Supplementary Information

A fully chip-embedded automation strategy for multi-step flow-based lab-on-a-chip devices

Junsu Kang, Donghyeon Lee, Young Jin Heo and Wan Kyun Chung

Department of Mechanical Engineering, Pohang University of Technology, Pohang, 37673, Republic of Korea.

Table S1 Parameter values used in simulations suggested in Fig. 1d, e

Variable	Value
P_{SS}	$30\ kPa$
P_{GS}	$30\ kPa$
P_i	$0{\sim}30\ kPa$
R_G	$3.63 \times 10^2\ kPa \cdot min/\mu L$
R_D	$1.44\ kPa \cdot min/\mu L$
t	$30\ \mu m$
E	$2.61\ MPa$
ν	0.5
μ	$1.00 \times 10^{-3}\ Pa \cdot s$
a_{V_M}	$300\ \mu m$
a_{V_R}	$150\ \mu m$
a_C	$600\ \mu m$
L_{V_M}	$70\ \mu m$
L_{V_R}	$35\ \mu m$
σ_x	$0\ kPa$
σ_y	$0\ kPa$

1. Membrane capacitor and valve model for simulation

We modeled deflection of the capacitor membrane (Fig. S1a) by applying a third-order approximation of a square membrane deflection[S1]:

$$\Delta P = 3\frac{t\delta_0}{a^2}\left(20.9\frac{E}{1-\nu^2}\frac{t^2}{a^2} + 2.32(\sigma_x + \sigma_y) + 12.3\frac{E}{1-\nu^2}\frac{\delta_0^2}{a^2}\right), \qquad (S1)$$

where ΔP is differential pressure across the membrane, t is membrane thickness, δ_0 is maximum deflection along z-axis, a is length of one side, E is the elastic modulus of the membrane and ν is its Poisson's ratio, and σ_x and σ_y are residual stresses. In the derivation of eq (S1), the membrane deflection is assumed to be parabolic[S1]:

$$\delta(x,y) = \delta_0\left(1 - \frac{4x^2}{a^2}\right)^2\left(1 - \frac{4y^2}{a^2}\right)^2.$$

The total liquid volume stored in the chamber due to the deflection is obtained by integrating the deflection as

$$V = \left(\frac{8a}{15}\right)^2\delta_0.$$

The rate of liquid inflow into the capacitor is obtained by calculating the time derivative of the volume:

$$Q = \frac{64a^2 d\delta_0}{225\ dt}. \tag{S2}$$

Eqs (S1) and (S2) complete the relationship between pressure difference across the membrane and liquid inflow; the membrane capacitor is modeled based on these equations.

In the case of membrane valve (Fig. S1b), liquid flows from source to drain when the membrane is deflected. The exact flowrate is extremely difficult to calculate, because the cross section is not constant along the valve and the passage is short. However, because we conducted the simulation just to check rough behavior of the circuit, we crudely estimated the flowrate by approximating the resistance of passage with parabolic channel resistance[S2]:

$$R_{valve} = \frac{105\mu L}{4\delta_0^3 a},$$

where μ is dynamic viscosity of liquid and L is length of passage generated due to membrane deflection.

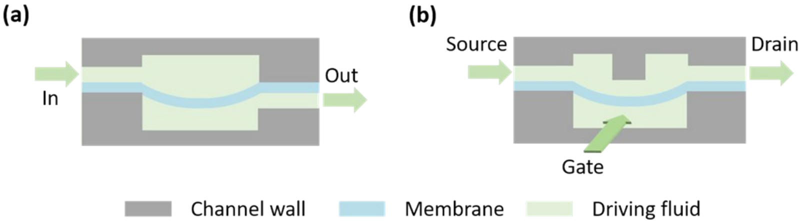

Fig. S1 Side view of (a) membrane capacitor and (b) membrane valve.

2. Simulation of timer unit

Using the capacitor and valve model described above, we built timer unit circuits (Fig. S2) with MATLAB/Simulink. We used the simulation parameters in Table S1 for simulation in Fig. 1d, e.

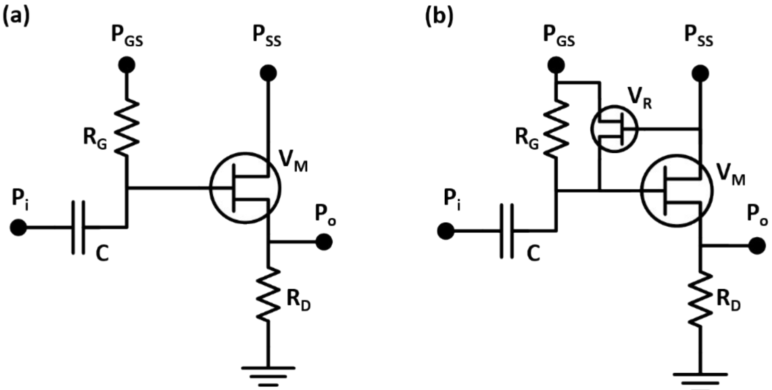

Fig. S2 Electric circuit diagram of simulated timer units (a) without relief valve and (b) with relief valve

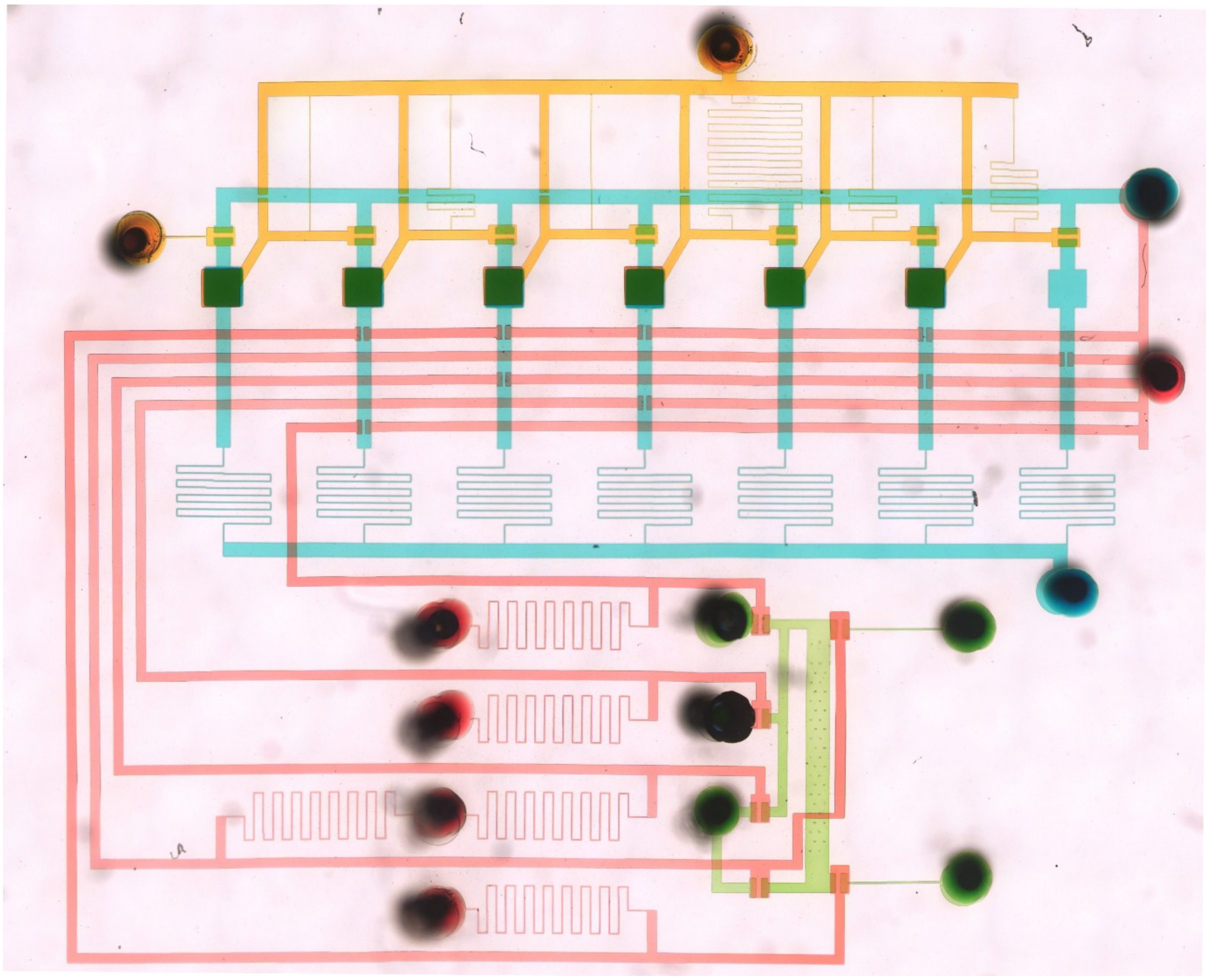

Fig. S3 A High-resolution image of the entire chip used to demonstrate fully-embedded automation of a multi-step liquid handling process.

Video S1. Full video of droplet color changing process in Fig. 5. The video shows self-driven six-step process of loading droplets, separating, injecting sample, incubating, clearing and unloading.

Reference

[S1] Schomburg, W. K. (2011). Membranes. *Introduction to Microsystem Design*, 29-52.

[S2] Bruus, H. "Theoretical microfluidics. Oxford master series in condensed matter physics." (2008).