ECF micropump fabricated by electroforming with novel self-aligned micro-molding technology

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Abstract. This paper proposes and presents a novel ECF (electro-conjugate fluid) micropump with TPSEs (triangular prism and slit electrode pair) fabricated by electroforming process using newly developed self-aligned micro molds. ECF is a kind of functional and dielectric fluid. ECF micropump is based on the principle of ECF jet, which is a powerful and active jet flow generated between electrodes immerged in ECF, when high DC voltage is applied to the electrodes. Our previous research experimentally demontrated that the ECF micropump had high power density thanks to the 2D-integraton (serialized integration and paralleled integration) of our proposed MEMS fabrication method by using micro-molding and electroplating. Moreover, it was also proved that higher aspect ratio of TPSEs by the multilayer fabrication process resulted in higher flow rate of the ECF micropump. However, the multi-layer fabrication has demerit to require precise alignment that is time-consuming and extremely difficult to be met. In order to improve alignment accuracy and alleviate fabrication difficulty, this paper proposes a novel self-aligned MEMS fabrication process for high aspect ratio TPSEs. The ECF micropump by this newly-proposed MEMS process was successfully fabricated and the feasibility was proved by experimentally investigating output performance of the ECF micropump.

1. Introduction

Micropumps as critical power sources play a significant role in increasing numbers of microfluidic fields such as micro liquid-forced cooling devices, micro total analysis systems (μTAS) and micro dosing systems [1]. Among them, microfluidic actuators, especially those with higher output power on the further microscale, recently have come to the fore and attracted considerable attention worldwide, which are undoubtedly in greatly need of micropumps having high power density. For example, Yoshida et al proposed a 3-DOF microactuator with built-in fluid inertia (FI) micropump and electro-rheological (ER) microvalves for in-pipe working micromachines of about 10 mm in diameter. This FI micropump with a volume of 2.3 cm^3 generated output fluid power up to 0.22 W for water pumping. That is to say, it had the output power density of 95.7 mW/cm^3 [2]. As mentioned in that paper, the volumetric power density is recognized as one of crucial performance index for micropumps, in micro

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hydraulics. Although a huge number of micropumps with various driving mechanisms have been developed as power sources for micro hydraulics, there are few micropumps to reach high power density with over a few hundred mW/cm^3 [3]

In order to achieve the aforementioned goal, we pay attention to electro-conjugate fluid (ECF) as a promising candidate for the driving mechanism. ECF is a kind of functional and dielectric fluid. An ECF micropump is based on the principle of ECF jet (figure 1), which is a powerful and active jet flow generated between electrodes immerged in ECF, when high DC voltage is applied to the electrodes. This phenomenon is defined as ECF effect [4]. Compared with other kinds of micropumps, the ECF micropump has the following advantages: (a) direct pumping mechanism (The energy is converted directly from electric energy into kinetic energy of the fluid by ECF effect.); (b) simple structure (Except for ECF and some electrode pairs, nothing else is needed for pumping.); (c) No mechanically movable parts (all the electrode pairs are fixed, resulting in low noise and vibration.). Therefore, the ECF micropump is preferable for micro hydraulic systems, such as micro fingers, hands, manipulation systems.

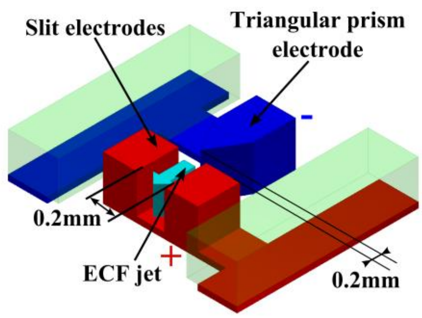

Figure 1. ECF jet by TPSE.

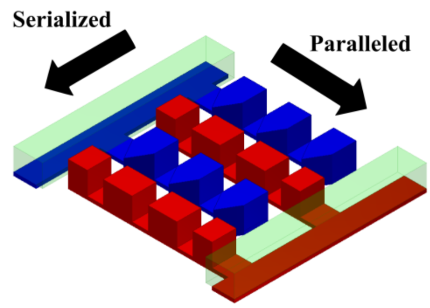

Figure 2. 2D–integration of TPSEs.

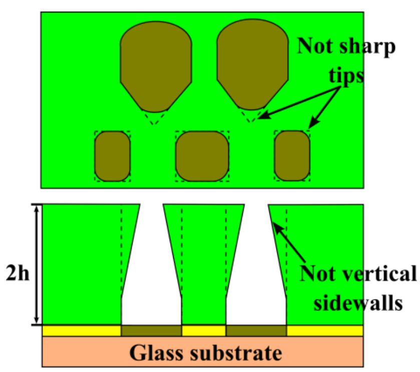

Figure 3. Deformed tip shape (top view) and sidewall profile (cross sectional view) of TPSE mold.

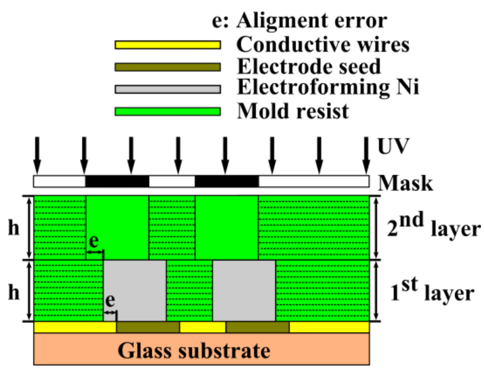

Figure 4. Misalignment of the multi-layer fabrication process.

In our previous research, it was proved that the ECF micropump consisting of TPSEs had higher power density, thanks to the 2D-integration (in series and in parallel) of TPSEs (figure 2). Moreover, we also proved that the output flow rate was increased by higher TPSE height [5]. For purpose of higher aspect ratio of TPSEs, a multilayer MEMS process based on our single layer process was proposed. However, there were some limitations. In the single layer fabrication of the relatively thick photoresist, the residual stress in cross-linking and swelling in mold exposure and developing could result in deformed TPSEs mold structures, including not sharp tips and not vertical sidewalls, as illustrated in figure 3. In the case of multi-layer fabrication of manual alignment operation, precise alignment is time-consuming and extremely difficult to be met, as shown in figure 4.

In order to improve the electrode profile and alignment accuracy of the TPSEs, this paper proposes a novel self-aligned micro molding technology for the ECF micropump with TPSEs. The concept of the novel self-aligned fabrication process is demonstrated in section 2. The proposed novel fabrication process in detail is described in section 3. The fabrication of ECF micropumps and characteristic experiments are mentioned in section 4. The conclusions are summarized in section 5.

2. Concept

In order to solve the problems that the previous fabrication processes are confronted with, we develop the ECF micropump fabricated by electroforming with novel self-aligned micro-molding technology. The concept is depicted in figure 5. The seed electrode pattern is nontransparent for UV light, while the glass substrate and negative photoresist KMPR (MicoChem Corp.) are both transparent. Therefore we can utilize back-side UV light and electrode seed pattern on the glass wafer for patterning thick photoresist, instead of using ordinary front-side UV light and mold photomask. After the bask-side UV exposure, the self-alignment is automatically realized between the mold pattern and the electrode seed pattern. The proposed self-aligned fabrication is also suitable for multi-layer fabrication process. For example, for the 2nd mold layer, the grown Ni electrode pattern in the 1st mold layer can be used as mold photomask for patterning the micro mold of 2nd layer. After the bask-side UV exposure, the self-alignment is also automatically achieved between the micro mold of 1st layer and that of 2nd layer, as shown in figure 6.

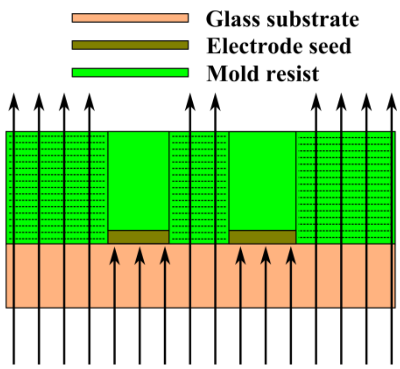

Figure 5. Concept of novel self-aligned fabrication for single layer.

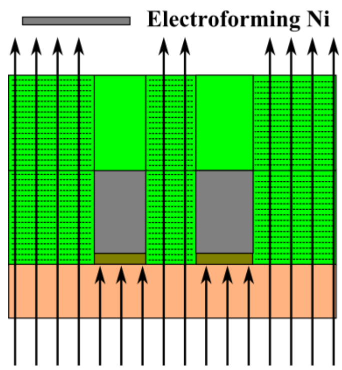

Figure 6. Concept of novel self-aligned fabrication for multi-layer.

3. Novel fabrication process

The proposed novel self-aligned fabrication process for ECF micropump with TPSEs is depicted in figure 7. First, Au/Ti are deposited and patterned as conductive seed layer, which is composed of electrode seed and conductive wires (single-line-pattern wires and parallel-lines-pattern wires). The electrode seed is used for positioning and formation of TPSE micro mold. The parallel-lines-pattern wires (line width = 10 μm, space = 39 μm) between the electrode seed, together with the single-line-pattern wires, are both utilized to confirm conductivity of electrode seed in the following electroplating. Then the thin negative photoresist (KMPR) with 5 μm thickness is formed to cover the whole surface except for the conductive seed layer for TPSE structures. Thick spin-coated KMPR for TPSEs is exposed and patterned by back-side UV exposure through transparent glass substrate on which the electrode seed pattern plays a role in forming micro-mold holes, so that self-aligned mold pattern is realized. By using this micro-mold, The TPSEs are formed by nickel electroplating. By selectively removing KMPR, the TPSE structures of nickel with height 440 μm were successfully fabricated and were coated with gold. Finally, another thick photoresist SU-8 (MicroChem Corp.) is patterned for the micro fluidic channels. The SEM picture of fabricated TPSEs and fluidic channels are displayed in figure 8.

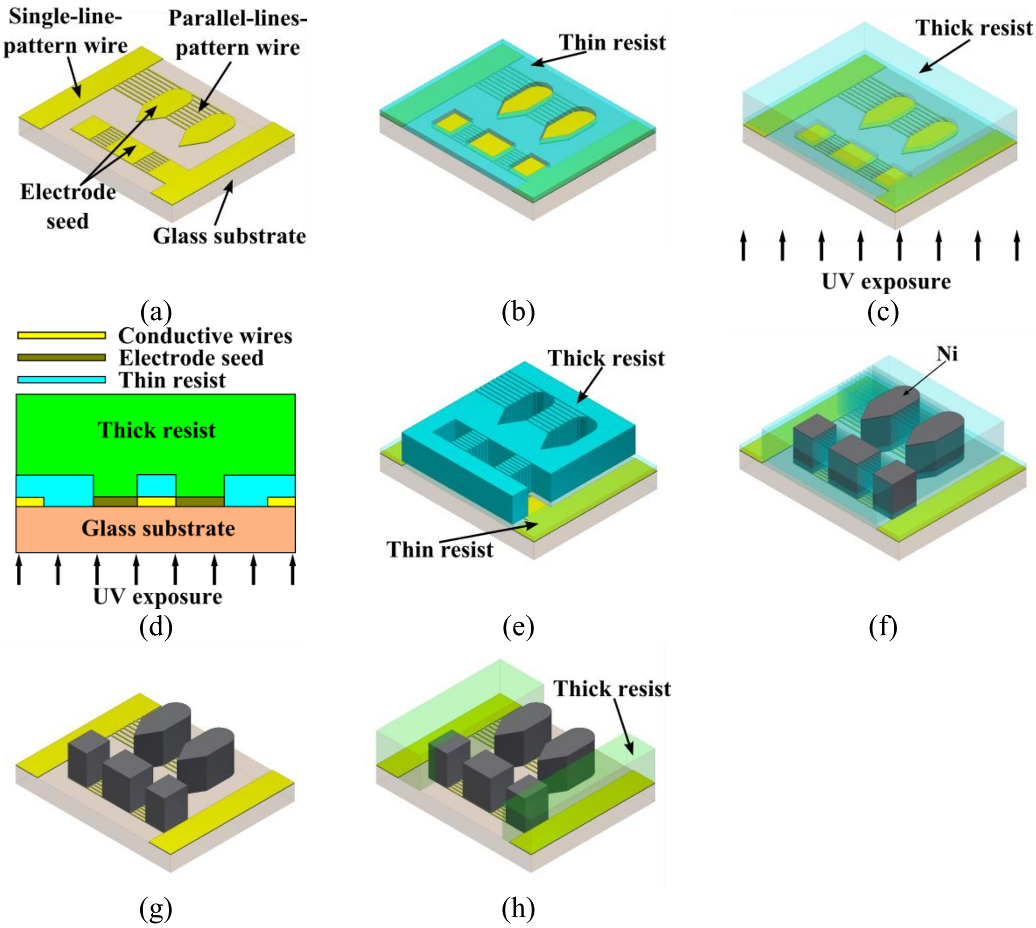

Figure 7. Proposed novel self-aligned fabrication process: (a) Seed layer patterning; (b) Insulation by cover; (c) Back-side UV exposure; (d) Cross sectional of back-side UV exposure; (e) Mold developing; (f) Ni electroplating; (g) Mold removal; (h) Channel forming.

4. Experiments and discussions

The fabricated ECF micropump (figure 8) occupies the volume of 30.6×7.3×1 mm^3 and adopts 3 paralleled TPSEs and 10 serialized ones. The ECF micropump is packaged with a based plate, a bottom silicon rubber sheet, a top silicon rubber sheet and a cover plate.

Then the characteristic experiments of the fabricated ECF micropump are conducted. The output pressure is measured by the calibrated pressure sensor and the electric balance is adopted to measure the mass of ECF flowing out in specific time. FF-909EHA2 (New Technology Management Co., Ltd.) is used as the working fluid. Based on the experimental results illustrated in figure 9, the output pressure and output flow rate are both increased with higher DC voltage. The maximum output pressure and flow rate are 88 kPa and 411 mm^3/s respectively at the applied voltage of 4 kV.

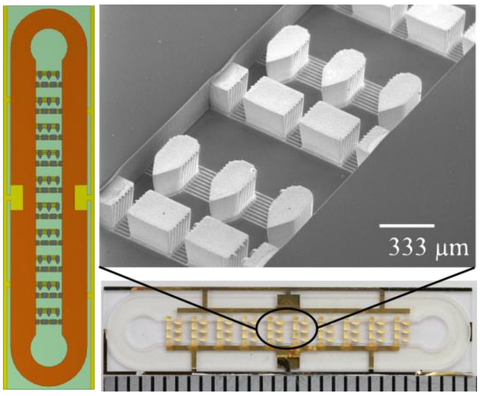

Figure 8. Design model (left) and fabricated prototype (right) of ECF micropump.

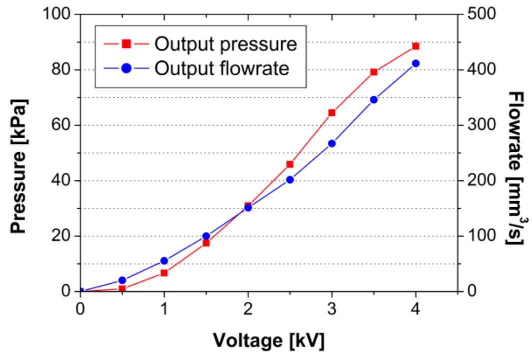

Figure 9. Output characteristics of the fabricated ECF micropump.

5. Conclusions

To improve electrode profile and alignment accuracy, we proposed the novel self-aligned micro-molding technology for ECF micropump with TPSEs, successfully fabricated the prototype, and experimentally proved the feasibility of the novel fabrication method. As future work, higher-aspect-ratio TPSEs will be realized by the multi-layer the back-UV multilayer process, in order to improve the output density of ECF micropumps.

References

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