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Tube-type micropump by using electro-conjugated fluid (ECF)

Joon-wan Kim[a,*], Toshiya Suzuki[b], Shinichi Yokota[a], Kazuya Edamura[c]

[a] Precision and Intelligence Laboratory, Tokyo Institute of Technology, R2-42, 4259 Nagatsuta, Midori-ku, Yokohama 226-8503, Japan
[b] Graduate School, Tokyo Institute of Technology, Japan
[c] New Technology Management Co. Ltd., Tokyo, Japan

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ABSTRACT

This paper proposes and presents an electro-conjugate fluid (ECF) micropump whose pumping sources are mounted on the inside of flow channels and are serially located through the flow channels. ECF is a kind of functional and dielectric fluid. A strong and active jet flow of ECF is generated between electrodes surrounded by ECF when high DC voltage is applied to the electrodes. To combine easy fabrication and high performance, we propose a novel ECF-jet generator that consists of a triangular prism electrode and a slit electrode for the tube-type ECF micropump. The maximum output pressure obtained is 64 kPa and the maximum flow rate is 1.12 cm^3/s at the applied voltage of 6 kV. The result shows that the proposed ECF-jet generator and whose tube-type ECF micropump can be a good candidate as a driving source for forced liquid cooling systems, new microactuators and so on.

1. Introduction

Since a micropump was first proposed by Smits in the 1980s, a huge number of micropumps have been developed for the purpose of the use in the wide range of applications: miniature systems for chemical and biological analysis (micro total analysis systems, μ-TAS) [1–3]; medical systems for implanted drug delivery [4,5]; cooling systems for microelectronic devices [6,7]; fluid power systems for microactuators [8,9]; and propulsion systems for microspacecraft in space exploration [10]. Desirable parameters relevant to the micropumps are different according to the functionality and performance of the applications, which can be divided into two main fields. Precisely controlled flow in spite of low output power is the first priority in the applications of μ-TAS and drug delivery, while high flow rate as well as high pressure are critical in the fields of cooling for microelectronic devices, micro hydraulic systems for microactuations, and micro propulsion systems for space exploration. Due to the potential advantage of high output power in micro systems, despite of the difficulties in realization, we are interested in the latter, that is to say, micropumps for cooling, actuation, and propulsion.

In order to appreciate the performance requirements of these micropumps mentioned above, to cool microelectronic devices is cited as an example. Flow rates of several hundred milliliters per minute are needed in single-phase cooling of a 100 W microchip and those of order 10 ml/min are necessary in two-phase cooling, according to the published papers [6,7]. In addition, 100 kPa or higher are required to maintain such high flow rates through microchannels in micro heat sink [7]. Although over 200 archival journal papers concerning micropumps have been published, there are no reports to perfectly and practically satisfy these requirements mentioned above [11].

In order to meet these requirements, we propose and consider a novel tube-type micropump whose power sources are inside-mounted on and serially located through the micro flow channels, shown in Fig. 1. The advantages of tube-type micropumps are as follows: (a) multiplication in output pressure and flow rate; (b) space saving; (c) space flexibility. Output pressure and flow rate can be easily increased by serial and parallel integration of power sources. In addition, tube-type micropumps do not need external micropump as shown in Figs. 2 and 3, so that the space can be saved. The micropumps can be located between complicated microstructures in Fig. 3, indicating the space flexibility.

In order to realize a tube-type micropump, we focus on an electro-conjugate fluid (hereafter ECF) as a promising candidate for the driving mechanism. ECF is a kind of functional and dielectric fluid [12]. A strong and active jet flow of ECF can be generated between electrodes surrounded by ECF, when high DC voltage is applied to the electrodes, as shown in Fig. 4. This phenomenon is defined as ECF effect and an ECF-jet generator consists of a pair of the electrodes or multiple pairs of the electrodes. ECF is appropriate to make a tube-type micropump, because of the following reasons: (a) dynamic pumping mechanism (An ECF-jet generator can convert electric energy directly into kinetic energy of the fluid by the

* Corresponding author.
E-mail address: woodjoon@pi.titech.ac.jp (J.-w. Kim).

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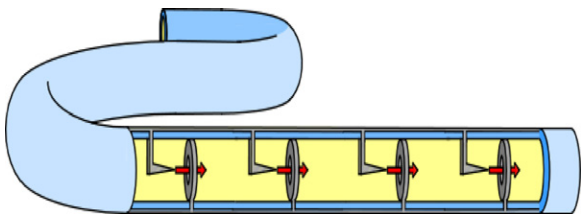

Fig. 1. Example of tube-type micropumps.

ECF effect.); (b) simple structure (Some pairs of electrodes and ECF are everything for pumping.); (c) low noise and vibration (there are no mechanical moving components).

Some of the authors have developed and experimentally investigated several types of ECF-jet generators that are mainly divided into two groups: a thin planar ECF-jet generator shown in Fig. 5 [13]; and a three dimensional ECF-jet generator having a needle-ring electrode pair (it is hereafter called as a needle-ring ECF-jet generator) shown in Fig. 6 [14]. A thin planar ECF-jet generator consists of two kinds (plus and minus) of numerous parallel electrodes that are patterned on a plane. It is easy to fabricate the planar ECF-jet generator thanks to planar structures formed by photolithography, while the output power density with respect to volume is not relatively high. On the contrary, a three dimensional needle-ring electrode pair can generate a strong ECF-jet, while there are problems in the reproducibility for downsizing and multiplication of the electrode pair because of the tradition way of precision machining process and hand-assembling.

In order to combine easy fabrication and high performance, we propose a novel ECF-jet generator for the tube-type ECF micropump. The concept and fabrication of the tube-type ECF micropump are proposed in Section 2 and its characteristics are experimentally investigated in Section 3. Finally, this study is concluded in Section 4.

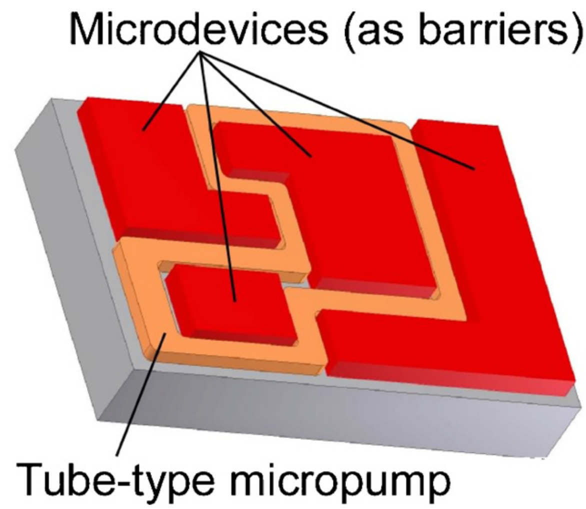

Fig. 3. Example of space flexibility.

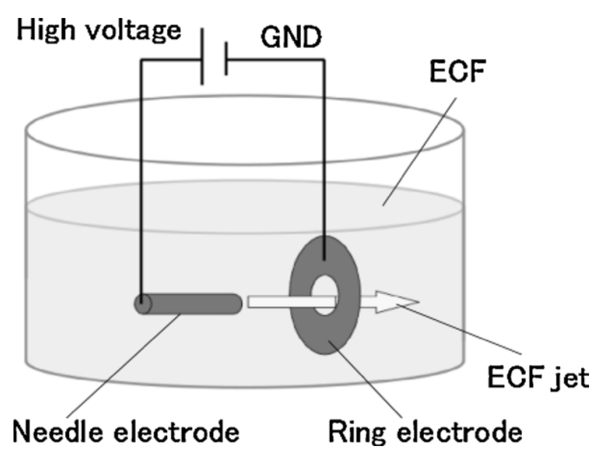

Fig. 4. ECF effect by a needle electrode and a ring electrode.

2. Tube-type ECF micropump

2.1. Concept

In order to realize the easy fabrication and high performance of a tube-type micropump, this paper focuses on integrating merits of both a planar ECF-jet generator and a needle-ring ECF-jet generator. Based on the advantages mentioned in Section 1, this paper proposes a novel ECF-jet generator shown in Fig. 7 for the tube-type ECF micropump. This ECF-jet generator consists of a triangular prism electrode and a slit electrode and is hereafter named as a triangular prism ECF-jet generator. To our best knowledge, there have been no trials to utilize a triangular prism electrode and a slit electrode as an ECF-jet generator for realizing the high performance as well as the easy fabrication.

Since a triangular prism electrode and a slit electrode are 2D-based and column-like structures, they can be easily fabricated by the traditional mechanical machining, that is to say, the wire electrical discharge machining. In addition, these structures are desirable for photolithography-based MEMS technology, by which the MEMS-fabricated ECF-jet generator will be realized in our future work. By adding the merit of easy fabrication, the triangular

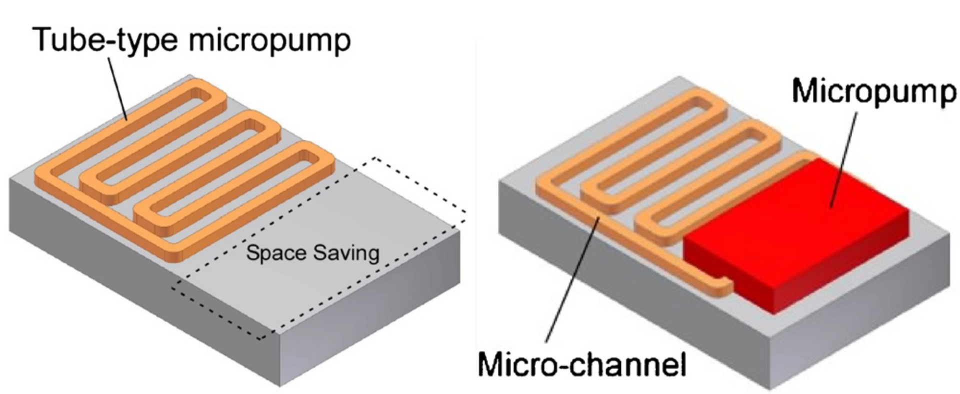

Fig. 2. Example of space saving in tube-type micropump (left: tube-type micropump that does not need an external micropump, right: ordinary micropump with micro-channel).