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Design Automation of Microfluidic Droplet Sorting Platforms

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1 INTRODUCTION

Both basic research and biological design require high throughput screening to parse through the massive amounts of variants generated in experiments. However, the cost and expertise needed for use of such technology limit accessibility. Simple and reproducible designs of a sorting platform would reduce the barrier for implementation of affordable bench-top screening platforms. Droplet microfluidics present a promising approach for automating biology, reducing reaction volumes to picoliter droplets and allowing for deterministic manipulation of samples. Droplet microfluidics have been used extensively for high throughput screening and directed evolution [1, 3], yet limitations in fabrication have prevented the characterization needed for a design tool and subsequent widespread adoption. Here, we present a finite element analysis (FEA) model-based design framework for dielectrophoretic droplet microfluidic sorters and its preliminary experimental validation. This framework extends previous work from our group creating microfluidic designs tools, increasing their usability in the lab [4, 6].

2 FEA MODEL OF DROPLET SORTING

Successful droplet sorting is characterized by deflection of the target droplet from the “waste” to “keep” channel (Figure 1). Total lateral deflection is a result of opposing dielectrophoretic (Eq. 1) and Stokes’ drag forces (Eq. 2), where V is the electrode voltage, r_d is the droplet radius, ϵ_{oil} is the oil permittivity, η_{oil} is the oil viscosity, \vec{v}_y is the lateral velocity, and k represents the geometry of the electric field gradient in the y -direction [2]. Droplets are assumed to be solid particles, with the same viscosity and permittivity as water.

$$F_{DEP} = 4k\pi\epsilon_{oil}r_d^3V^2 \quad (1)$$

$$F_D = 6\pi\eta_{oil}r_d\vec{v}_y \quad (2)$$

Upon entering the electrode region, droplets quickly approach terminal velocity (\vec{v}_t), providing an analytical solution to the total lateral displacement of the droplet, assuming that the period at terminal velocity contributes to the majority of deflection (Eq. 3). Here, t_r is the residence time of the droplet in the electrode region, determined by the droplet throughput.

$$\Delta y = \vec{v}_t t_r = \frac{2k\epsilon_{oil}r_d^2V^2}{3\eta_{oil}} t_r \quad (3)$$

3 RESULTS

FEA modeling of dielectrophoretic sorting found three distinct regimes of droplet behavior: no deflection, deflection, and model failure, where the force applied prevents further droplet movement (Figure 1). Sweeping across input voltages showed distinct regions that resulted in successful droplet sorting, given an input droplet diameter or throughput (velocity). However, no single voltage was compatible with all parameter combinations. Preliminary experiments have shown similar regions, where high voltage causes failure by merging adjacent droplets. Varying geometric design parameters will change the total lateral deflection required for sorting (w_i and θ_B) or the resistance ratio of the bifurcation (w_{o1} and w_{o2}), which alter the number of streamlines going

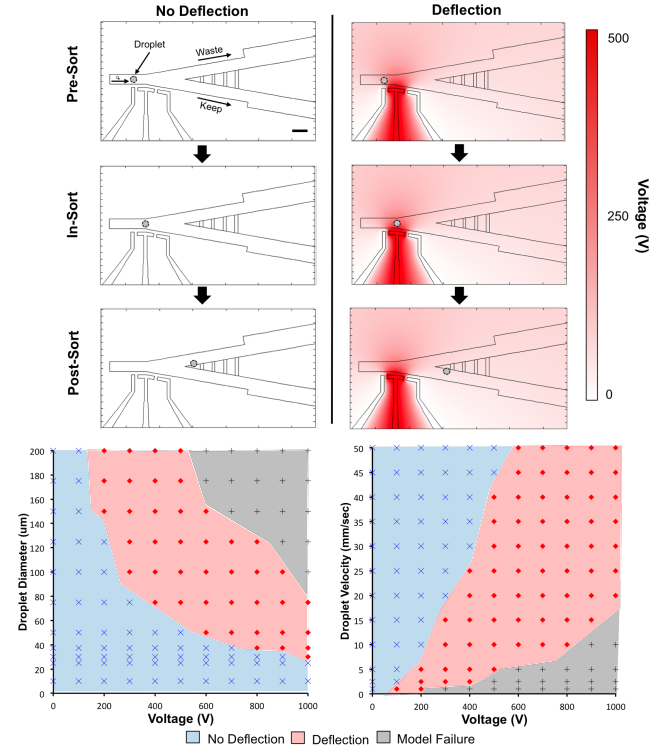


Figure 1: FEA model of droplet microfluidic sorter in different regimes (Top). Effect of voltage, droplet diameter, and velocity on sorter regime (bottom). Scale bar is $250\mu m$.

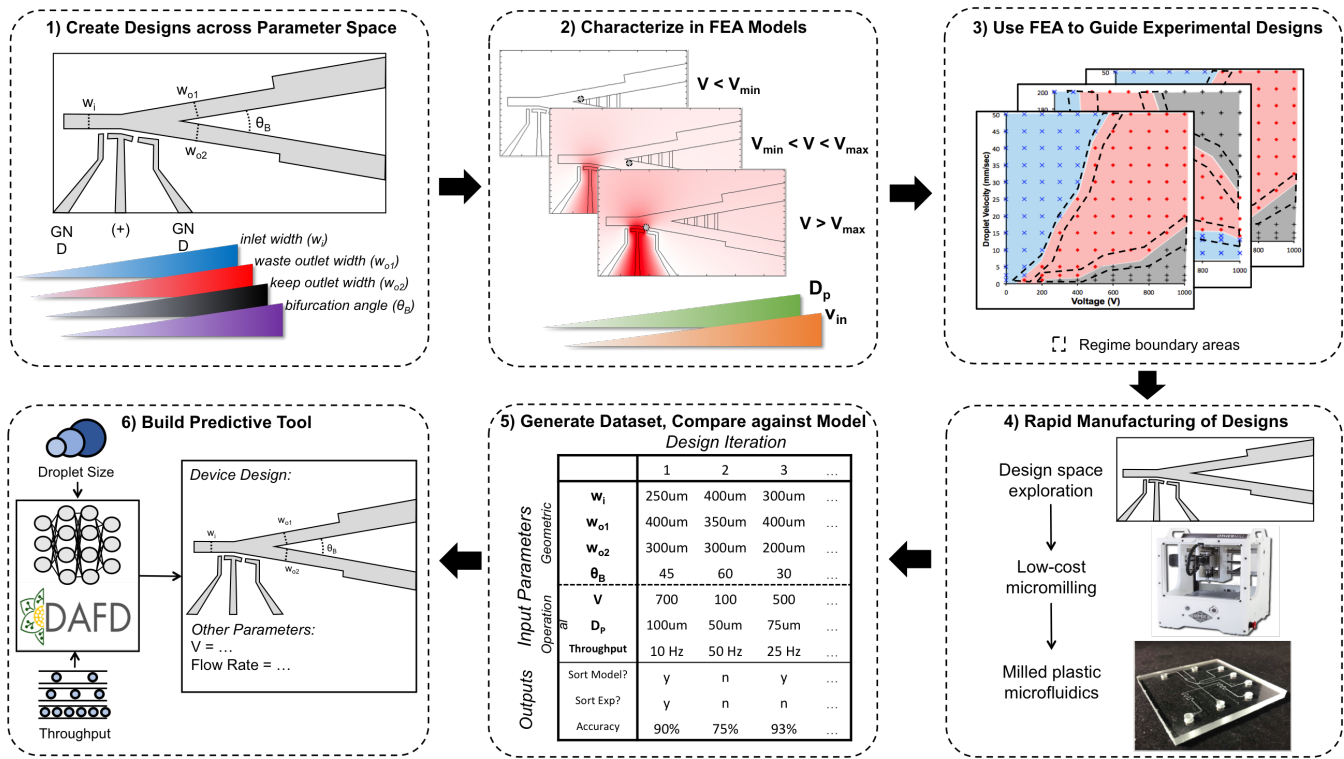


Figure 2: Workflow of design tool development. Designs covering the parameter space (Box 1) will be characterized by an FEA model (Box 2), reducing the parameter space to regime boundaries (Box 3). These designs will be fabricated with CNC milling (Box 4), compared against the FEA model (Box 5), and used to create a predictive tool based on machine learning (Box 6).

into each channel (Figure 2, Box 1). These initial results highlight the need for a design tool capable of predicting sorter behavior given user specifications.

4 CONCLUSIONS AND FUTURE WORK

This design framework will help guide development of a design automation tool for microfluidic droplet sorting and downstream integration into screening platforms (Figure 2). Further experimental characterization of the design space is needed to assess the FEA model accuracy and validity of simplifying assumptions. Rapid, affordable microfluidic fabrication with CNC milling developed in our group enables collection of the data sets necessary for predictive models, not feasible with standard photolithographic methods [5]. Once developed, this tool will take user-specified droplet size and throughput and return the variable parameters needed for successful, accurate sorting, compatible with the user’s detection system of choice. A design automation tool for droplet microfluidic sorting combined with a low-cost fabrication method would enable miniaturization of screening platforms onto the bench-top, increasing accessibility of synthetic biology to non-experts.

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REFERENCES

- [1] AGRESTI, J. J., ANTIPOV, E., ABATE, A. R., AHN, K., ROWAT, A. C., BARET, J.-C., MARQUEZ, M., KLIBANOV, A. M., GRIFFITHS, A. D., AND WEITZ, D. A. Ultrahigh-throughput screening in drop-based microfluidics for directed evolution. *Proceedings of the National Academy of Sciences* 107, 9 (2010), 4004–4009.
- [2] AHN, K., KERBAGE, C., HUNT, T. P., WESTERVELT, R. M., LINK, D. R., AND WEITZ, D. A. Dielectrophoretic manipulation of drops for high-speed microfluidic sorting devices. *Applied Physics Letters* 88, 2 (jan 2006), 024104.
- [3] GUO, M. T., ROTEM, A., HEYMAN, J. A., AND WEITZ, D. A. Droplet microfluidics for high-throughput biological assays. *Lab on a Chip* 12, 12 (may 2012), 2146.
- [4] LASHKARIPOUR, A., RODRIGUEZ, C., ORTIZ, L., AND DENSMORE, D. Performance tuning of microfluidic flow-focusing droplet generators. *Lab on a Chip* 19 (2019), 1041–1053.
- [5] LASHKARIPOUR, A., SILVA, R., AND DENSMORE, D. Desktop micromilled microfluidics. *Microfluidics and Nanofluidics* 22, 3 (mar 2018), 31.
- [6] LIPPAI, J., SANKA, R., LASHKARIPOUR, A., AND DENSMORE, D. Function-driven, graphical design tool for microfluidic chips: 3dof. International Workshop on Bio-Design Automation (IWBDA).