

Microfluidic Thermal Cycler with Electrowetting

A close-up photograph of a microfluidic thermal cycler. The device features a green substrate with several gold-colored electrodes. Two electrodes are labeled with the number '2'. The electrodes are arranged in a row, and the device is used for electrowetting to control the flow of liquids in microfluidic channels.

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Intent of Project

- Goal: Investigate droplet microfluidics as a method for manipulating 10 microliter scale volumes utilizing electrowetting for the completion of thermal cycling protocols.
- Application: The Polymerase Chain Reaction

Background Overview

- Background: Polymerase Chain Reactions
- Electrowetting: The relationship between surface tension and electric field
- Application to lab protocols

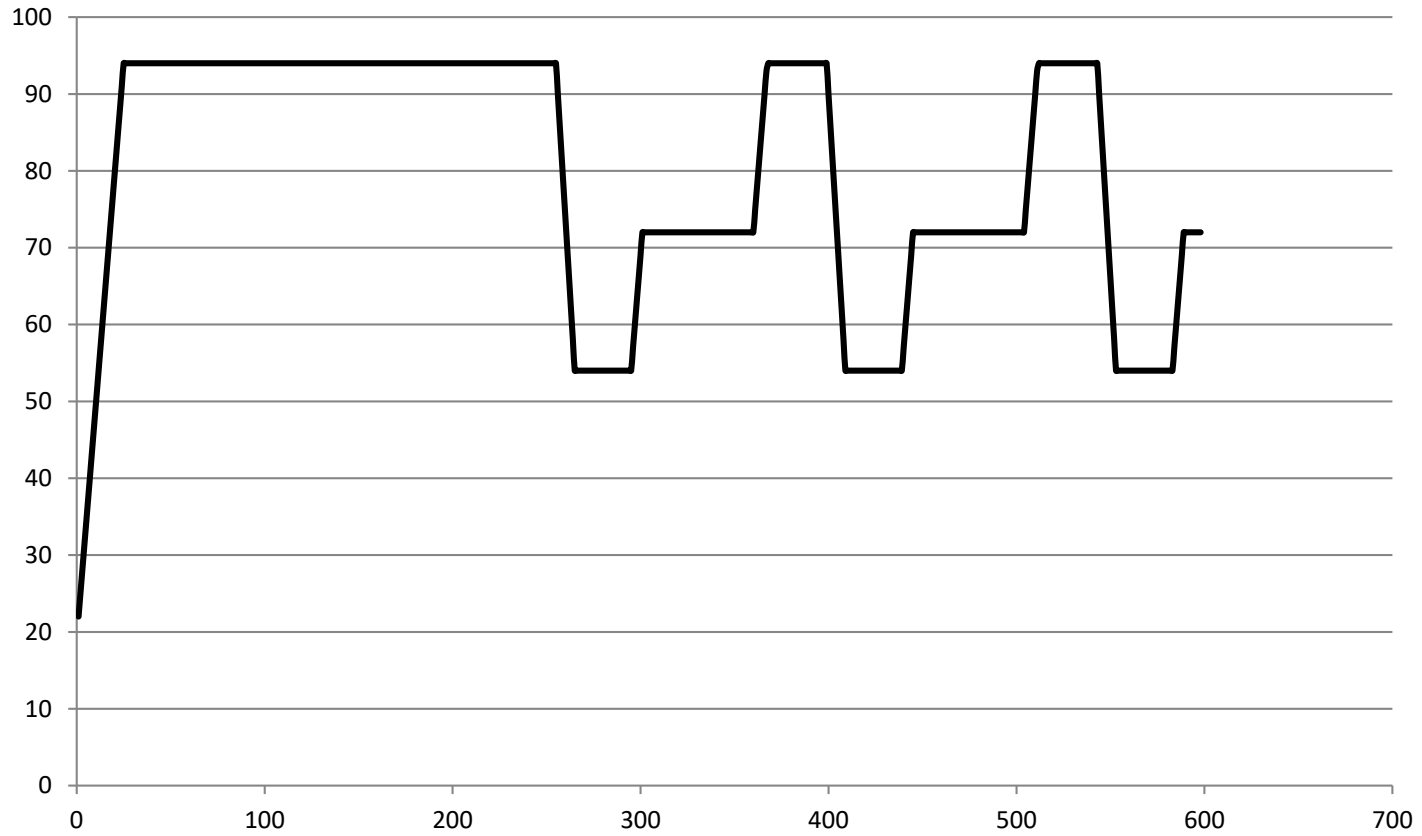
Background

- PCR: method of amplifying DNA segments by repeated melting, reannealing and copying.
- Ubiquitous in medicine and biology
- Typical heating / cooling rates: 3 / 2 °C / s⁻¹

PCR

- Denaturation: 94°C
- Reannealing: $\sim(T_m - 4^\circ\text{C})$
- Extension 72°C
 - Taq polymerase processes $\sim 300 \text{ nt} \cdot \text{s}^{-1}$

PCR Thermal Cycle



Electrowetting

- First described by Gabriel Lippmann in 1875 [2].
- Now being investigated for automation and downscaling of lab protocols.

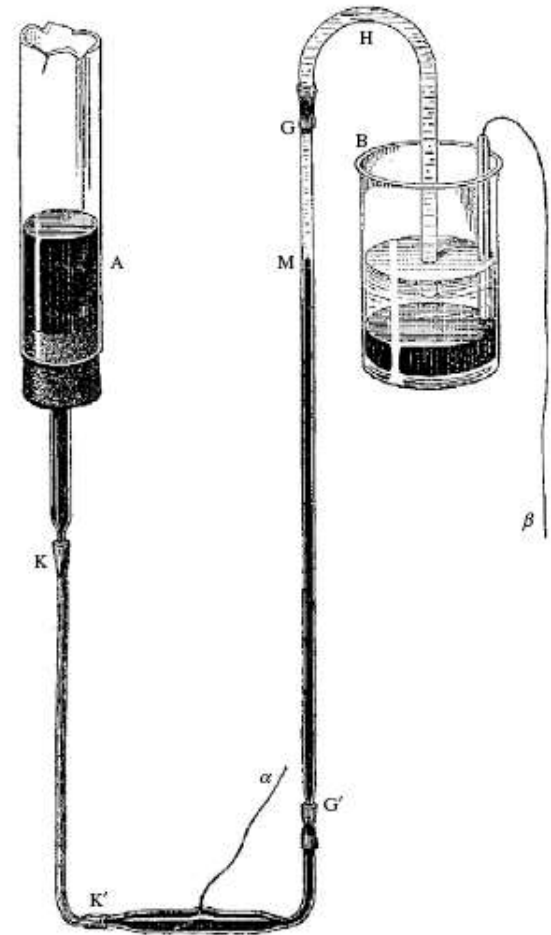
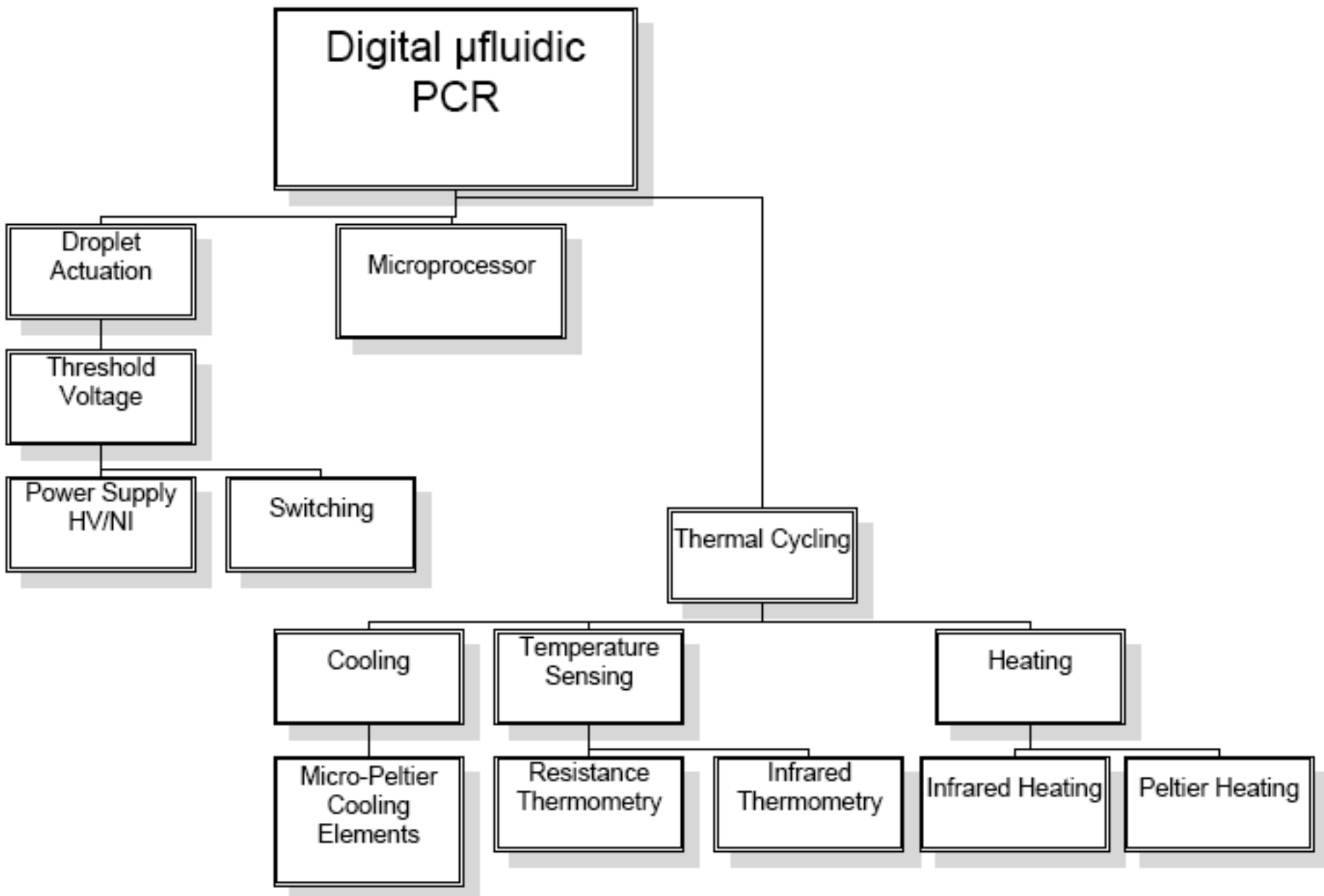


Figure A.1.

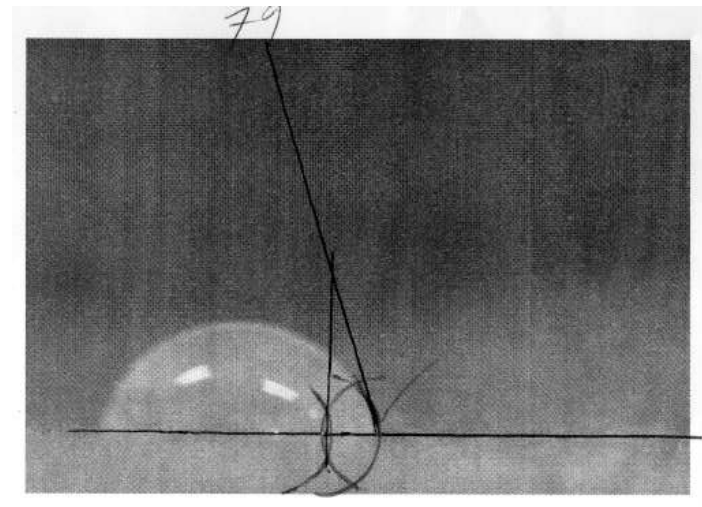
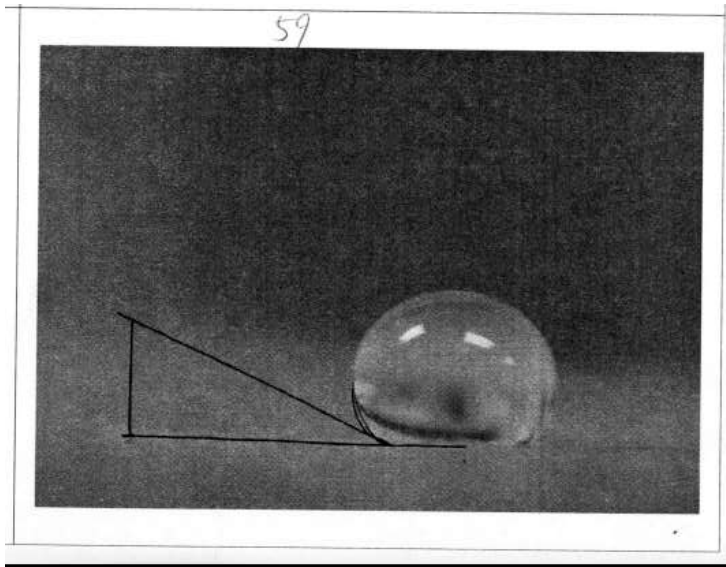
Project Overview

- Requires experiment to determine unknowns: surface hydrophobicity, droplet actuation and heating.
- Project components:
 - Voltage source
 - Switching array
 - Temperature sensing
 - Heating



Surface wettability

- Wettability is the tendency of a liquid to spread out over a surface.
- Contact angles are a method of measured the wettability of a surface, e.g:



Contact angle is related to electric field by the Young-Lippmann eqn.

- Young equation:

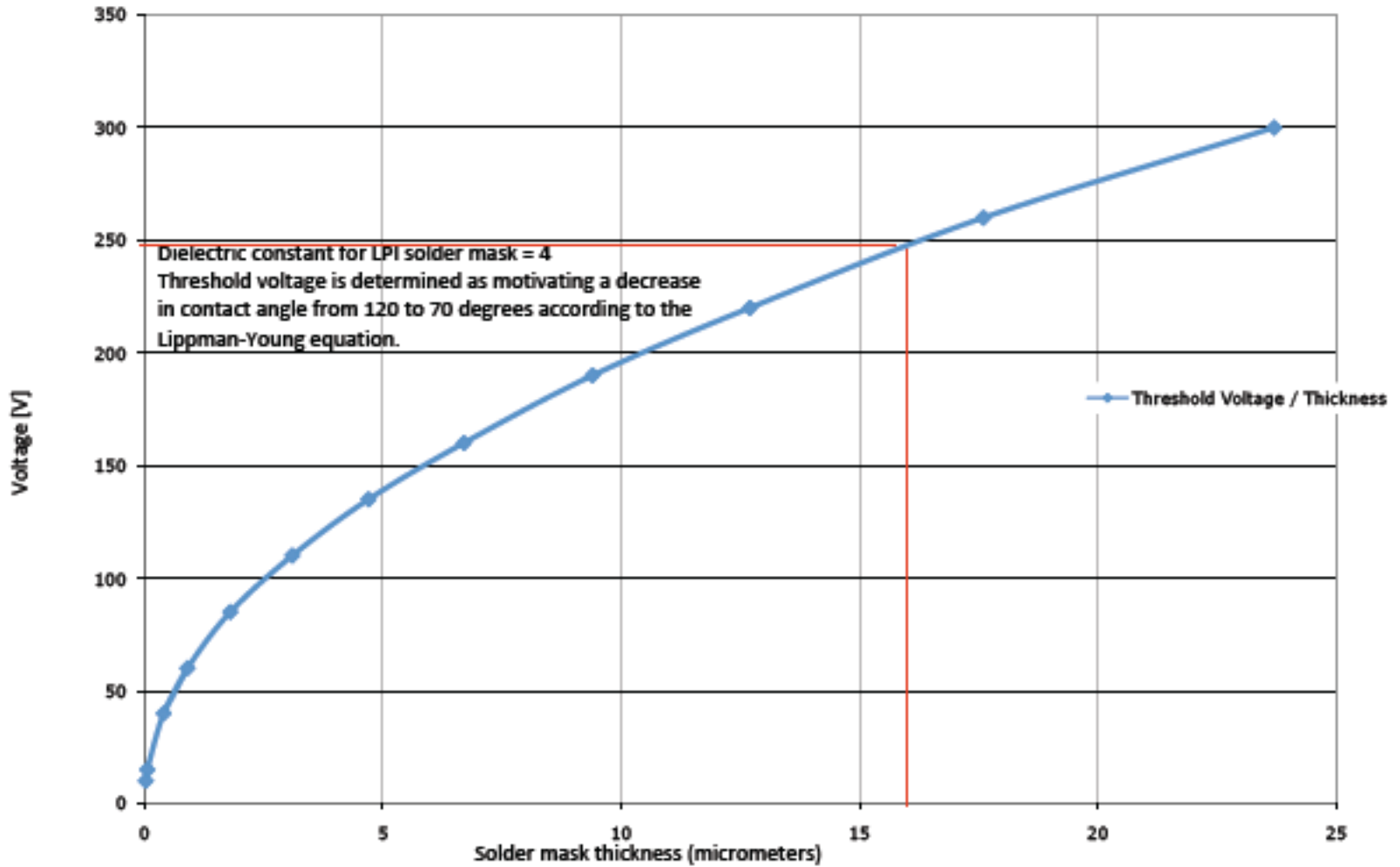
$$\cos \theta_Y = \frac{\sigma_{sv} - \sigma_{sl}}{\sigma_{lv}},$$

- Lippmann-Young equation relates contact angle to electric potential, dielectric strength and thickness:

$$\cos \theta = \cos \theta_Y + \frac{\epsilon_0 \epsilon_d}{2d\sigma_{lv}} U^2 = \cos \theta_Y + \eta.$$

- (Mugele and Baret 2005)

Electrowetting threshold voltage

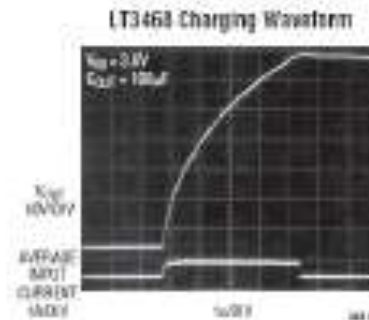
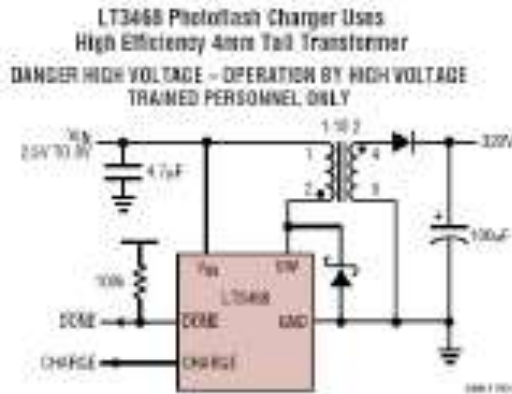


Solder mask thickness from (Paik 2005)

Voltage Source

Power Supply: Produce voltages up to 350V (negligible current)

TYPICAL APPLICATION

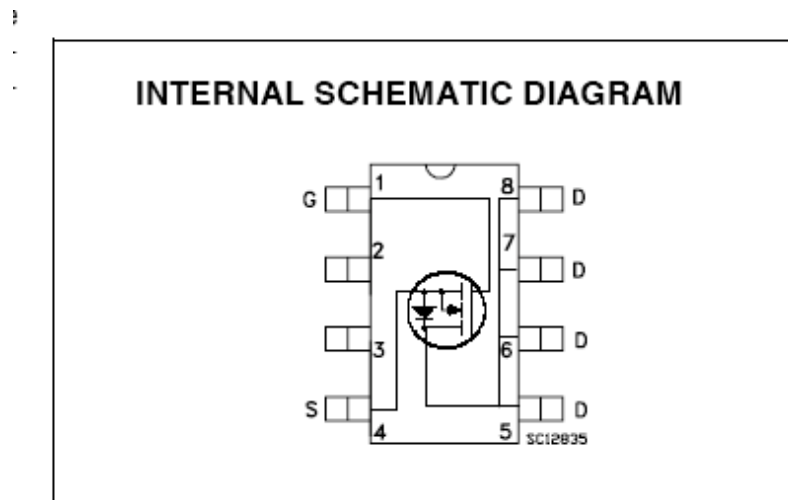


- Voltage depends on transformer turns (from data sheets)

$$N = \frac{V_{OUT} + 2}{31.5}$$

Switching

- STS1HNK60, N-channel MOSFET with $V_{DSMax} = 600V$, logic-level input with Threshold $2.25 < V_{GS} < 3.0$
- 74HC154 Active-low demultiplexer ($V_{OH} \geq 0.95 * V_{DD}$)
- Used 3 input pins for $2^3 = 8$ switch control.



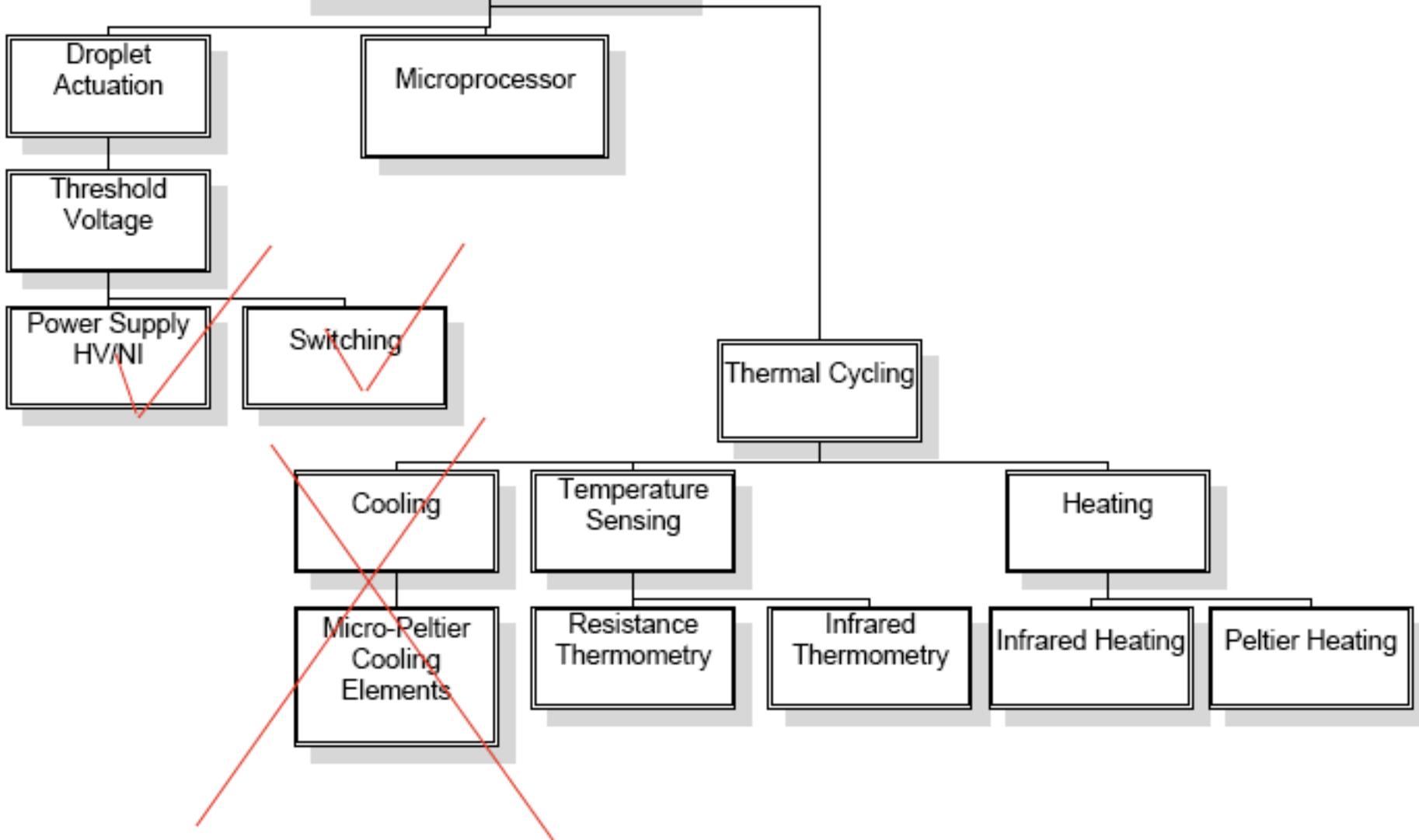
Radiation cooling obviates the need for active cooling

$$J = \sigma T^4 A$$

Stefan-Boltzmann equation

radius (mm)	Δt_{in} (mW)	Δt_{out} (mW)	max cool (mW)	Thermal Capacity (mJ)	T_c (max cool) ($^{\circ}\text{C} \cdot \text{s}^{-1}$)
2.5	52.81152394	80.78620314	27.9746792	0.273973059	24.39
5	211.2460958	323.1448126	111.8987168	2.191784475	12.20
10	844.9843831	1292.57925	447.5948672	17.5342758	6.10

Digital μ fluidic PCR



Non-Contact Infrared Thermometry uses SMBus Serial Communication Protocol

- Derivative of I₂C uses one data line (SDA) and one clock line.
- MLX90614 IR thermometers are individually addressable by unique 7-bit addresses.

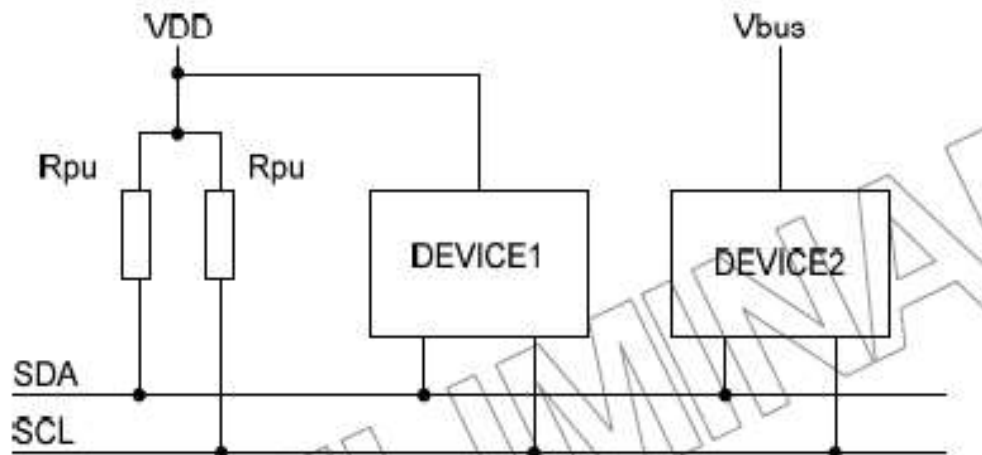
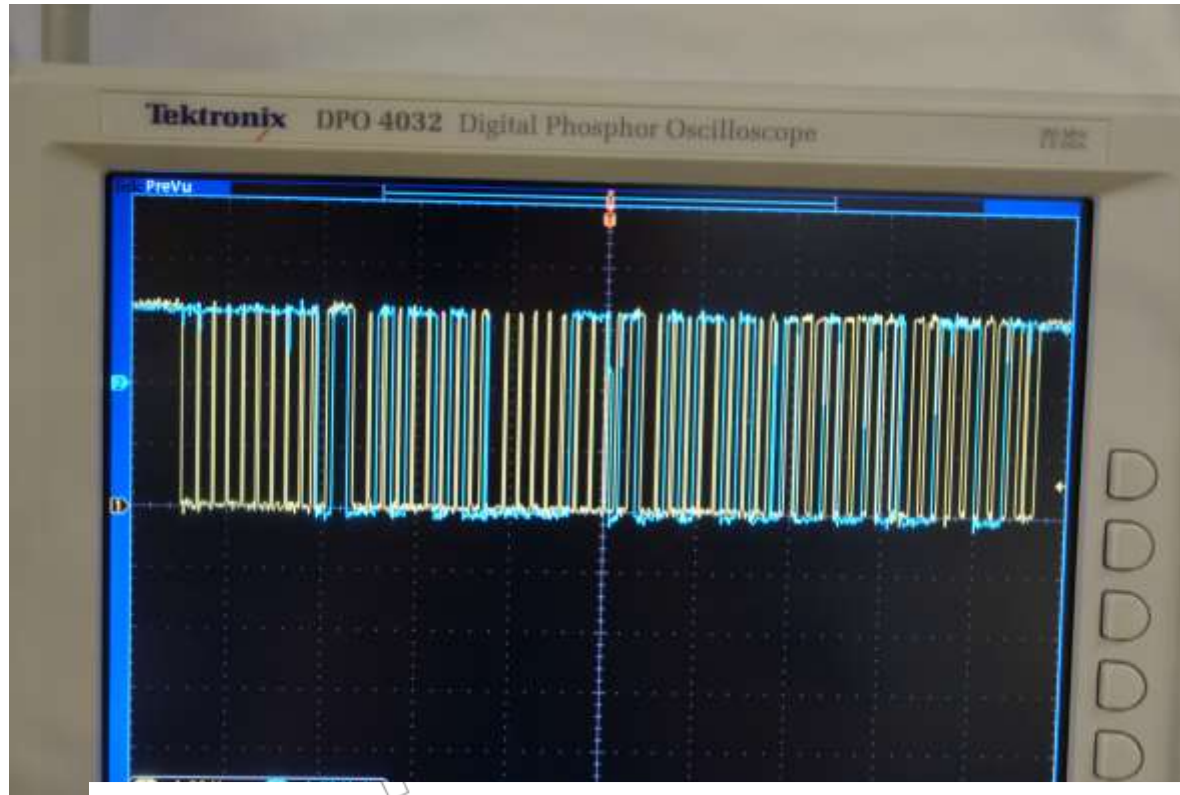
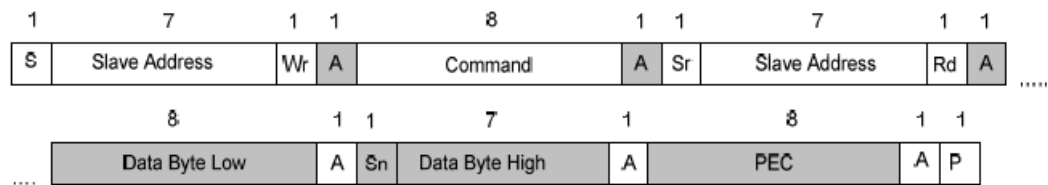


Fig.1: SMBus Topology

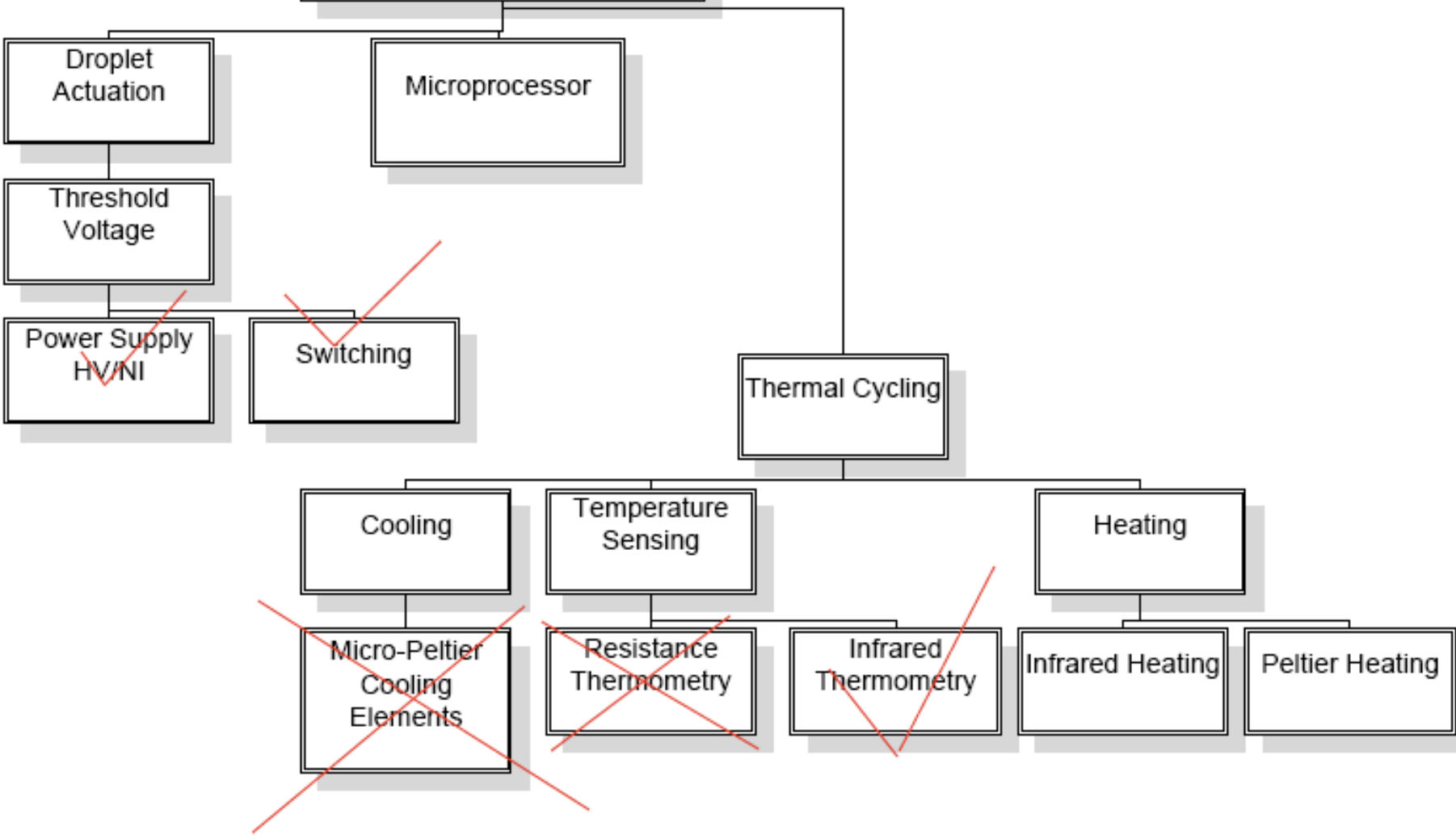
SMBus Communication cont'd



The format of SMBus reading from RAM is:

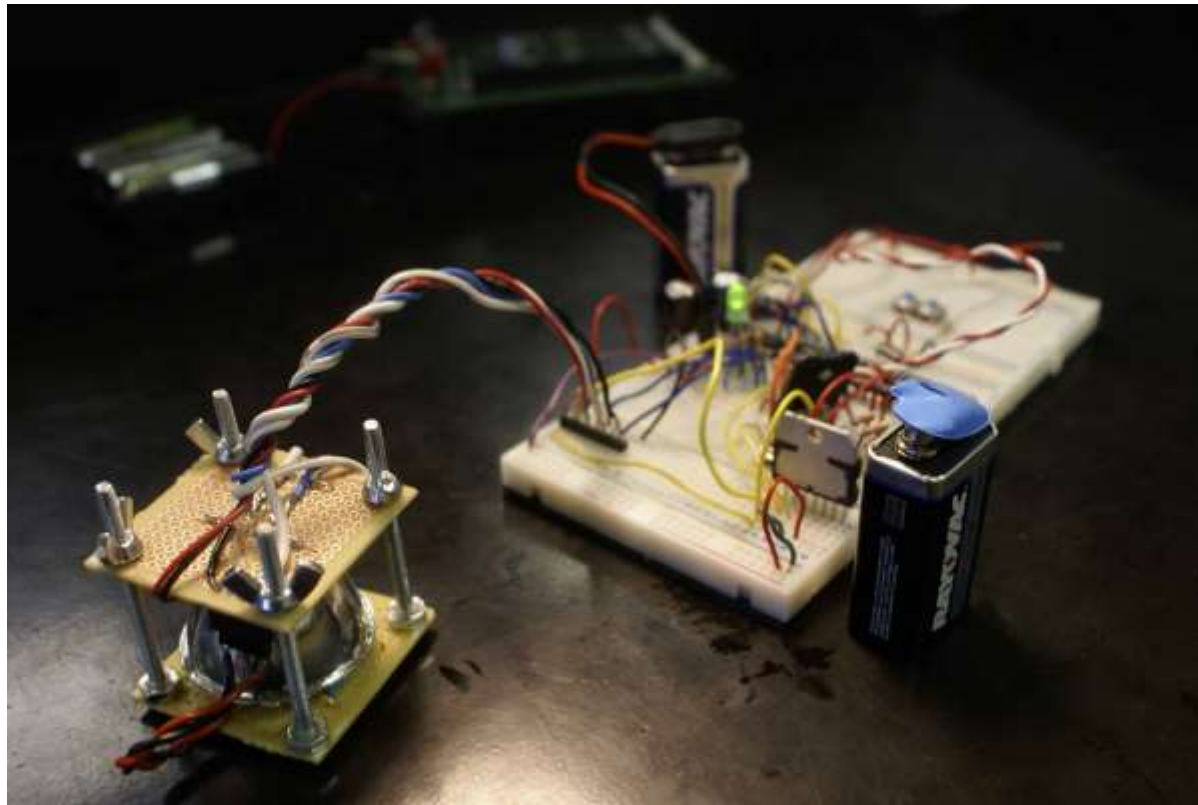


Digital μ fluidic PCR

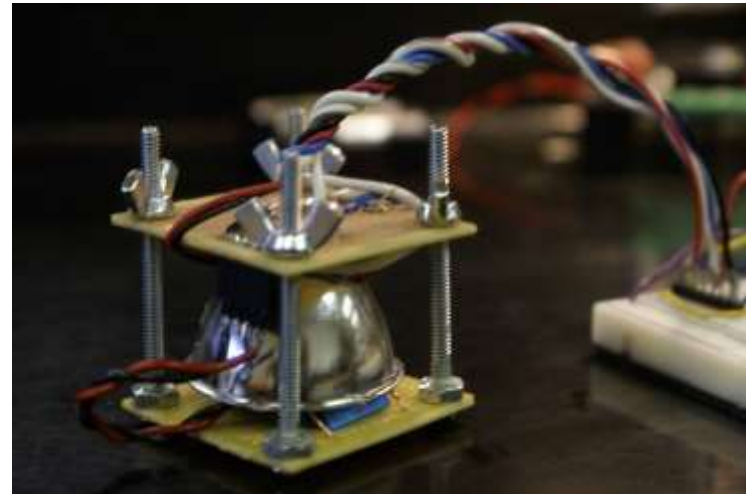
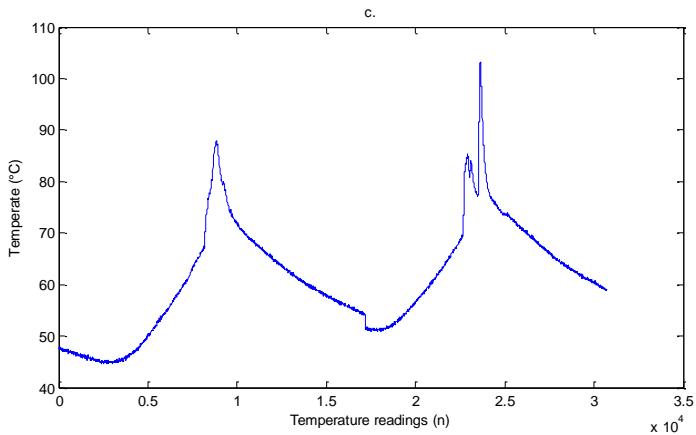
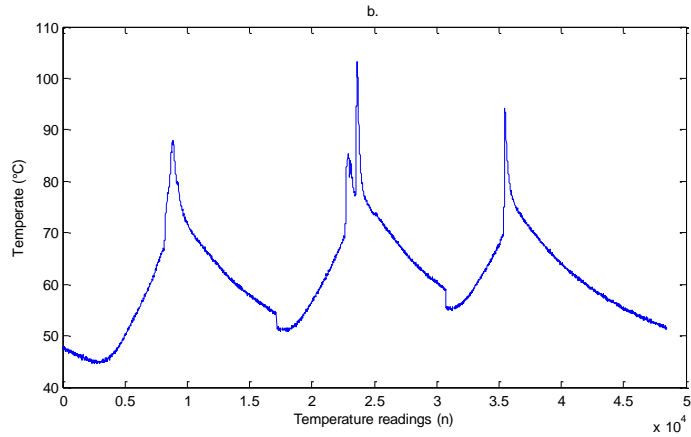
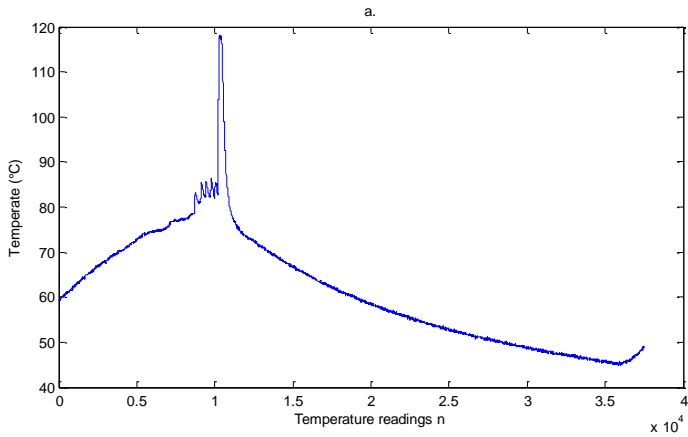


Temperature sensing and heating platform

- An large scale model for a microfluidic thermal reaction chamber

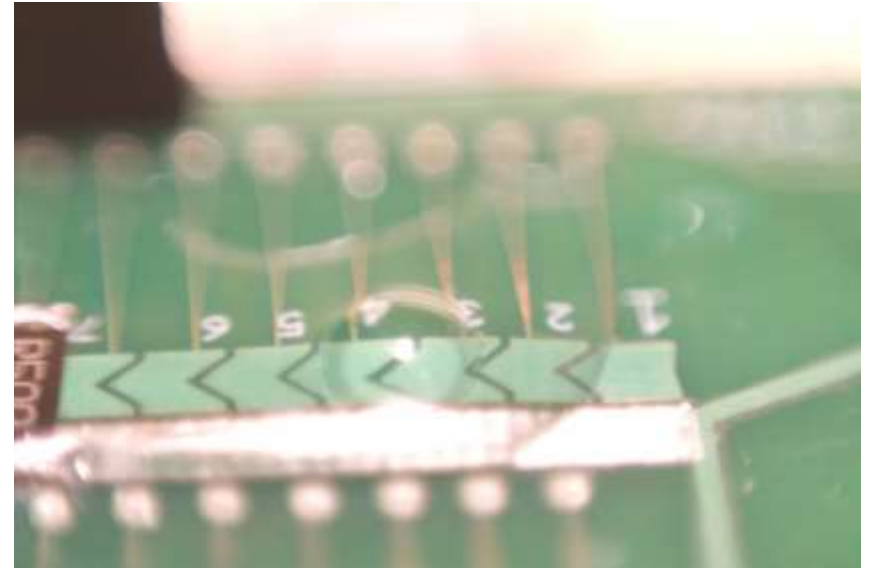
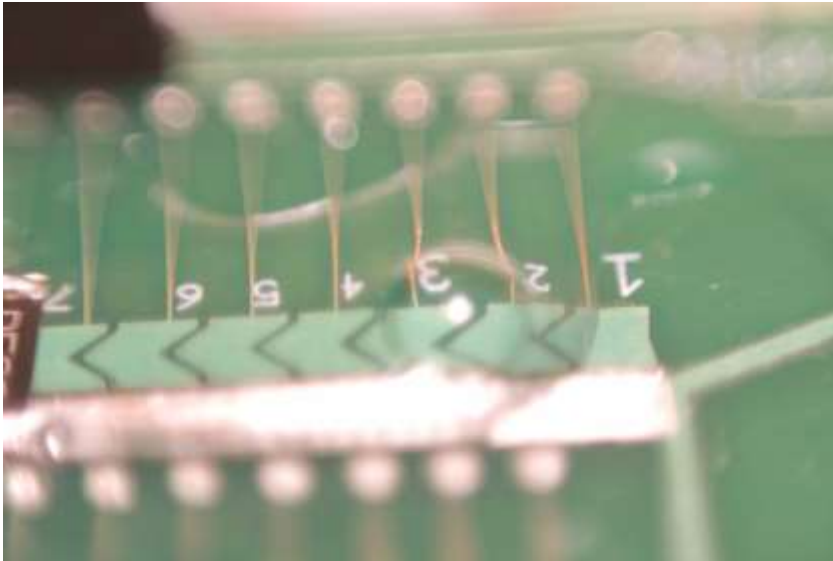


Thermal cycling test results

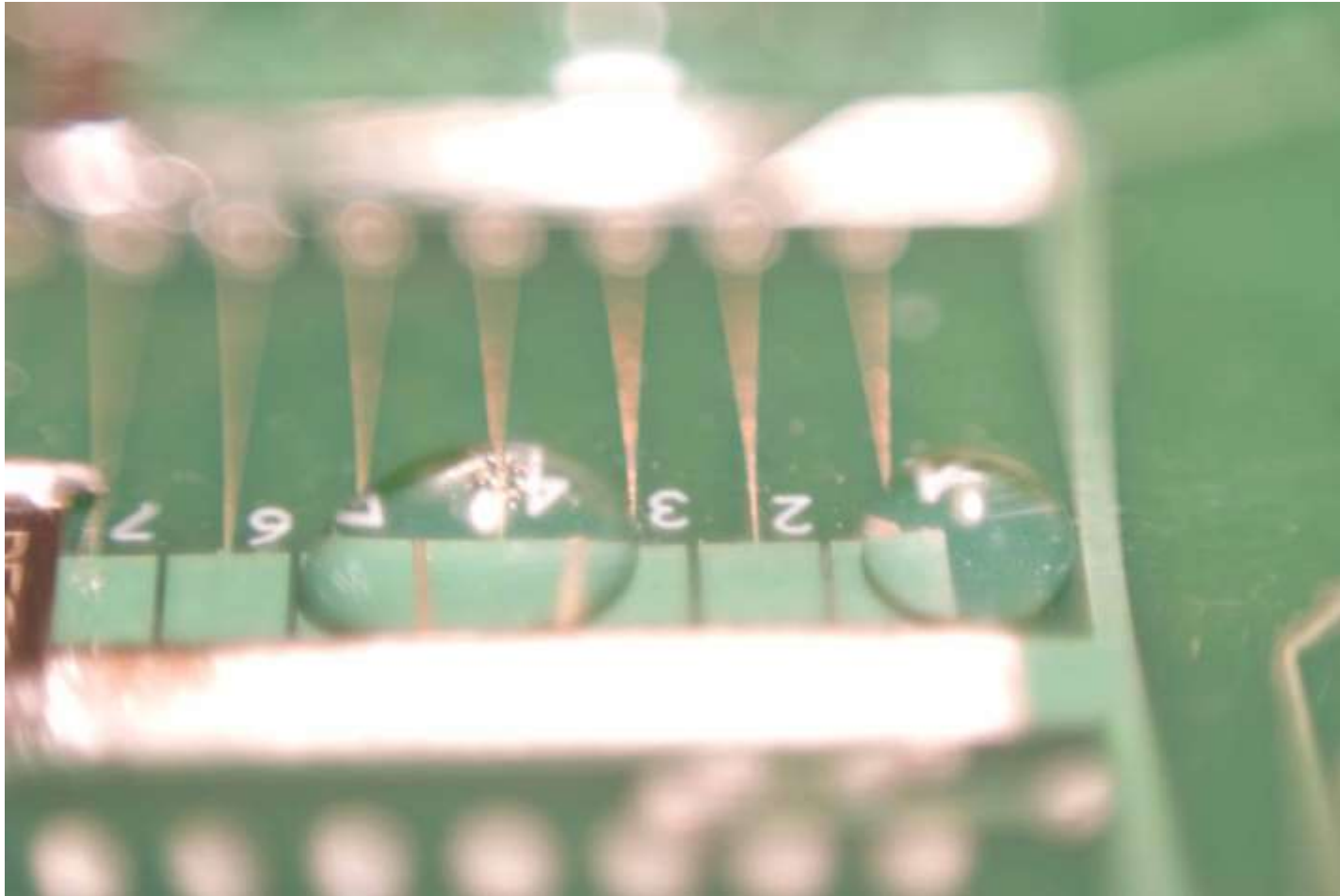


Boiling point at 7200 ft: $\sim 92.7^\circ\text{C}$

Electrowetting



Electrowetting Cont'd



Conclusions

- Inconsistent droplet actuation at ~ 300 V.
- Teflon is an undesirable coating for biological laboratory applications due to cost, licensing, lack of robustness and a lack of adherence to many surfaces, including the solder mask used in this project.
- For low-volume throughput applications such as a typical MOLB lab or rural medical diagnostics, electrowetting represents an unnecessary jump in complexity for PCR.

Acknowledgements

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- [4] Neuzil P, Zhang C, Pipper J, Oh S, Zhuo L. Ultra fast miniaturized real-time PCR: 40 cycles in less than six minutes. 2006. Nucleic Acids Res. 34(11). e77-e86.