Warren J. Baker Endowment
for Excellence in Project-Based Learning
Robert D. Koob Endowment *for Student Success*

CAL POLY

FINAL REPORT

I. Project Title

Fabrication of Microfluidic Devices with Integrated Electronic Components via Dual Extrusion-Based 3D Printing (originally titled: Electrical characterization of proteins and nucleic acids in solution via impedance measurements)

II. Project Completion Date

January 15th, 2019

III. Student(s), Department(s), and Major(s)

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(5) Jonah Holbrook, Biomedical Engineering, Biomedical Engineering

IV. Faculty Advisor and Department

Andres Martinez, Chemistry & Biochemistry

V. Cooperating Industry, Agency, Non-Profit, or University Organization(s)

N/A

VI. Executive Summary

Microfluidics channels as small as 50 µm in width were produced via extrusion-based 3D printing. Multi-layered, multi-electrode devices were fabricated with inlaid conductive filament. Electrodes were used for simple electroanalysis of proteins. Prototyping of microfluidics devices via extrusion-based 3D printing may ultimately allow for an easy, cost-effective, high-throughput, high-resolution, and single-step method of rapidly prototyping electronic microfluidic devices, principally suited for use in diagnostics applications.

VII. Major Accomplishments

Current microfabrication techniques typically require complex, labor-intensive processes, and often necessitate the use of clean rooms (i.e., photolithography, soft lithography, metal evaporation & sputtering). An alternative method of economical and rapid prototyping is 3D printing. While there are many examples of 3D printing being used as a prototyping modality (i.e., prosthetics, biomedical implants), it has more recently been applied to the field of microfluidics. Since the current generation of microfluidics devices require the integration of electronic components, we utilized dual extrusion-based 3D printing, thereby allowing for the prototyping of multi-material microfluidic devices with integrated electronics. To our knowledge, there is currently no easy method of rapidly prototyping electronic microfluidic devices.

Devices were designed in SolidWorks (modeling software), exported to BCN3D Cura (slicing program), and printed via BCN3D Sigma R17 (dual-extrusion 3D printer). For devices with electronic components, conductive polylactic-acid (PLA) was inlaid within a non-conductive PLA framework to create an internal circuitry.

Functional open-faced microfluidics channels as small as 50 µm in width were produced. However, 200 µm width channels were more highly reproducible (Figure 1). Fully enclosed horizontal (200-500 µm) and vertical (750-1000 µm) channels were also fabricated. Hybrid devices contained both vertical and horizontal channels to create 3D fluidic arrays. Multi-layered electronic devices with multi-electrode microfluidic wells were created (Figure 2) and allowed for simple electroanalysis of proteins (Figure 3). 3D printed electronic circuits were also used to thermally actuate paraffin valves in microfluidics channels, which may allow for greater control of fluid flow within capillary networks. This increased control could be especially important for the automation of complex multi-step assays, which are particularly important in diagnostics applications. Rapid prototyping via dual extrusion-based 3D printing may ultimately allow for an easy, cost-effective, high-throughput, high-resolution, and single-step method of rapidly prototyping electronic microfluidic devices, principally suited for use in diagnostics applications.

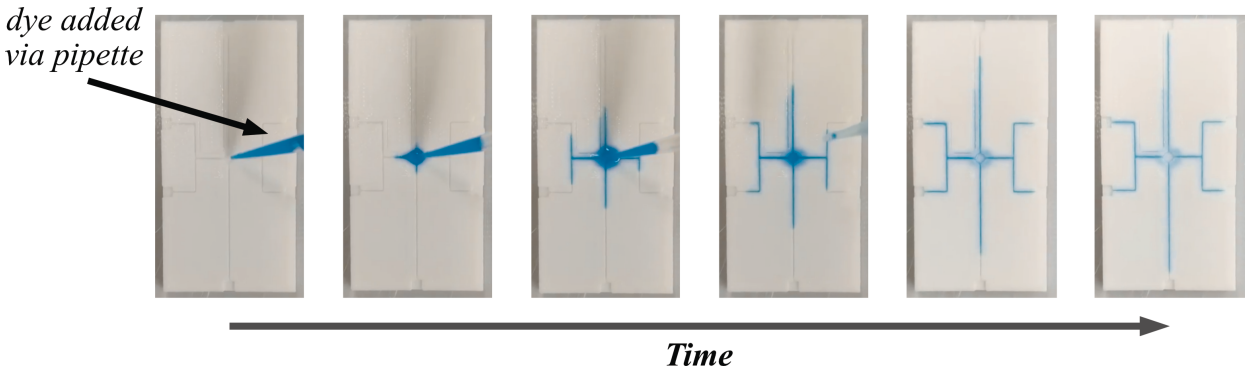

Figure 1. *Photographs of a fully-functional microfluidic channel network (200 µm width) over time (~5 seconds) when 5 µL of blue dye are added. Functional*

channels as small as 50 µm in width were fabricated via extrusion-based 3D printing.

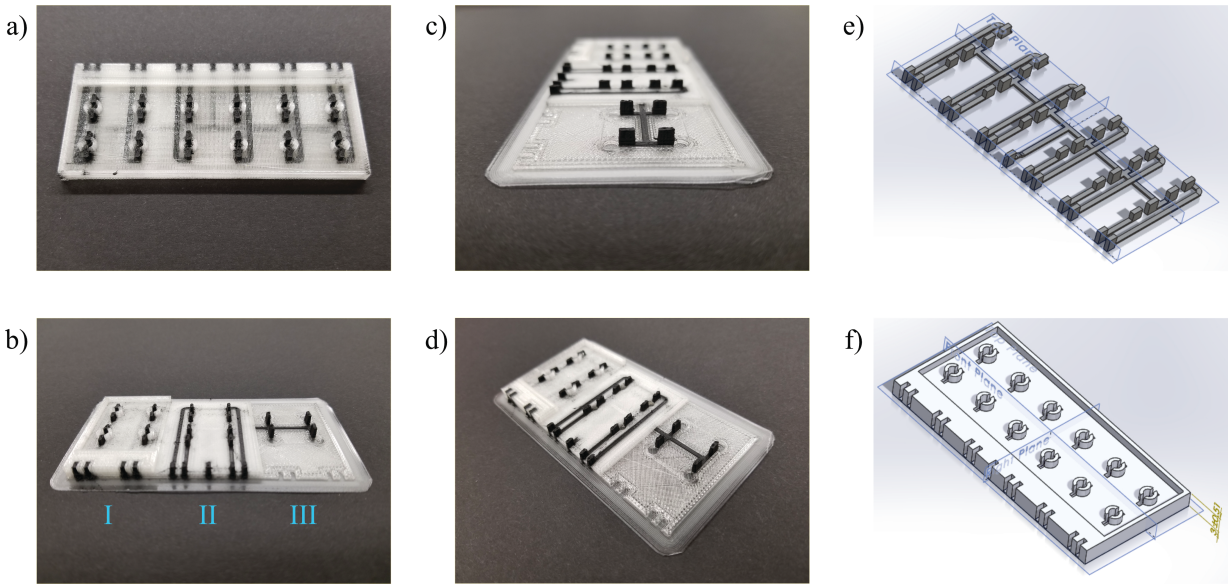

Figure 2. *Photographs and diagrams of multi-layered, multi-well microfluidic devices with integrated electronic components (made from conductive polylactic acid, cPLA). a) Fully printed device (12 wells with dual electrodes). b) A deconstructed device showing the multi-level electronic components, including complete wells with two electrodes (b-I), cPLA circuit layer (b-II), and the base of the well with ground electrodes (b-III). c-d) Alternate views of deconstructed device displaying print resolution. e-f) Digital diagrams of cPLA circuit (e) and PLA housing (f).*

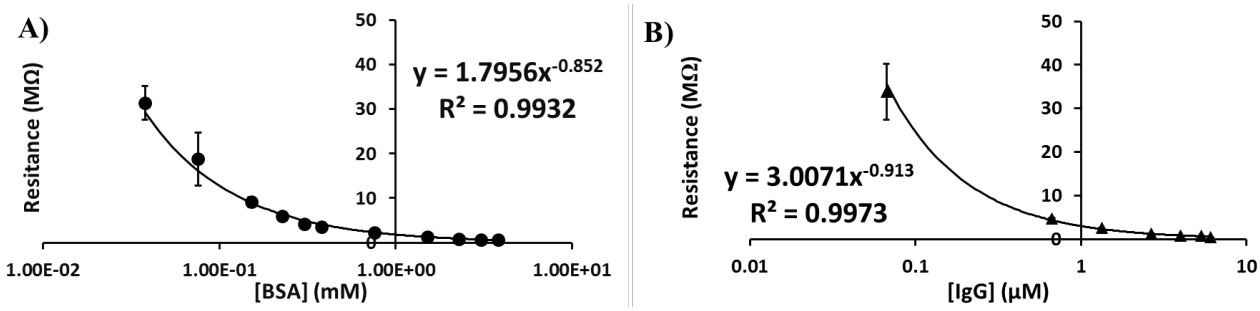

Figure 3. *Simple electroanalysis of proteins performed on 3D printed microfluidic devices with integrated electronics components (Figure 2). Graph of resistance measurements as a function of protein concentration (in nanopure water, n>300 measurements for all data points, n =1 replicates per data point) for both bovine serum albumin (MW = 66 KDa) (A) and mouse Immunoglobulin G (MW = 150 KDa) (B). Protein concentration inversely related to solution resistance (R2 > 0.99). Electroanalysis on these devices may ultimately be utilized in microfluidic diagnostic applications. Error bars = +/- 1 standard deviation. Logarithmic (base 10) scale used on X-axis.*

VIII. Expenditure of Funds

The majority of our funds were spent on a dual-extrusion 3D printer (BCN3D Sigma R17). The remainder of the funds were spent on support materials, including non-

conductive thermoplastics (i.e., PLA & ABS), conductive filaments (i.e., graphite-doped PLA), electronics components (i.e., microcontrollers & solid-state relays), and biological reagents used for simple electroanalysis (i.e., IgG & BSA).

IX. Impact on Student Learning

As STEM undergraduates, we believe that Cal Poly's 'Learn by doing' motto is the most important part of our education experience. While learning in the classroom is important, a motivated student can ultimately learn much of that information independently. Conversely, there is no substitute for the hands-on learning that takes place in a research environment. However, a common issue that interferes with our ability to carry out this type of work is adequate funding. The Baker-Koob Endowment allows us to pursue projects as undergraduate students that would otherwise be impossible.