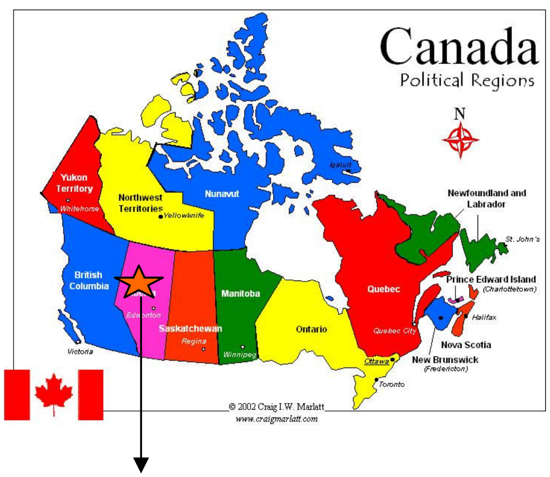
Electrical and Computer Engineering Research Facility




University of Alberta, Edmonton, Alberta

# Optimization of Thin Film Heater/Sensor Design for Miniature Devices Using Finite Element Analysis

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Femlab-2005, Boston

# Need for thin film resistive heaters

- Compatible with microfluidic devices.
- Standard semi-conductor fabrication procedures.
- Very low power consumption.
- Rapid change in temperature
  - both heating and cooling.
- Low thermal mass.
- Precision localized heating.

Peltier elements:
**3-5 °C /second**
Thin film resistive heaters:
**20-50 °C/second**

# Aims and objectives

- Develop a paradigm for thin-film resistive heaters to derive rules for design.
- Parametric study to define the temperature uniformity of the resistive heaters.
- Simultaneous heating and temperature sensing capabilities.
- Precision temperature stability.

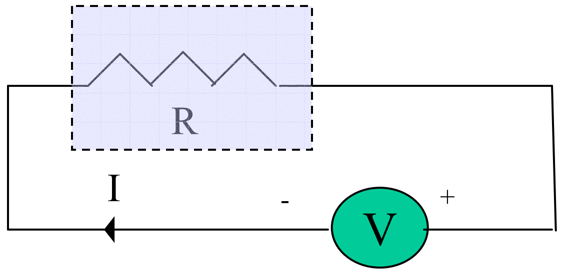
# Applications

- Microfluidic devices for practical medical diagnosis applications.
- Require complex bio-chemical reactions to be catalyzed at precision temperature environment.
- Low-power, portable, economical and localized heating applications.

# Principle of resistive heating

Involves passing a direct current through the film. The power generated due to the resistance is calculated by Ohm's law.

$$P = VI = I^2 R = \frac{V^2}{R}$$




It is assumed that almost all the electrical power generated is dissipated into heat.

$$\nabla^2 T + \frac{q_{gen}}{k} = \frac{\rho c}{k}\frac{\partial T}{\partial t}$$

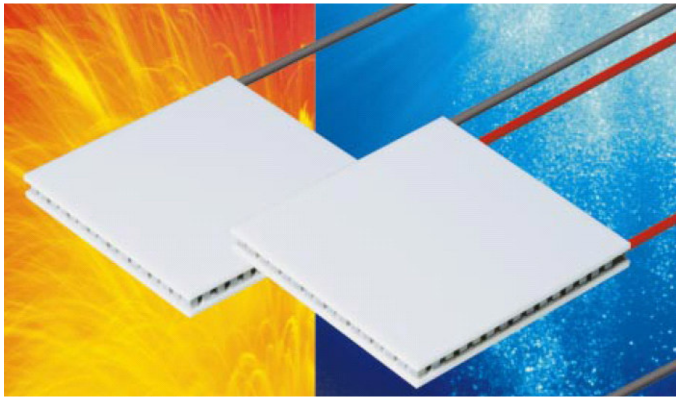
T is a function of location and time,
$Q_{gen}$ is the heat generated per unit volume
K is the thermal conductivity of the material

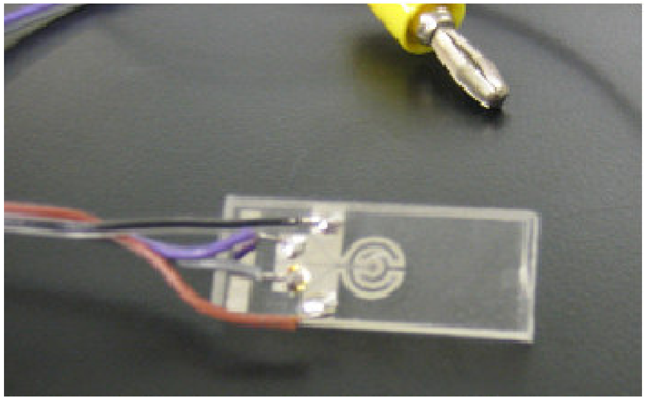
ρ is the mass density of the material.
C is the specific heat of the material.

# Need for finite element analysis

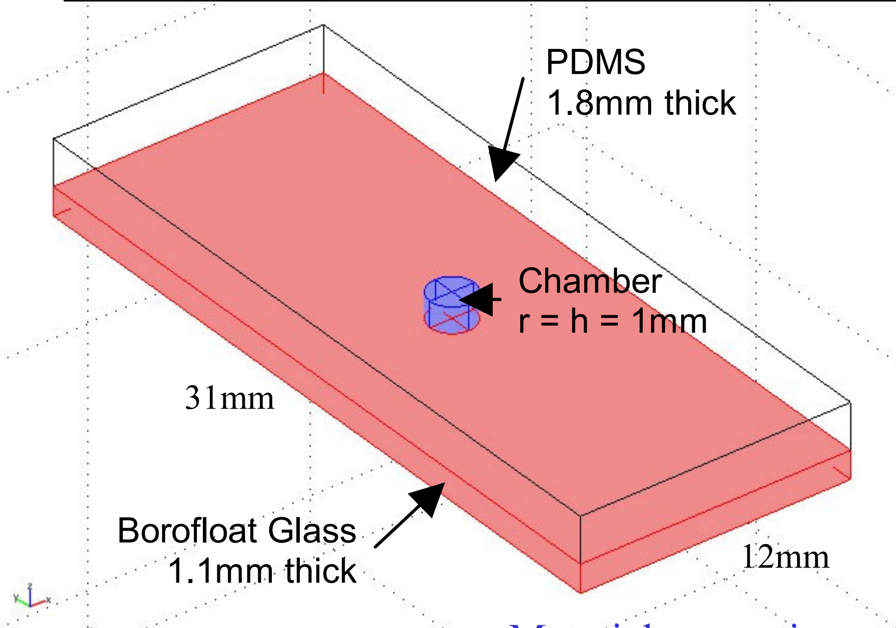
- Not all of the power dissipation is uniform.
- Minor variations of the heat-flux path generates non-uniformities.
- Temperature uniformity is a complex function of the geometry and environment of the thin-film heater.

*First principles modeling would be infeasible!*





# Geometry of representative chip



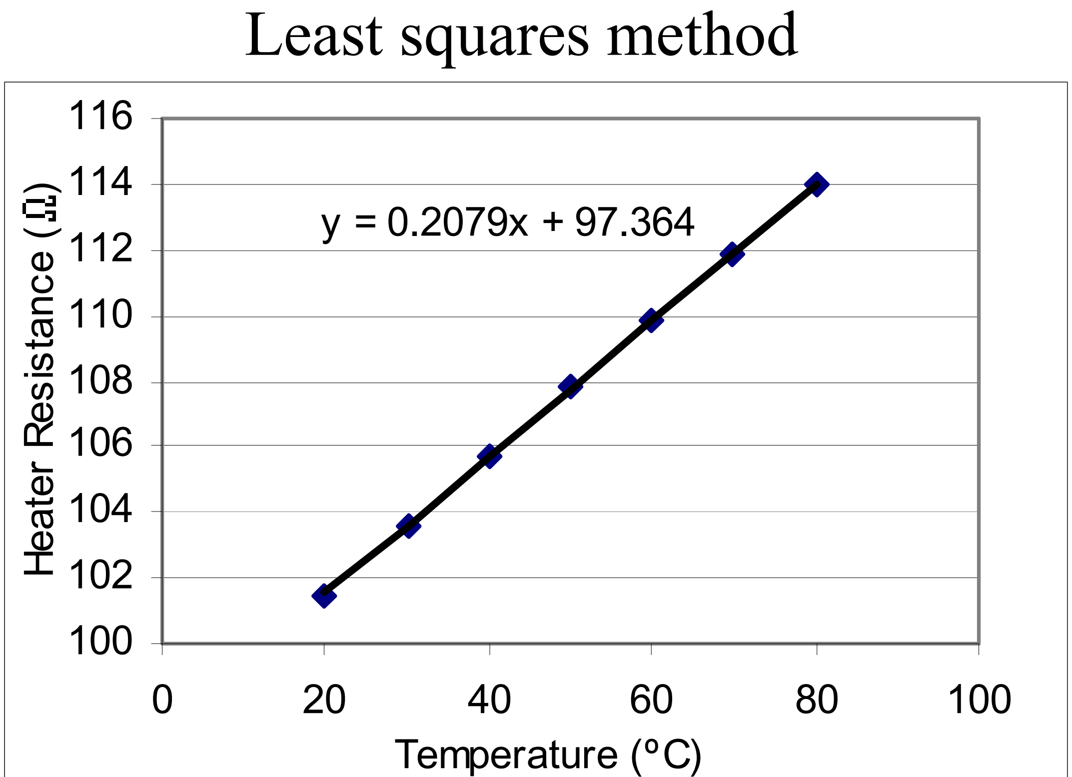

**Boundary Conditions**

- Natural convection and radiation on top surface.
- Constant Room Temperature on the sides.
- Thermal insulation on the bottom surface.

Material properties used in FEA simulations

| Material | Thermal Conductivity (W/m·K) | Specific Heat Capacity (J/kg·K) | Density (kg/m$^3$) |
|---|---|---|---|
| Glass | 1.11 | 830 | 2200 |
| PDMS | 0.18 | 1100 | 1030 |
| Water | 0.58 | 4187 | 1000 |
| Platinum | 72 | 133 | 21500 |

# Calibration experiments



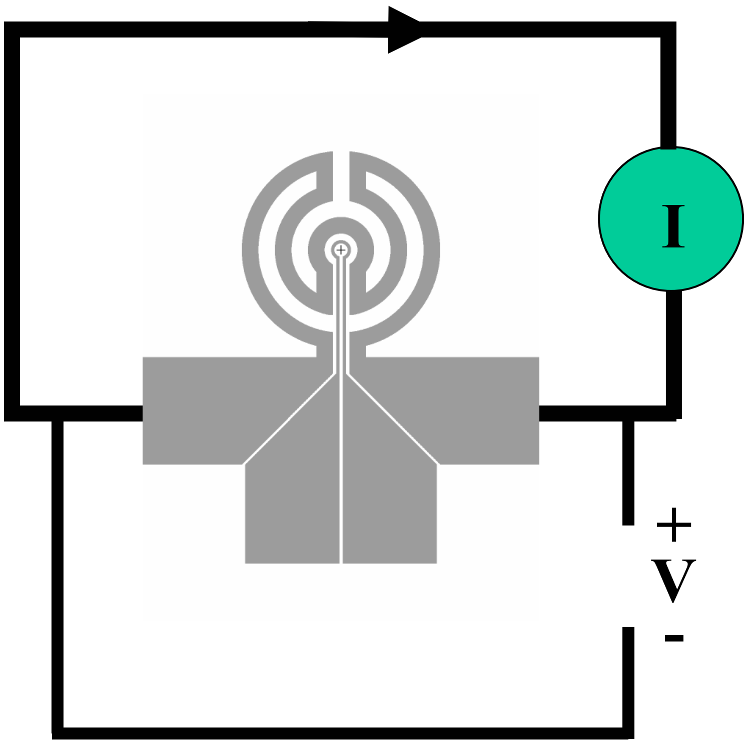

Dependence of resistance on temperature for platinum thin film heater

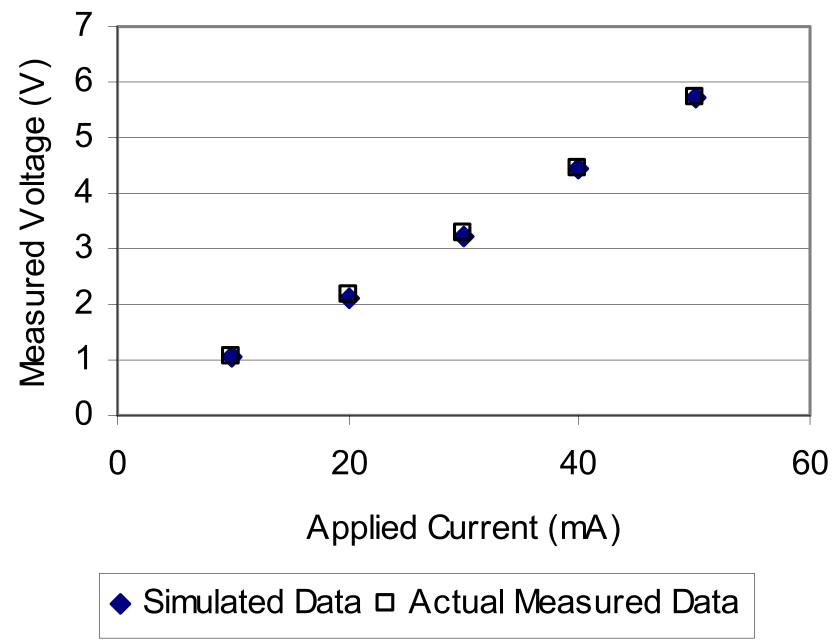
Differs from bulk materials

Resistively = f(temperature)

# Validation Experiments – approach 1

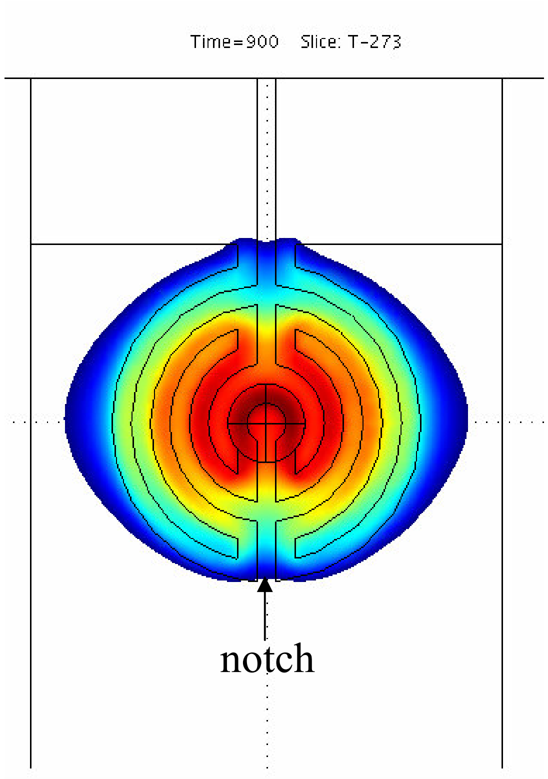
For non-optimized heaters testing was done - Apply a known current and measure the resulting voltage



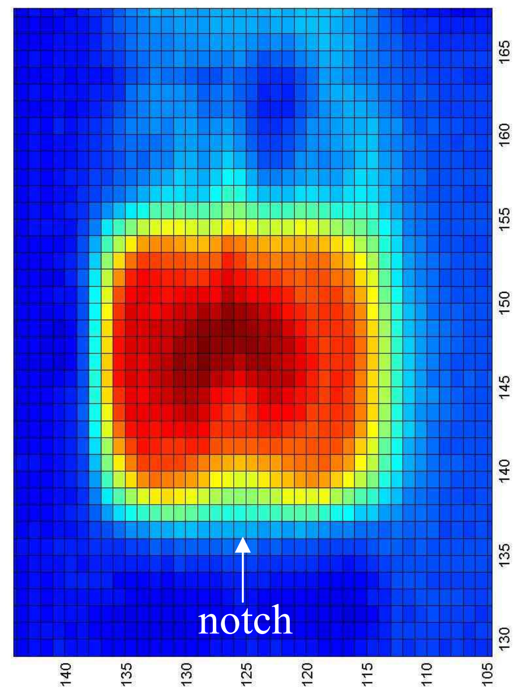




Comparison of simulated and actual measured voltages

# Validation experiments – approach 2

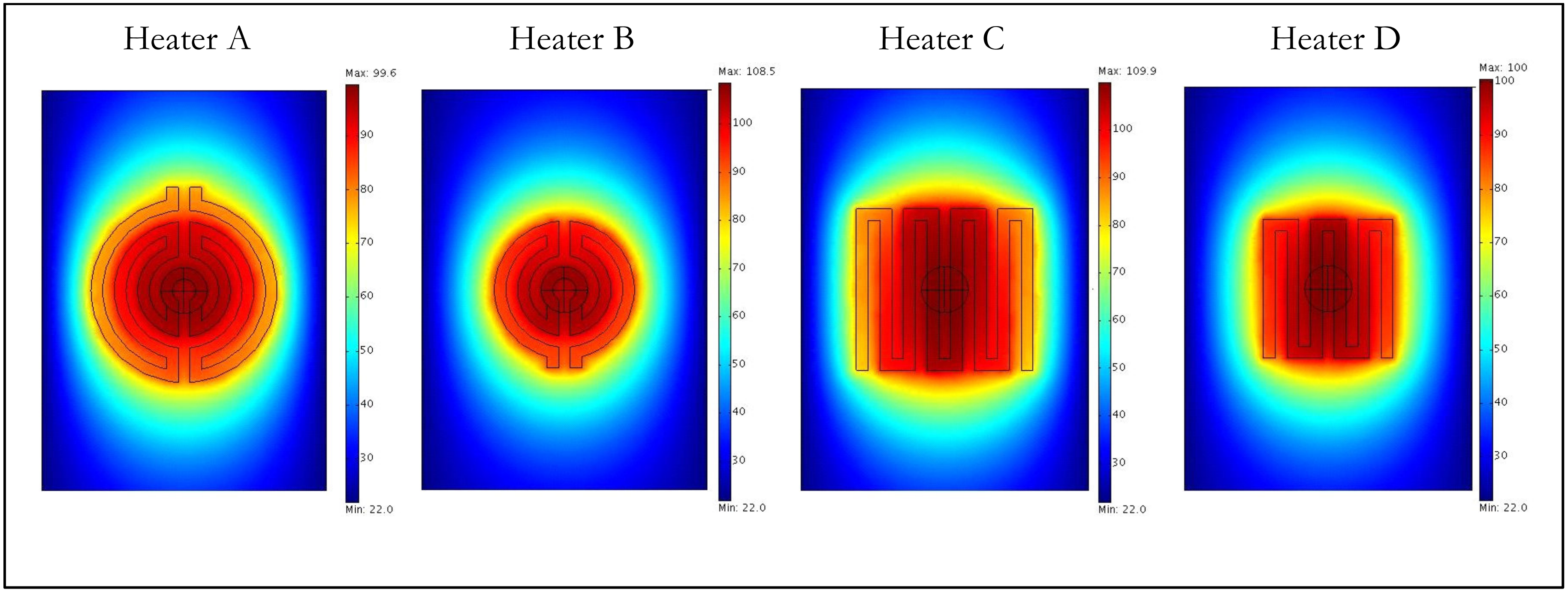



Simulation

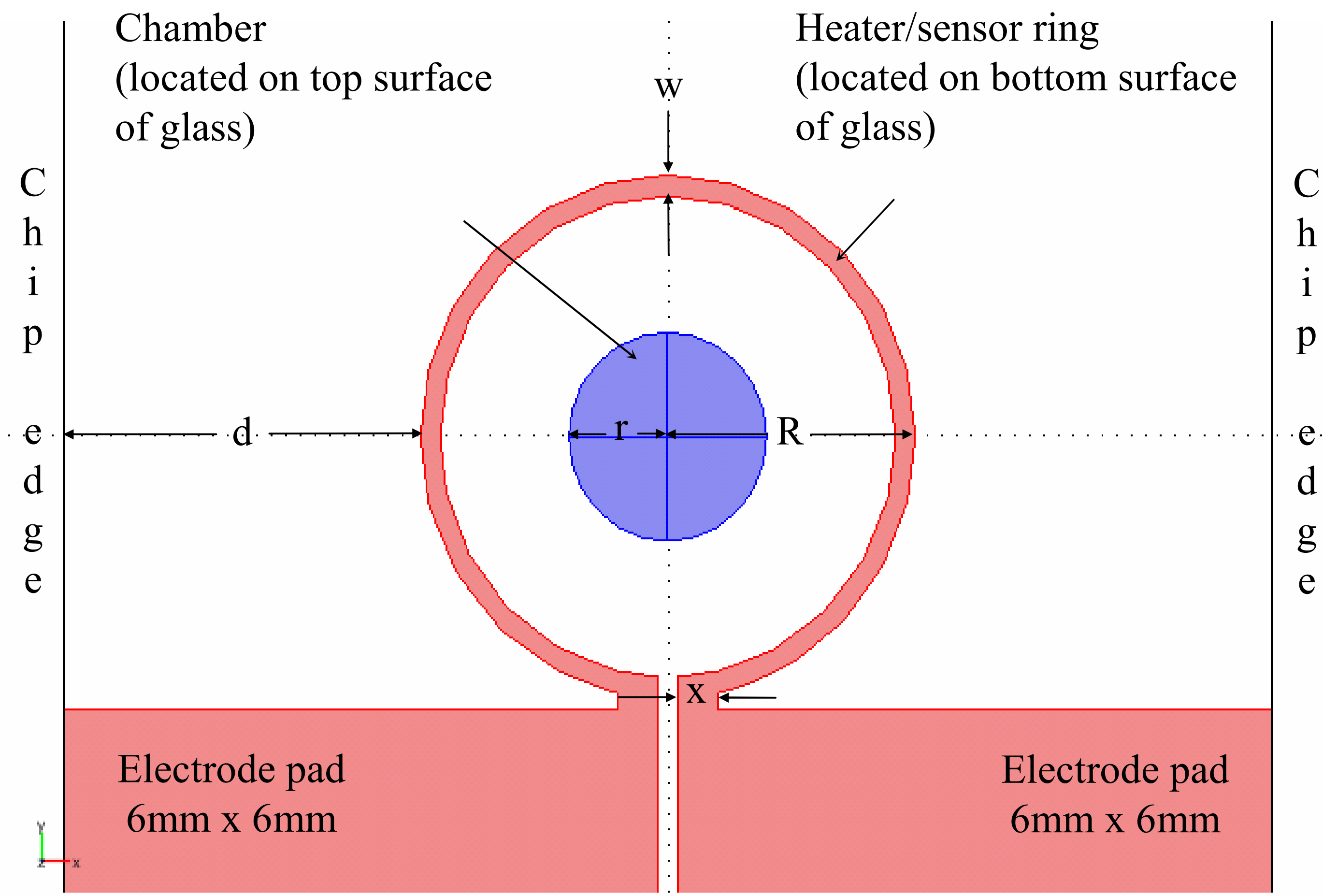



IR image of actual chip

# Simulation outcome with different heater geometries



# Single ring heater/sensor geometry



# Environment

- General heat transfer (htgt) mode of the heat transfer module was used to simulate the heat transfer.
- Lagrange quadratic elements
- 200K -300L dofs.
- The metal film being very thin were modeled using the shell mode in 2D (shell conductive media DC).

# Parametric study

Primarily the temperature dependency is a complex function of -

(a) Electrode pad connection width (x).
(b) Proximity of chip edges (d).
(c) Chamber height (h).
(d) Heater radius (R).

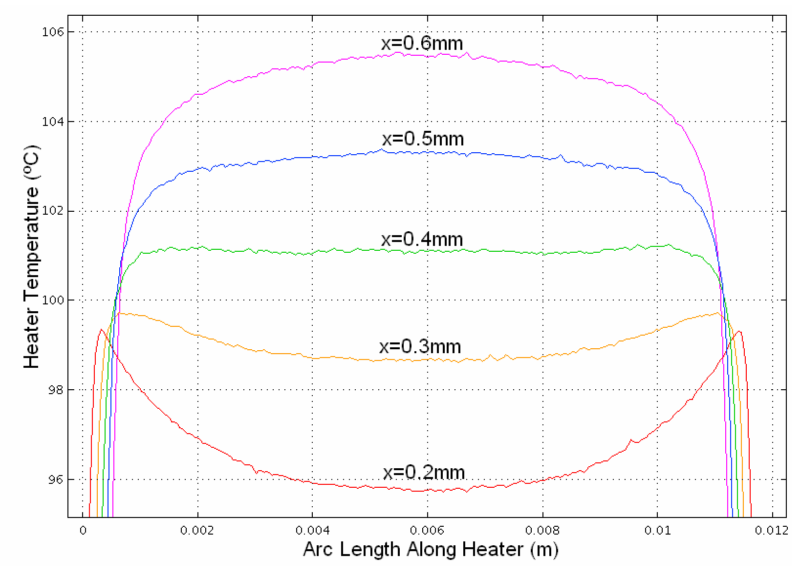
(e) Material used to fabricate the chip.
(f) The temperatures to which the chip is heated.

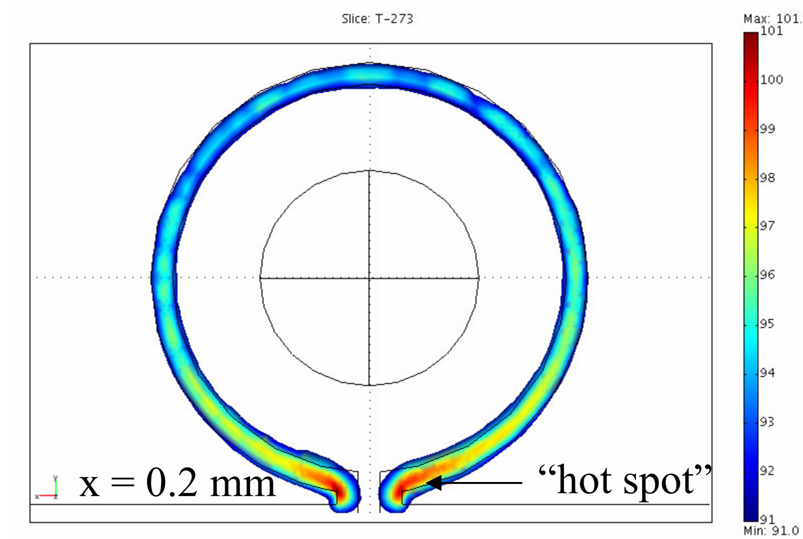
# Requirement-I: Temperature uniformity of the heating/sensing element

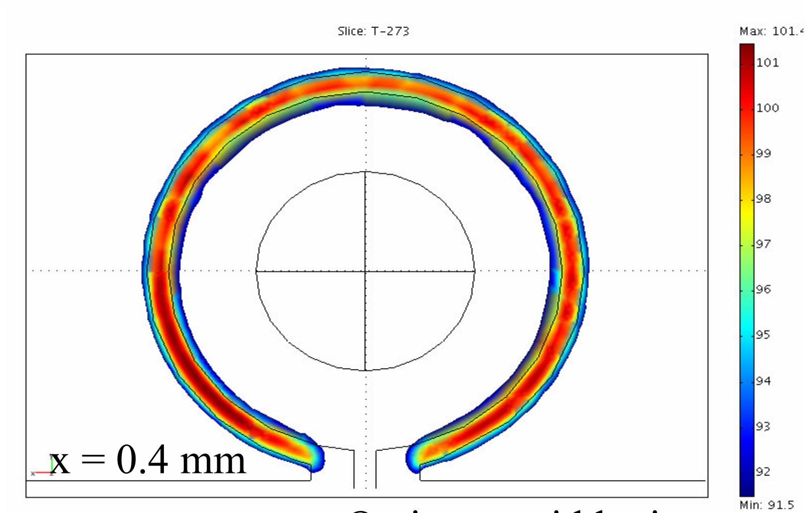
(a) Electrode pad connection width (x).
(b) Proximity of chip edges (d).

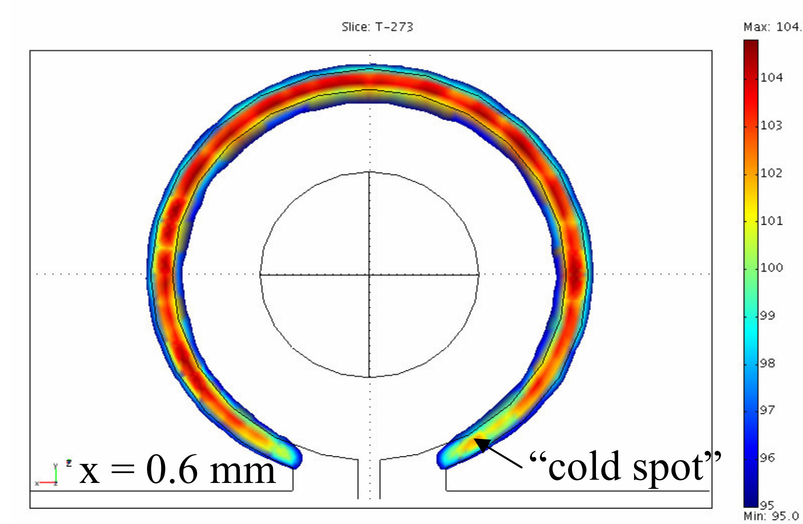
Help avoid using separate elements for heating and sensing!

# Effect of electrode pad connection width (x)



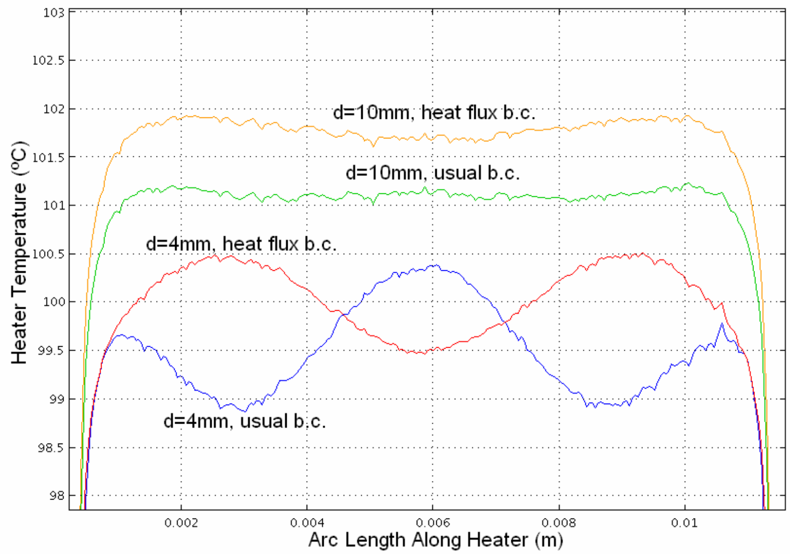



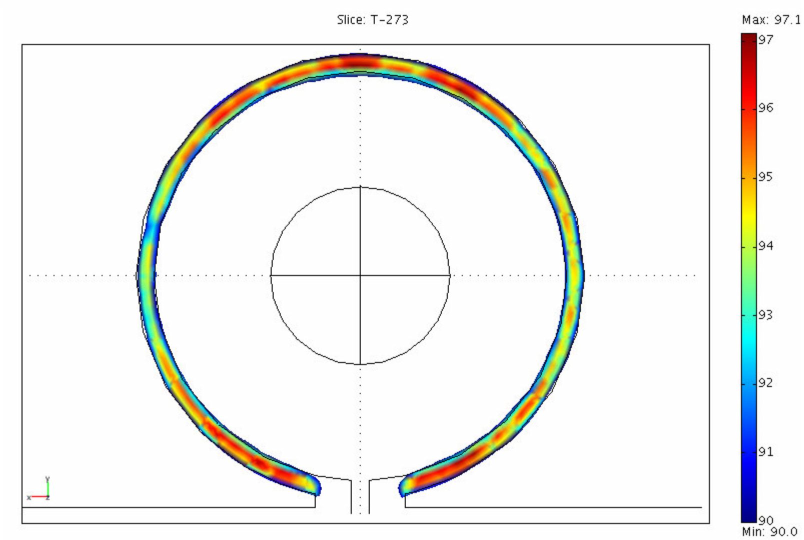




Optimum width gives uniform temperature distribution

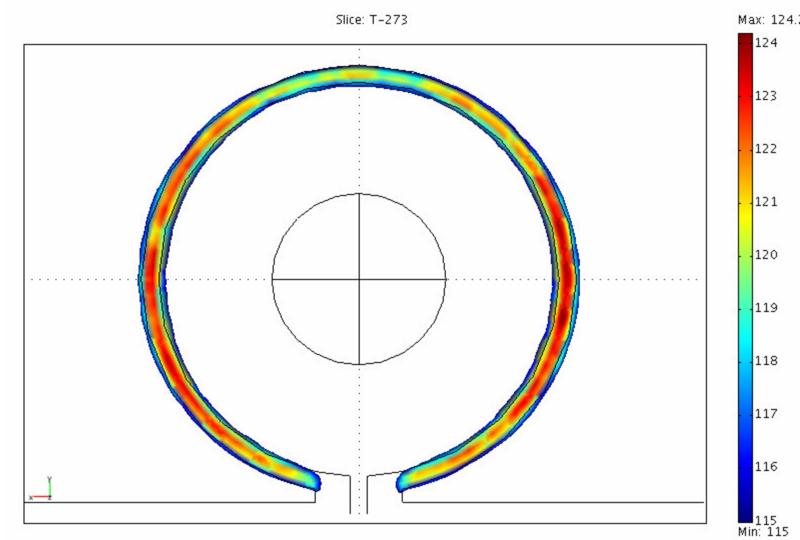
# Effect of proximity of the chip edges (d)




If edges are too close, heater temperature distribution very sensitive to external boundary conditions.




Usual boundary conditions
d = 4 mm




All boundary conditions are heat flux
d = 4 mm

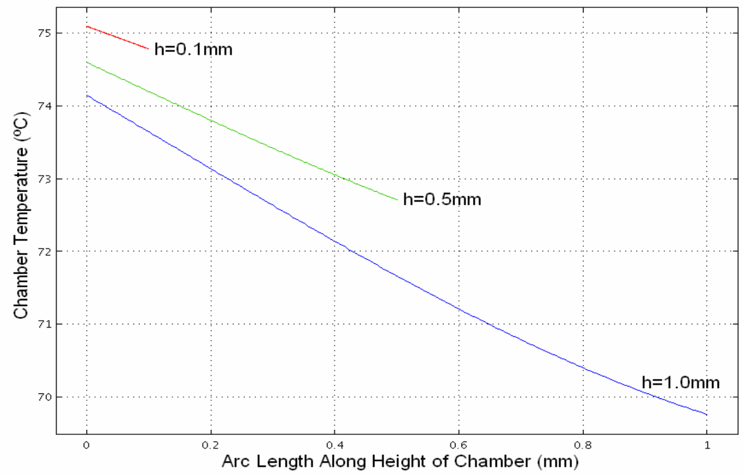
# Requirement-II: Temperature uniformity chamber

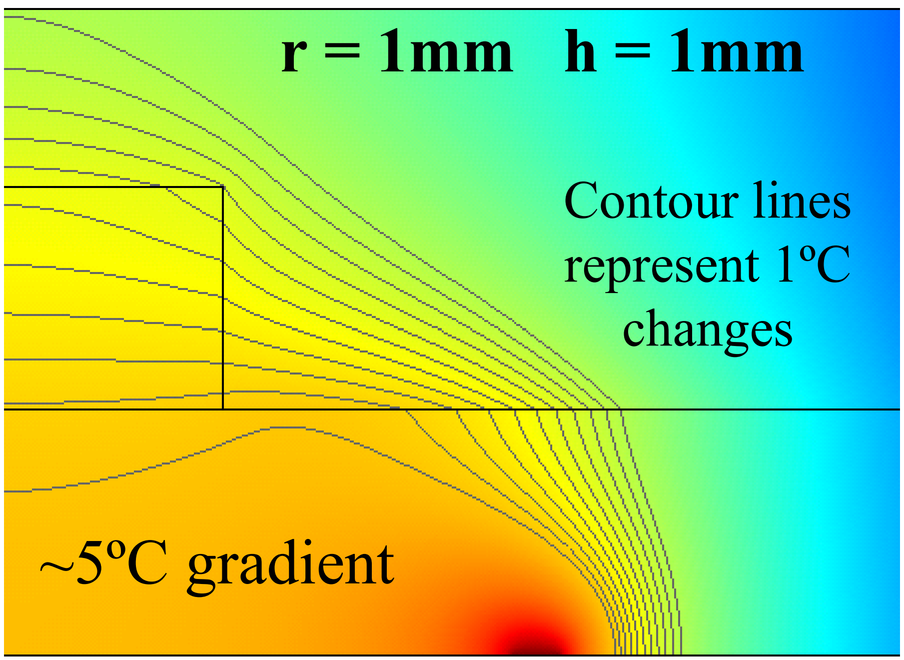
(c) Chamber height (h).
(d) Heater radius (R).

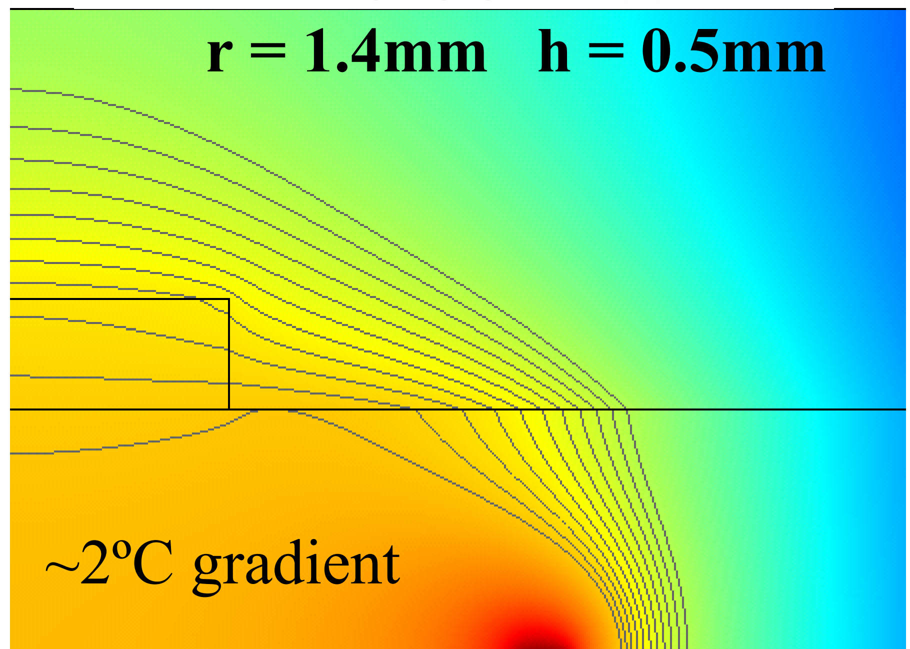
Uniform temperature might enhance uniform reaction progression within the fluidic chamber!

# Effect of chamber height (h)

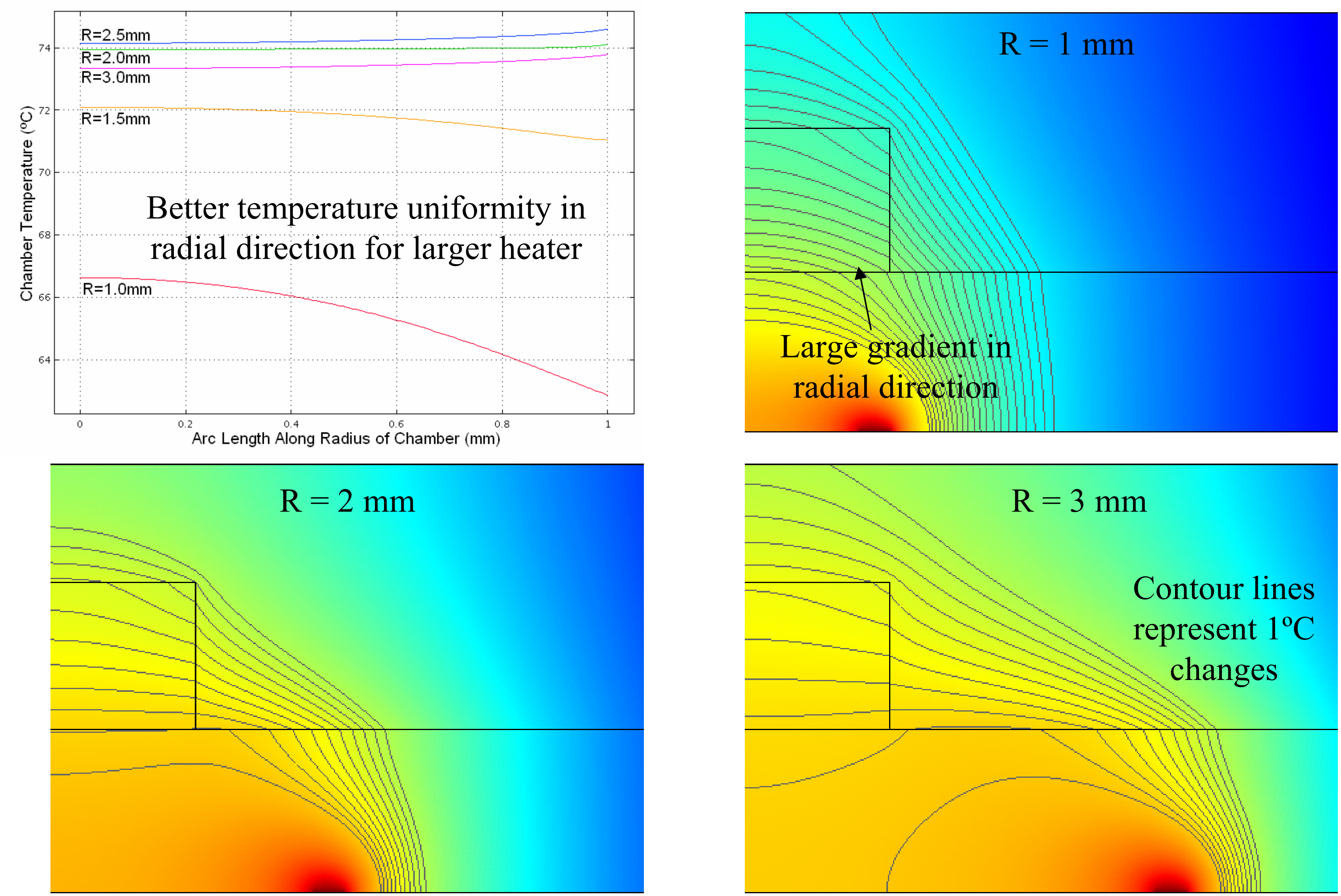
Shorter chamber gives better temperature uniformity in the z-direction of the chamber



# Effect of heater radius (R)



# Summary

- Pt thin films useful for catalyzing many bio-chemical reactions requiring precision temperature.

- Heater and the temperature sensing element the same, hence, less interconnects facilitate scaling for high throughput applications.

- Low power, localized heating elements in place that forms a practical and portable diagnostic assay.

- Design such that no additional bio-compatible layer is required; heat flow engineered such that non-contact heating with bio-fluids is efficiently possible.