INKJET PRINTING OF MAGNETIC / NON-MAGNETIC POLYMER MICROFLUIDIC ACTUATORS

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ABSTRACT

Magnetic actuation is an interesting manipulation method for lab-on-a-chip. The fabrication of magnetic microfluidic actuators is usually done by photolithographic processes which are not always compatible with the required polymer system and which form a rather expensive technology. Therefore, we explore the possibility to use inkjet printing to fabricate microfluidic actuators. Inkjet printing can compete with lithography, since it is simple, flexible and cost effective. Our results show that the successfully inkjet printed magnetic microfluidic actuators do respond to an external magnetic field. In particular, the actuator rotates conform to an applied magnetic field.

KEYWORDS: magnetic actuation, microfluidic actuator, inkjet printing

INTRODUCTION

In lab-on-a-chip devices, magnetic actuation is of interest, because a magnetic field can be easily generated, can be used remotely and does not interact with bio-fluids [1]. Usually, the magnetic micro-actuators are fabricated by conventional photolithographic processing [2]. The disadvantage of this approach is that many processing steps including masking, exposure and etching, etc. are required and this makes the process expensive, especially for application in disposable micro-fluidic devices.

Here we propose an alternative approach in which microfluidic actuators are fabricated by inkjet printing. This is a well-developed technology, and compared with the conventional lithographic approach, it reduces the processing steps and material consumption by directly depositing the materials on the substrate to fabricate the actuators. Moreover, it allows the structuring of material combinations that are otherwise difficult to fabricate [3].

EXPERIMENTAL

Glass slides (28x28mm) were used as substrates for all the experiments. The substrates were cleaned for 5min in acetone in an ultrasonic bath and dried before using.

The monomer mixture used to structure the polymer actuator was prepared by mixing 2-Ethylhexylacrylate (2EHA) (Aldrich), crosslinking agent 1,6-hexanediol diacrylate (HDDA) (Alfa Aesar), photo initiator Irgacure 2959 with the weight ratio of 51.1% 2EHA, 7.7% HDDA and 0.5% Irgacure 2959. Additionally, 40.7wt% of Poly (ethylene glycol) diacrylate (PEGDA) (Aldrich) was added to increase the viscosity of the monomer mixture. The compound was heated to 75˚C to ensure that Irgacure 2959 dissolved completely. When the solution became clear, it was cooled down to room temperature. An orange dye, 4-(Dicyanomethylene)-2-methyl-6-(4-dimethylaminostyryl)-4H-pyran was dissolved in the solution to increase the visibility of the printed pattern. Based on the total weight of monomer mixture, 20wt% toluene based ferrofluid (Liquid Research) which consists of 10nm diameter magnetite particles (Liquid Research) was added to achieve the magnetic functionality .

Inkjet printing of an uncured mixture of monomer and magnetic particles was carried out with a commercially available Fuji Dimatix inkjet printer (DMP 2800). It is equipped with a piezoelectric cartridge (DMC-11601) that nominally dispenses droplets with a volume of 1 pL. Both the magnetite containing monomer mixture and the non-magnetic monomer solution were filtered through a 2.5um filter before use. During printing only one nozzle was used. The nozzle was heated to 45˚C and the substrate was kept at room temperature. Drop spacing, that is the center to center distance between two adjacent droplets, should be chosen such that it is smaller than or equal to the droplet diameter to obtain a continuous structure, in this case 30µm. In order to obtain the optimal printing result, the printer's writing sequence should be along with the actuator's long direction.

The polymerization of the actuator was carried out in a nitrogen environment by illumination with UV light (EXFO Omnicure S2000 lamp) at the intensity of 30mW/cm^2 for 20sec when using the ink without magnetic particles. The illumination time was 2min for the magnetic ink which has longer curing time because the magnetic particles absorb UV light.

RESULTS AND DISCUSSION

Figure 1 shows the typical results of the dispersion of the magnetic particles in the monomer compound after polymerization. It shows that magnetic particles are dispersed relatively evenly in the monomer compound, although some clusters still observed. All the optical investigations were performed using a Leica 600 microscope.

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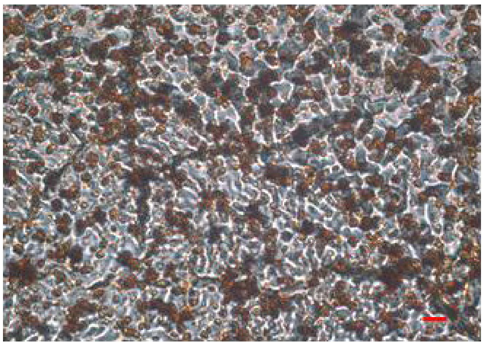

Figure 1: Optical microscopy image of magnetic particles dispersed in the polymer. The scale bar indicates 5µm

Figure 2 shows a printed magnetic actuator after UV curing which is close to what we designed and was indicated by the red dashed contour.

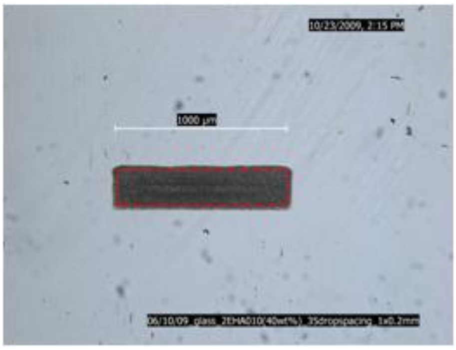

Figure 2: Optical microscopy image of the printing result. The original design is a 1mmx0.2mm rectangle, represented as the dashed contour.

As for the composite magnetic/non-magnetic polymer actuator, a two-step printing routine was performed. First, the monomer and magnetic particle mixture was printed; in a second round the non-magnetic monomer was printed which started without UV curing of magnetic structures. The non-magnetic monomer ink was printed last because it de-wets without curing in a short time. A camera integrated in the printer was used to achieve the correct alignment. The UV polymerization was performed immediately after both parts were printed and an example of the resulting structure is shown in figure 3.

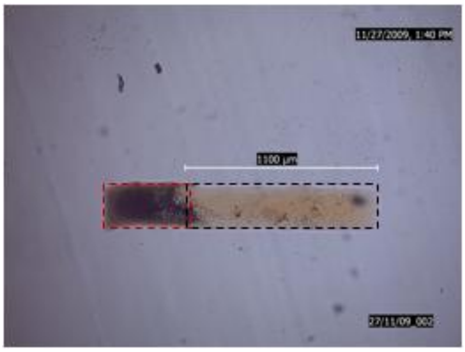

Figure 3: Optical microscopy image of a composite magnetic/non-magnetic polymer actuator. The darker magnetic part is 0.2x0.6mm, the non-magnetic part is 0.2x1.1mm, and the two parts have an overlap of 0.1mm at the joint.

After curing, the printed actuator was released from the substrate by water and immersed in water in an open micro-fluidic camber. The chamber was placed in the center of a rotating magnetic field where the magnetic field is homogenous. Figure 4 shows the magnetic quadrupole set-up used for creating a rotating magnetic field. Working distance is 13.2mm when using 5x lenses. Each coil is addressed with a sinusoidal current that has a phase lag of 90° with respect to the adjacent coil. This creates a rotating magnetic field in the space between the coils.

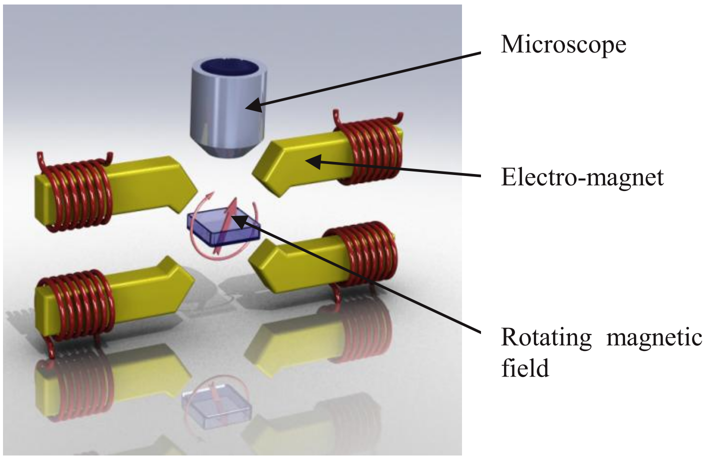

Figure 4: Sketch of the quadrupole; the red arrow indicates the rotation direction of the magnetic field

With a high speed camera(MotionPro_HS-3, Redlake) mounted on a microscope positioned above the magnetic set-up as shown in figure 4, the response of the magnetic actuator to the applied magnetic field (40mT, 1Hz) was recorded. Results are given in figure 5. Clearly, the flap-like micro-actuator rotates along with the magnetic field and could be transported in a magnetic field gradient. In future experiments, we will use the actuators to create micro-mixing and controlled transportation through micro-fluidic devices. In particular, simulations show that the micro-actuators could act as autonomous swimmers [4] and we will investigate this experimentally.

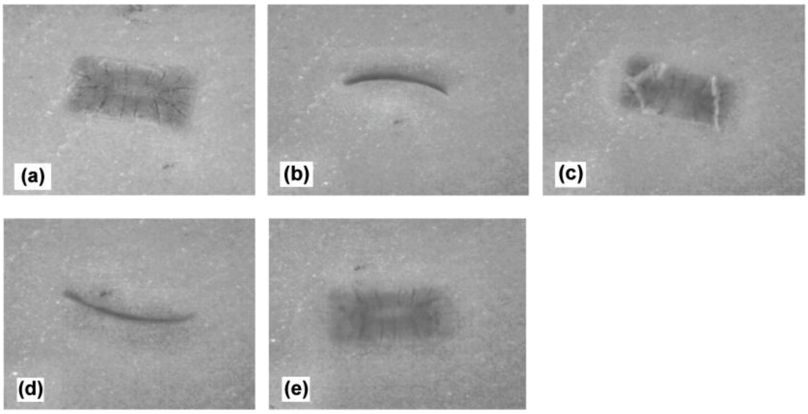

Figure5: Magnetic actuator rotates along with the magnetic field. Without magnetic field (a) ; snapshots at different angles of field rotation (b) 90˚, (c)180˚, (d) 270˚, (e) 360˚

CONCLUSION

In this work we present a novel method to fabricate magnetic microfluidic actuators via inkjet printing. We demonstrate that, after releasing from the substrate, the actuators can be manipulated by applying an external magnetic field. Furthermore, we show that hybrid magnetic / non-magnetic composite structures can be made by inkjet printing. The micro-actuators could be used for mixing, capturing and transporting target molecules, and other micro-fluidic functions.

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