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# Design and fabrication of a magnetic fluid micropump for applications in direct methanol fuel cells

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ABSTRACT

Direct methanol fuel cells (DMFCs) are widely considered to have great potential for portable electric applications, and the power requirements for many of them are only a few watts. Therefore, a low power liquid pump is especially desirable for driving the methanol solution fuel for an active direct methanol fuel. The main objective of this paper is to design and fabricate a magnetic fluid micropump that has characteristics of low operation voltage and current and is suitable for use in DMFCs. Two prototypes were developed and tested. The magnetic fluid micropumps are successfully applied to drive the fuel to a DMFC, and measurements of the cell performance are also conducted.

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## 1. Introduction

The direct methanol fuel cell (DMFC) uses a methanol solution as fuel. Methanol is a readily available and low-cost fuel source, which has higher volumetric energy density than hydrogen. In addition, the DMFC has the main advantages of near-room-temperature operating conditions, safety, low cost of fuel, quick and convenient refueling, silence, ease of storage and carrying, and conversion of methanol directly into electricity without a bulky reformer. Thus, the DMFC is particularly suited for compact design. One of the most promising short term uses would be in portable applications that only need small amounts of power but high energy density, such as in third-generation (3G) cell phones, high specification person digital assistants (PDAs), and digital movie cameras. DMFC systems are attractive candidates to replace Li-ion batteries due to recent advances in the minimization of DMFC stacks [1,2].

The applications for small portable 3G products such as PDAs, cell phones, and MP3 or MP4 players are suitable for DMFCs because the power required for those products is in the range of a few watts and the power output of DMFCs is also low. For low-power DMFCs, there are two considerations for the liquid fuel feed: passive (pump-less) or active (with pump). The main characteristic of a passive DMFC system is that no pumping and no external power sources are needed. Therefore, many studies have been published on passive DMFCs in recent years, which have been investigated from different aspects, such as optimal fuel concentration, membrane thickness, fabrication of the membrane electrode assembly (MEA), flow field and current collectors, fuel delivery through porous media, and vapor feed via heat recovery from DMFCs [3–7]. Active fuel feed is the primary design for DMFC applications because the fuel circulation system is easier to control. In an active DMFC, a liquid pump such as a squirrel pump, HPLC micropump, or other type of pump must be adopted [8–11]. However, the power consumption of the pumps is up to a few watts and is difficult to integrate into small portable DMFCs, which generate only a few watts of power. Therefore, a low power micropump for DMFC applications would be attractive. Zhang and Wang [12] presented a valveless piezoelectric micropump in a miniaturized DMFC. Even though the total power consumption of the micropump was low, around 70 mW, the required operation voltage of 100 V was still very high for portable DMFCs that operate in the low power (few watts) range. Kim et al. [13] developed a continuous peristaltic magnetic fluid (MF) micropump, which was fabricated using MEMS technology. In their experiments, the input current of their micropump was around 100–600 mA. The maximum flow rate of their microp-

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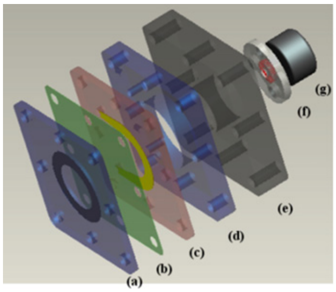


**Fig. 1.** Exploded view of the 1st MF micropump.

ump was 2.8 μl min$^{-1}$ at 4 rpm and 3.8 μl min$^{-1}$ at 8 rpm, which is quite low for DMFC applications. Shen et al. [14] presented a high-efficiency and self-priming active-valve micropump consisting of a microfluidic chamber structure in glass, which was assembled with a PDMS elastic sheet. This micropump used arc-shaped permanent magnets mounted on the rotational axis of the DC minimotor in a six-phase configuration, which allowed low voltage (0.7 V) and low power (a few tens of milliwatts) operation of the micropump. The flow rate was 2.4 mL min$^{-1}$ at a resonance frequency of around 12 Hz. Hsu et al. [15] demonstrated the fabrication of a peristaltic diffusion-type micropump on polymethylmethacrylate (PMMA) substrates. The maximum flow rate of their micropump was 114.8 μl min$^{-1}$ at a driving frequency of 400 Hz and driving voltage of 100 V. The driving voltage is also quite high for DMFC usage in low power portable applications.

This study will develop a MF micropump, which modifies the characteristics of the micropumps described above and is more suitable for low-power-range DMFCs applications. The proposed micropump has the main advantages of low operation voltage and current, easy fabrication, low cost, and high rigidity, which can potentially allow for mass production of DMFC applications. In this research, two prototype micropumps were designed and fabricated. The prototype micropumps were also applied to feeding methanol fuel to a single cell DMFC test fixture, and the cell performance was measured and compared with the fuel fed by a conventional squirm pump.

## 2. Design and fabrication of the MF micropumps

### 2.1. 1st MF micropump

The 1st MF micropump was a prototype for the feasibility study. The exploded view of the first MF micropump is shown in Fig. 1. The poly(methyl methacrylate) (PMMA) base contained 5 cc of magnetic fluid inside a ringed groove. A (PDMS) thin film covered the PMMA substrate. Above the thin film, there was a PMMA plate with a grooved flow channel for transporting the liquid. A PMMA plate with two drilled holes was attached to the flow channel substrate for liquid inlet and outlet to the flow channel substrate. At the top, a low-power DC motor was adopted, and the end of the motor spindle was fixed to a rotary plate, which had neodymium magnets. The DC motor was attached to a motor fixed plate. All components were then screwed together. A complete picture of the first MF micropump is shown in Fig. 2. The main fabrication process of the 1st MF micropump is briefly described as follows. First, the shapes, holes, or grooves of the PMMA related components were milled or drilled using a CNC milling machine. The PDMS thin film was made by adding 10 g of PDMS colloidal solution to the center of a rotating circular glass plate in a spin coater and baking the plate in a vacuum dry oven for 1 h at 75 °C. After the PDMS thin film was fabricated, it was taken out of the vacuum dry oven and cut into several pieces with a predesigned shape. Then, some

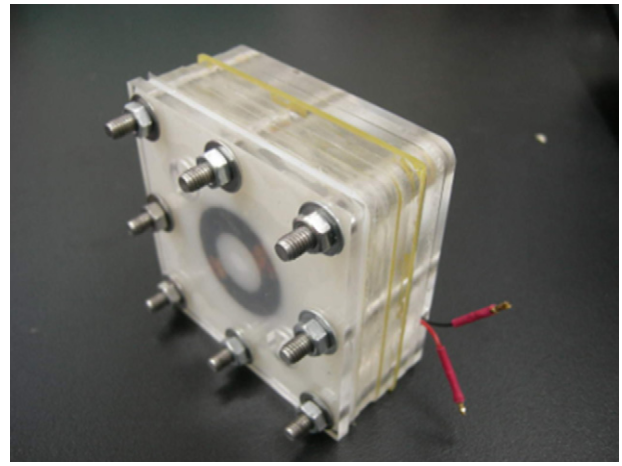

**Fig. 2.** Picture of the 1st MF micropump.

PDMS colloidal solution was used to coat the surface of the circular groove side of the base with a magnetic fluid and surface of the flow channel side of the flow channel substrate. After injecting 5 cc of magnetic fluid into the circular groove of the base, the PDMS thin film, base with magnetic fluid, and flow channel substrate were bonded at 75 °C and baked for 1 h inside a vacuum dry oven. The last step was to assemble and screw all of the components together.

### 2.2. 2nd MF micropump

After confirming the feasibility of the 1st MF micropump, the 2nd micropump was designed and developed to reduce the size of the pump. In addition, the structure of the 2nd MF micropump eliminated the screws from the first design. The exploded view of the 2nd MF micropump is shown in Fig. 3. A polypropylene (PP) base contained 2 cc of magnetic fluid inside a circular groove. A PDMS thin film covered the PMMA substrate. Above the thin film, there was a PMMA substrate with a grooved flow channel for transporting liquid, and it also contained the flow inlet and outlet. At the top, a DC motor was attached to a motor fixed base, and the end of the motor shaft was fixed to a rotary plate, which included neodymium magnets. All components were then bonded together. The complete picture of the 2nd MF micropump is shown in Fig. 4. The main fabrication process of the 2nd MF micropump is briefly described as follows. First, the shapes, holes, or grooves of the PMMA and PP components were milled or drilled using a CNC milling machine. The PDMS thin film was made by adding 10 g of PDMS colloidal solution to the center of a rotating circular glass plate on a spin coater and then baking the plate in a vacuum dry oven for 1 h at

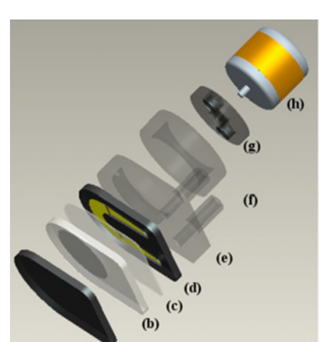


**Fig. 3.** Exploded view of the 2nd MF micropump.

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