Surface MEMS Design Examples

Dr. Lynn Fuller

Webpage: http://people.rit.edu/lffeee
Microelectronic Engineering
Rochester Institute of Technology
82 Lomb Memorial Drive
Rochester, NY 14623-5604
Tel (585) 475-2035
Email: Lynn.Fuller@rit.edu
Department webpage: http://www.microe.rit.edu

OUTLINE

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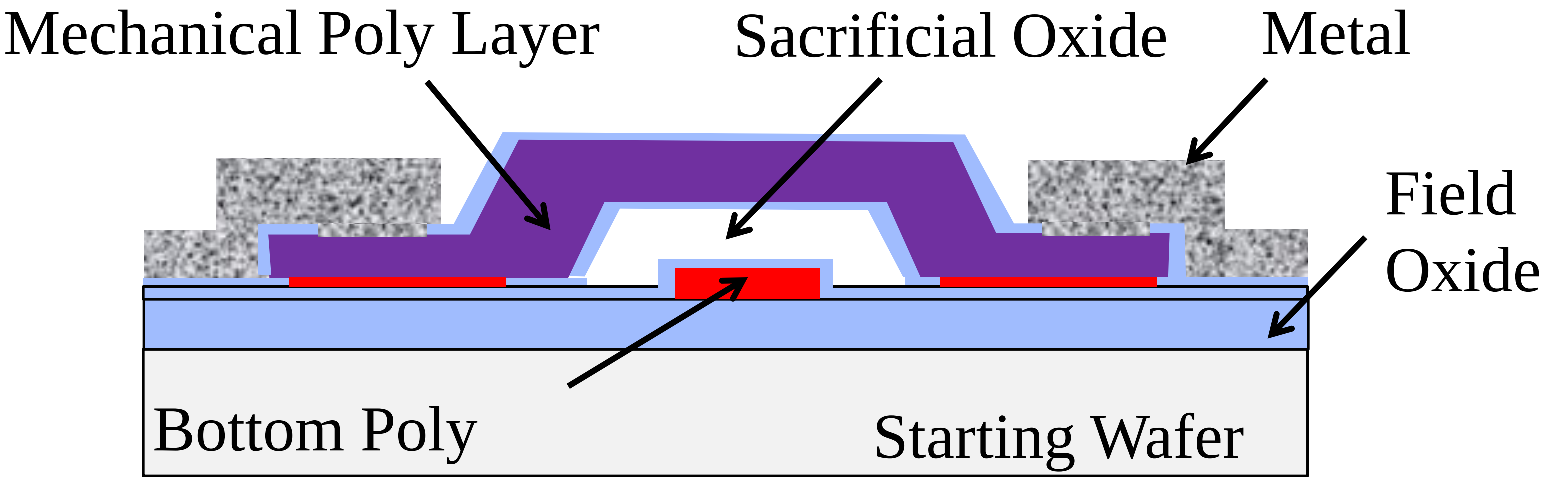
Cross Section
Test Structures
Cantilever
Thermally Actuated Speaker
Microphone
Chemical/Humidity Sensor
Mirror – Electrostatic – Torsional
Heater and Sensors
AC/DC Switch
Thermal Actuators - Microgripper
Comb Drive Actuators
Probe
Resistor- Bolometer
Gas Flow Sensor
Peltier Cooling
Magnetic Field Sensor

INTRODUCTION

This document provides example layouts for devices made with RIT's surface micromachine process. This process is capable of making many different types of MEMS devices. This MEMS fabrication process is CMOS compatible (with some modifications) back end module that can be added to realize compact microsystems (CMOS plus MEMS).

DEVICE CROSS SECTION



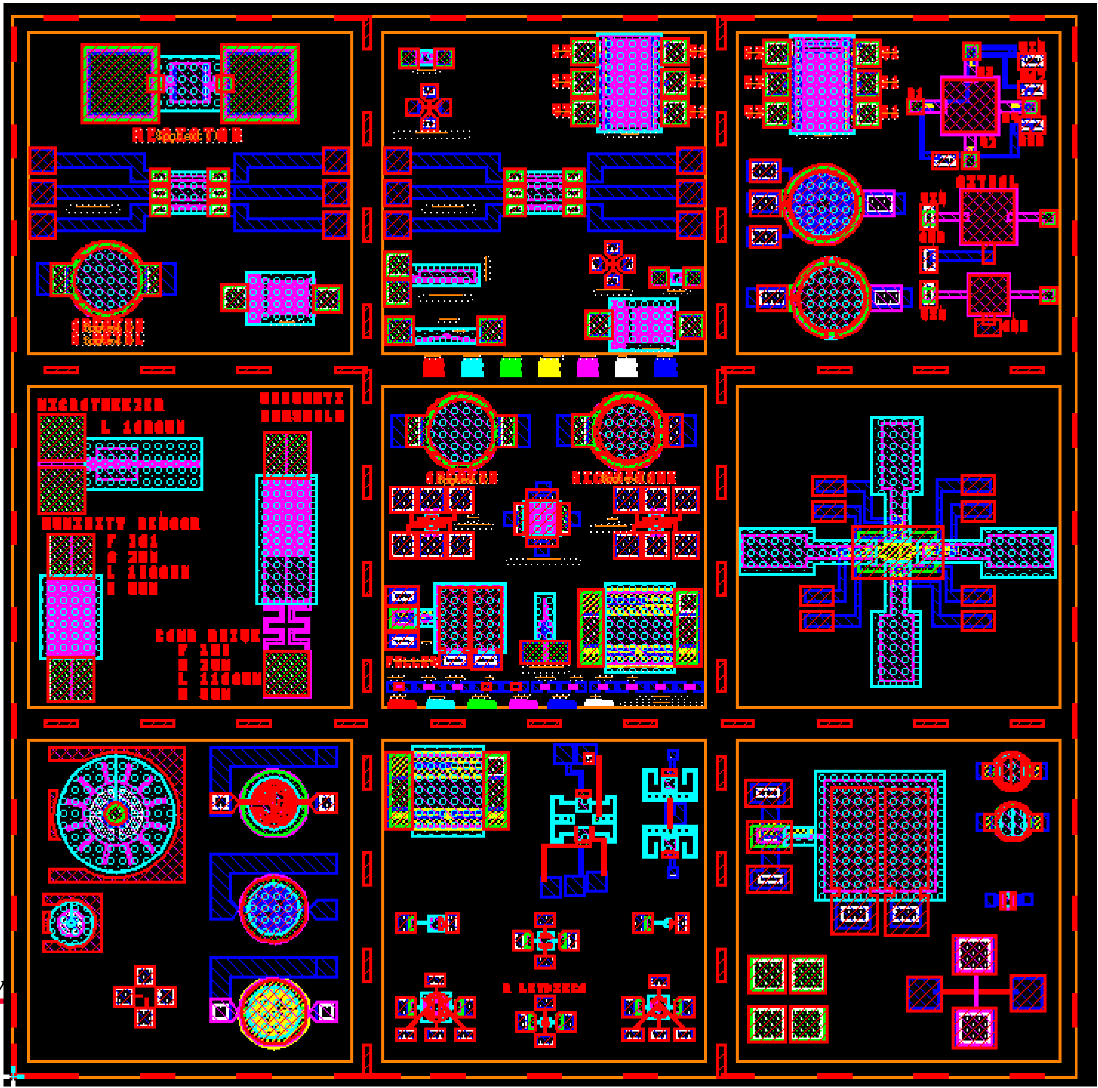
Bottom Poly 1 (Red) Layer 1	🟥
Sacrificial Oxide (Blue Outline) Layer 2	▨
Anchor (Green) Layer 3	🟩
Mechanical Poly 2 (Purple) Layer 4	🟪
Contact Cut (White) Layer 6	⬜
Metal (Blue) Layer 7	🟦
Outline (Yellow Outline) Layer 9	☐
No Implant Yellow Layer 15	🟨
Holes Layer 16 (combined with Poly 2)	▨

2014 MEMS MULTICHIP PROJECT DESIGN

Total 15 mm by 15 mm plus 500 um for sawing into 9 chips for overall 16.5mm by 16.5mm size.

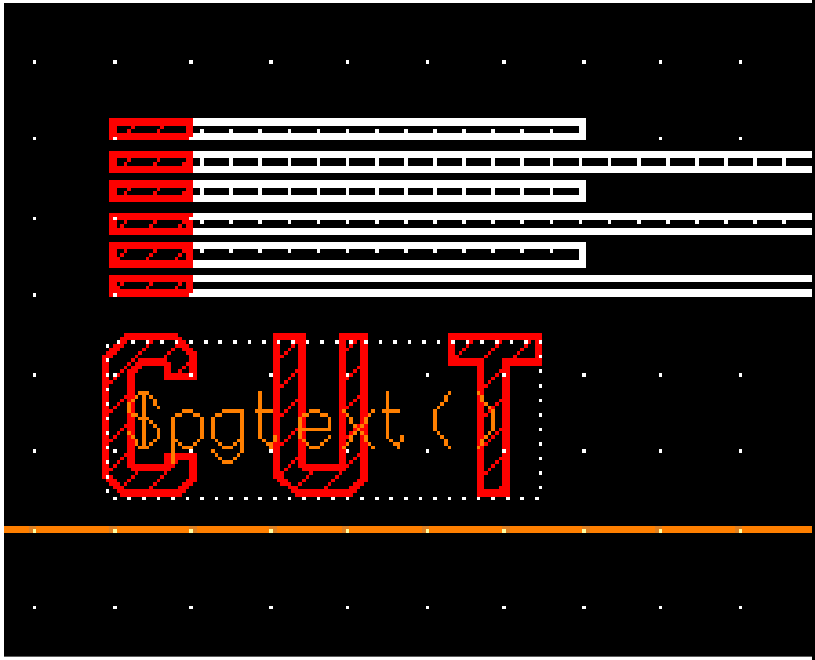
Wafer sawing is easier if all chips are the same size

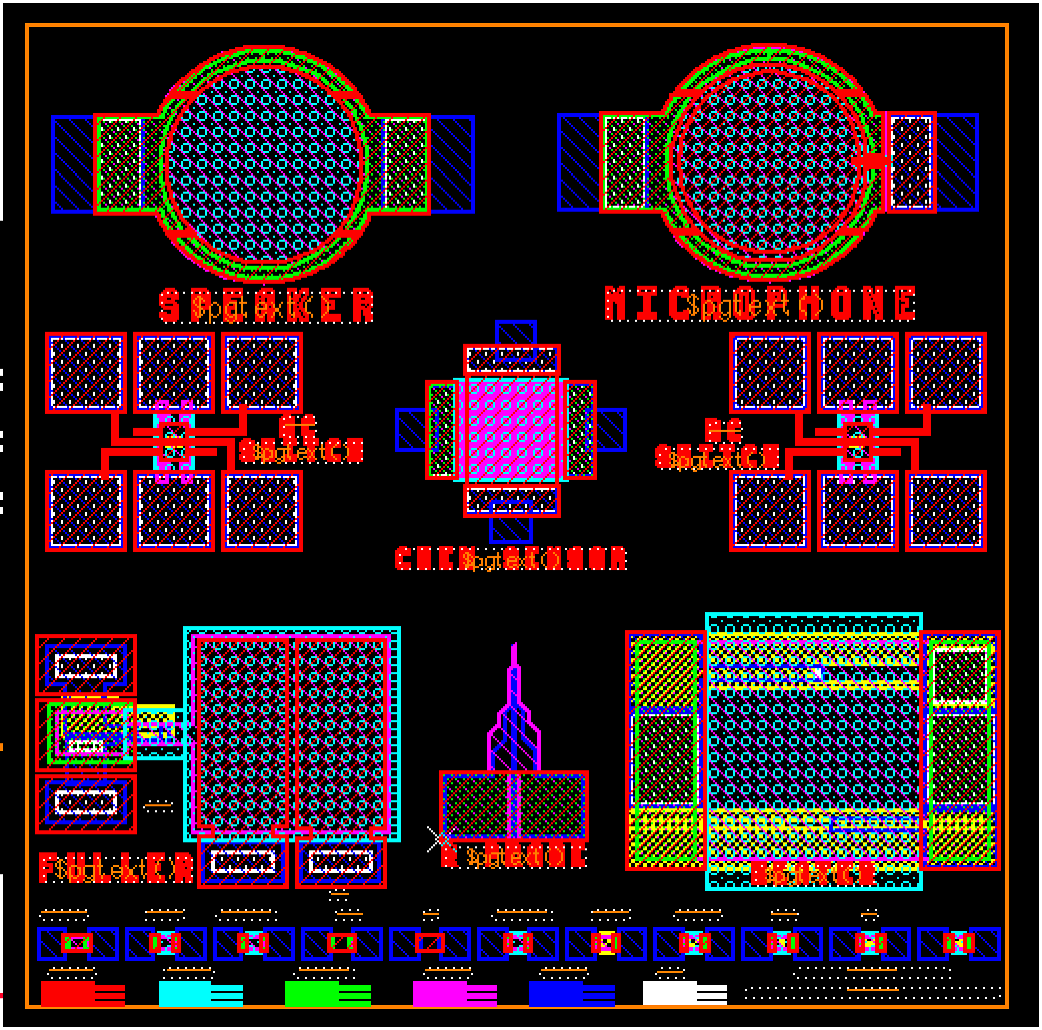
5mm by 5mm design space for each project



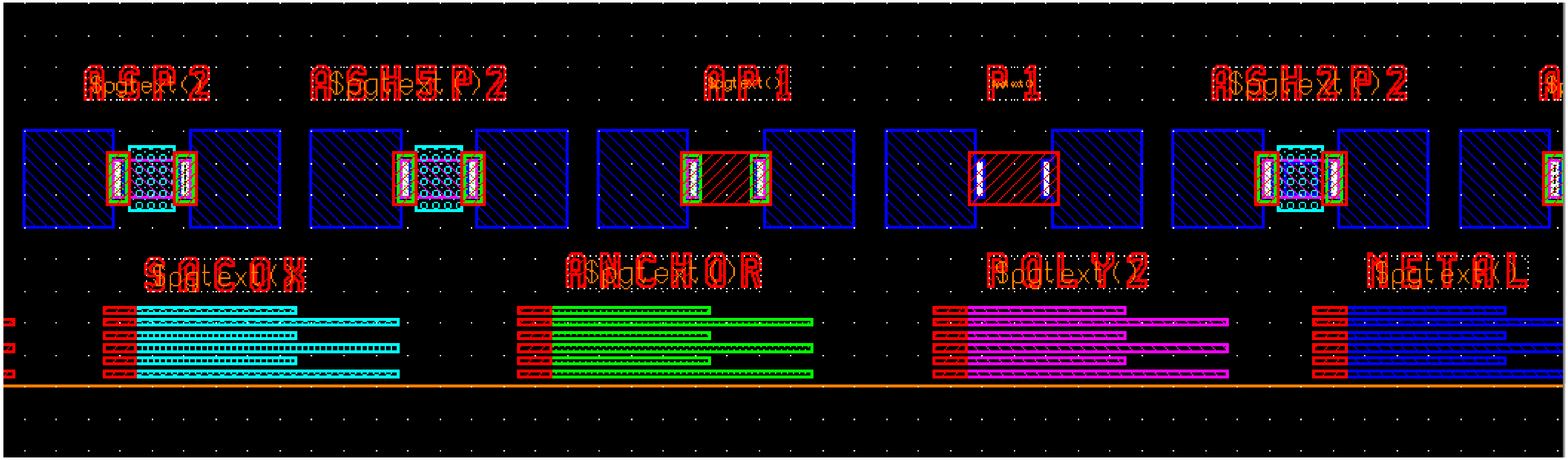
TEST STRUCTURES

One of the cells will have test structures along the bottom edge for resolution/overlay,etc.





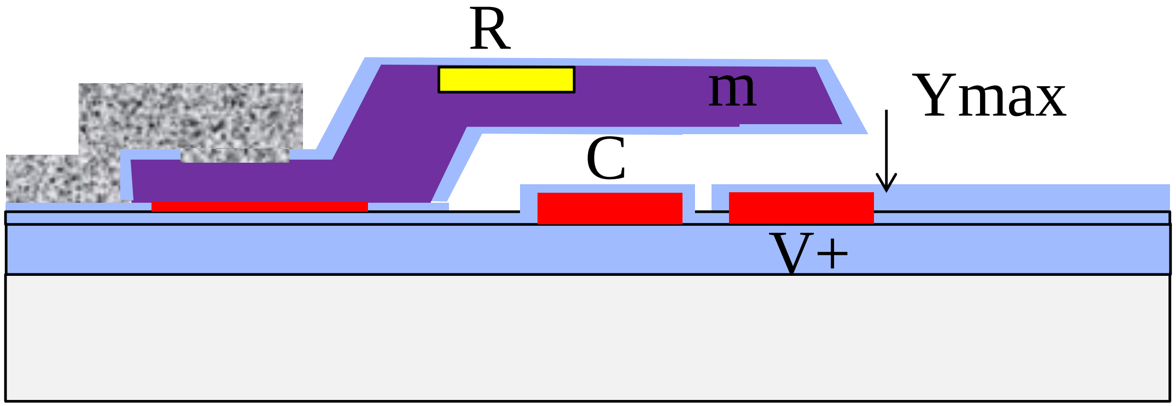
TEST STRUCTURES



1. Poly1 in Parallel with Poly2
2. No Etch Holes Poly 2
3. 5um Etch Holes Poly2
4. Metal contact to Poly2 to Poly1
5. Metal contact to Poly1
6. 2um Etch Holes Poly2
7. Poly2 No Implant, No SacOx
8. Poly2 No Implant
9. Poly2 No Implant 5um Gap
10. Poly2 No Implant 5um Resistor
11. Poly 2 No Implant 10um Resistor

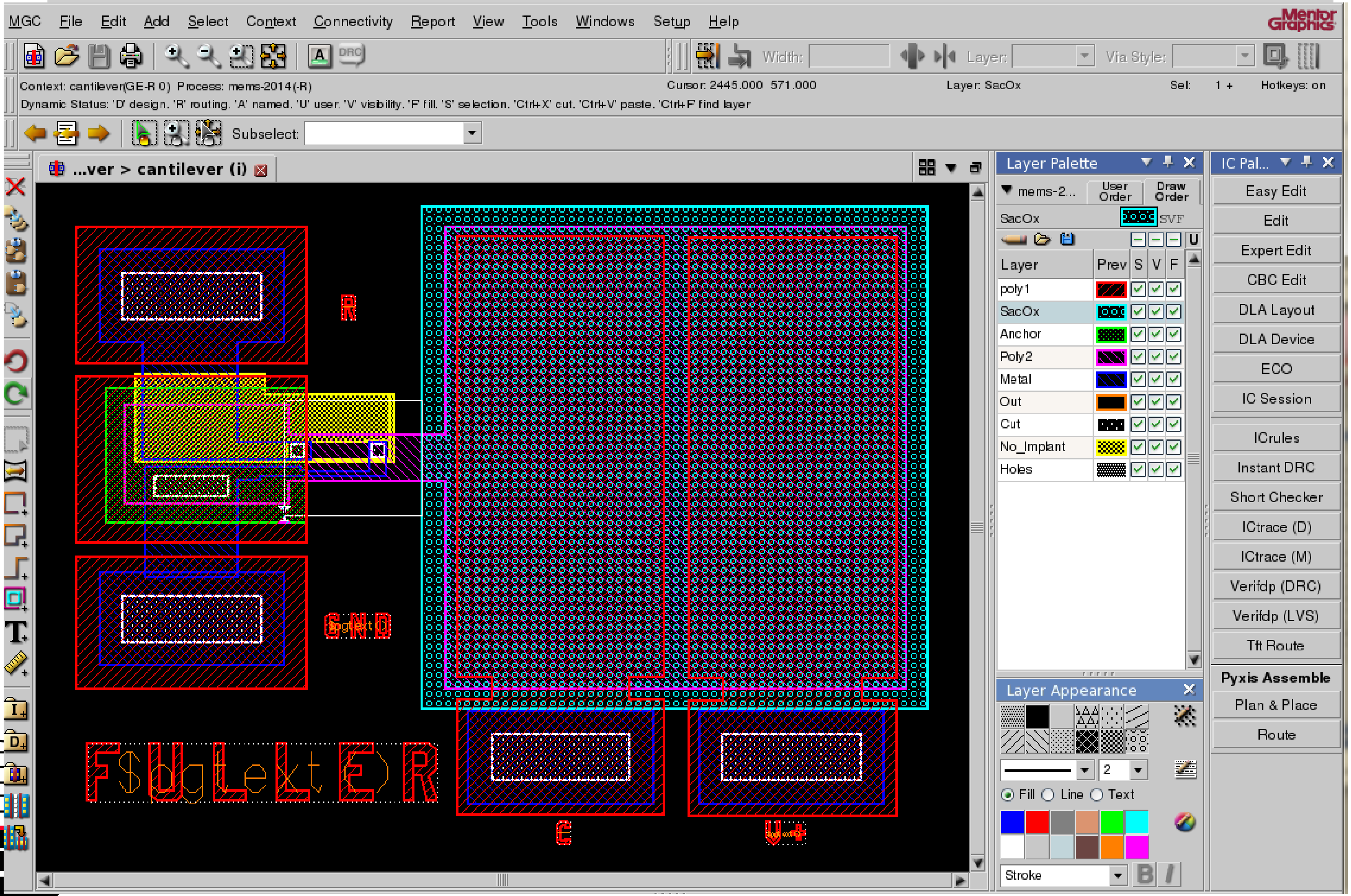
Starting from Left Resistors
L = ~100µm W = ~50µm

CANTILEVER, MIRROR OR ACCELEROMETER



Electrostatic Actuation
Capacitor Sensor
Resistor Sensor
Accelerometer or Mirror

MENTOR GRAPHICS LAYOUT OF CANTILEVER



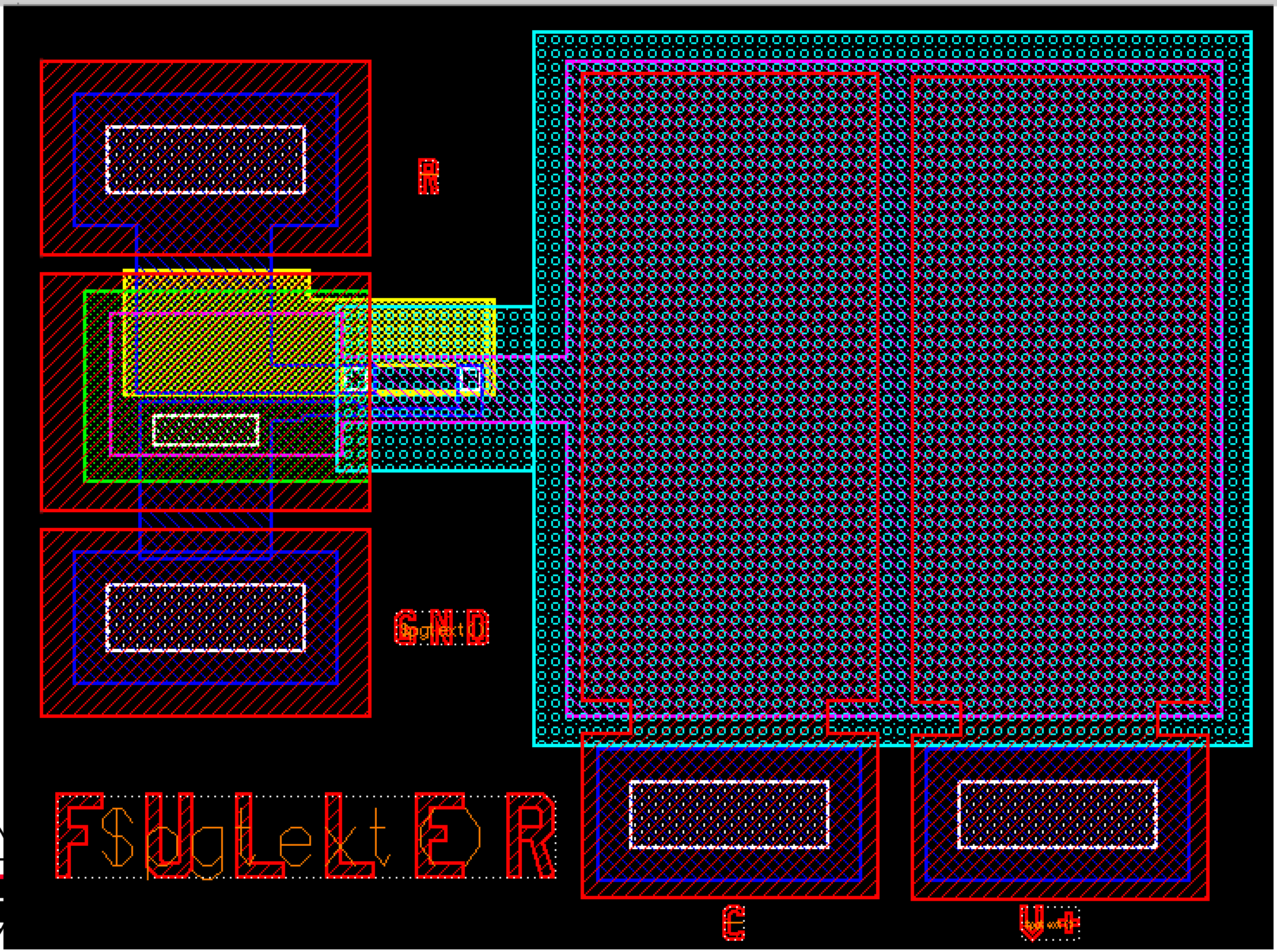
Context: cantilever(GE-R 0) Process: mems-2014(-R) Cursor: 2445.000 571.000 Layer: SacOx Sel: 1 + Hotkeys: on

Dynamic Status: 'D' design. 'R' routing. 'A' named. 'U' user. 'V' visibility. 'F' fill. 'S' selection. 'Ctrl+X' cut. 'Ctrl+V' paste. 'Ctrl+F' find layer

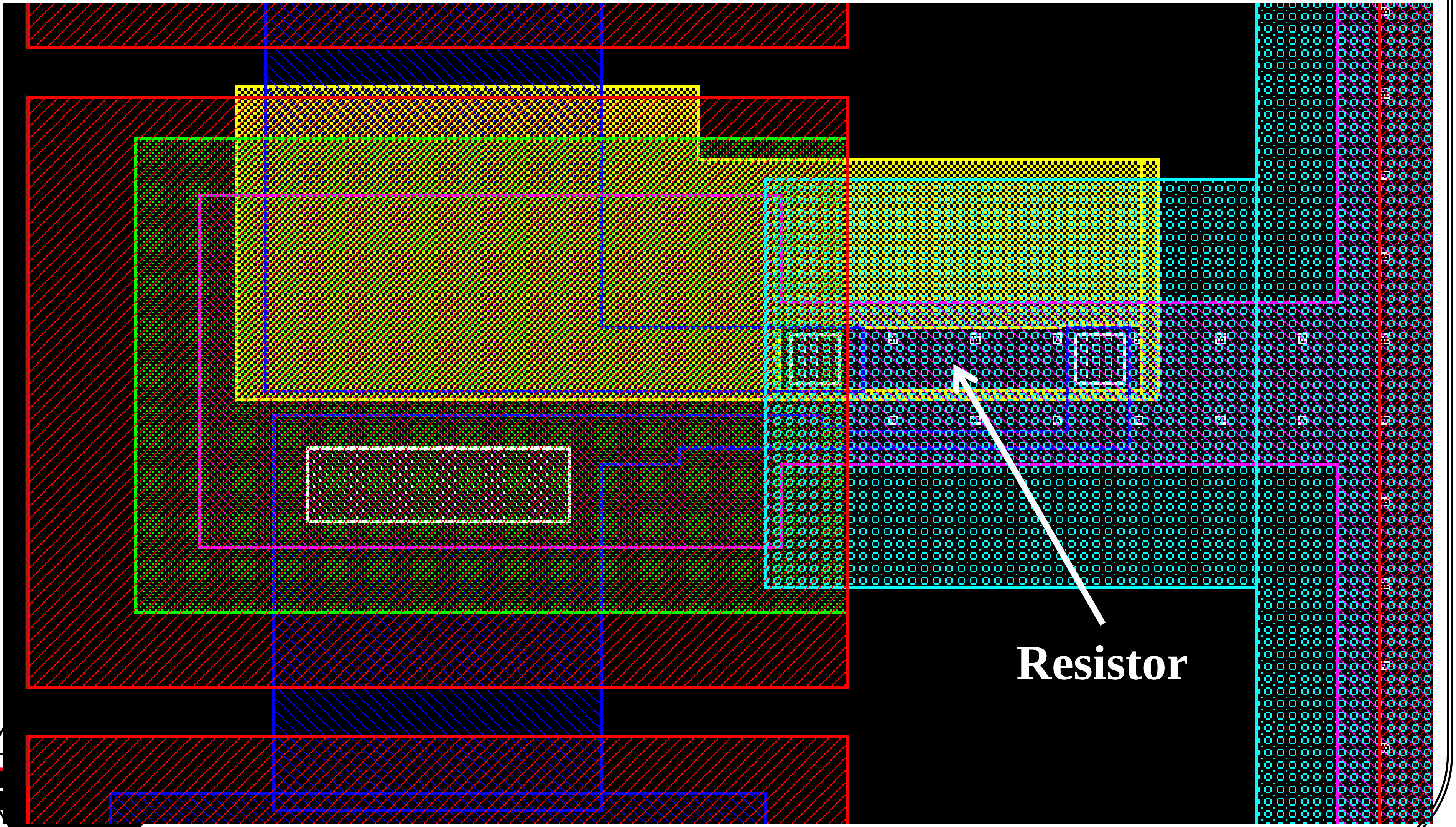
SacOx

Layer	Prev	S	V	F
poly1	🟥	☑	☑	☑
SacOx	▨	☑	☑	☑
Anchor	🟩	☑	☑	☑
Poly2	▨	☑	☑	☑
Metal	🟦	☑	☑	☑
Out	🟧	☑	☑	☑
Cut	■	☑	☑	☑
No_Implant	🟨	☑	☑	☑
Holes	▨	☑	☑	☑

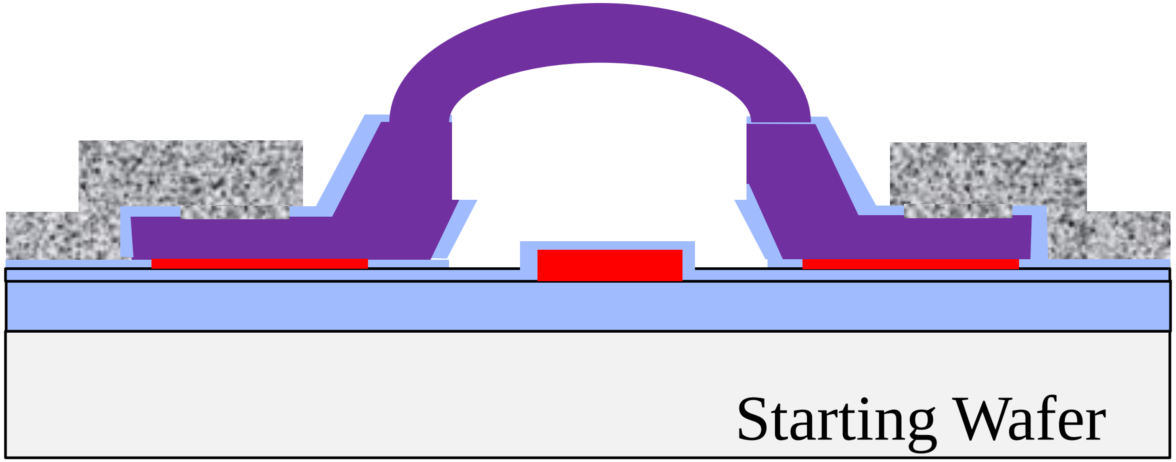
MENTOR GRAPHICS LAYOUT OF CANTILEVER



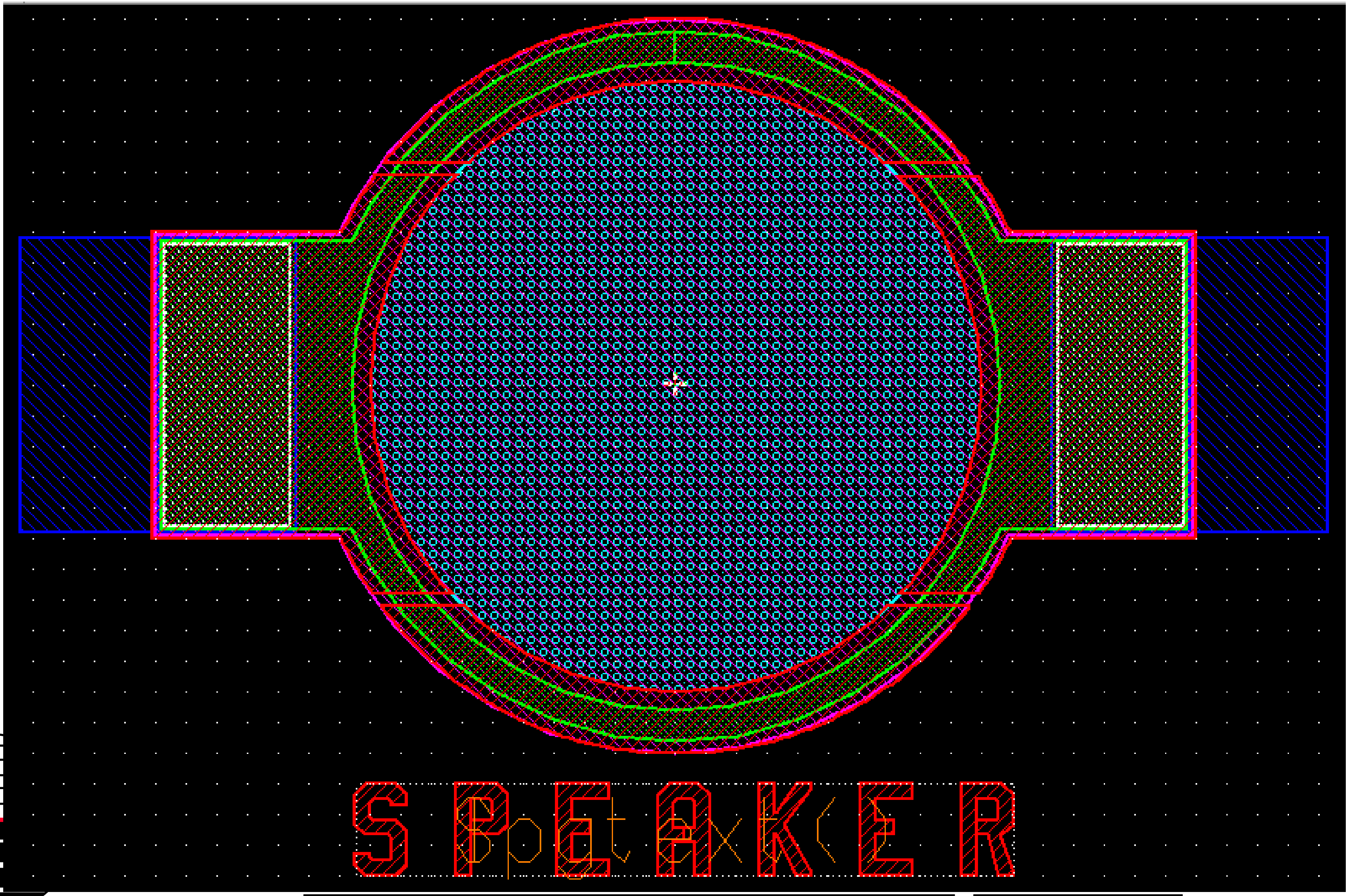
MENTOR GRAPHICS LAYOUT OF CANTILEVER



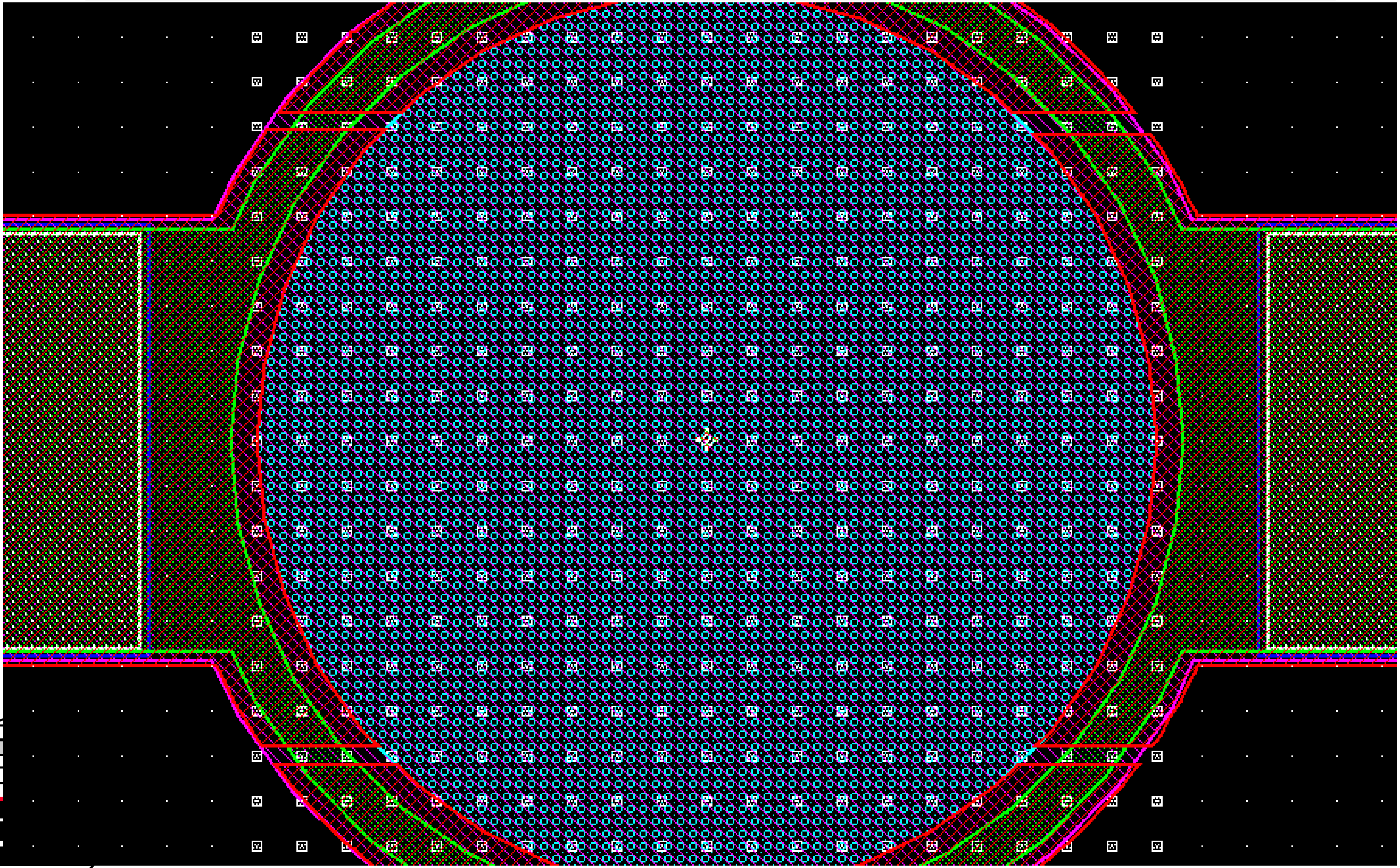
THERMALLY ACTUATED SPEAKER



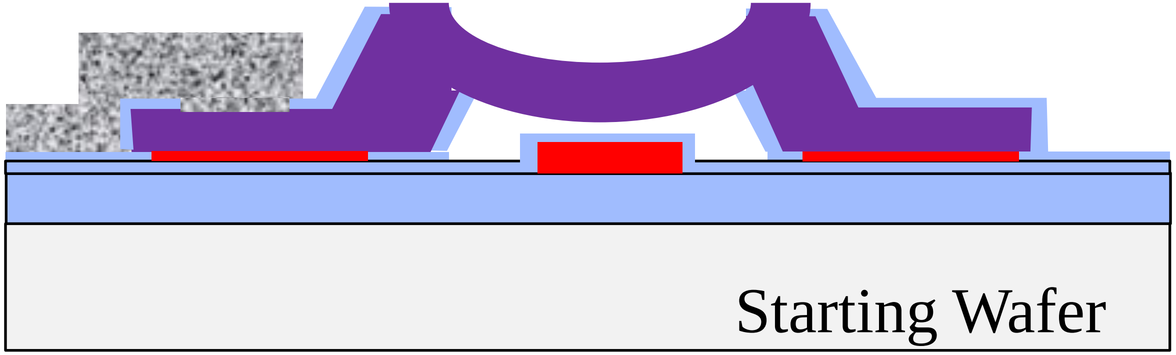
THERMALLY ACTUATED SPEAKER

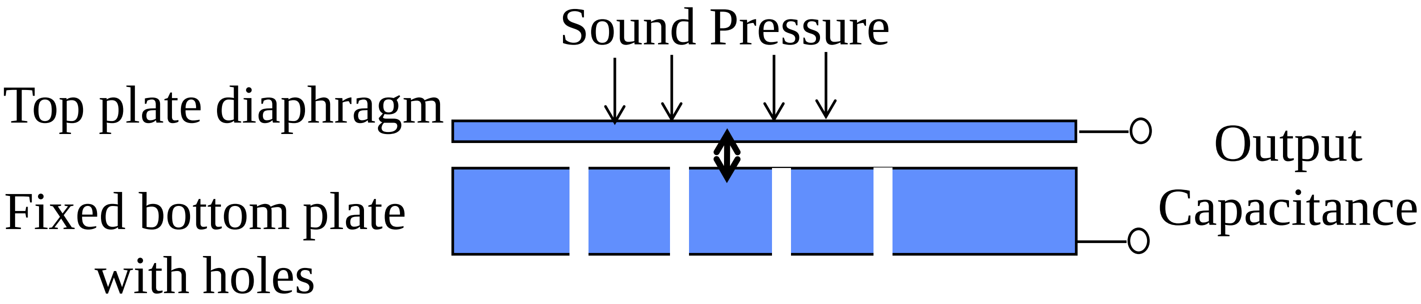


THERMALLY ACTUATED SPEAKER

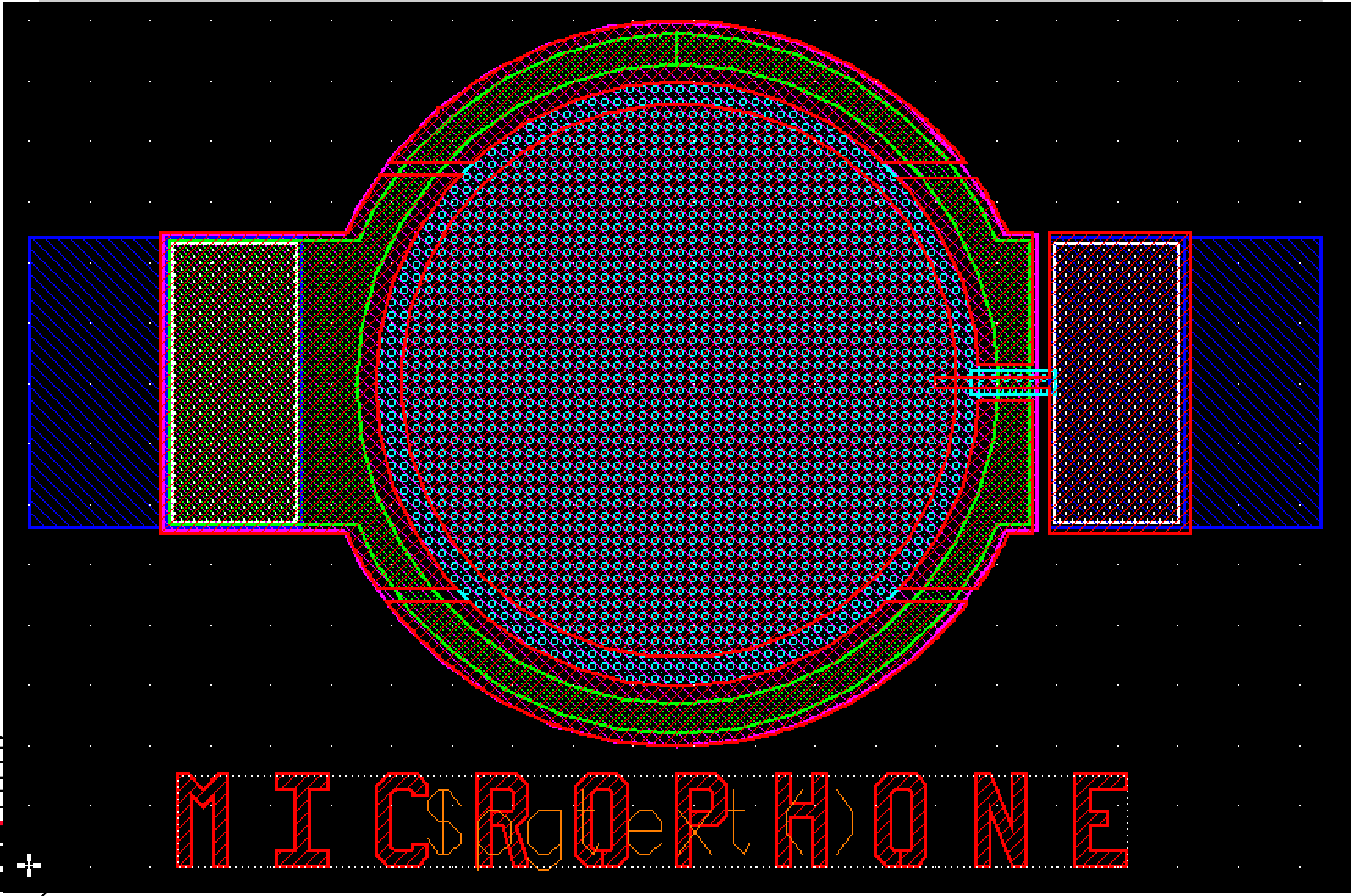


MICROPHONE

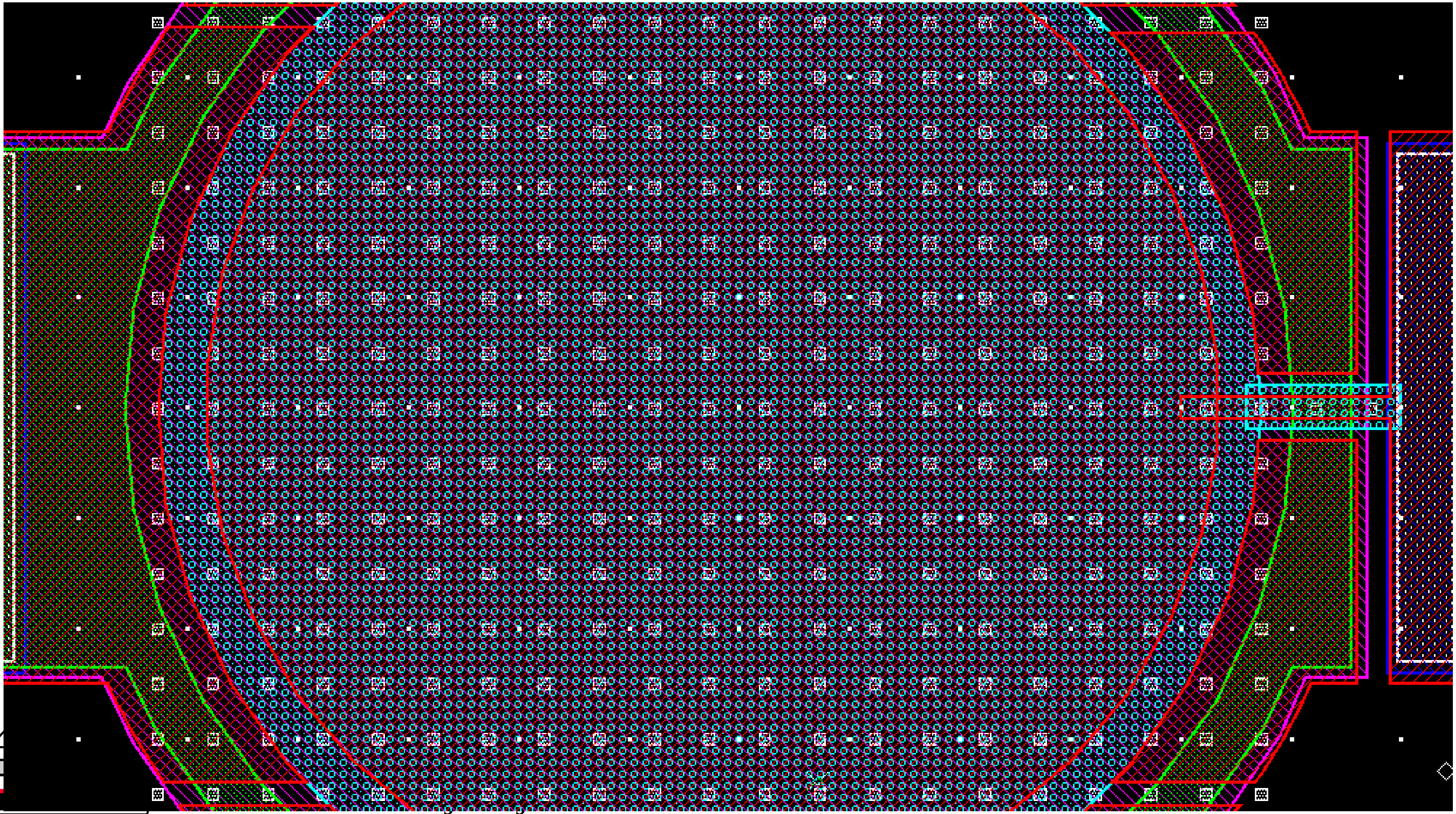

Starting Wafer


Sound Pressure
Top plate diaphragm
Fixed bottom plate
with holes
Output
Capacitance

MICROPHONE

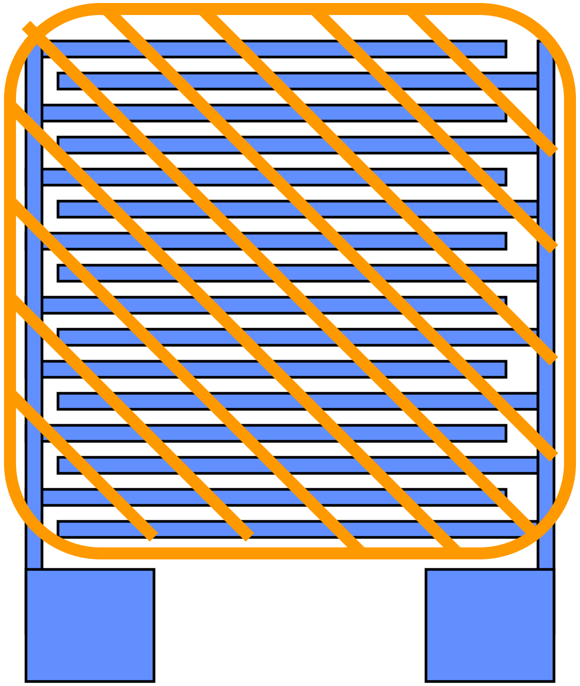


MICROPHONE



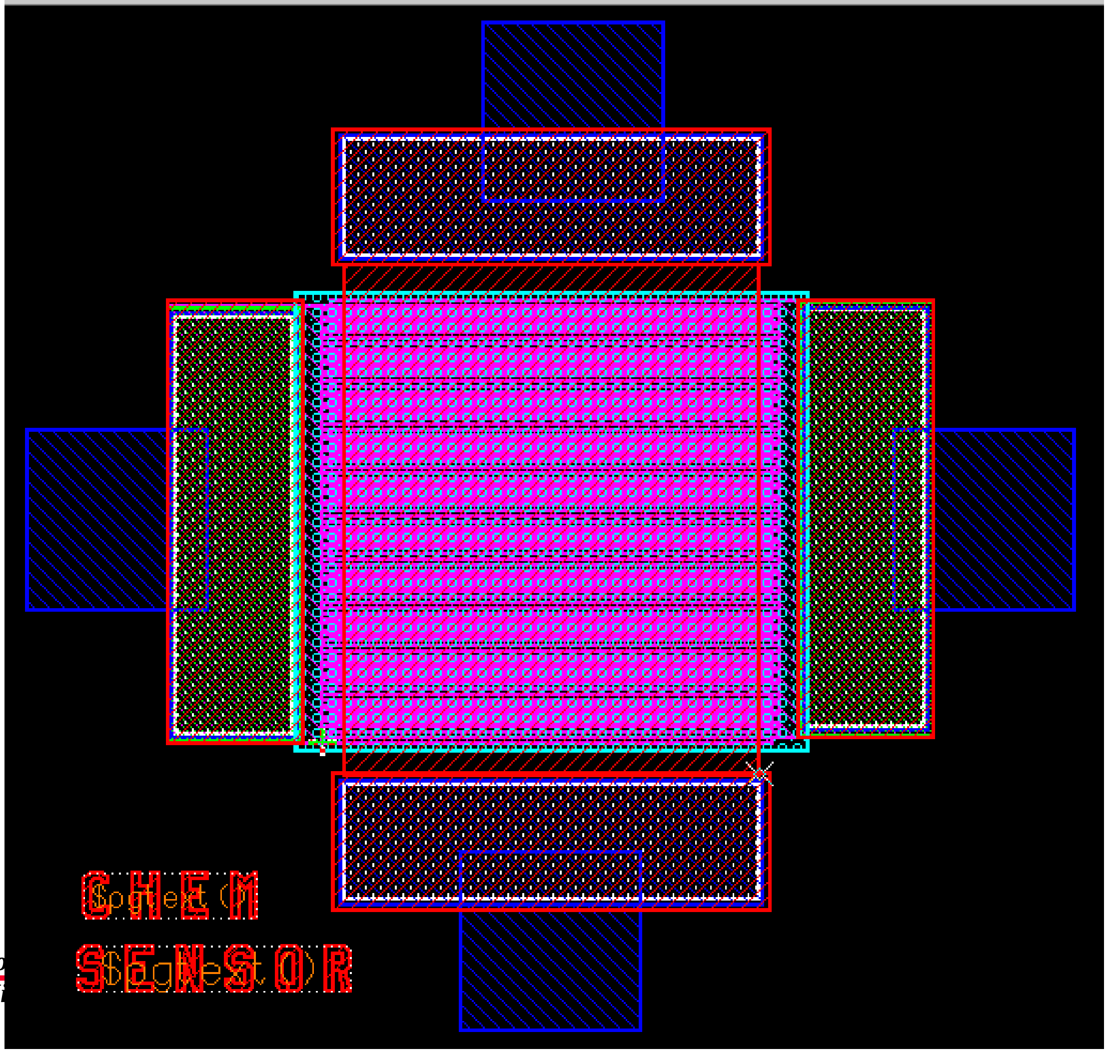
CHEMICAL SENSOR OR HUMIDITY SENSOR

Interdigitated fingers form electrodes for either resistive or capacitive sensors. For capacitive sensors the fingers are closely spaced. The chemically sensitive coating is resistive and the resistance changes in the presence of some chemical to be sensed or the coating is not conductive but the dielectric constant changes in the presence of some chemical to be sensed.

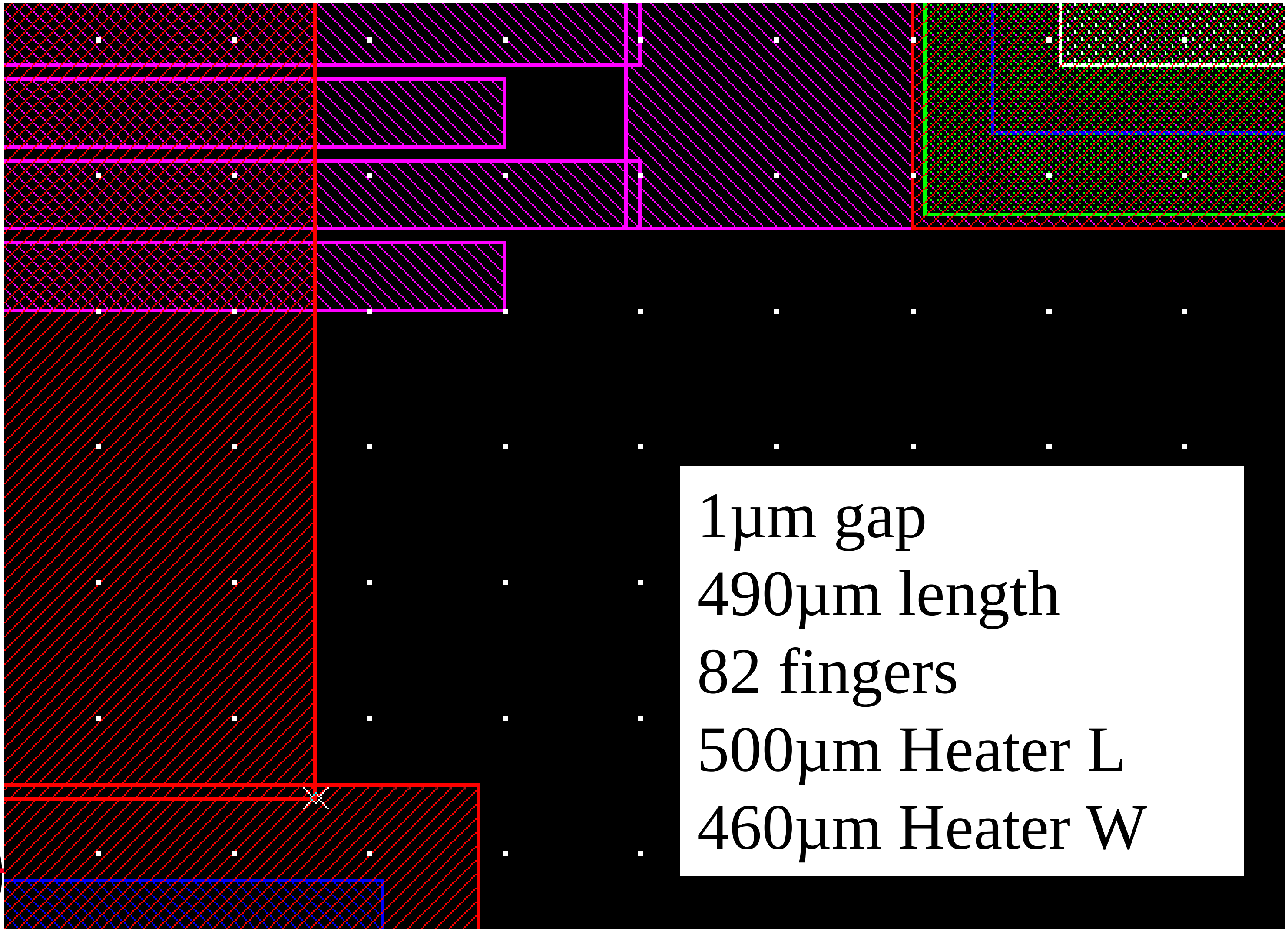


ΔC or ΔR

CHEMICAL SENSOR OR HUMIDITY SENSOR

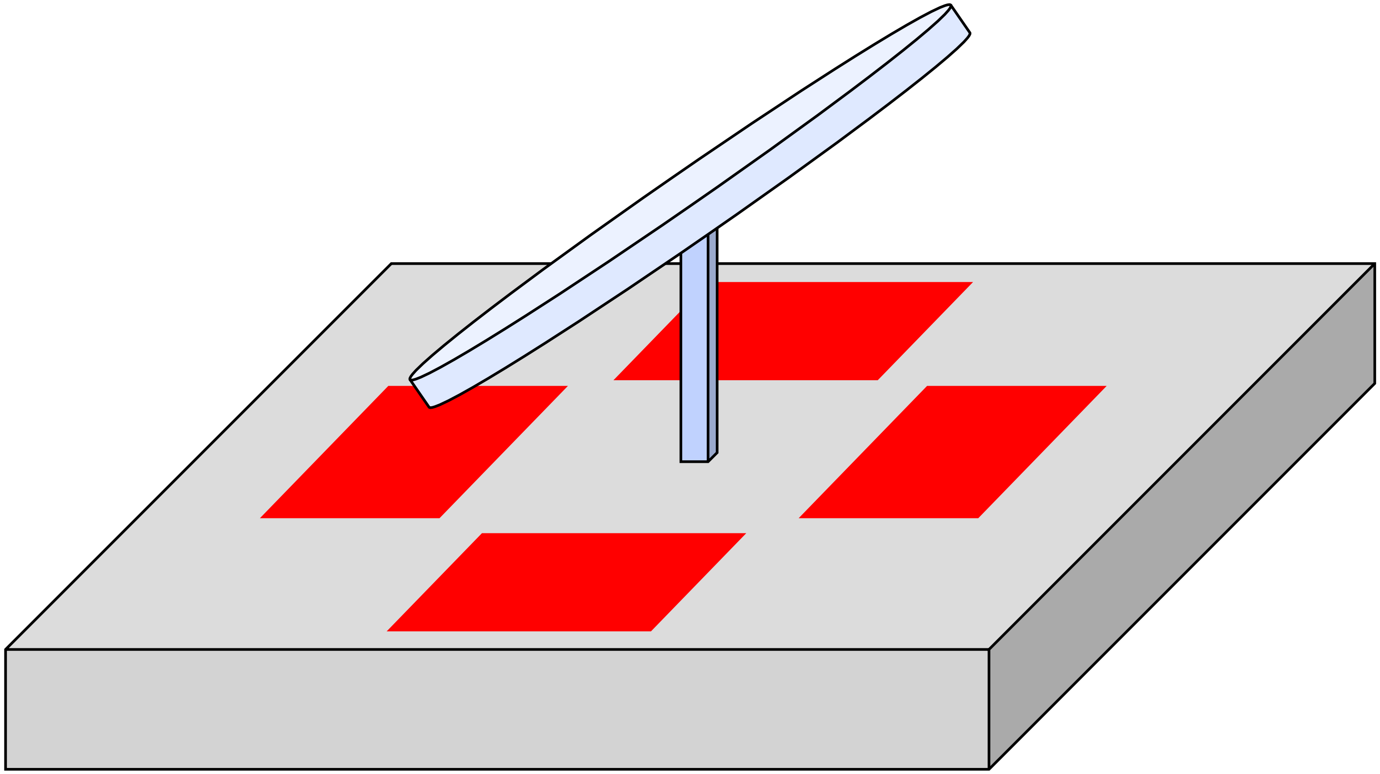


CHEMICAL SENSOR OR HUMIDITY SENSOR

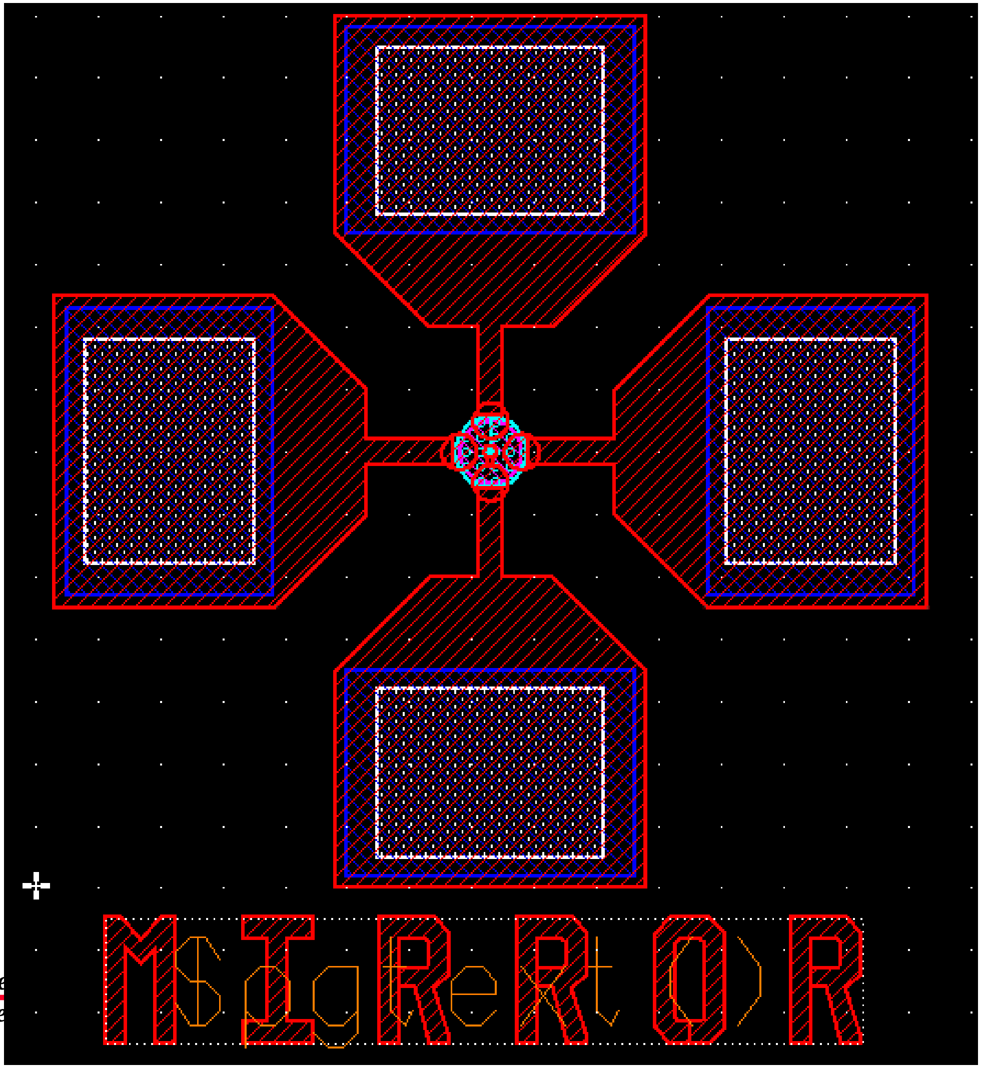


1µm gap
490µm length
82 fingers
500µm Heater L
460µm Heater W

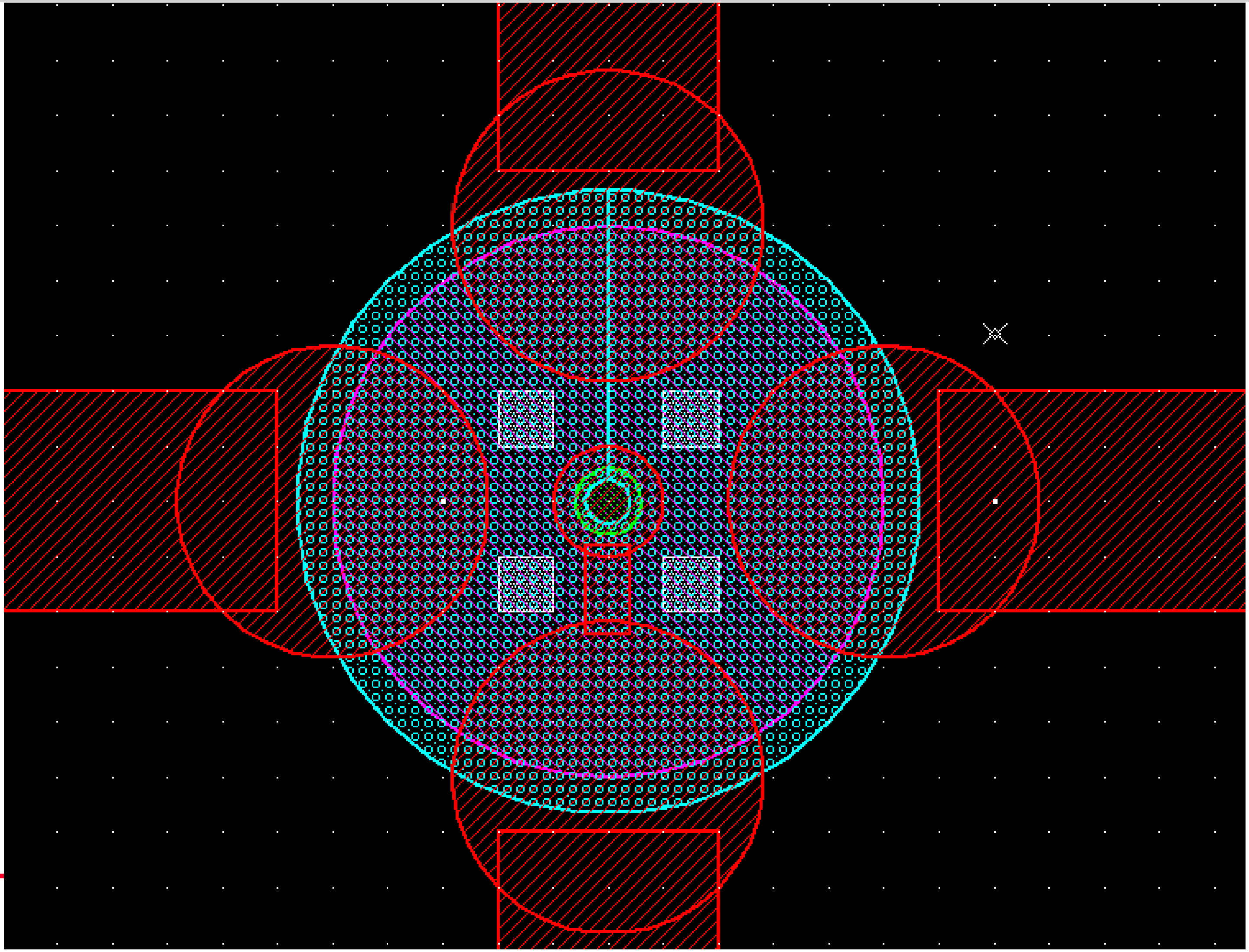
MIRROR



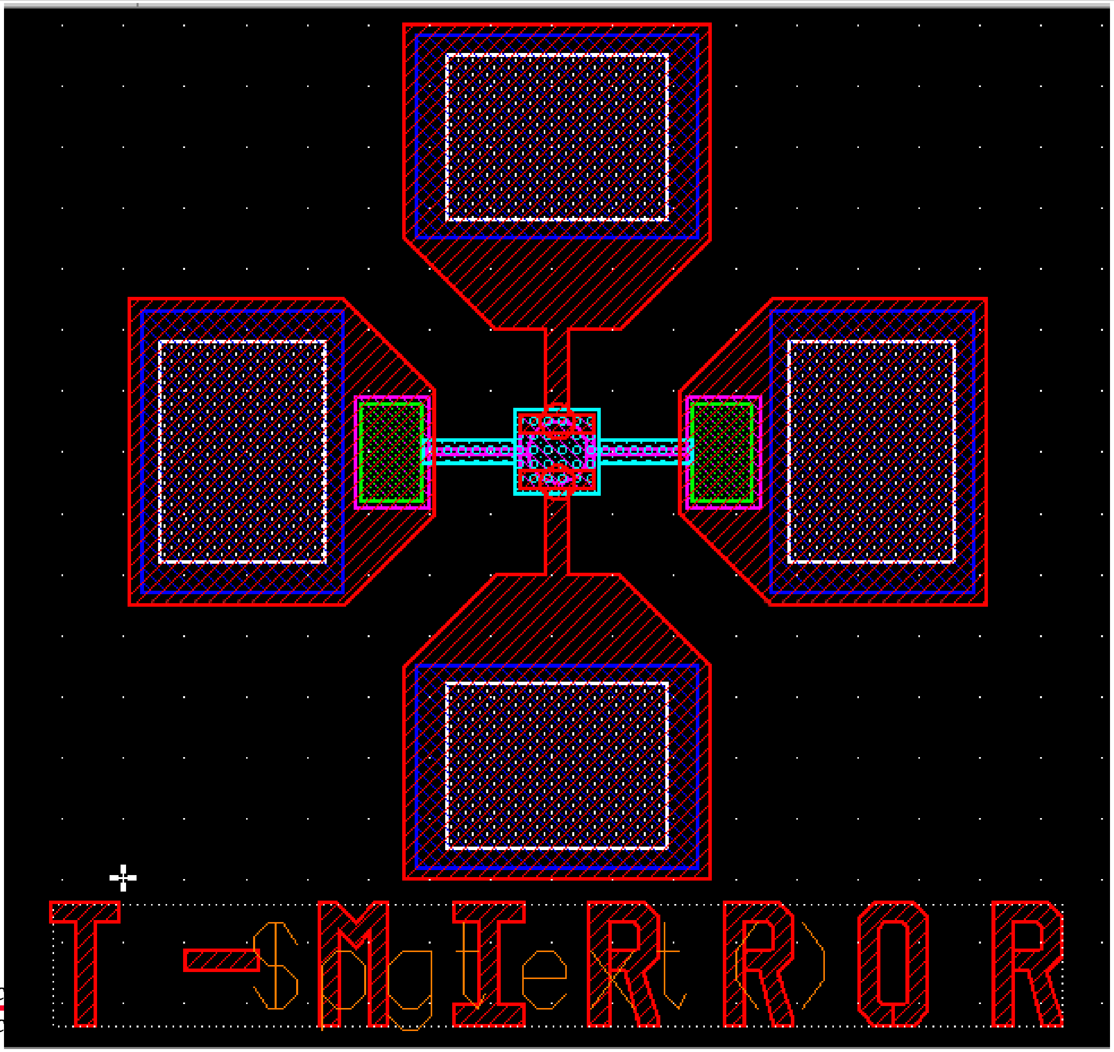
MIRROR



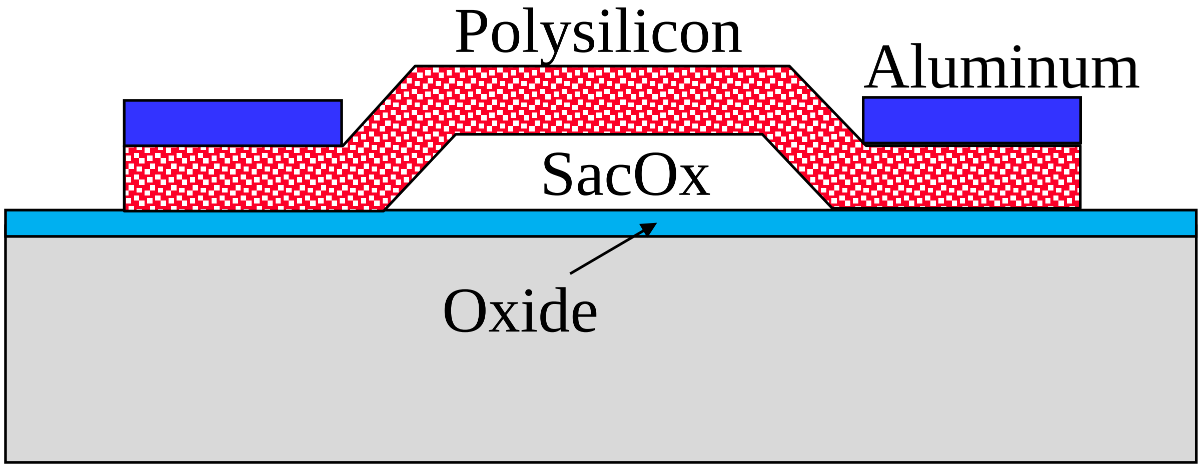
MIRRORS



TORSIONAL MIRROR



HEATERS AND TEMPERATURE SENSORS



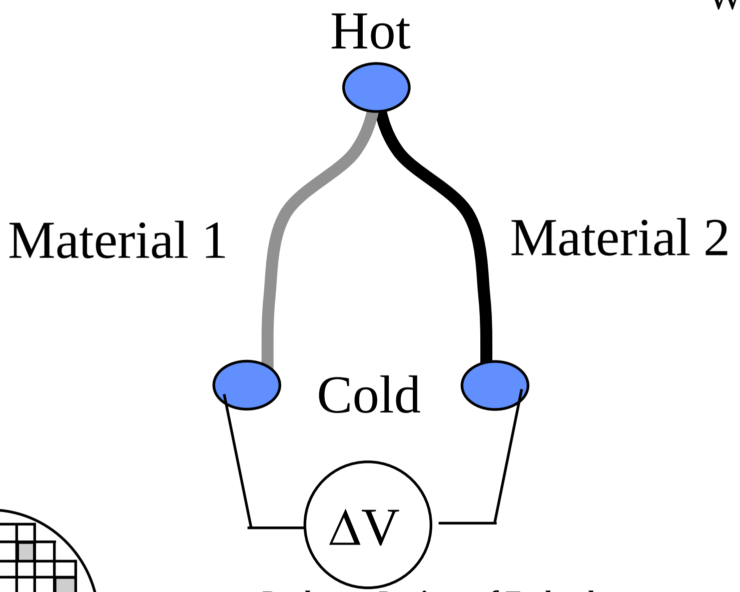
Resistor Heater
Thermocouple Sensor
Resistor Sensor

SEEBECK EFFECT

When two dissimilar conductors are connected together a voltage may be generated if the junction is at a temperature different from the temperature at the other end of the conductors (cold junction) This is the principal behind the thermocouple and is called the Seebeck effect.

$$\Delta V = \alpha_1(T_{cold}-T_{hot}) + \alpha_2\,(T_{hot}-T_{cold})=(\alpha_1-\alpha_2)(T_{hot}-T_{cold})$$

Where α_1 and α_2 are the Seebeck coefficients for materials 1 and 2



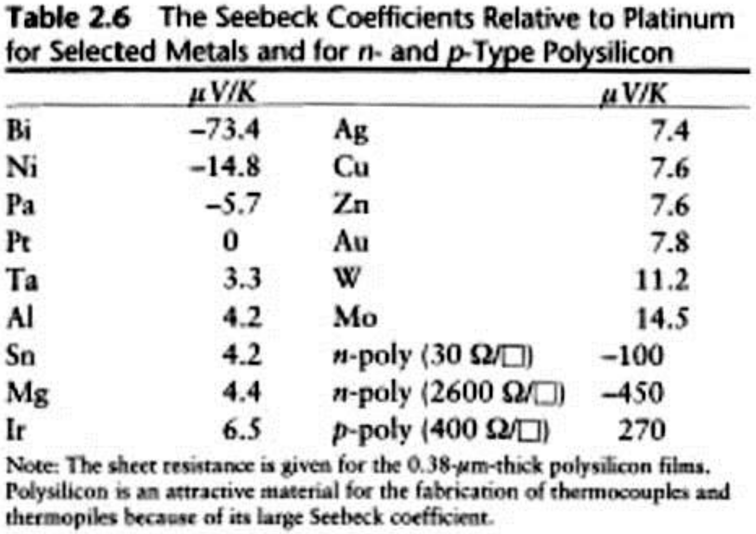


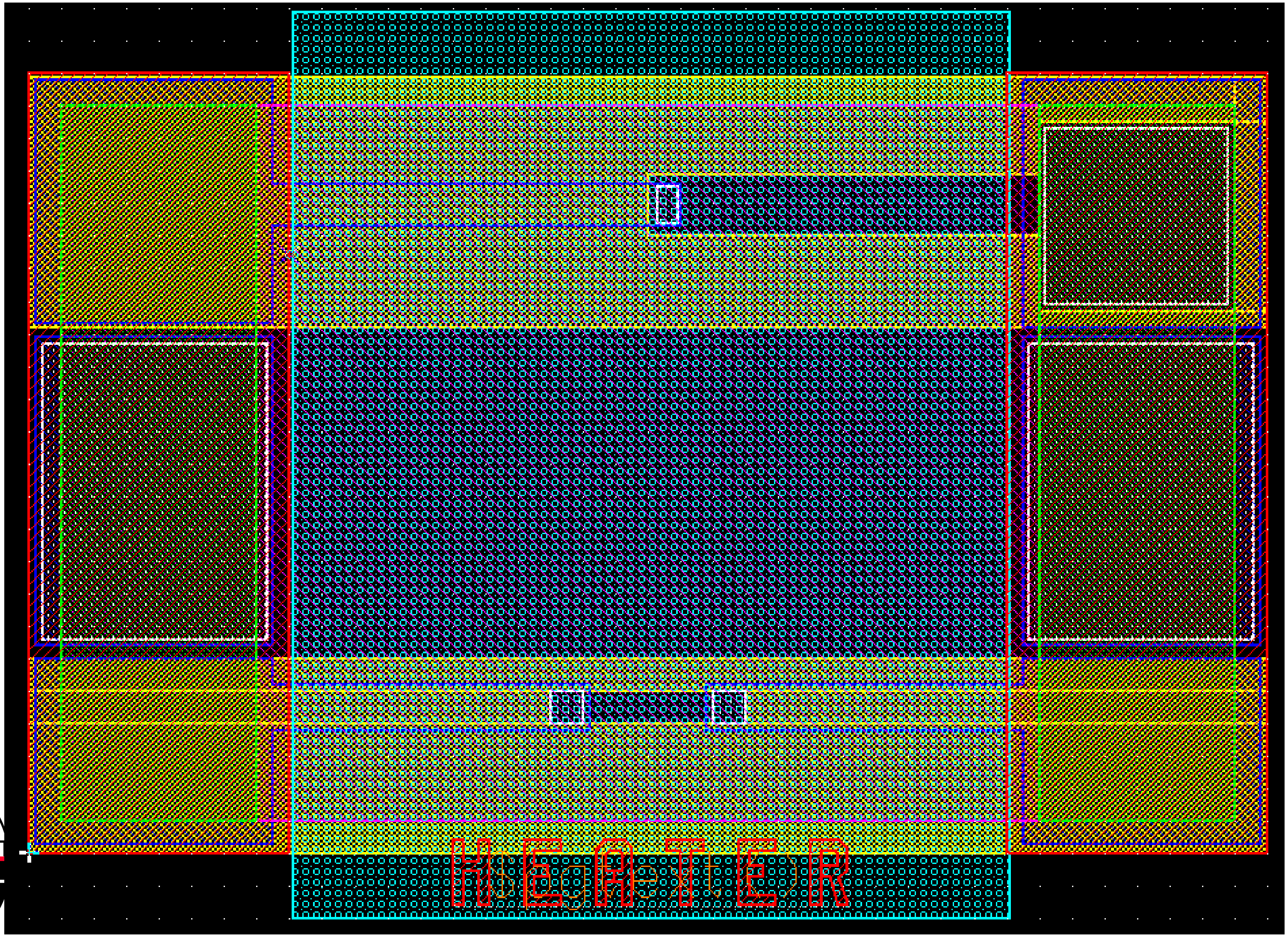
Table 2.6 The Seebeck Coefficients Relative to Platinum for Selected Metals and for *n*- and *p*-Type Polysilicon

	μV/K		μV/K
Bi	–73.4	Ag	7.4
Ni	–14.8	Cu	7.6
Pa	–5.7	Zn	7.6
Pt	0	Au	7.8
Ta	3.3	W	11.2
Al	4.2	Mo	14.5
Sn	4.2	*n*-poly (30 Ω/□)	–100
Mg	4.4	*n*-poly (2600 Ω/□)	–450
Ir	6.5	*p*-poly (400 Ω/□)	270

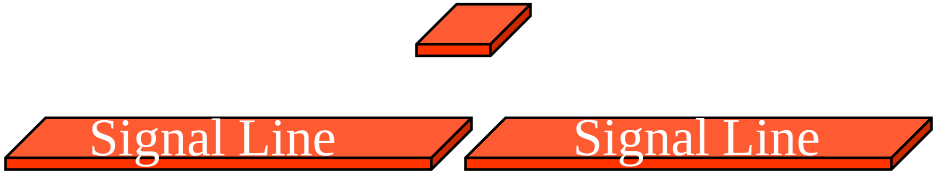
Note: The sheet resistance is given for the 0.38-μm-thick polysilicon films. Polysilicon is an attractive material for the fabrication of thermocouples and thermopiles because of its large Seebeck coefficient.

Nadim Maluf, Kirt Williams, An Introduction to Microelectromechanical Systems Engineering, 2nd Ed. 2004

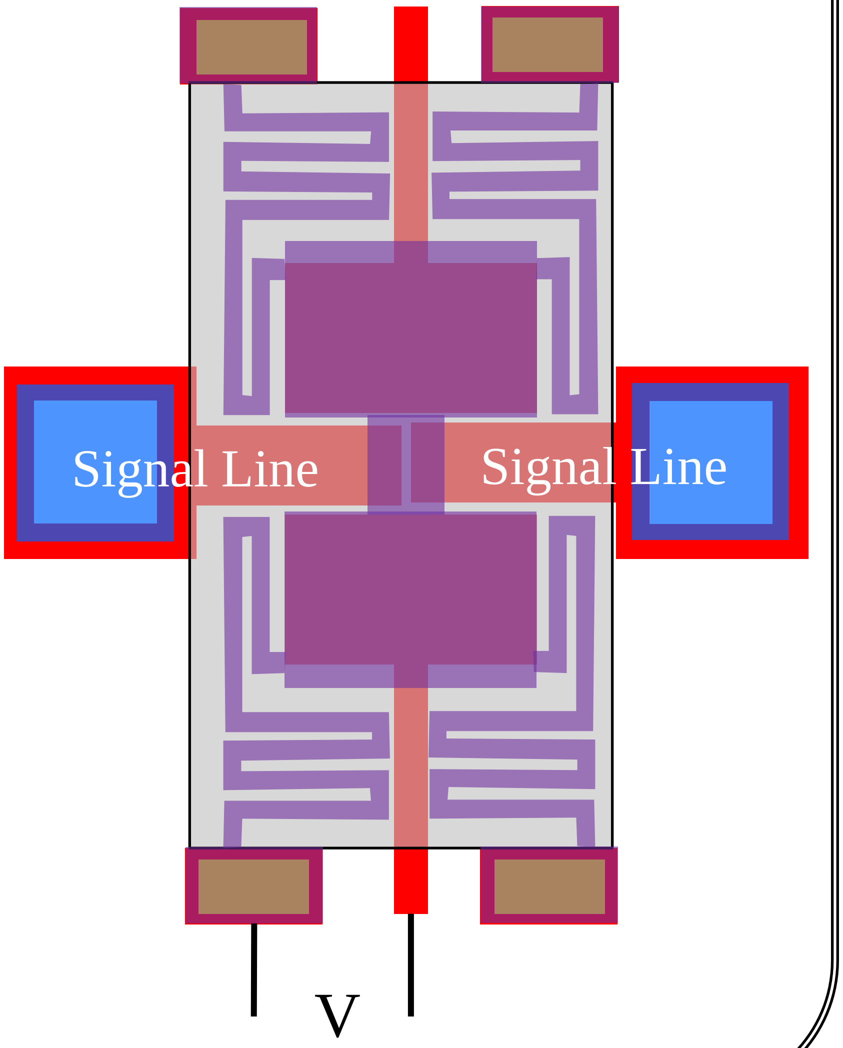
HEATER AND TEMPERATURE SENSORS



MEMS SWITCH



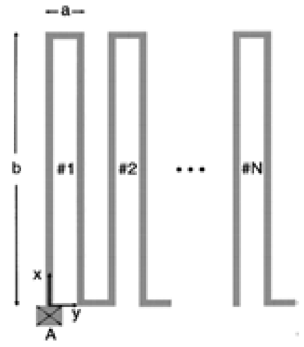
Electrostatic actuation (V) pulls down contactor to make connection along the signal line.



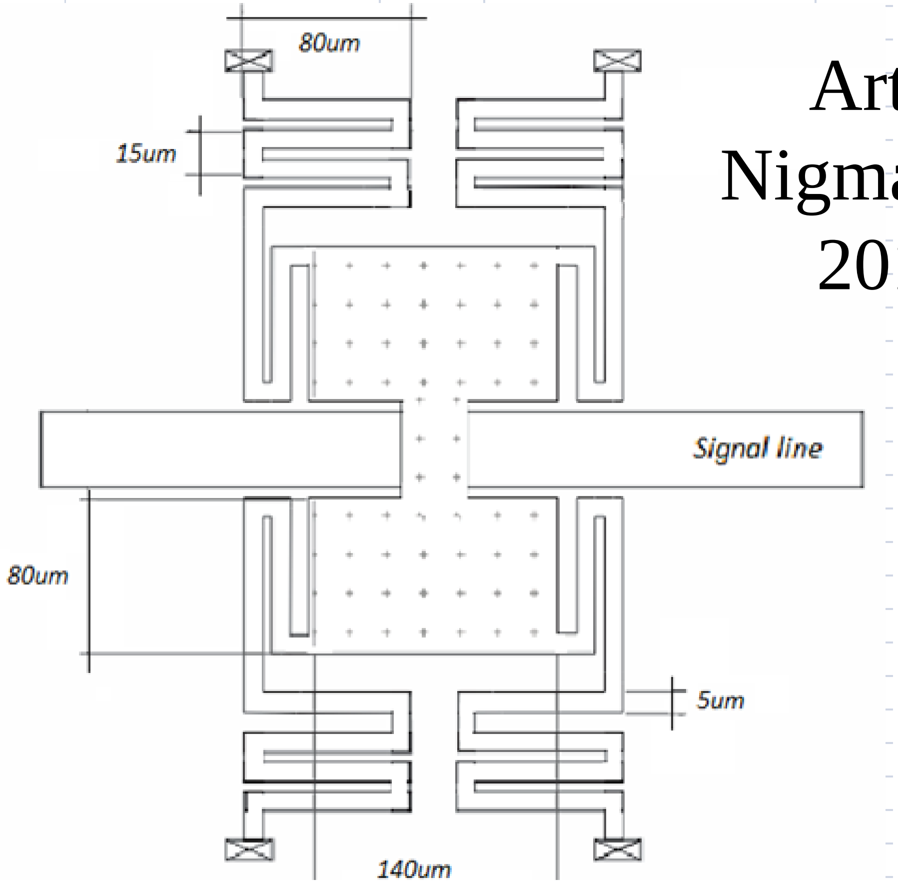
SWITCH CALCULATIONS PLUS DIMENSIONS

Each project has 5mm x 5mm layout space

Number of turns in meander	3
Primary length (a)	1.50E-05
Secondary length (b)	1.00E-04
Thickness (t)	2.00E-06
Beam width (w)	5.00E-06
Poly (Youngs Modulus) (E)	1.60E+11
Poly (Poissons Ratio) (v)	0.22
Shear Modulus (G)	6.56E+10
X-axis moment of inertia (Ix)	3.33E-24
Z-axis moment of inertia (Iz)	2.08E-23
Polar moment of inertia (Ip)	2.42E-23
Torsion Constant J	9.98E-24
Initial gap (g0)	2.00E-06
Area	1.12E-08
Number of meanders	4
Spring constant of 1 meander	0.498796
Actuation Electrodes length	1.40E-04
Actuation Electrodes width	8.00E-05

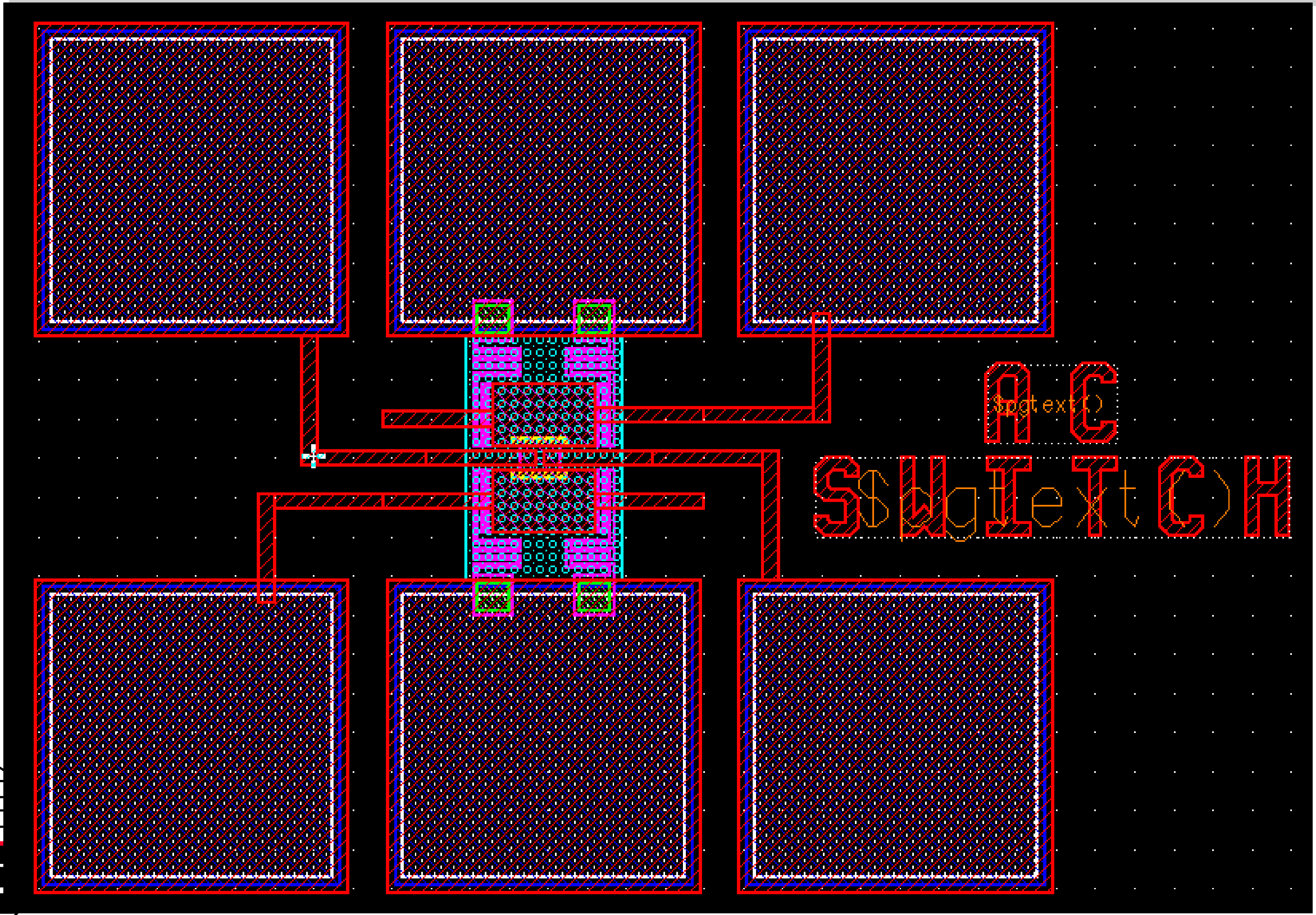


Total spring constant	**K**	**1.995183044**
Pull down voltage	**Vp**	**6.919204614**

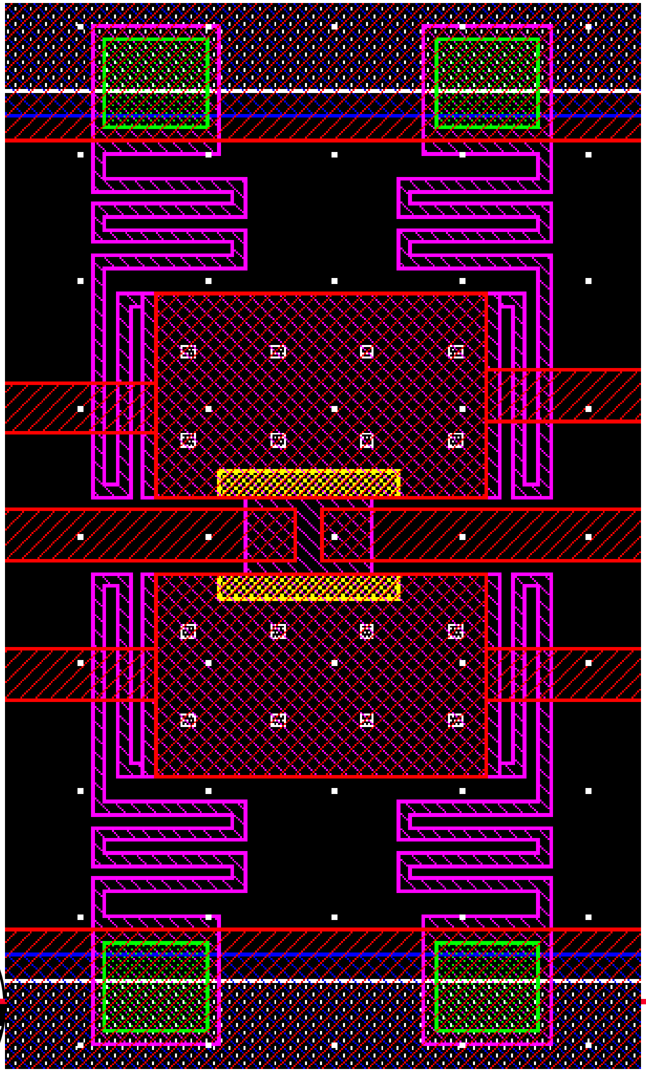


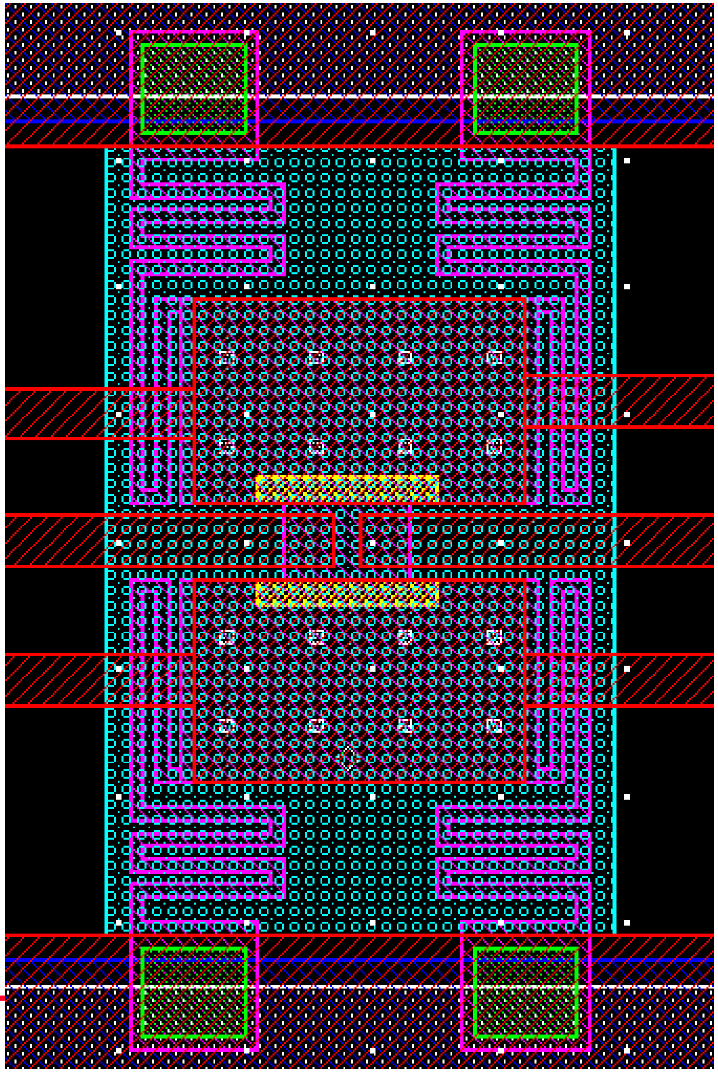
Artur
Nigmatulin
2011

AC MEMS SWITCH

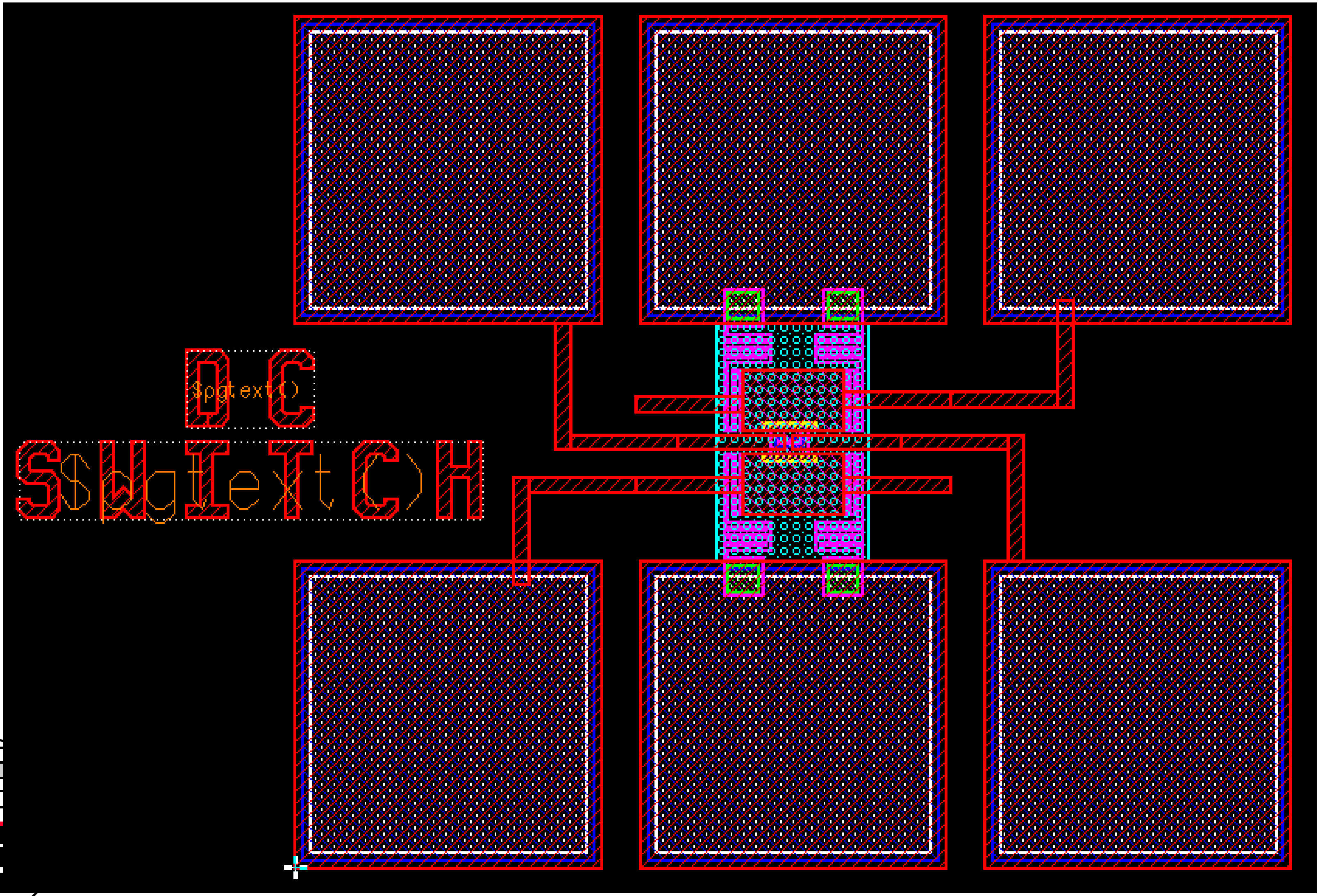


AC MEMS SWITCH

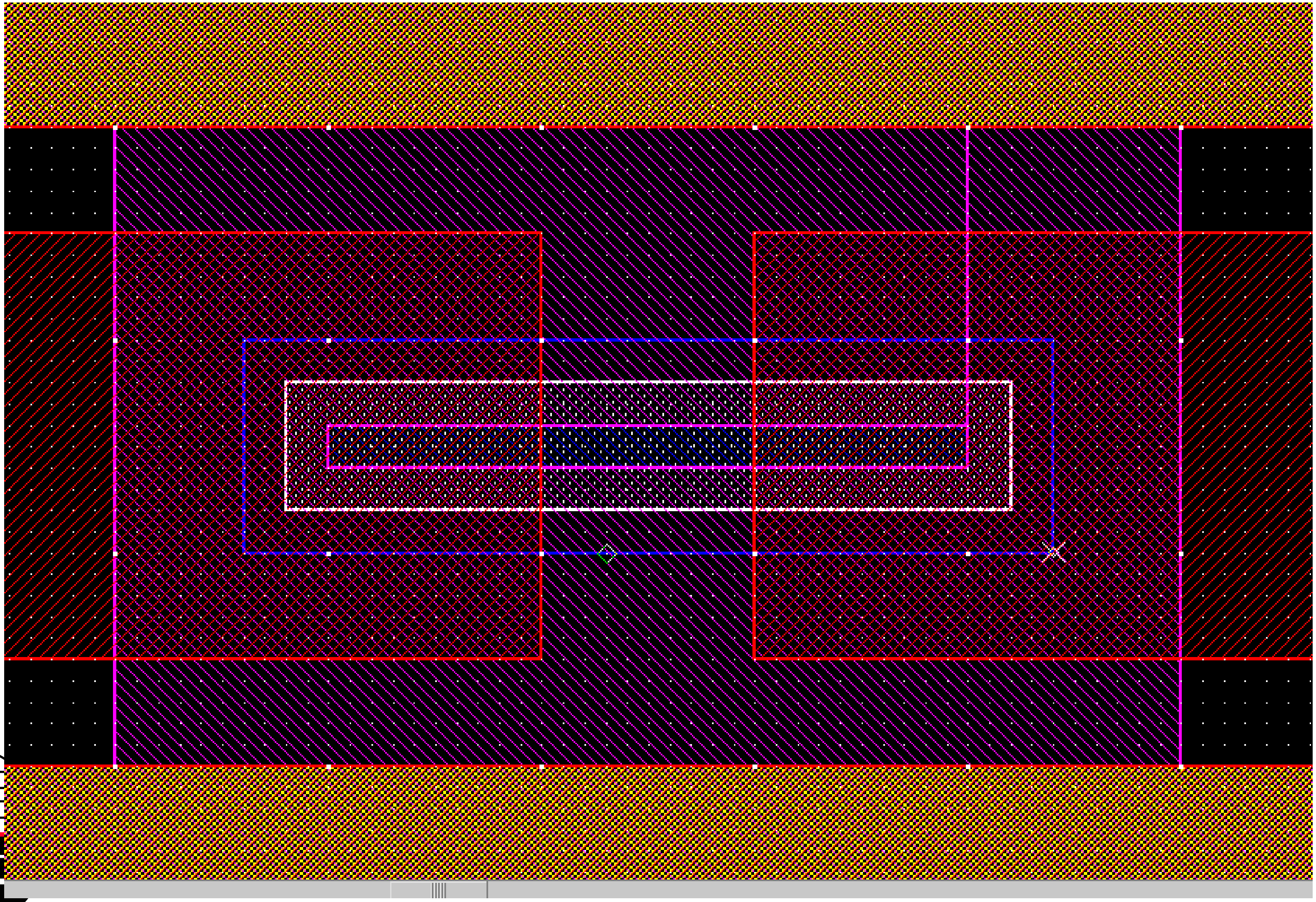




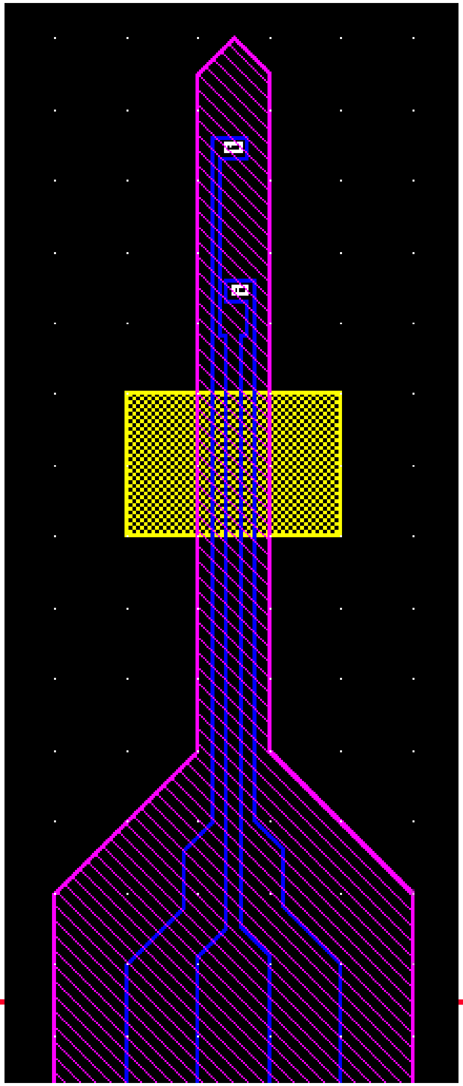
DC MEMS SWITCH

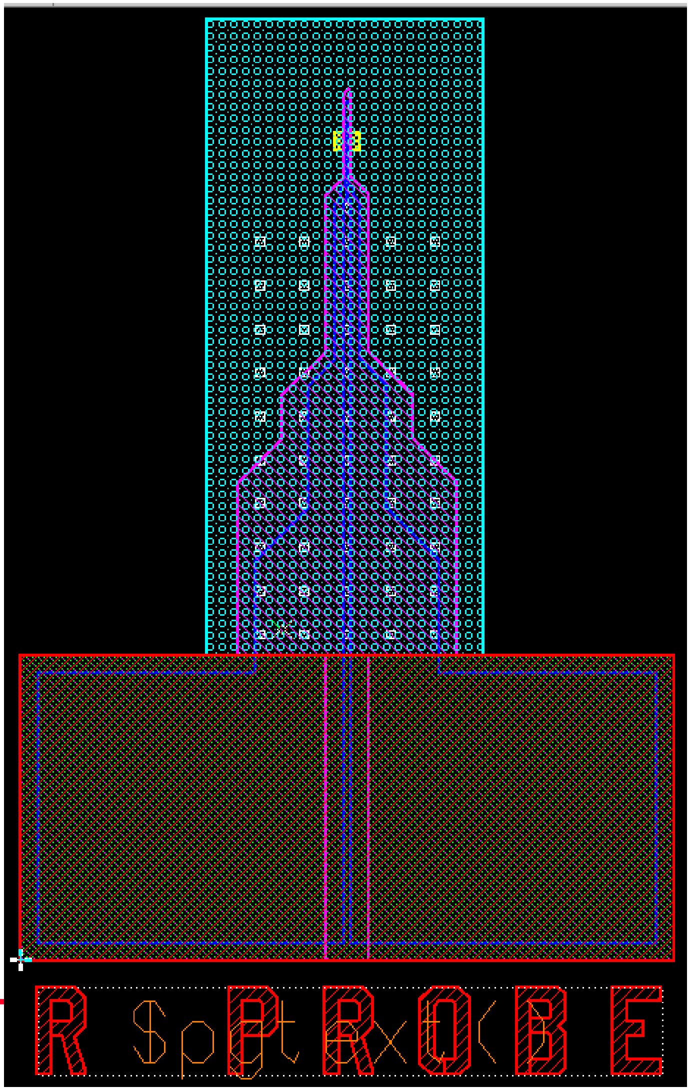


DC MEMS SWITCH



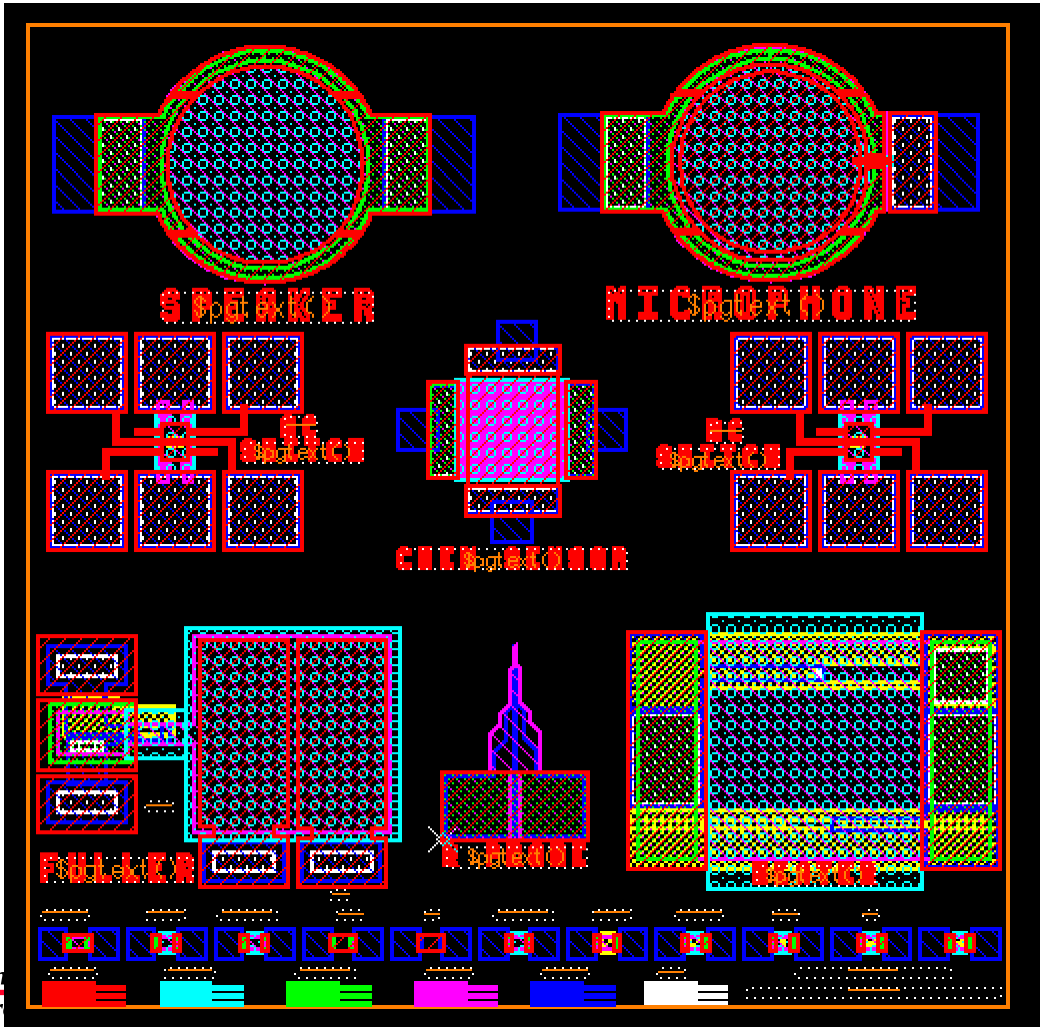
PROBE



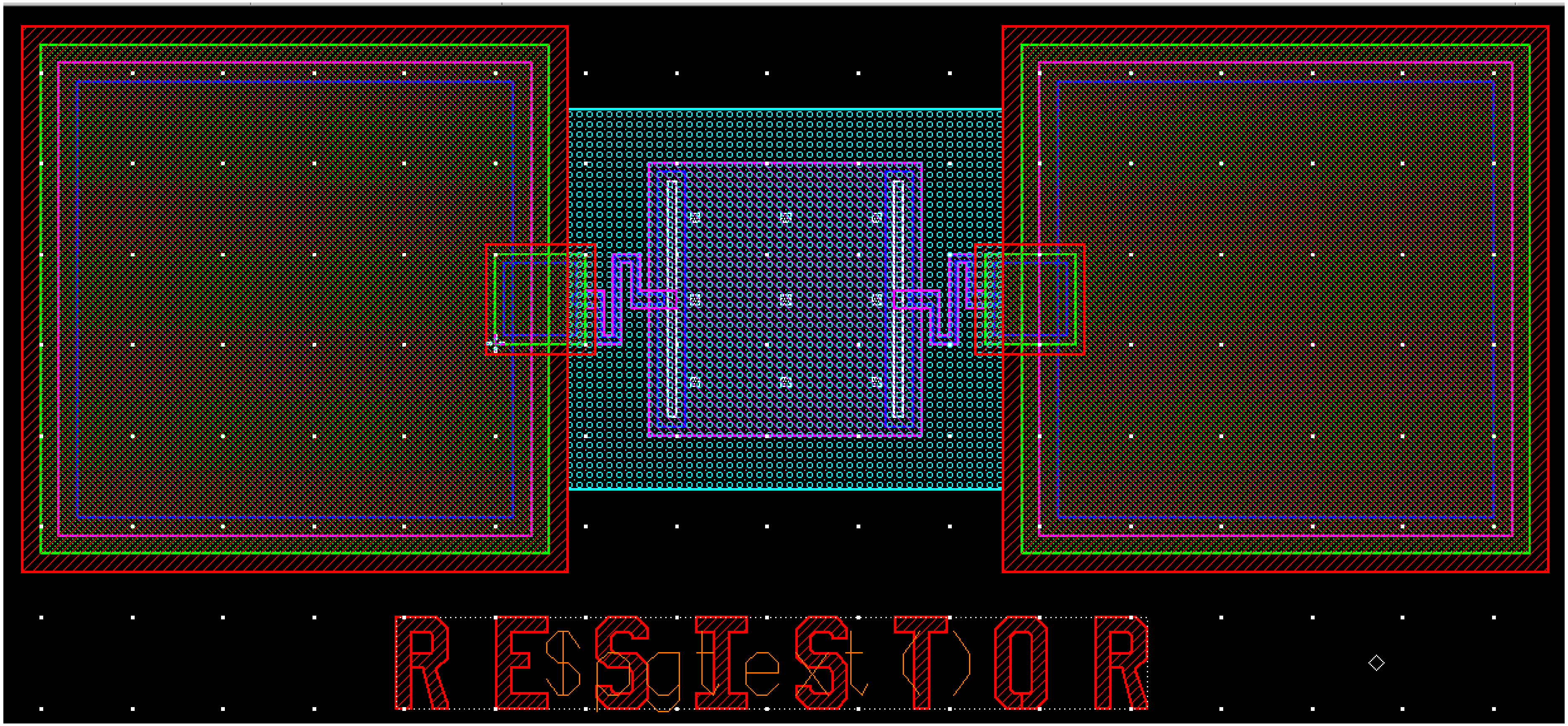


Surface MEMS Design Examples

ALL ABOVE CELLS

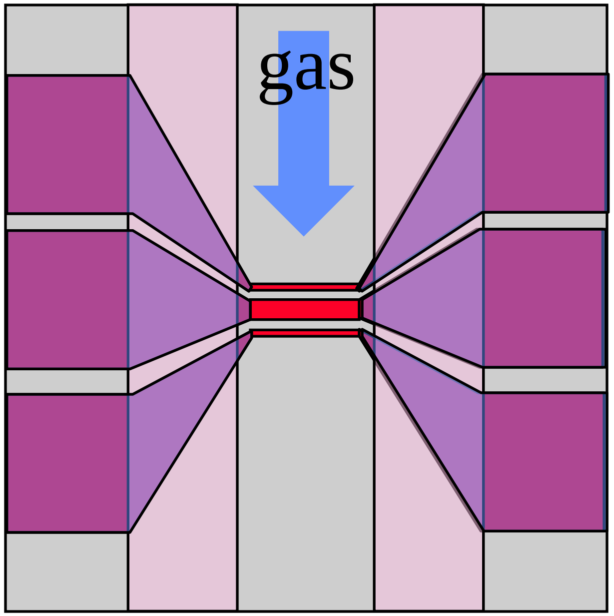


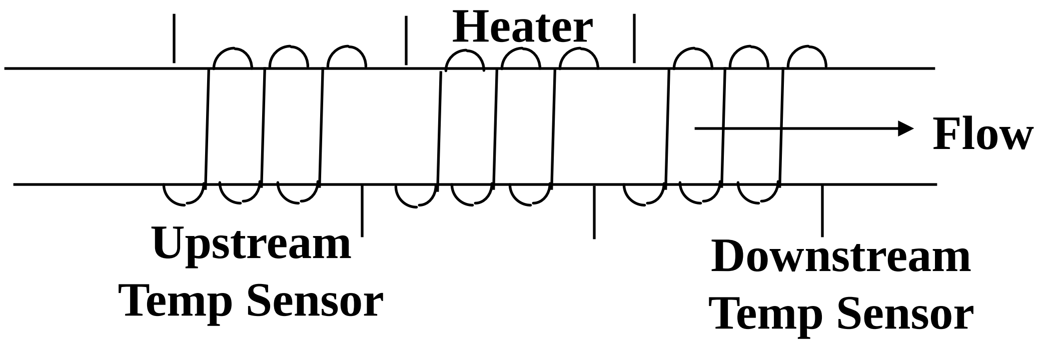
RESISTOR - BOLOMETER

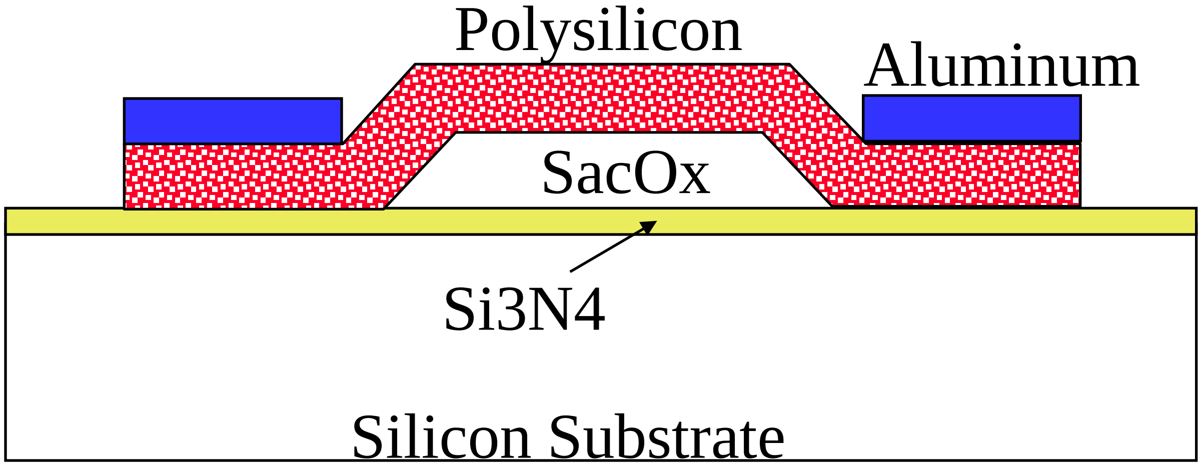


Resistor is suspended in air.

THERMAL FLOW SENSORS

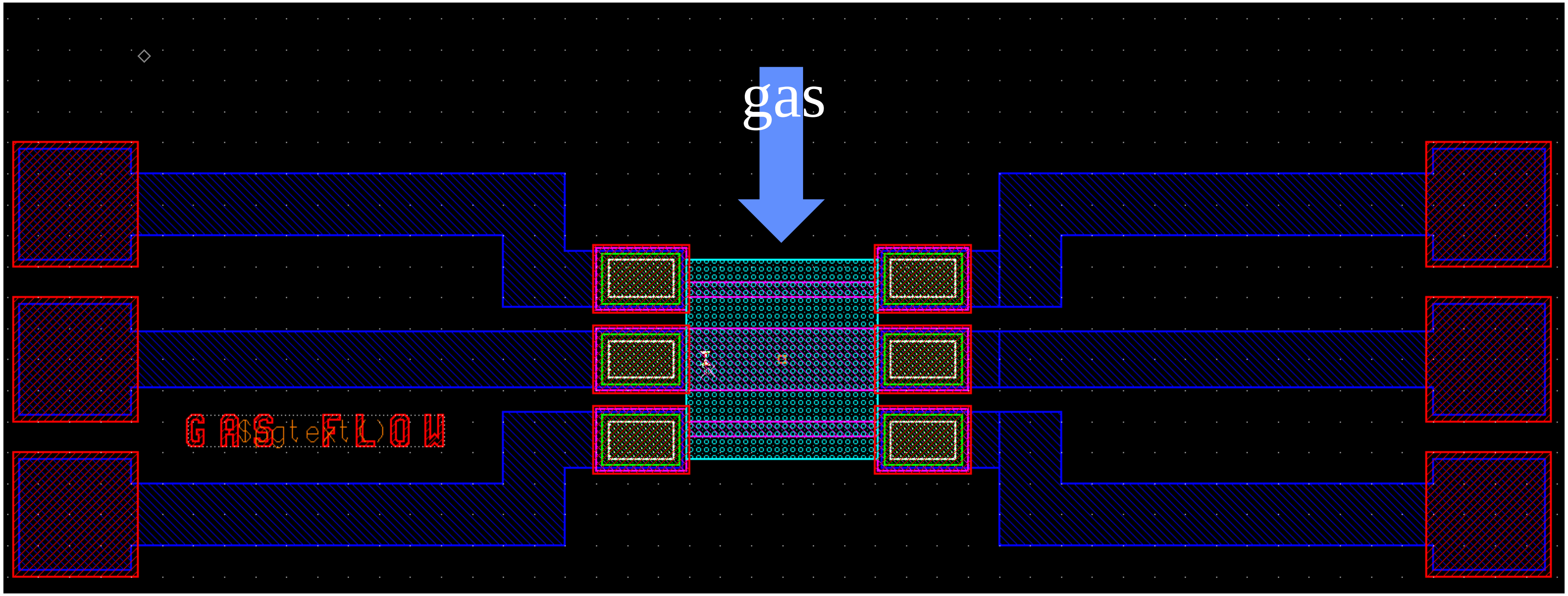






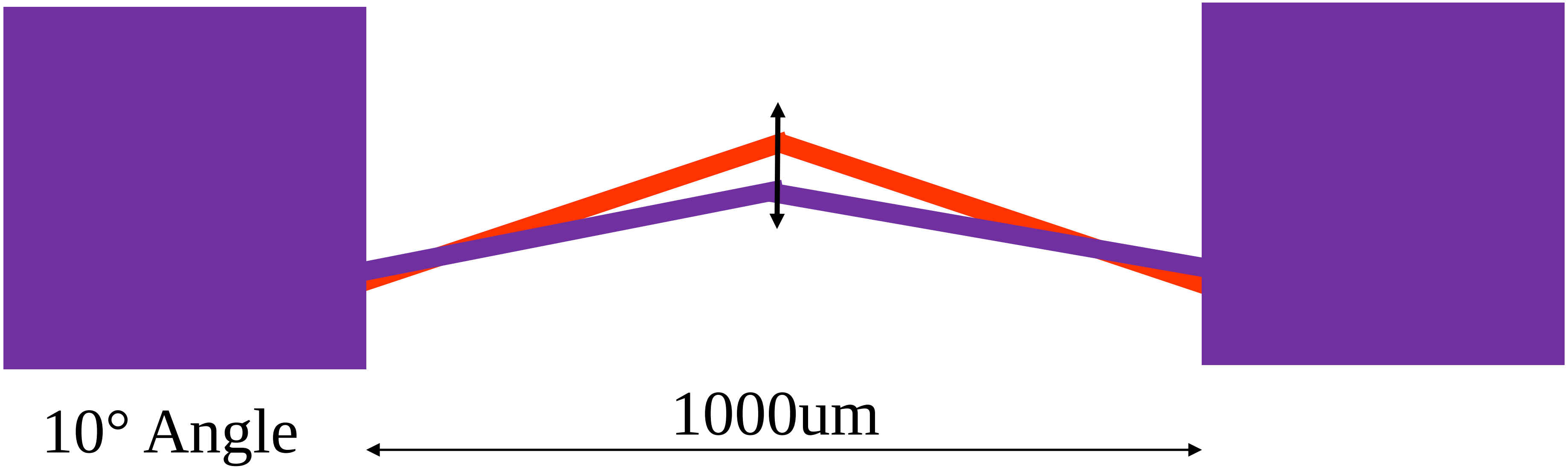
Spring 2003
EMCR 890 Class Project
Dr. Lynn Fuller

GAS FLOW SENSOR



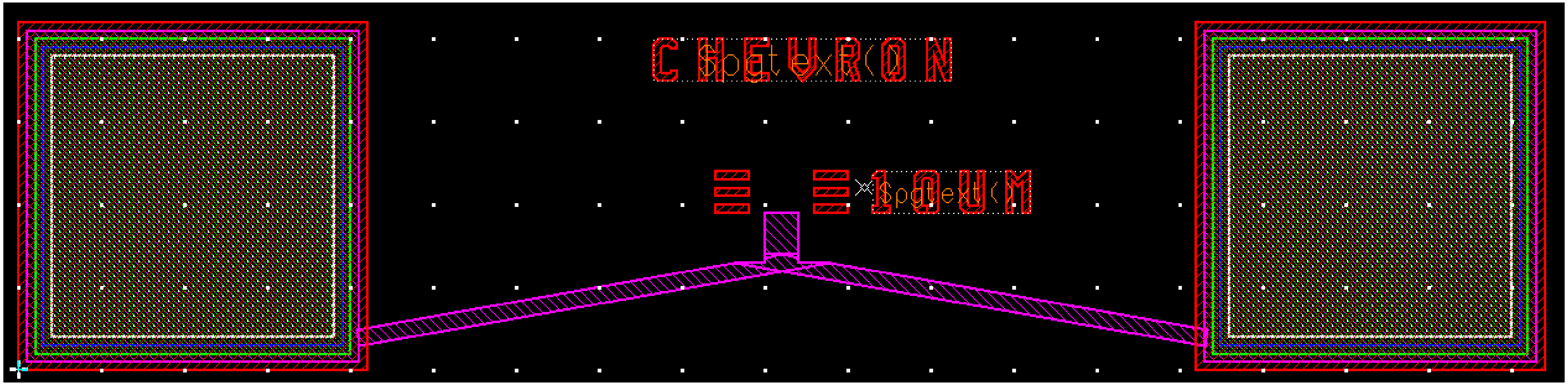
Overall Size 5000um x 1400um
Heater 700um x 200um
Sensors 700um x 50um

CHEVRON ACTUATOR



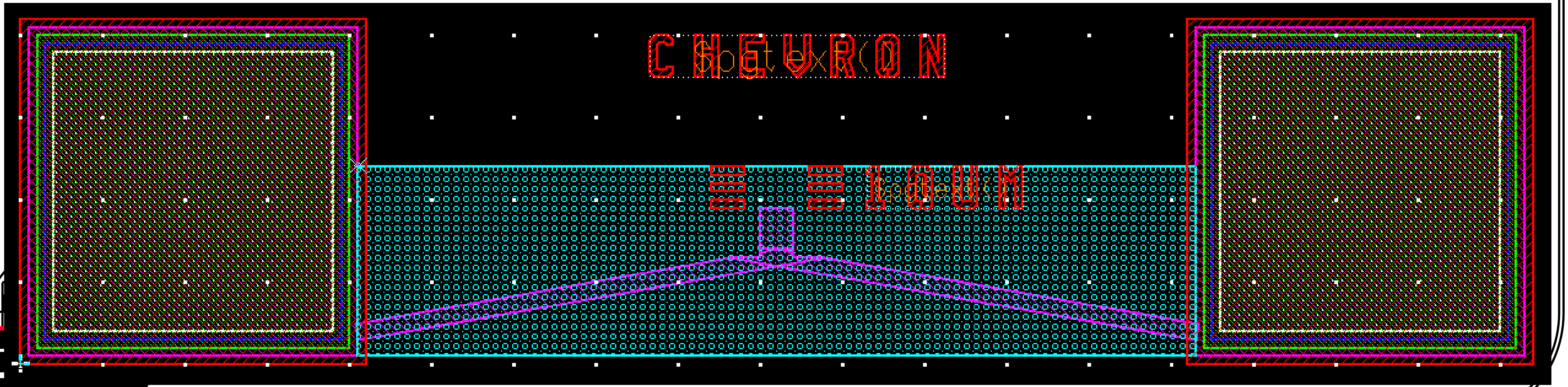
Thermal Expansion for Si is 2.33E-6/°C
Current flow causes heating and movement

CHEVRON ACTUATOR

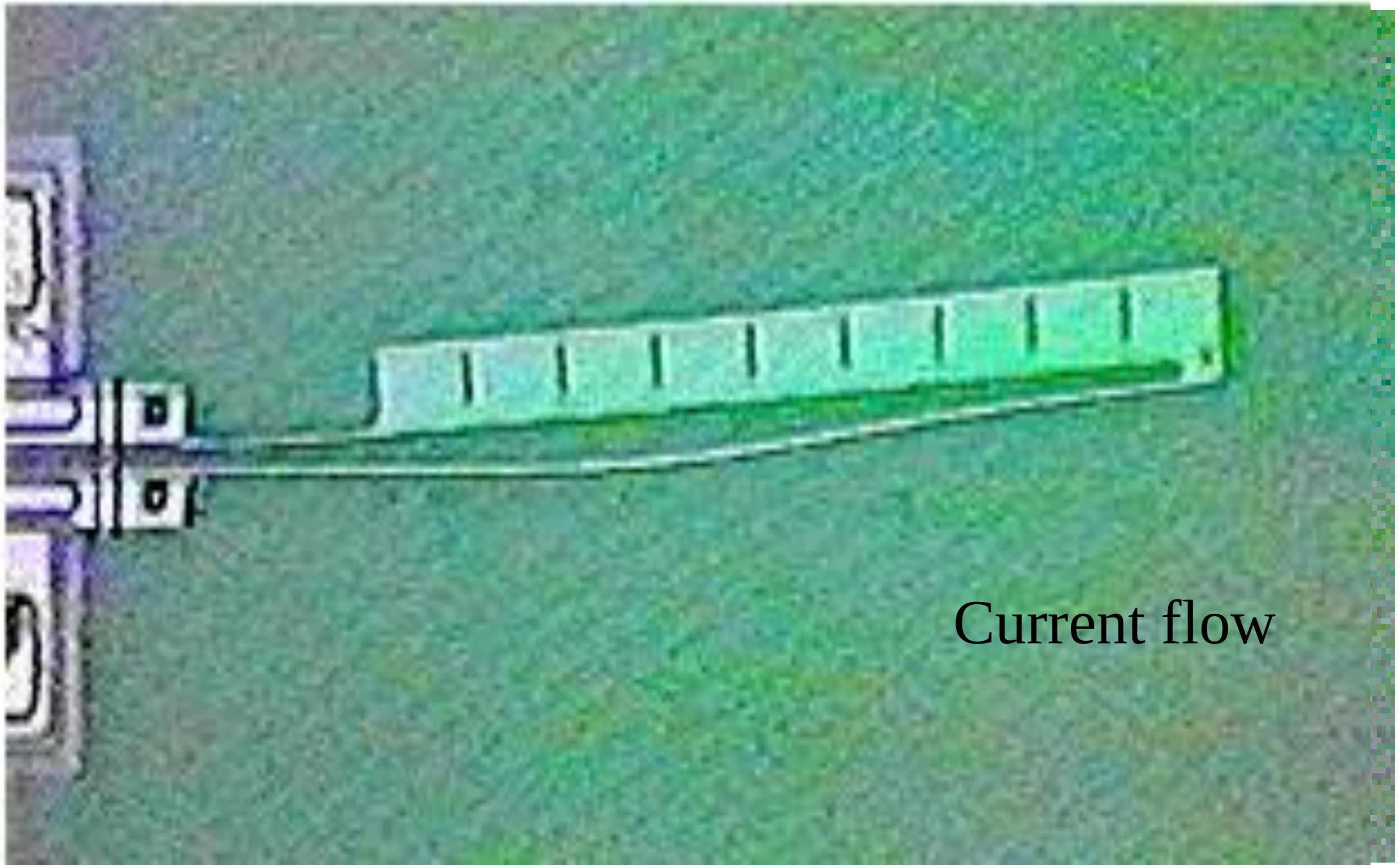


10° Angle

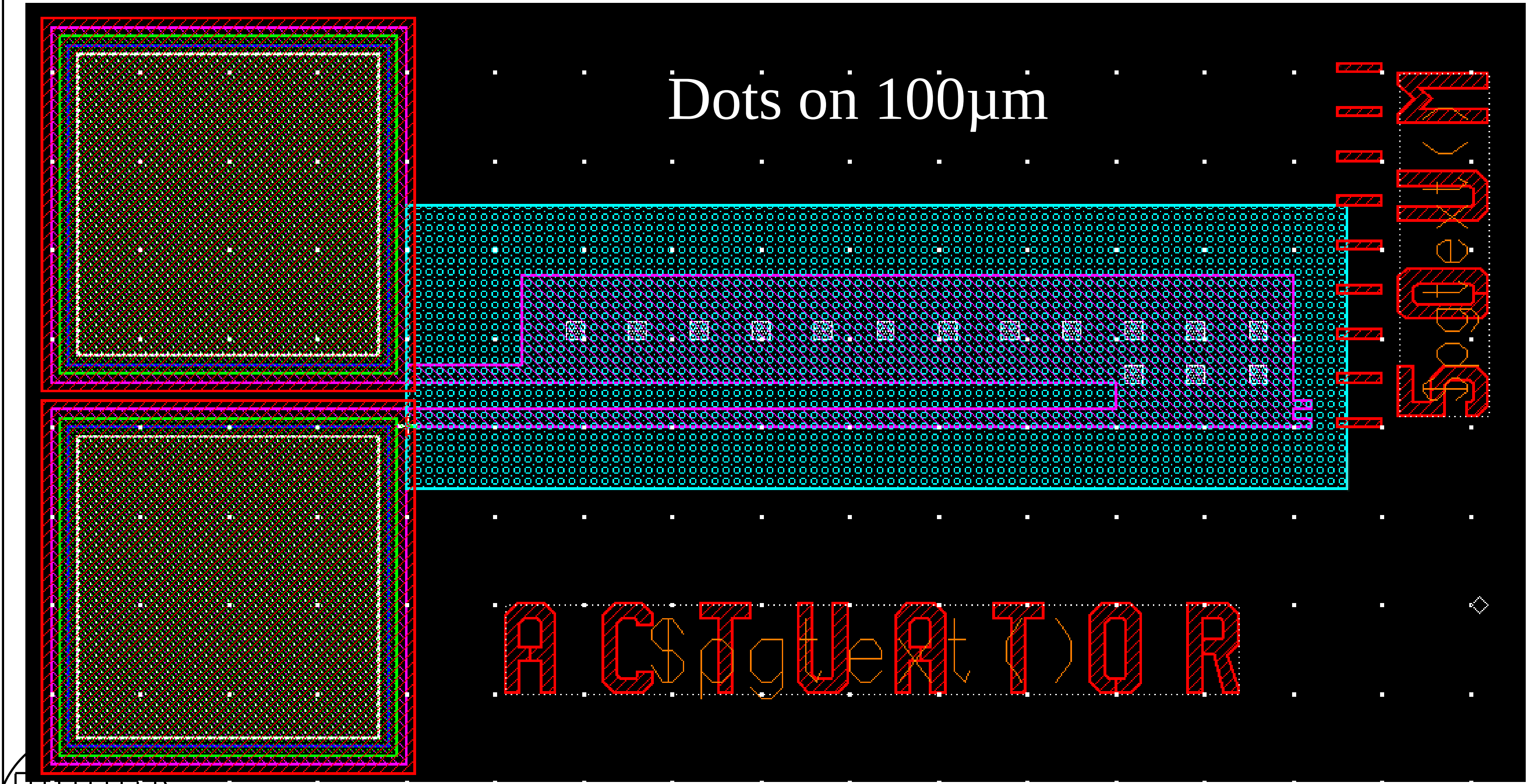
1000um



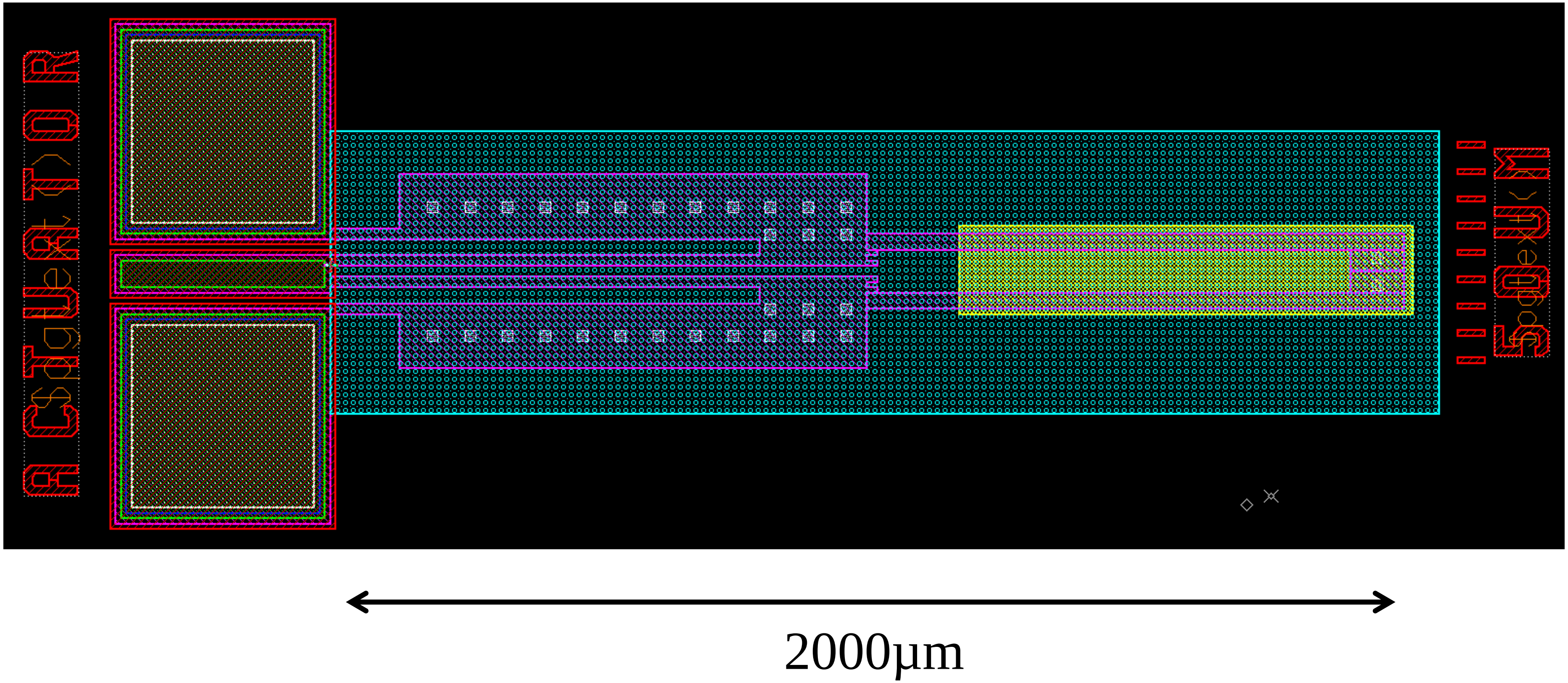
POLYSILICON THERMAL ACTUATORS



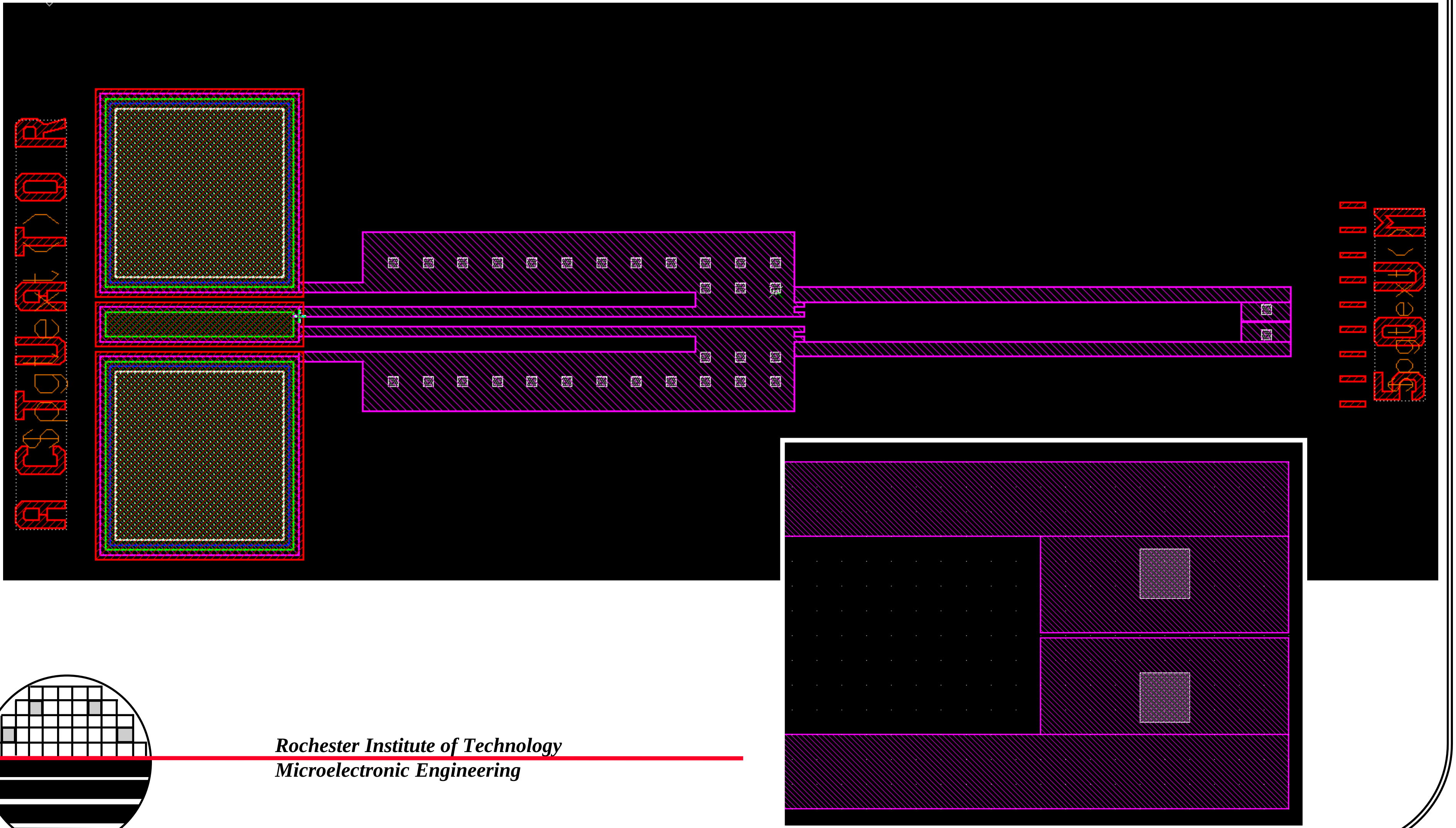
TWO ARM THERMAL ACTUATOR



MICRO GRIPPER

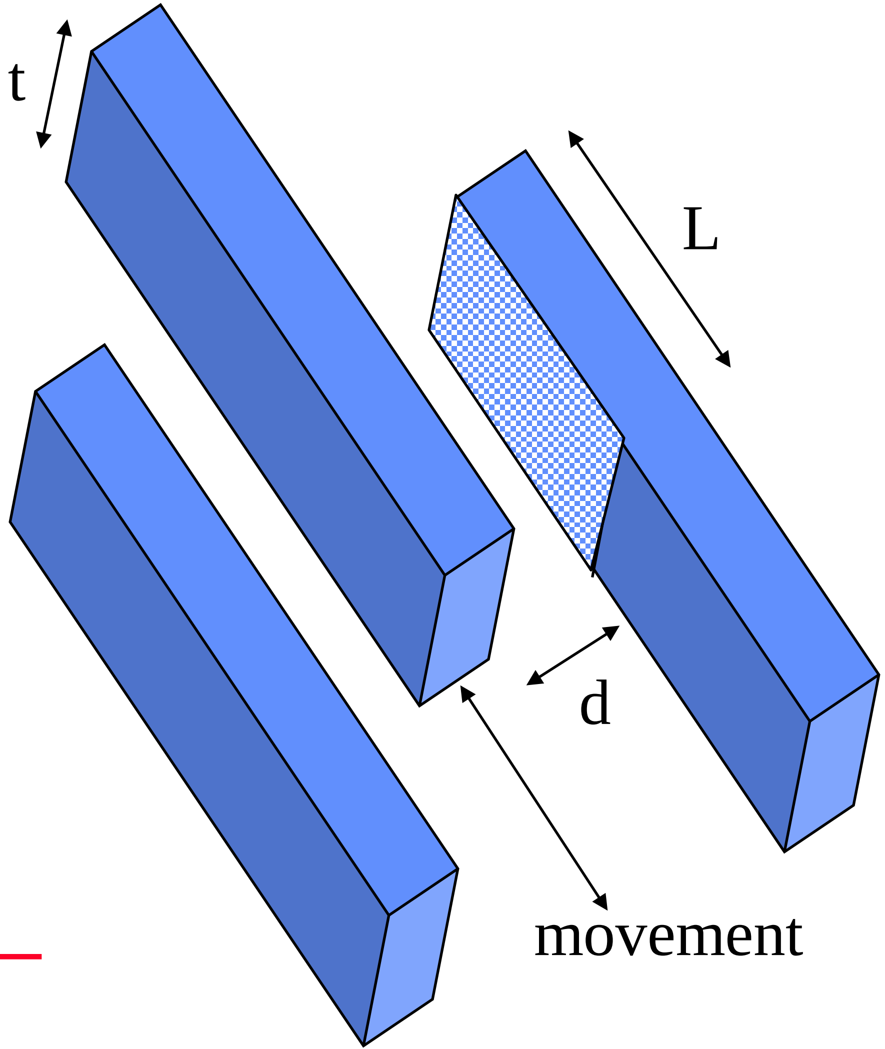


MICRO GRIPPER

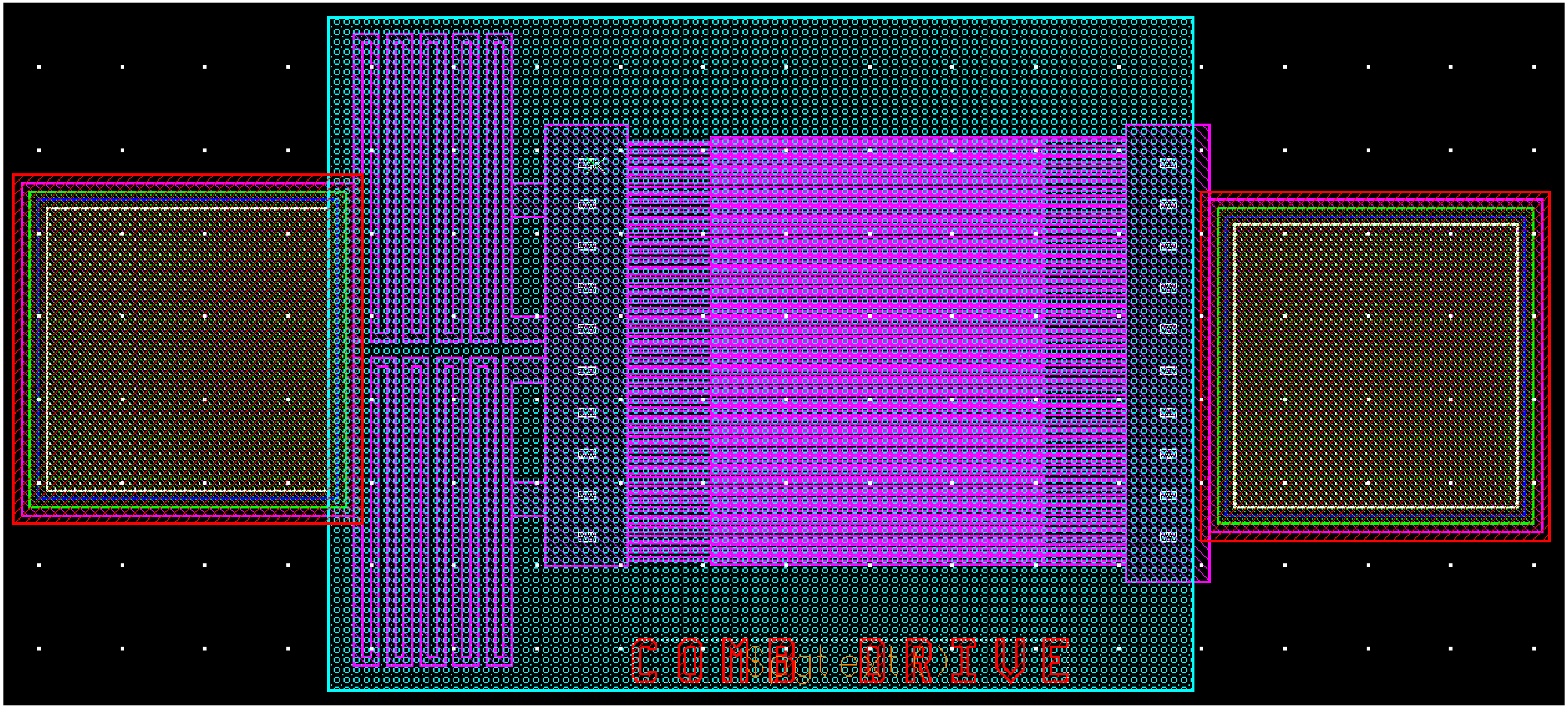


CALCULATION OF DISPLACEMENT VS VOLTAGE

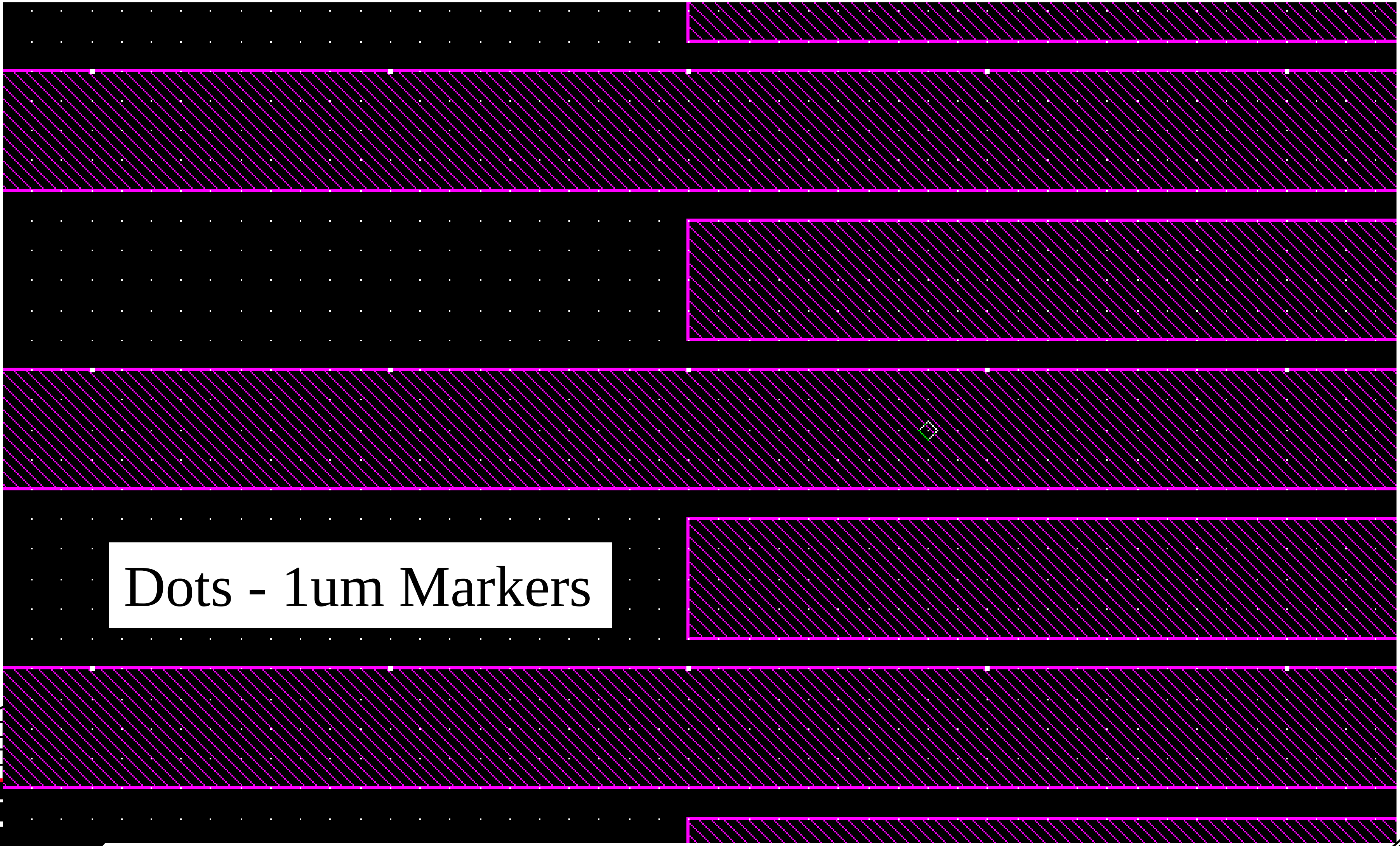
$$F = \varepsilon r\ \varepsilon o\ t\ V^2 / 2\ d$$



COMB DRIVE ACTUATOR



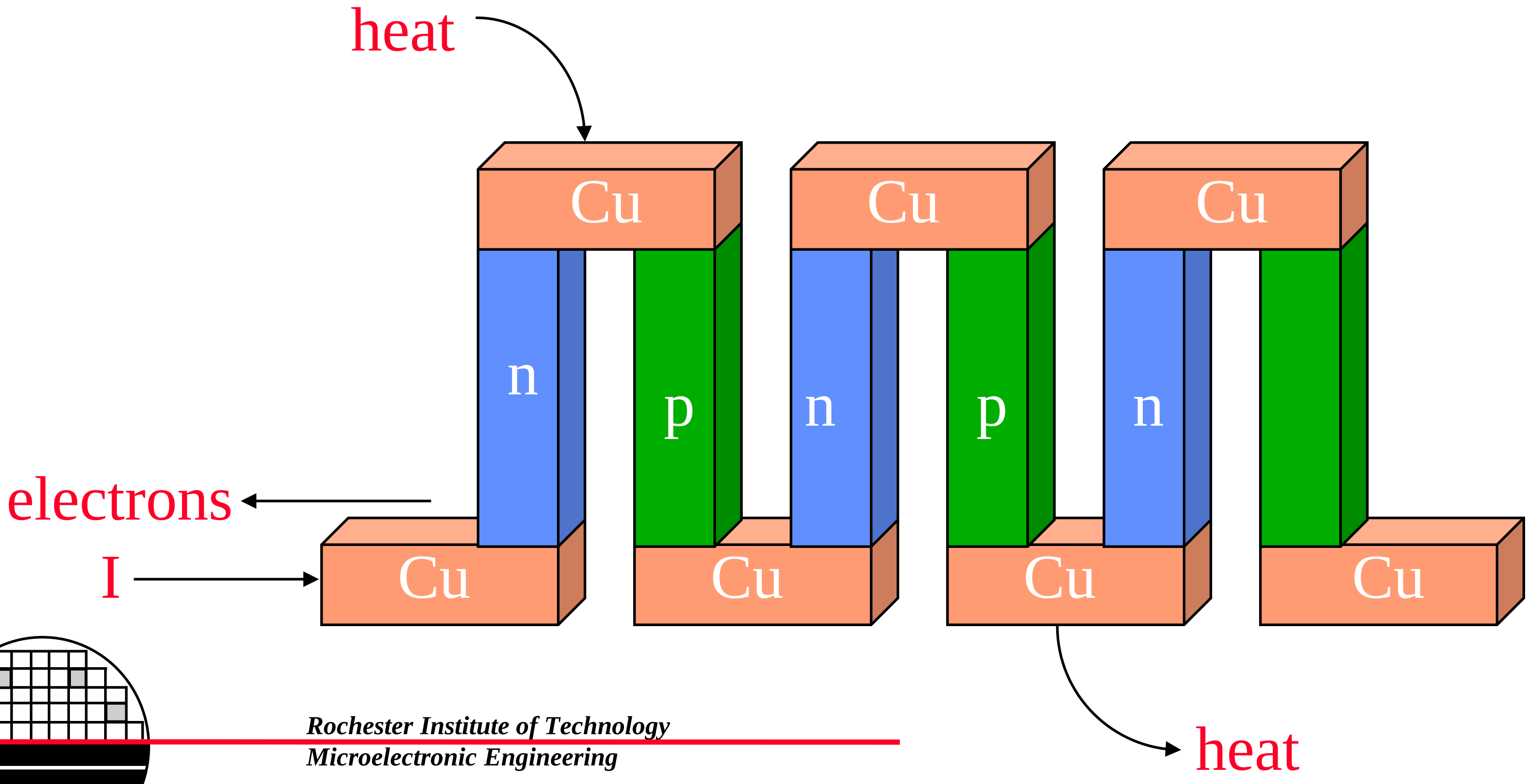
COMB DRIVE ACTUATOR



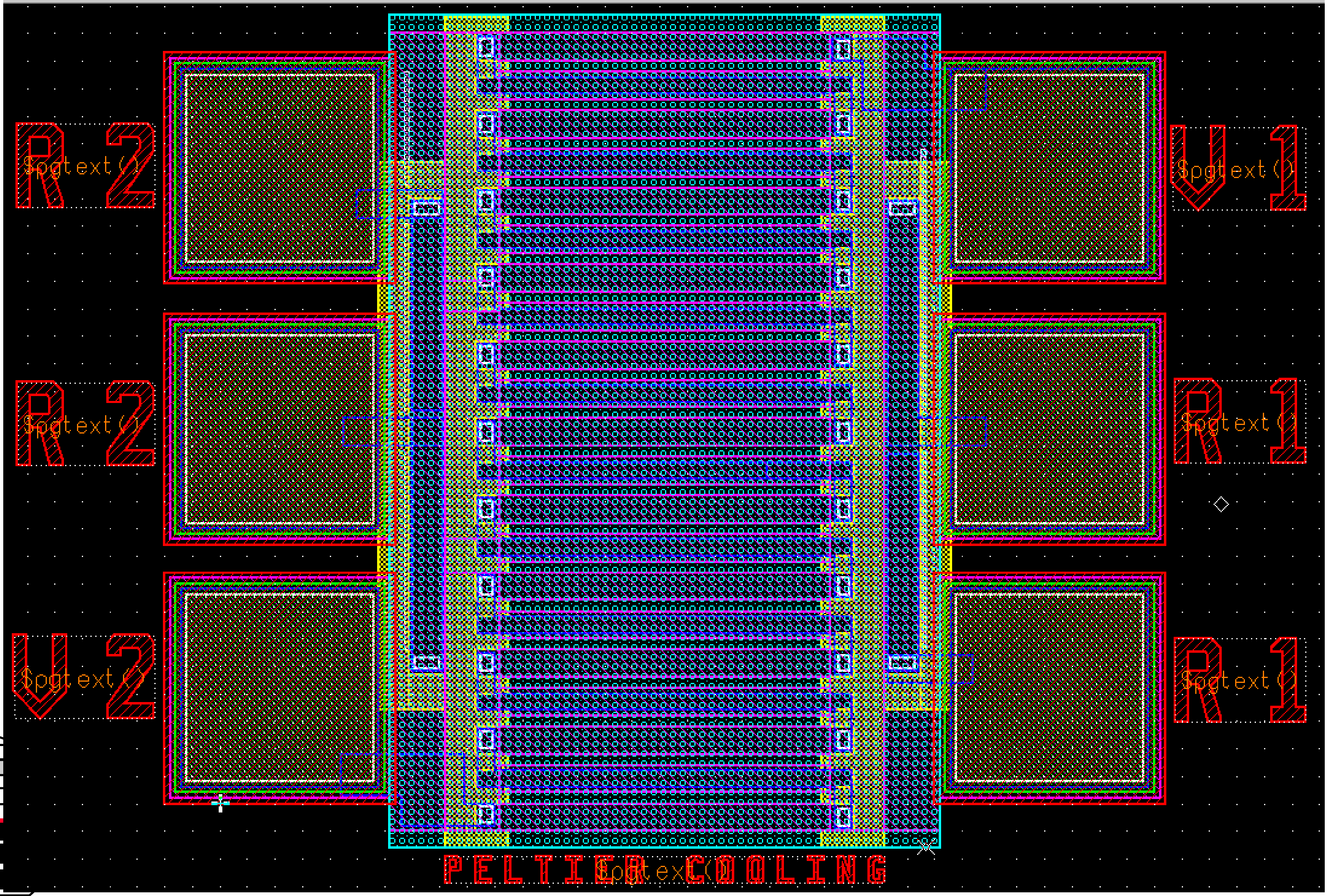
Dots - 1um Markers

PELTIER EFFECT

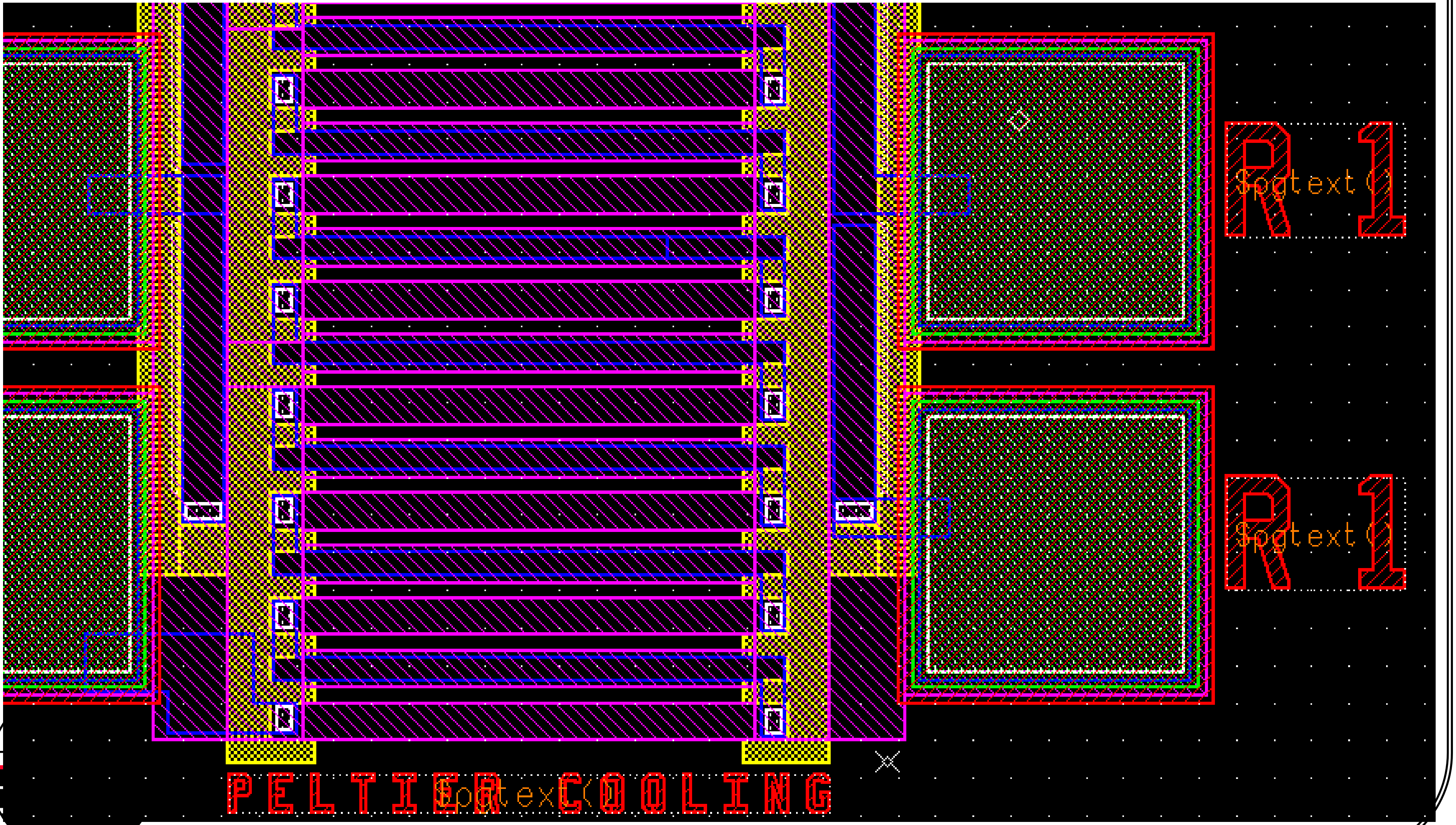
Heat pump device that works on the gain in electron energy for materials with low work function and the loss in energy for materials with higher work function. Electrons are at higher energy (lower work function) in n-type silicon.



PELTIER COOLING



PELTIER COOLING

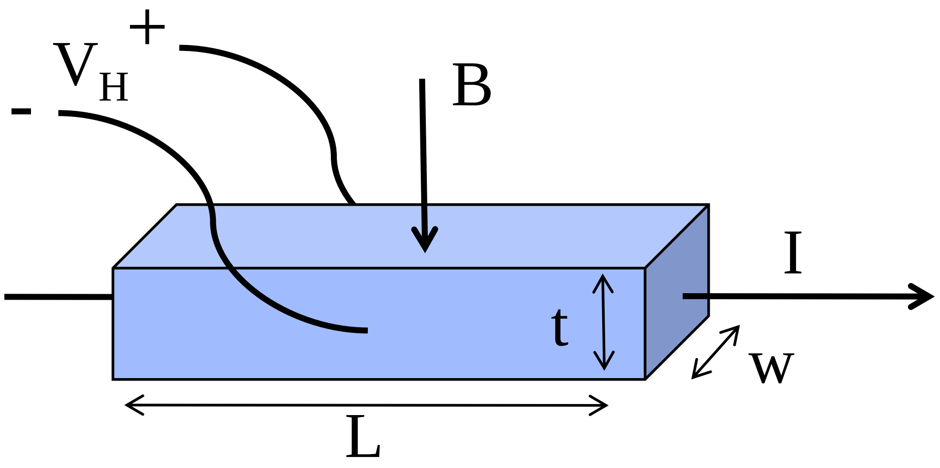


THE HALL EFFECT

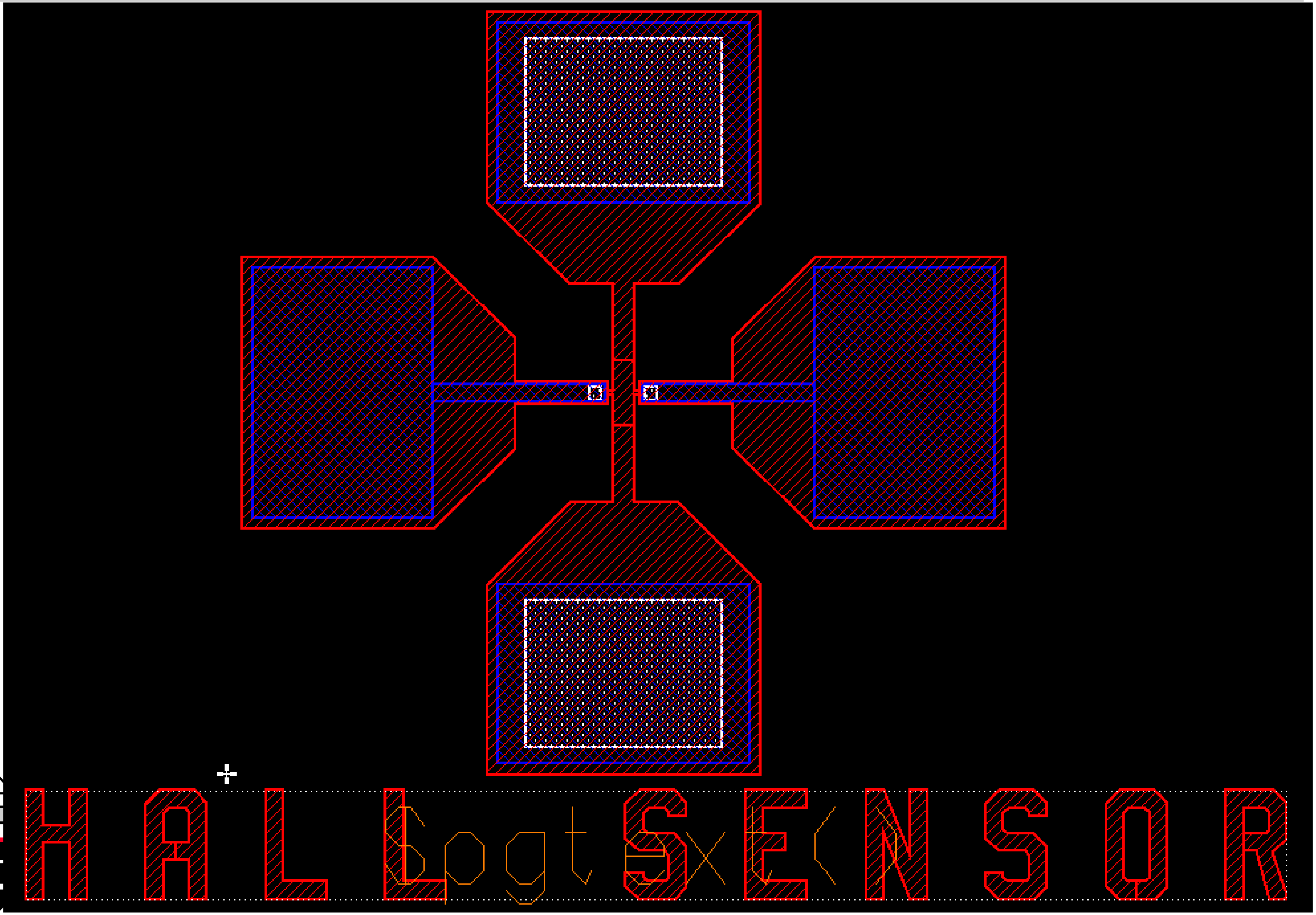
The Hall effect was discovered in 1879 by Edwin H Hall.

The Hall voltage (V_H) is created across a conductor, transverse to the current flow (I) and perpendicular to a magnetic field (B). The Hall coefficient is defined as the ratio of the Hall voltage to the product of Current and magnetic field. The Hall coefficient is a function of the carrier type (+ or -), charge (q=1.6E-19), and carrier concentration (n).

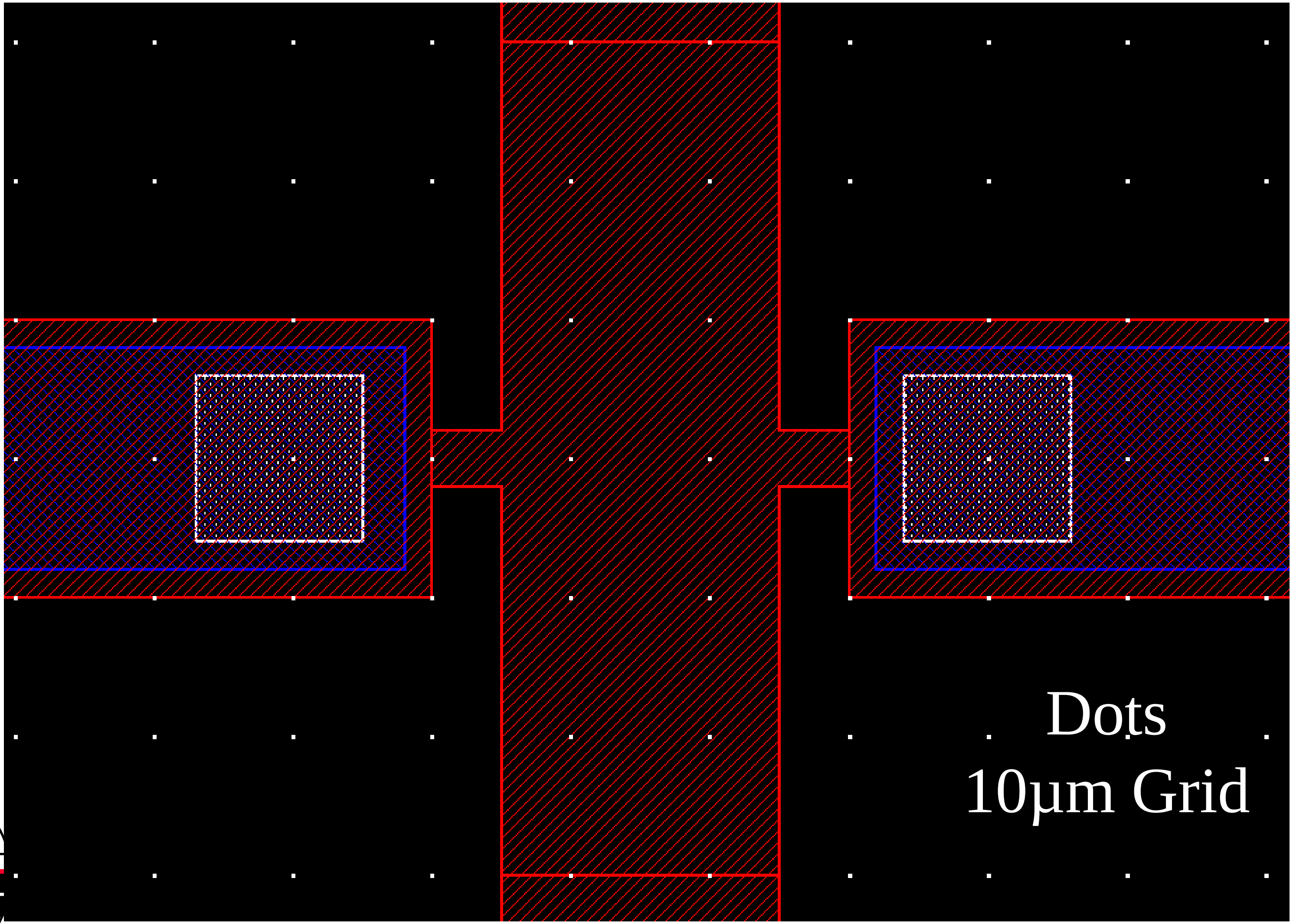
$$V_H = \frac{-I\,B}{q\,n\,t}$$



HALL EFFECT MAGNETIC FIELD SENSOR



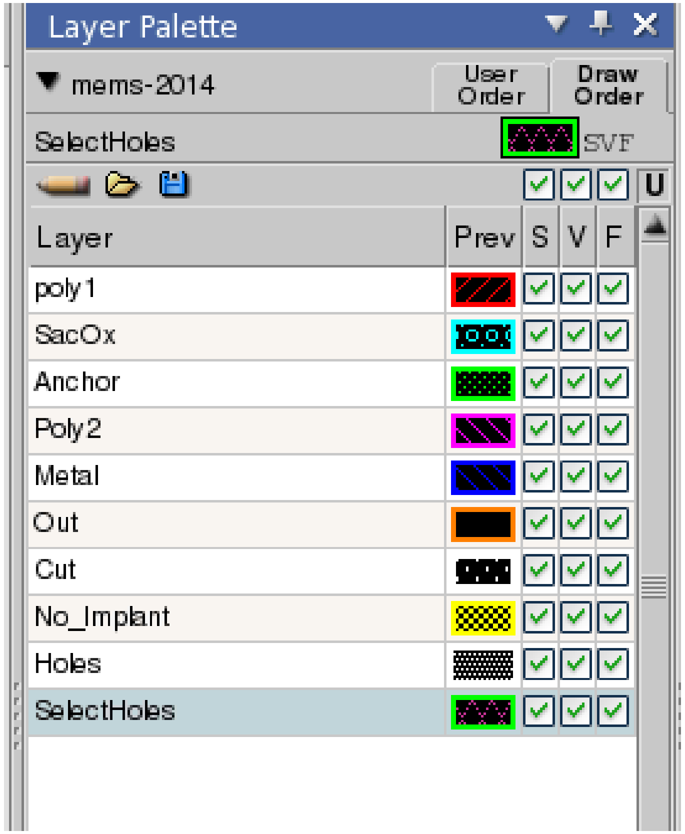
HALL EFFECT MAGNETIC FIELD SENSOR



HOMEWORK – DESIGN EXAMPLES

1. Draw the Layout for a device you would like to build.
2. Export the GDS-II file and email it to your instructor.

Use the process
/tools/ritpub/process/mems-2014



Layer	Prev	S	V	F
poly1	▨	☑	☑	☑
SacOx	▨	☑	☑	☑
Anchor	▨	☑	☑	☑
Poly2	▨	☑	☑	☑
Metal	▨	☑	☑	☑
Out	▨	☑	☑	☑
Cut	▨	☑	☑	☑
No_Implant	▨	☑	☑	☑
Holes	▨	☑	☑	☑
SelectHoles	▨	☑	☑	☑

HOMEWORK – DESIGN PRESENTATION

1. Prepare a PowerPoint presentation and present it to the class.
    1. Title page, Name, Date, Rochester Institute of Technology, MCEE770 MEMS Fabrication
    2. Introduction and Overview (1 or 2 pages)
    3. Appropriate Calculations (1 or 2 pages)
    4. Layout (a few pages) with dimensions added, zoom in to some areas, show all layers, show selected layers
2. Bring your PowerPoint on a Flash Drive and load on the instructors computer at the start of class.