Portable general microfluidic device with complex electric field regulation functions for electrokinetic experiments

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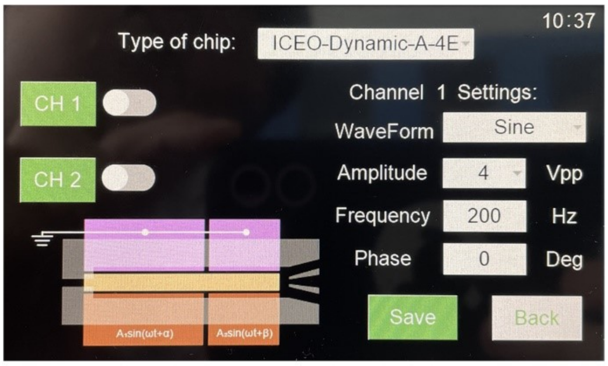
Supplementary Information

(a)



(b)

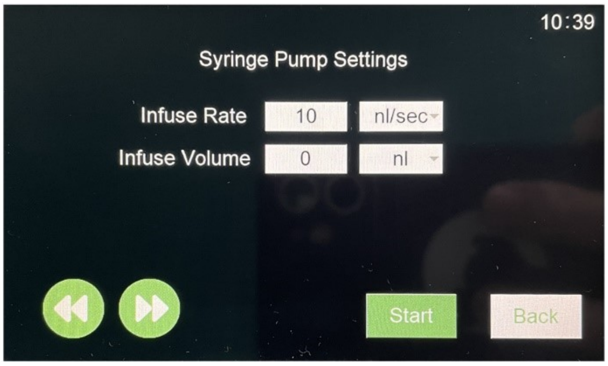


Fig. S1. The GUI on the display. (a) Electric field signal setting interface; (b) Micropump setting interface.

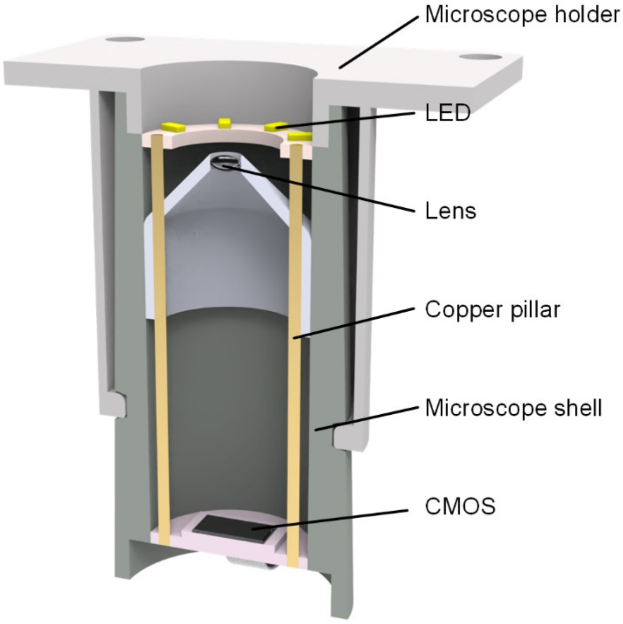


Fig. S2. Sectional view of microscope.

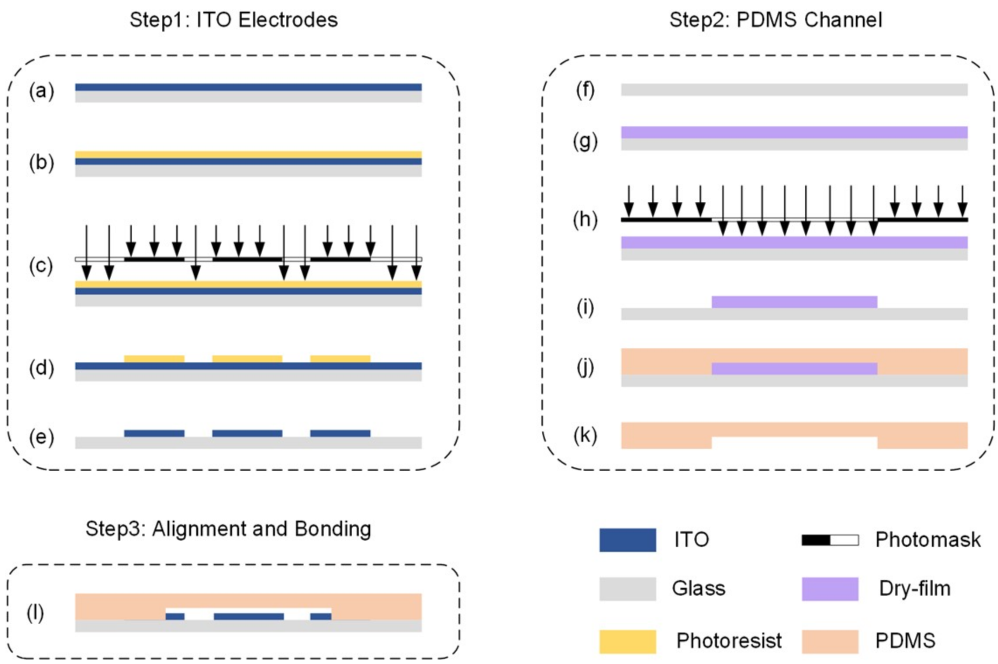


Fig. S3. The fabrication process of the microfluidic chip. (a) The ITO-coated glass slide cleaned; (b) The negative dry film laminated; (c) Ultraviolet light exposure; (d) Development; (e) ITO etching; (f) Glass cleaned; (g) Dry film stuck; (h) Ultraviolet light exposure; (i) Development; (j) Microchannel reproduced with PDMS; (k) PDMS channel stripped off; (l) Alignment and bonding.

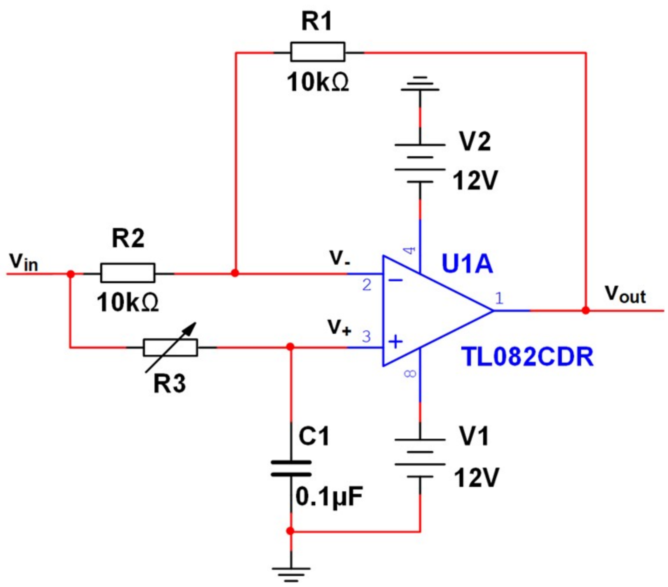


Fig. S4. Circuit diagram of phase lag regulator.

Note: Due to the characteristics of operational amplifier, if $v_{in} = \sin(\omega t)$, due to the virtual break of the op-amp, it can be deduced from the circuit:

$$v_+ = \frac{\frac{1}{j\omega C_1}}{R_3 + \frac{1}{j\omega C_1}} v_{\text{in}} = \frac{1}{1 + j\omega C_1 R_3} v_{\text{in}} \tag{S1}$$

$$v_- = v_{\text{in}} + \frac{(v_{\text{out}} - v_{\text{in}}) \cdot R_1}{R_1 + R_2} = \frac{R_2 v_{\text{in}} + R_1 v_{\text{out}}}{R_1 + R_2} \tag{S2}$$

Where ω is the angular frequency, v_{in} is the input signal and v_{out} is the output signal. When $R_1 = R_2$, due to the virtual short of the op-amp, the magnification of the op amp is:

$$\frac{v_{\text{out}}}{v_{\text{in}}} = \frac{1 - j\omega C_1 R_3}{1 + j\omega C_1 R_3} \tag{S3}$$

It can be seen from equation (S3) that the output signal amplitude is not attenuated, and the phase lag is $2\arctan(2\pi f C_1 R_3)$.

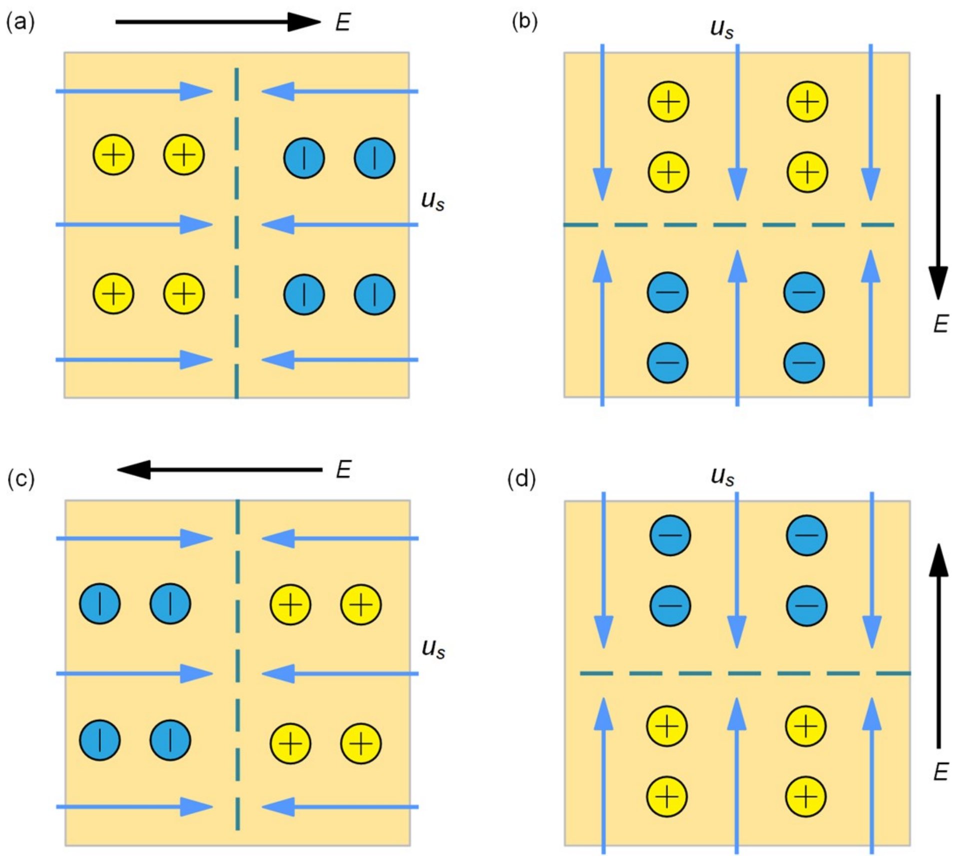


Fig. S5. Transient ionic charge polarity and slip flow direction at different time instants. (a) t=0; (b) t=T/4;(c) t=T/2;(d) t=3T/4.

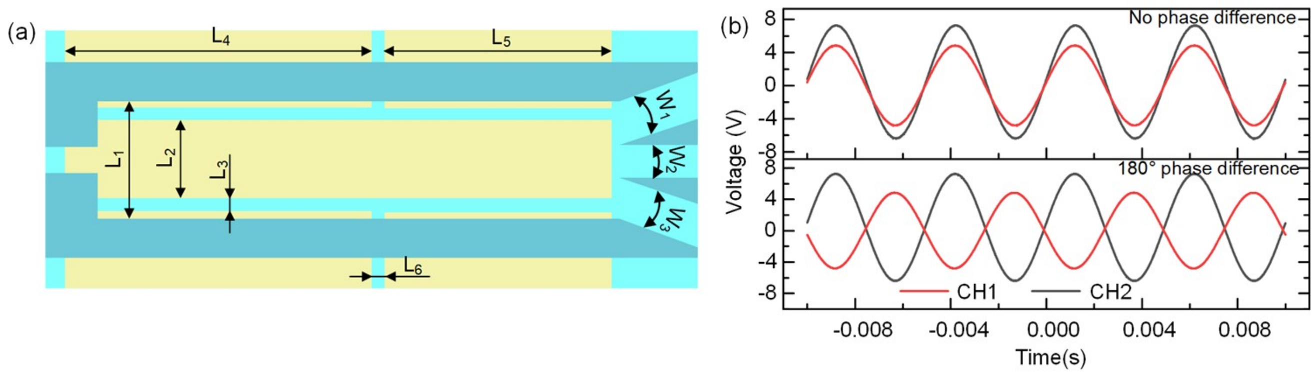


Fig. S6. (a) Structure size in particle beam switching experiment; (b) AC signals applied in particle beam switching experiment.

Note: When the applied AC signal has no phase difference, the particle beam flows out of the middle outlet. When the phase difference is 180 °, the particle beam can be deflected to one side, and the deflection direction depends on the polarity of the applied signal.

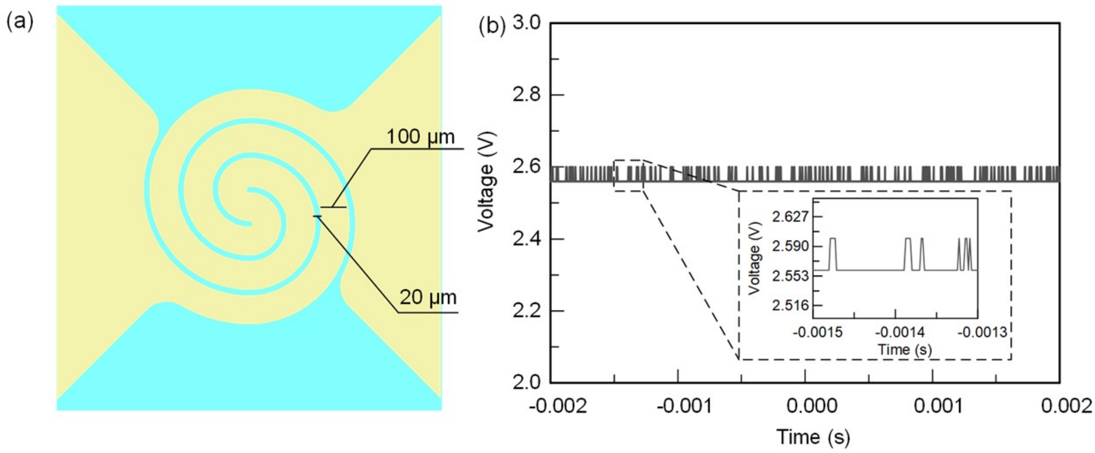


Fig. S7. (a) Structure size in thermal buoyancy convection experiment; (b) DC signal applied in thermal buoyancy convection experiment.

Note: The applied DC signal has a certain fluctuation, but the fluctuation range is less than 0.1V, which is normal. Although capacitors are used for filtering and decoupling in the circuit, there will still be some fluctuations due to device errors and environmental interference.

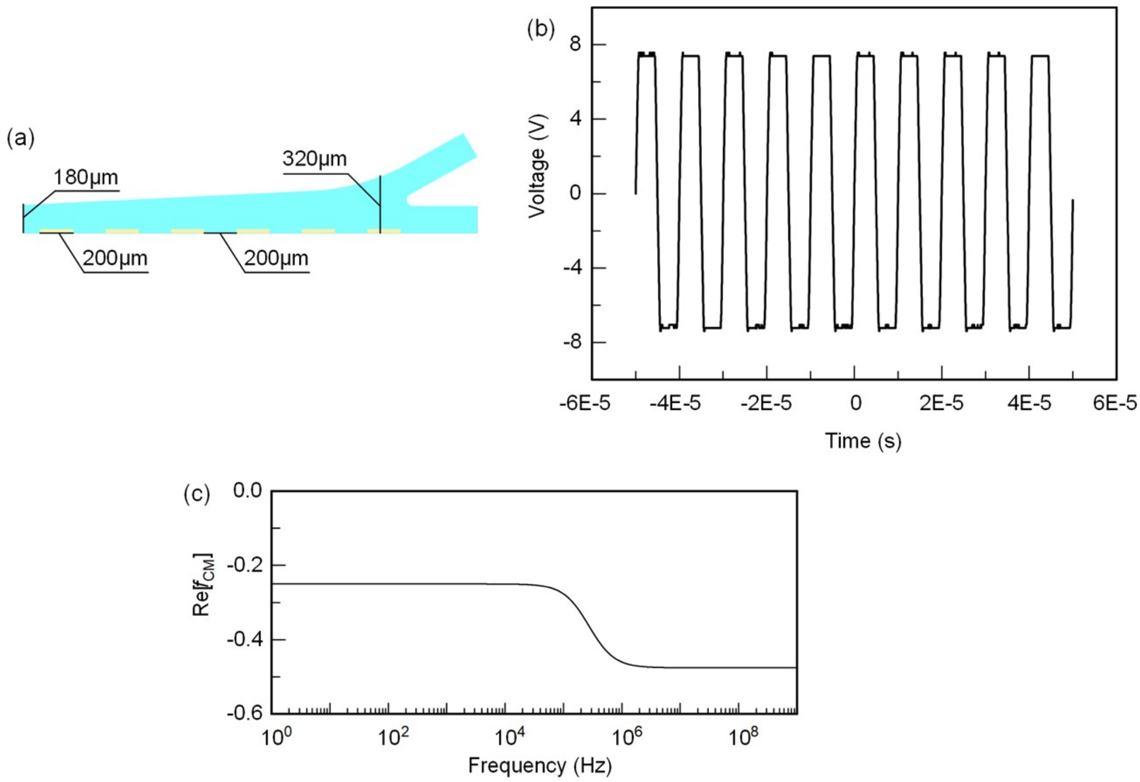


Fig. S8. (a) Structure size in DEP experiment; (b) AC signal applied in DEP experiment; (c) Frequency dependence of the real part of the CM factors in the buffer solutions.

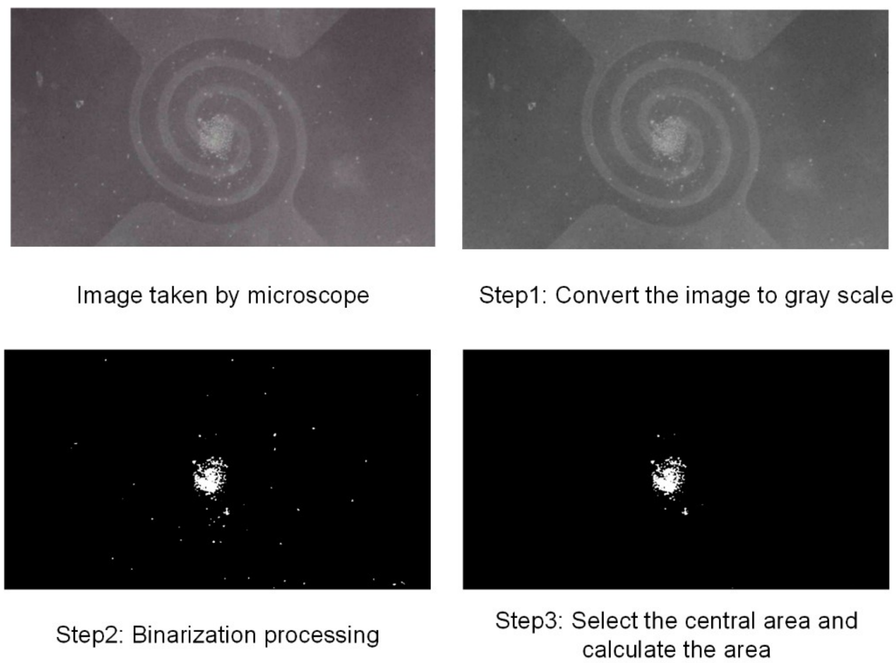


Fig. S9. Image processing steps for calculating focusing area

Table S1. Output specifications of PGMD

Parameters	Value	
Microscope magnification	20-50x	
AC signal	Number of channels	4
	amplitude	2-14 Vpp
	frequency	0.1-400K Hz
	Phase difference of adjacent channels	0-90°
DC signal	1 channel with amplitude of 0.1-5 V	
Micropump flow rate	5.7-4560 nL/s	

Table S2. Boundary conditions applied in numerical simulation.

Boundary	B.C. for electrical problem $\nabla^2\tilde{\phi} = 0$
Electrode of 0° voltage	$\tilde{\phi} = A$
Electrode of 90° voltage	$\tilde{\phi} = jA$
Electrode of 180° voltage	$\tilde{\phi} = -A$
Electrode of 270° voltage	$\tilde{\phi} = -jA$
Floating electrode	$\sigma n \cdot \nabla\tilde{\phi} = j\omega C_0 \left(\tilde{\phi} - \tilde{\phi}_0\right),\ \tilde{\phi}_0 = 0$
Insulating wall/electrolyte interface	$n \cdot \nabla\tilde{\phi} = 0$

Where $\tilde{\phi} = Ae^{j\theta}$ is complex phasor amplitude of electrostatic potential; n denotes the unit normal vector pointing into electrolyte; C_0 is the total interface capacitance of induced double layer.

Table S3. Structure size of particle beam switching chip based on ICEO.

Symbol	Value (μm)
L_1	520
L_2	300
L_3	60
L_4	2000
L_5	1000
L_6	200
W_1, W_3	200

W_2	100