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# 基于电液动力效应的离子拖曳微泵

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**摘要:**介绍了一种新型电子冷却系统—离子拖曳电液动力微泵,运用 MEMS 技术在硅片上加工了离子拖曳微泵并进行了测试,微泵由一组平面电极组成,电极的宽度为 40  $\mu\text{m}$ ,发射极和集电极之间的间距为 50  $\mu\text{m}$ ,共有 90 对电极对,每组电极对之间的距离为 100  $\mu\text{m}$ 。微泵静压力实验以 HFE7100 和无水乙醇作工作流体,通过施加直流电压来驱动工作流体,当输入电压为 200 V 时,微泵可以得到 250 Pa 的静压力。实验结果表明:微泵的静压力与施加的输入电压成二次方关系,同微流道的高度成反比。实验发现工作介质的物性参数也是决定泵性能的一个重要因素,选择合适的流体可以提高整个微泵冷却系统的性能。研究还表明,微泵的性能与工作寿命和实验环境的洁净度以及工作流体提纯密切相关。

**关键词:**电液动力效应;离子拖曳;微机电系统;微泵

**中图分类号:**TH38;TK124 **文献标识码:**A

## Development of ion-drag EHD micropump

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**Abstract:** A novel electronics cooling system—ion drag Electrohydrodynamic (EHD) micropump was introduced. The ion drag EHD micropump containing a planar electrode array on a silicon substrate was fabricated and tested, in which the electrodes were paired as an emitter and a collector with 40  $\mu\text{m}$  width and 50  $\mu\text{m}$  gap between them, the number of electrode pairs was 90 and the gap between two electrode pairs was 100  $\mu\text{m}$ . Static pressure tests were performed by a DC driving voltage and by HFE7100 and ethyl alcohol as working fluids. Experimental results show that the static pressure is quadratic proportion to the input voltage and inverse proportion to the channel height and the maximum pressure head achieved by this micropump is 250 Pa at an applied voltage of 200 V. These data proves that the performance of the ion-drag pump can be improved significantly by selecting the fluid with high permittivity and low viscosity. It also indicates that the cleanness degree of devices and the purification of the working fluid will greatly influence the performance and working lifetime of the EHD micropump.

**Key words:** electrohydrodynamic (EHD); ion-drag; MEMS; micropump

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## 1 Introduction

With the development of microfabrication technology, MEMS has shown promising potential in microfluidic systems and microelectronics cooling devices. The design and functionality of micropump play an integral role in microfluidic system and microelectronics cooling technology<sup>[1-4]</sup>.

The electrohydrodynamic (EHD) phenomena involve the interaction of electric fields and flow fields in a dielectric fluid medium<sup>[5-6]</sup>. Many theoretical and experimental investigations concerning Electrohydrodynamic (EHD) pumping because of its advantage of no moving parts and simply design. Stuzter and Pickard<sup>[7-10]</sup> were the first who proposed and studied the ion-drag EHD pump in the early 1960s. Up until the early 1990s the research in EHD was done with large-scale systems. Development of MEMS fabrication technology enable the fabrication of EHD pumping research efforts has been made toward micro-scale. Richter<sup>[11]</sup> fabricated a micro-machined ion-drag EHD pump using bulk silicon machining technique. Ahn<sup>[12]</sup> fabricated a micro ion drag pump with planar electrodes on a glass substrate. It demonstrated the bi-direction pumping capability with simpler fabrication process. Darabi<sup>[13-14]</sup> addressed various aspects of ion drag pumping mechanism, including the effect of three-dimensional electrodes design and its favorable effect on the performance of ion drag micropump.

## 2 Basic theory and model

This interaction between electric fields and flow fields can induce the flow motion by electric body force. The electric body force acting on the

molecules can be expressed as<sup>[6]</sup>:

$$f_e = qE - \frac{1}{2}E^2 \nabla \epsilon + \frac{1}{2} \nabla \left[ E^2 \left( \frac{\partial \epsilon}{\partial \rho} \right)_T \rho \right], \quad (1)$$

where  $q$  is charge density,  $E$  is the electric field,  $\epsilon$  is the fluid permittivity,  $\rho$  is the fluid density and  $T$  is the fluid temperature. The first term represents the Coulomb force, which is the force acting on the free charges in an electric field. The second and third terms represent the polarization force acting on polarized charges. The Coulomb force is the only mechanism for generating EHD pumping when working fluid is an isothermal single phase liquid.

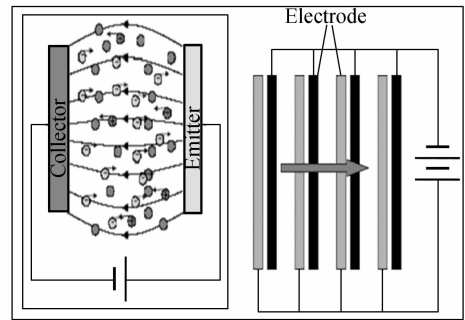


Fig. 1 Mechanisms of EHD

Ion drag pump is a particular type of EHD pump, the main driving force in ion-drag pump is the Coulomb force; the charge can be injected into liquid by field emission or field ionization processes. Working fluid neutral molecules get dragged along with charged ions that are moving between the electrodes (as showed in Fig. 1). Ion drag pump has been studied since the early 1960s. Pickard arrived at the relation between pressure and electric field intensity<sup>[9-10]</sup>:

$$P(x) - P_0 = \frac{\epsilon}{2} (E(x)^2 - E_0^2). \quad (2)$$

## 3 Ion drag pump design and fabrication

An ion-drag EHD pump was designed with an array of planar comb finger electrodes. Fig. 2 shows a schematic diagram of emitter and collector electrode patterns, the emitter and the col-

lector have a width of  $40\ \mu\text{m}$  with  $50\ \mu\text{m}$  gap between them. The gap between the electrode pairs is  $100\ \mu\text{m}$ . The electrodes were fabricated on silicon disc or glass plate by deposition of Ti/Cu, the overall patterned area is  $17\ \text{mm} \times 22\ \text{mm}$ , allowing fabrication of 90 electrode pairs along the length of the micropump.

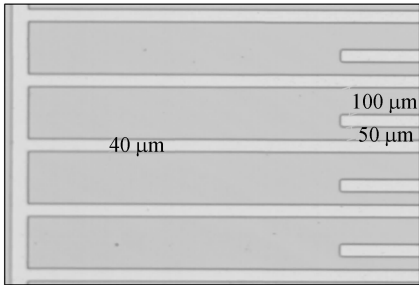


Fig. 2 Schematic diagram of electrodes

Electrodes are the key component for EHD micropump, the design and making of electrodes were involved in the optimization of the micropump design. Selection of material, geometrical design and fabrication technique of electrodes are the three main keys for micro-electrodes. The electrodes were fabricated on the silicon disc by the deposition of Ti/Cu, 500 Å titanium and 3 500 Å copper were deposited over the entire substrate. Kit-off process was used to form electrodes. Fig. 3 displays whole fabrication process.

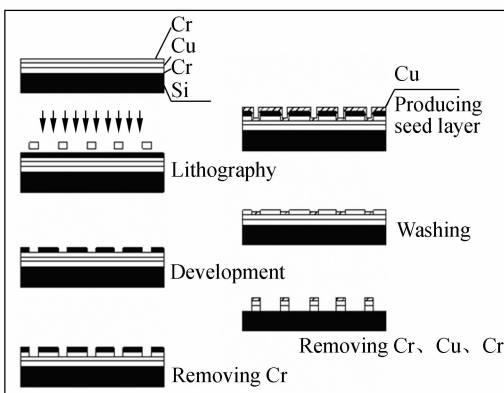


Fig. 3 Fabrication process for EHD pump

The overall dimensions of the EHD pump were  $20\ \text{mm} \times 30\ \text{mm} \times 3\ \text{mm}$ . The top cover of

EHD pump is made of polymethy, in order to test the pumping capability of micropump, a glass tube was mounted on the exit port of the cover using transparent epoxy. Assembly was completed with an epoxy film to create the cavity sidewalls, and there are three size thickness epoxy film:  $50\ \mu\text{m}$ ,  $100\ \mu\text{m}$  and  $200\ \mu\text{m}$  to form three different channels height.

## 4 Experimental description

As showed in Fig. 4, the static pressure test was performed in a Petri dish container, the pump was placed in a bath of working fluid and a positive DC voltage was applied to the emitter electrodes and collector electrodes were grounded. 3M's HFE7100 and ethyl alcohol were used as working fluid. We get a maximum pressure of 250 Pa at an applied voltage of 200 V for HFE7100 as for 90 electrodes stage micropump.

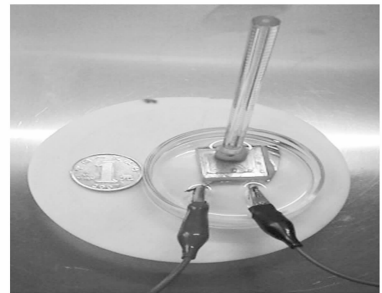


Fig. 4 View of static pressure testing

The behavior of the static pressure after applying the DC voltage is showed in Fig. 5. In this figure, the static pressure show quadratic dependence on the electric field as predicted by Eq. (2), the results clearly showed that the pumping performance is proportional to the input voltage and inverse proportion to the channel height, as showed in Fig. 5 and Fig. 6.

According to Crowley studied<sup>[15]</sup>, EHD pumping performance relies critically on the electric properties of working fluid. Such as permittivity ( $\epsilon$ ), conductivity( $\sigma$ ) and viscosity( $\mu$ ). high dielectric constant and low viscosity would lead to

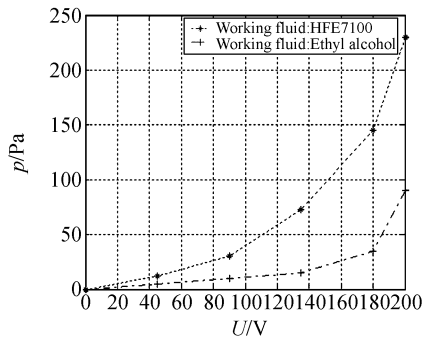


Fig. 5 Static pressure for different working fluids

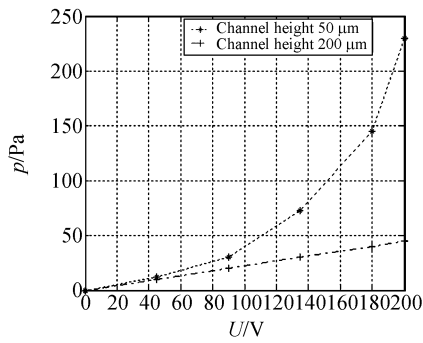


Fig. 6 Comparison with different channel heights

high flow velocity, while low electric conductivity and mobility would promote high efficiency. In this experimental, 3M's HFE7100 and ethyl alcohol were used as working fluid. Both of them have some advantages, such as liquid state under normal temperature, good dielectric constant, low vapor pressure, a relatively low viscosity and a relatively high thermal conductivity. Other thermo-physical properties of this fluid are listed in Tab. 1.

Tab. 1 Comparison of parameters of different working liquids

Thermophysical property	HFE7100	Ethyl alcohol
Boiling point(°C)(1 kPa)	6 100	7 830
Dielectric constant	7.4	25.8
Liquid density(kg/m <sup>3</sup> )	1 478	800
Liquid viscosity(CP)(25 °C)	0.61	1.078
Dielectric strength(V/μm)	11	3

The experimental results for different working fluid are presented in Fig. 5. The results clearly

showed that the performance of ion-drag pump could be increased significantly by selecting the ethyl alcohol as work fluid instead of HFE7100, so the fluid with high permittivity and low viscosity will increase the pumping performance.

The useful life is the key criterion for micropump. In the former experimental, the static pressure showed a decrease after half hour. The detailed observation of electrodes under photomicrographs shows a thin layer of degradation products was formed on the collector electrodes, which probably due to electrochemical reactions and cause pumping performance decay (as showed in Fig. 7 and Fig. 8). The reason for electrochemical maybe comes from the water and impurity in the working fluid. Therefore, all experiments were performed inside the clean room and working fluids were distilled before experimental. The results showed that improvement of the cleanness degree of device and purification of working fluid has greatly increased pumping effect and working hours.

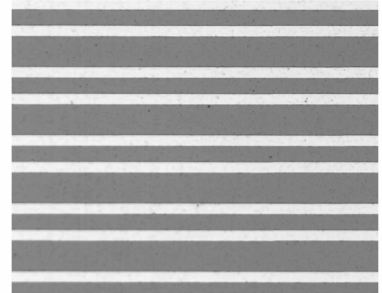


Fig. 7 Electrodes before testing

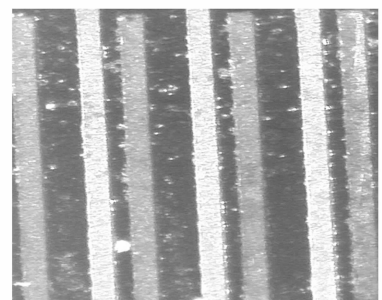


Fig. 8 Electrodes after aging

## 5 Conclusions

In this paper, an ion drag micropump with a series of planar comb electrodes on a silicon substrate is designed and tested. Static pressure tests were performed with HFE7100 and ethyl alcohol as working fluid, and driven by DC voltage. It was found that the micropump is capable of generating static pressure head of 250 Pa at an applied voltage of 200 V. The results showed that pumping performance is proportional to the

input voltage and inverse proportion to the channel height. It was observed that the static pressure could be increased significantly by selecting the working fluid with high permittivity and low viscosity. In addition, the cleanliness degree of device will greatly influence EHD micropump ageing, and purification of working fluid will greatly increase pumping effect and working hours. These results are very promising for further development of source integrated cooling device using EHD micropump.

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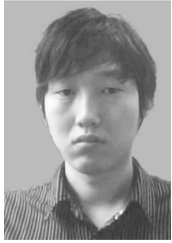
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## ● 下期预告

## 基于智能寻北系统的快速初寻北方法

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机械陀螺经纬仪初寻北时间的长短, 是决定其寻北效率的关键因素。从陀螺仪寻北的原理出发, 在智能寻北系统中引入了一种快速寻北新方法——加速度判定法。该方法通过计算光标运动的速度与加速度值, 能够在陀螺开始寻北数秒后即可测量出真北值, 并且能够弥补电子罗盘初寻北精度过低的问题, 是全自动寻北策略的重要组成部分。以 JT-15 陀螺仪为样机的寻北实验表明, 将加速度判定法应用于智能寻北系统中, 仪器初寻北测量精度优于  $3'54''$ , 完全能够满足 JT-15 陀螺仪精寻北的条件要求。加速度判定法的应用能够有效地保证全自动寻北的速度和精度, 对于机械陀螺的快速及智能化寻北具有现实意义。