Supplementary Material

A Feedback Control System for High-Fidelity Digital Microfluidics

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Reagents and Materials

Methanol, glycerol, RPMI 1640 (cell culture media) and pluronic F68 and F127 were purchased from Sigma Chemical (Oakville, ON). Dulbecco's phosphate buffered saline (PBS), fetal bovine serum (FBS) and E6638 Enzchek protease assay kit were purchased from Life Technologies (Burlington, ON). Parylene-C dimer was from Specialty Coating Systems (Indianapolis, IN), A-174 silane was from GE Silicones (Albany, NY), and Teflon-AF was from DuPont (Wilmington, DE). In all experiments, solvents were HPLC-grade and deionized (DI) water had a resistivity of 18 MΩ·cm at 25 °C.

Device Fabrication

Devices were fabricated in the University of Toronto Emerging Communications

Technology Institute (ECTI) fabrication facility. Glass substrates bearing patterned chromium electrodes (used as bottom plates of DMF devices) were formed by photolithography and etching as described previously[1] using photomasks printed with 20,000 dpi resolution by Pacific Arts and Design (Toronto, ON). After patterning, devices were primed for parylene coating by immersing them in silane solution for 15 min, allowing them to air-dry and then washing with isopropanol. After priming, devices were coated with Parylene-C (~7.5 μm) and Teflon-AF (150 nm). Parylene was applied by evaporating 15.5 g of dimer in a vapor deposition instrument (Specialty Coating Systems, Indianapolis, IN), and Teflon-AF was spin-coated (1% Fluoinert FC-40, 2000 rpm, 60 s) and then post-baked on a hot-plate (160 °C, 10 min). Dicing tape was placed on the electrode contact pads prior to parylene coating and was removed after coating. Unpatterned top plates were formed by spin-coating indium tin oxide (ITO) coated glass substrates (Delta Technologies, Stillwater, MN) with Teflon-AF (150 nm, as above). Two device geometries were used, with parameters listed in Table S1.

Device Assembly and Operation

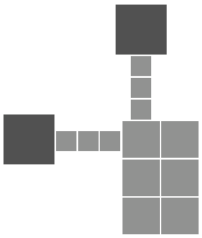
Devices were assembled with an unpatterned ITO/glass top plate and a patterned bottom plate separated by a spacer formed from one or two pieces of double-sided tape (70 or 140 μm thick). Droplets were sandwiched between the two plates and were actuated by applying electric potentials between the top electrode and sequential electrodes on the bottom plate. Two device designs were used, each bearing square driving electrodes separated by gaps of 30 μm; electrode patterns and dimensions are listed in Table S1. Each driving electrode and reservoir was connected to a contact pad in

an array of pads on the side of the device (contact pads and connectors are not shown in Table S1). Droplet actuation was monitored and recorded by a CCD camera mounted on a stereomicroscope. Reagents were manually loaded into the reservoirs (or directly onto driving electrodes for devices without reservoirs).

Droplet motion was managed using an automated control system with a measurement circuit depicted in Figure 1. Briefly, a computer running a custom LabVIEW (National Instruments, Austin, TX) program* interfaced to a digital/analog switching board (DAQPAD 6507, National Instruments) controls the states of 96 high-voltage relays (RT424012F, Tyco Electronics, Berwyn, PA) via dedicated transistors and comparators. The 96 relays are arranged into 48 pairs (S1 and S2) configured to designate three states: high-voltage (S1: off, S2: on), ground (S1: on, S2: off) or float (S1: off., S2: off). (High-voltage driving potentials of 140-150 V_{rms} were generated by amplifying a sine-wave output of a function generator operating at 15 kHz.) The outputs of each pair of relays are mated to contact pads on the bottom plate of a device via a 40-pin connector (Compar Inc., Burlington ON). To minimize capacitive coupling between driving signals, every second pin on the 40-pin connector is grounded. The un-patterned top plate is connected to the measurement circuit (see Figure 1) via an alligator clip, and the feedback voltage, V_{feed}, is connected to the computer via a digital/analog converter and a voltage sensor (NI 9221, National Instruments). In practice, the user inputs a series of desired droplet movement steps into the control software, after which all droplet actuation is controlled automatically by the system.

* The control program is included with the online supplementary materials for this paper. Readers are welcome to use and revise the program for their purposes; please cite this paper in any publications describing its use. Questions can be directed to the corresponding author.

Table S1. Digital microfluidic devices

	Electrode pattern	Reservoir electrode size	Driving electrode size	Spacer height	Droplet volume
Device 1		N/A	3 mm	140 µm	~1.3 µL
Device 2		4 mm	2 mm (dispensing), 3 mm (mixing)	70 µm	~1.1µL (reservoir), ~0.3 µL (dispensed), ~0.6 µL (merged)

References

1. H. Yang, V. N. Luk, M. Abelgawad, I. Barbulovic-Nad and A. R. Wheeler, *Anal Chem*, 2009, 81, 1061-1067.