 0.333 μm/s and electric current was 1 A, the separating rate was 90%. The separating rate of the polystyrene particles increased as the flow velocity increased and was 85% when the flow velocity was 0.6 μm/s. These results demonstrate that this particle sorting system has potential applications in bio-molecular studies.

1. Introduction

Recently, microelectromechanical systems (MEMS) have been applied to the biomedical field, and biochip research is developing quickly. A cell chip has been suggested for quickly separating and purifying particular cells in a mixed-cell solution, and cell sorting has become a very important biomedical technology. There are some reported disadvantages and inconveniences associated with some particle manipulation technologies such as dielectrophoresis and ultrasound [1–3]. Optical tweezers can be used to manipulate and sort particles, but this technique is less efficient because of the need to adjust the size and shape of particles by artificial vision [4–7]. In previous studies, magnetic tweezers have been used to transport and manipulate magnetic beads using a planar conducting microstructure, but these studies have used only one type of bead [8–11]. The sorting method that manipulates nonmagnetic and magnetic materials with an electromagnet has the advantages of being simple, inexpensive, noninvasive, and easy to manipulate, all of which are important requirements in physical and biological research.

Based on the development of MEMS, some electromagnet designs and magnetic bead manipulation technologies have been developed. Three-layer structures involving electroplating copper with SU-8 photoresist for a high aspect ratio and combined with electroplating nickel have been suggested for fabricating electromagnets, but these fabricating processes were complicated [12,13]. In another study, the semi-encapsulated spiral electromagnet and microfluidic channel were integrated to form a magnetic bead separator [14]. Two electromagnets have also been used to separate magnetic beads by switching the electromagnets at different times, and the separating rate can reach 75% [15]. Electromagnets of three designs, i.e., straight conductors, mesh-shaped electromagnets, and rosette-shaped electromagnets, have been used to decrease the number of masks in fabrication, which is a relatively simple process [16]. Alternatively, an on-chip electromagnet and top and bottom channel layers in the vertical direction were used to transfer magnetic beads from the bottom inlet to top outlet in a binding experiment involving magnetic beads and Jurkat cells [17–19]. An array of individually addressable microelectromagnetic actuators has also been suggested, and an optimal working range of coils has been defined. However, it was necessary to perform a spatial manipulation of magnetic beads by sequentially actuating a set of microcoils, thus complicating the performance process [20]. Finally, a spiral-coil electromagnet and electroplating nickel were used to trap magnetic particles, but the separation was not complete during the experiment [21].

The general design of electromagnets has typically been complicated, time consuming, and three dimensional. In this study, we

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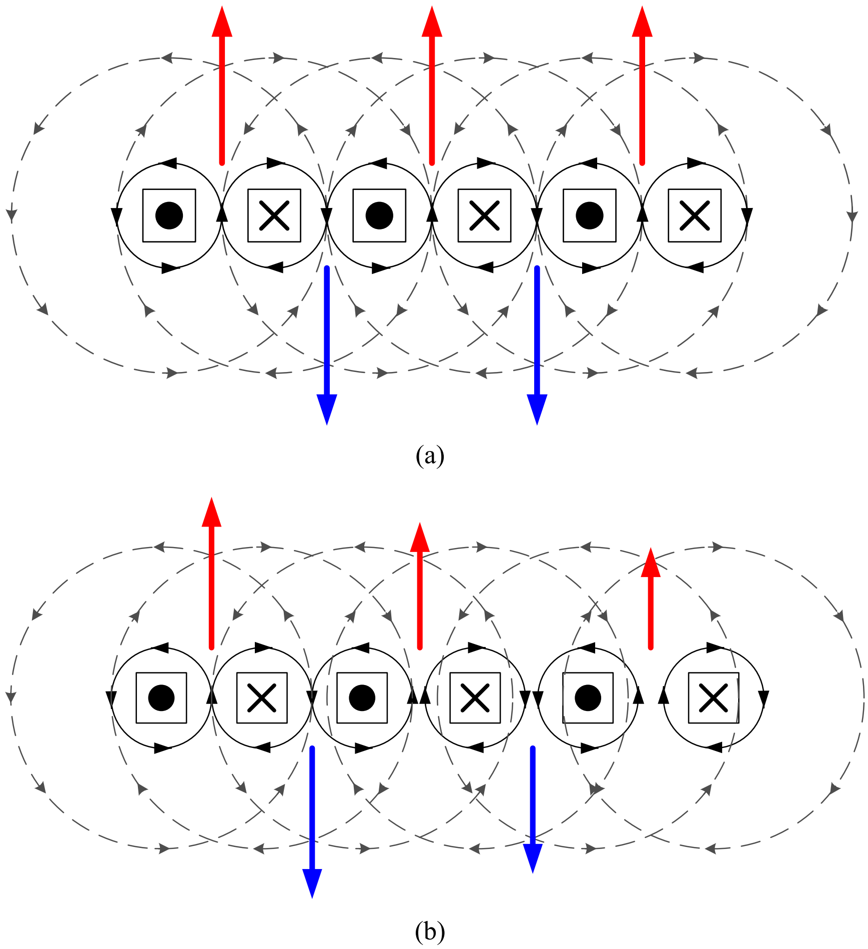

Fig. 1. Schematic drawings of (a) uniform magnetic field, and (b) gradually changed magnetic field.

adopted a simple, quick, and two-dimensional electromagnet using MEMS, which sorts particles efficiently. Here, we present a chip-based observation and measurement system that uses microelectromagnets and a flow channel design, and we obtain separating rates for two types of particles at various velocities and electric currents.

2. Method and fabrication

2.1. Principle of operation

The electric current in microconducting wires produces a magnetic field, and generates a uniform magnetic field when there is an equal distance between the wires. As shown in Fig. 1(a), ● and ✖ represent the current directions, and the magnetic field is uniform because of the equal distance between the wires. In Fig. 1(b), a magnetic field gradient is generated due to the unequal distance between the wires. Here we propose using a microelectromagnet with a magnetic field gradient and flow channels of different widths to automatically separate magnetic beads and polystyrene particles. As shown in Fig. 2(a), a mixture of magnetic beads and polystyrene particles is pumped into the channel, and they flow along with the fluid and pass through the electromagnetic area. Because magnetic beads tend to be attracted to the area with the maximum magnetic field, when they pass through the electromagnetic area, they are attracted to outlet 2 by the generated magnetic field gradient, as shown in Fig. 2(b). Because the area of outlet 1 is larger than that of outlet 2, the flow resistance of outlet 1 is lower than that of outlet 2, so the polystyrene particles tend to move toward outlet 1, thereby separating the magnetic beads and the polystyrene particles by the electromagnet and flow channel design, as shown in Fig. 2(c).

2.2. Chip design and fabrication

The microelectromagnet was designed, as shown in Fig. 3 (a) and (b), with a wire width of 10 μm, an average distance between the wires of 12.5 μm, and distance increments between the wires of 0.5 μm and 1.0 μm, respectively. The area of the main current wires in the two designs is about 500 × 500 μm. Fig. 3 (c) and (d) show the designs with different average distances between the wires. The width of the wires is still 10 μm, but the average distance between the wires is 15 μm, and the distance increments between the wires are 0.5 μm and 1.0 μm, respectively. The width of the main flow channel is 500 μm, as shown in Fig. 3 (e), and the widths of outlets 1 and 2 are 400 μm and 200 μm, respectively.

The fabrication process is illustrated in Fig. 4(a). We used a 4-inch glass wafer as the substrate. After the substrate was cleaned, the 20-nm titanium and 200-nm copper were evaporated, and the positive photoresist AZ-9260 was spin-coated onto the substrate with a spin-coater (PM490, SWIENCO, Taiwan) at 1800 rpm for 30 s. It was then baked at 100 °C for 180 seconds to drive the solvent from the photoresist. A pattern was obtained by exposure and development, and next it was electroplated with copper for 440 seconds to generate a 5-μm copper layer and to erase the photoresist. The unwanted titanium and copper layers