AN ELECTROLYTIC MICROPUMP FABRICATED ON PRINTED CIRCUIT BOARD FOR INTEGRATED MICROFLUIDIC SYSTEM

Hakhyun Kim[1†], Heewon Hwang[1†], Jongwon Kim[2], and Dohyun Kim[1*]

[1]Myongji University, SOUTH KOREA, and

[2]Lab Genomics Inc., SOUTH KOREA

[†]Both authors contributed equally to this work

ABSTRACT

We report an electrolytic micropump fabricated on printed circuit board (PCB). Gas bubbles produced by electrolysis on gold IDT (interdigitated) electrodes generate the maximum flow rate of 22.8 ml/min, substantially high compared to the previous work. As predicted by the electrolysis theory, the flow rate shows a linear relationship with current at a wide range (1~1500 mA). Performance metrics of two PCB-based micropumps are compared with that of a conventional, micromachined pump; the PCB micropump with electroplated IDT electrode shows the best performance in terms of pumping efficiency, lifetime, cost, and dimensional accuracy.

KEYWORDS: Micropump, Electrolysis, Electrochemical actuator, Printed circuit board, Micromachining

INTRODUCTION

A self-contained microscale pump has been an active research field owing to its applications in micro total analysis systems (μTAS) [1]. A micropump, based on water electrolysis, has drawn much attention since 1980s because of large volume expansion, excellent back pressure, high efficiency, and low power consumption [2]. Moreover, as relying on electrodes and electrolyte with no moving parts, simple construction and straightforward fabrication render the electrolytic pump well-suited for a pressure source in μTAS. Electrolytic pumps have been traditionally fabricated using micromachining, which is costly and is not always accessible. On the other end of the spectrum, simple metal-wire electrodes were employed but resulted in reduced manufacturing precision and performance reproducibility.

To overcome these limitations, we opt for the PCB technology for micropump manufacturing. The PCB is an attractive platform for integrated microfluidics because it has a suitable precision and various components can be readily assembled on the circuit board [3]. Besides, PCB manufacturing can be outsourced through a standardized foundry service at a low price. In order to examine the potential of the PCB-based electrolytic micropump, we tested it and compared its performance metrics with those of a micromachined pump.

THEORY

In aqueous solution, a reduction takes place at a cathode giving four electrons to four hydrogen ions to form two hydrogen gas molecules. At an anode, an oxidation occurs receiving four electrons from two water molecules to generate one oxygen gas molecule. The produced gases contribute to a volume expansion of ×1350 greater than the consumed liquid volume. This large volume change can be used as an excellent pressure source [2].

EXPERIMENTAL

An interdigitated (IDT) electrode chip was mounted into an custom-made acrylic jig capable of replacing chips when needed (Figure 1a). 1 M sodium sulfate solution was injected into the electrolyte chamber using a syringe pump. A source meter was used to apply a constant current (1~1500 mA) to the IDT electrodes for electrolysis and to accurately measure power consumption. When current applied, gas bubbles were generated in the chamber, which induced liquid flow in the flow-rate measurement channel (1.5 mm×2.5 mm×20 mm). The flow was recorded with a ruler imprinted nearby the channel using a video camera. Flow rate was measured by motion-image analysis of moving electrolyte front end. Three types of electrode chips were fabricated and tested: (1) A glass-slide chip with wet-etched gold electrodes (100 nm thick) microfabricated in a clean room at Myongji University (Figure 1b), and (2) A PCB chip with electroless gold (37.5 nm, measured) electrodes and (3) A PCB chip with electroplated gold (300 nm, in the manufacturer's specification) electrodes, both fabricated using a PCB manufacturing service (Figure 1c). The feed lines of the PCB chips were protected by a solder mask.

RESULTS AND DISCUSSION

The three types of chips were compared for the pump performance at 1~10 mA. Figure 2a shows linear relationship between current and flow rate as the electrolysis theory predicts [3]. The best performing chip, the PCB with electroplated gold, yielded a linear relationship ($R^2=0.99$) between current and flow rate at a wide range of 1~1500 mA (Figure 2b). Probably owing to the pronounced edge effect, the PCB chip generated the maximum flow rate of 22.8 mL/min (1500 mA), which was significantly large compared with the previously reported data [1]. The PCB chip also had the longest lifetime because of a thick gold electrode. The micromachined chip showed the shortest lifetime probably owing to an easily damaged, thin titanium adhesion layer (20 nm). The PCB manufacturing was reasonably precise, compared with our microfabrication result. The manufacturing cost of the PCB chips were also significantly lower. The tabulated performance metrics in Figure 2c indicate that the PCB chip with electroplated gold electrodes delivers the overall best performance.

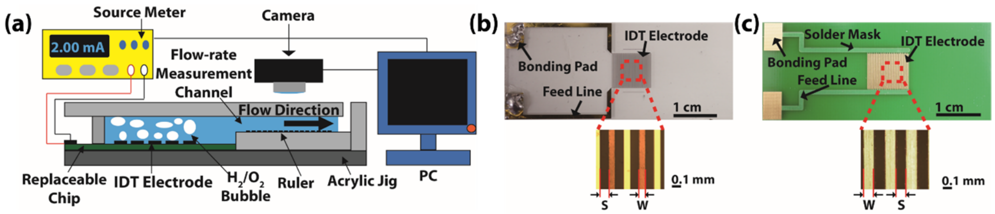
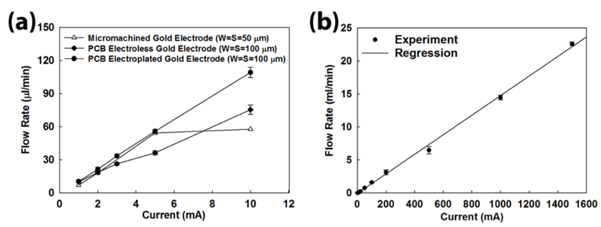


Figure 1: Experimental setup and IDT chips. (a) A schematic diagram of the experimental setup. (b) Micromachined chip (2.5 cm×7.5 cm) with IDT-electrode dimension of width (W)= 50 μm, spacing (S)=50 μm and area (A)=27.85 mm^2. (c) A PCB chip (2.5 cm× 7.5 cm) with IDT-electrode (electroless or electroplated) dimension of W=S=100 μm and A=35.88 mm^2



(c)

	Pumping Efficiency (μl/C)	Lifetime (min)	Machining Error (μm)	Cost ($)
Micromachined	114	10.3	±8.08	276
PCB (Electroless)	130.7	11.3	±1.86	10
PCB (Electroplated)	251.2	30.6	±4.83	19

Figure 2: (a) Flow rates of the micropumps with the three types of chips at 1~10 mA. (b) The best performing chip, the PCB with electroplated gold, shows high flow rates of 0.01-22.8 ml/min at 1-1500 mA. (c) The performance metrics ("Pumping Efficiency" indicates volume expansion per consumed charge. "Lifetime" measures how long an IDT electrode survives electrolysis before significant degradation. "Machining error" is measured using microscope images of the IDT electrodes. "Cost" is an estimate of fabrication cost, in-house microfabrication or PCB manufacturing services.)

CONCLUSION

The PCB-based electrolytic pump with the electroplated gold electrode showed the best pumping efficiency, lifetime, cost and reasonable dimensional accuracy. Our micropump can be a viable pressure source for integrated microfluidic systems due to simple design, small power consumption, and low-cost outsourceable manufacturing.

ACKNOWLEDGEMENTS

This material is based upon work supported by the Ministry of Trade, Industry & Energy (MOTIE, Korea) under Industrial Technology Innovation Program. No.10052106, 'Development of CMOS/MEMS hybrid biosensor array platform'.

REFERENCES

[1] D.J. Laser, and J.G. Santiago, "A Review of Micropump," *J. Micromech. Microeng.*, 14, R35-62, 2004.
[2] C.G. Cameron, and M.S. Freund, "Electrolytic Actuators: Alternative, High-performance, Material-based Devices," *Proc. Natl. Acad. Sci. U.S.A*, 99, 7827-7831, 2002.
[3] S. Richter et al, "Microfluidic Devices on Printed Circuit Board," Microfluidic and BioMEMS applications 2002, Springer International Publishing AG, US, 185-217, 2002.

CONTACT

*Dohyun Kim, phone: +82-31-324-1425; dohyun.kim@mju.ac.kr