Bulk Micromachined MEMS Design

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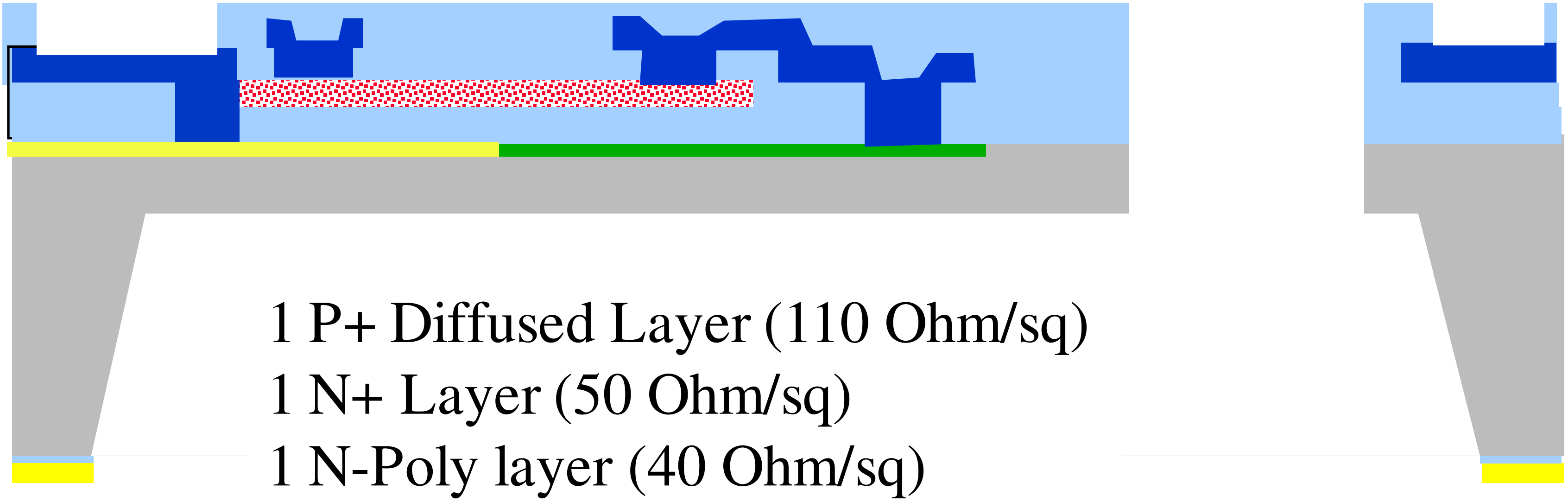
Rev. 3-29-2011 MEMS_Bulk_Design.ppt

OUTLINE

Introduction to MEMS Multichip Projects
Design Rules
Examples
Masks
Mentor Graphics IC Layout

INTRODUCTION - RIT MEMS BULK PROCESS



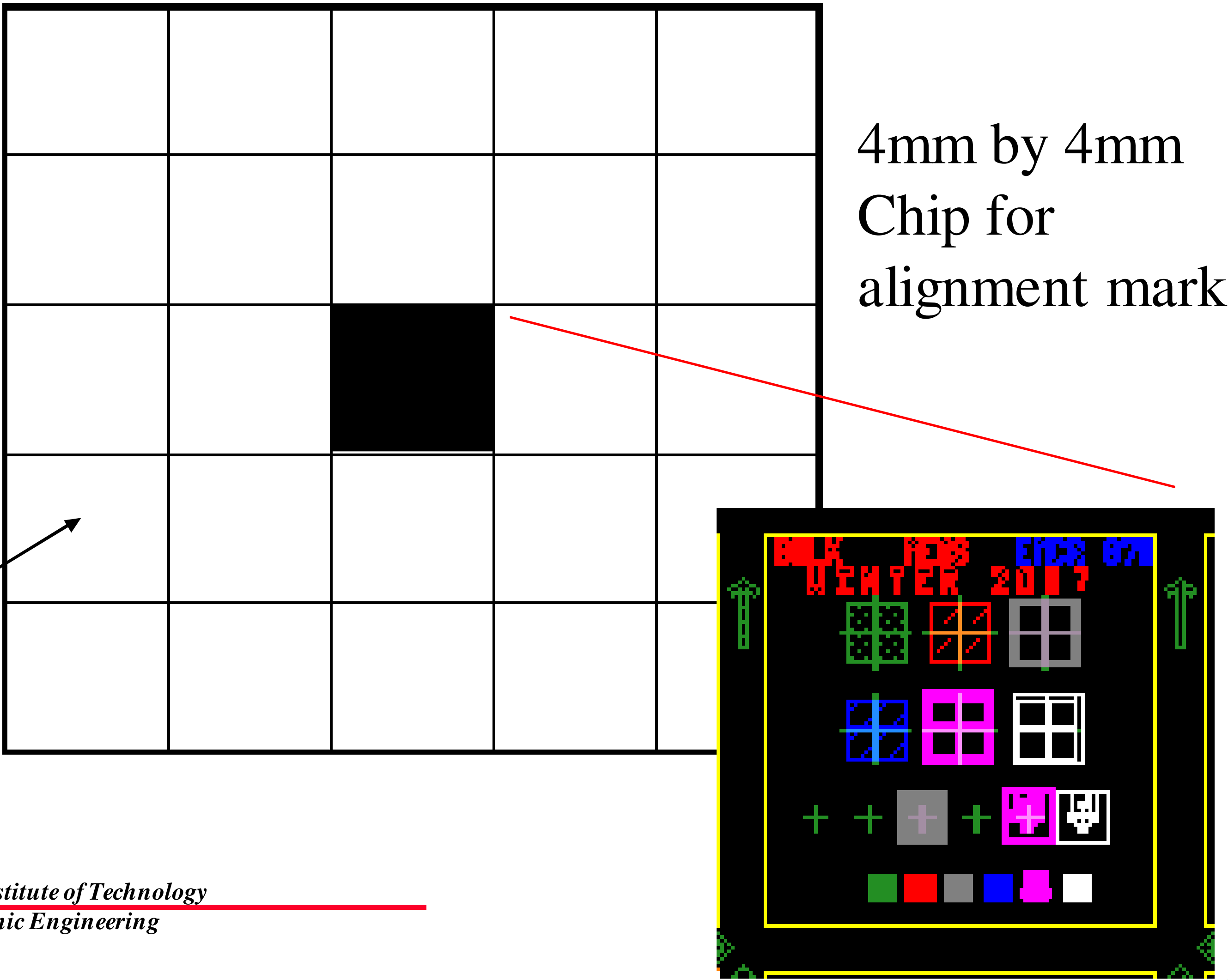
1 P+ Diffused Layer (110 Ohm/sq)
1 N+ Layer (50 Ohm/sq)
1 N-Poly layer (40 Ohm/sq)
Contact Cuts
1 metal layer (Al 1µm thick)
Top Passivation and Via
20-30 µm Si diaphragm

MEMS MULTI-PROJECT CHIP LAYOUT

Total 20 mm by 20 mm for 24 student projects

Wafer sawing is easier if all chips are the same size

4mm by 4mm Design Space for Each Project



4mm by 4mm Chip for alignment marks

Rochester Institute of Technology
Microelectronic Engineering

DESIGN GUIDELINES

Microelectromechanical Systems

The basic unit of distance in a scalable set of design rules is called Lambda, λ

For the current MEMS process λ is ten microns (10 µm)

The process has eight mask layers, they are:

P+ Diffusion (Green)(layer 1) 🟩

N+ Diffusion (Yellow)(layer 2) 🟨

Poly Resistor (Red)(layer 3) 🟥

Contact (Gray)(layer 4) ◼

Metal (Blue)(layer 5) 🟦

Diaphragm (Purple) (layer 6) 🟪

Top Via (White)(layer 7) ⬜

/shared/0305-870/mems_bulk_092

DESIGN RULES

Construction Line and module layers are not mask layers but aid in layout. The module layer should be used to define the 4mm x 4mm work space. The construction line layer might be used to show the size of the diaphragm which is smaller than the diaphragm opening on the back of the wafer.

Minimum pad size for probing 100 µm by 100 µm
Minimum pad size for wire connections 150 µm by 150 µm
All probe pads have metal top layer.

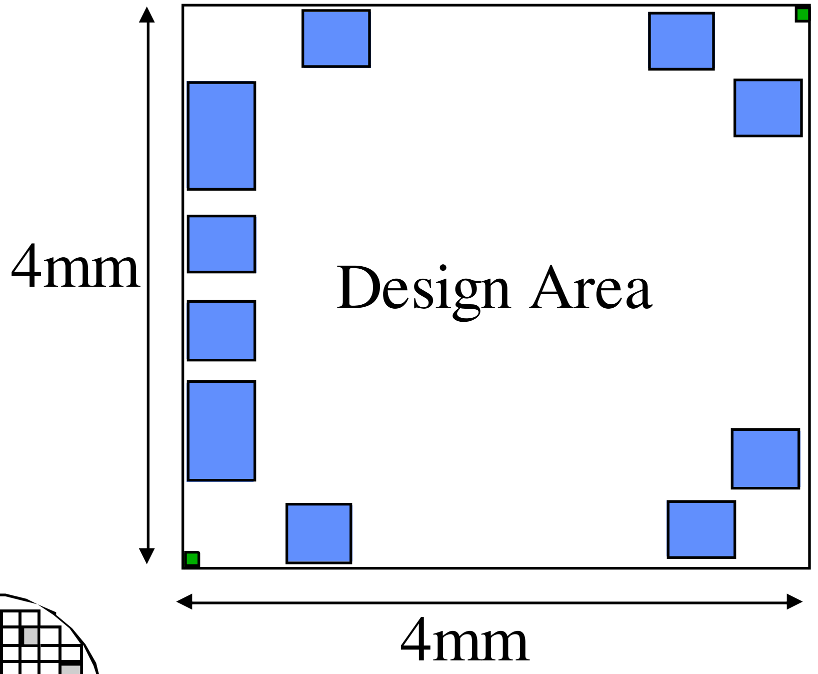
10 µm by 10 µm box needed in four corners of 4000 µm by 4000 µm work space. (for design placement accuracy)

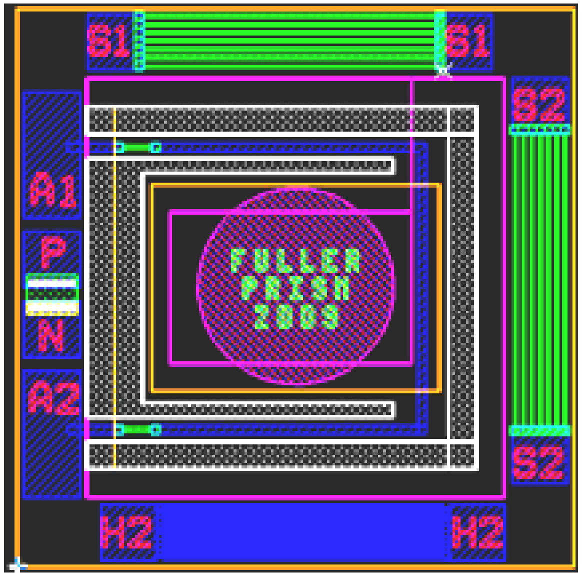
Suggest using Poly Layer for lettering

DESIGN AREA AND PROBE PADS

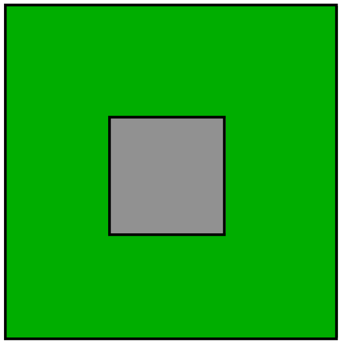
Probe pads and connections must be as large as possible and placed around the perimeter

Minimum wire bond pad is 150 x 150 um (bigger is often better, except for capacitor connections).

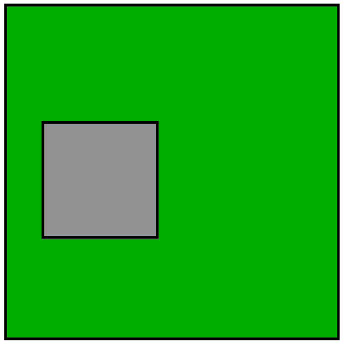




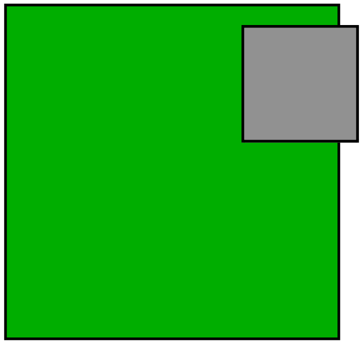
LAYOUT RULES



Perfect Overlay



Slight Overlay
Not Fatal



Misalignment
Fatal

Layout rules prevent slight misalignment from being fatal. Also, rules help make device performance consistent (minimum width for resistor will make values more consistent)

RULES FOR DIFFUSION LAYER

Level 1 – Design Layer 1 – P+ Diffusion 1 (green)

Rule 1.1 Minimum Width

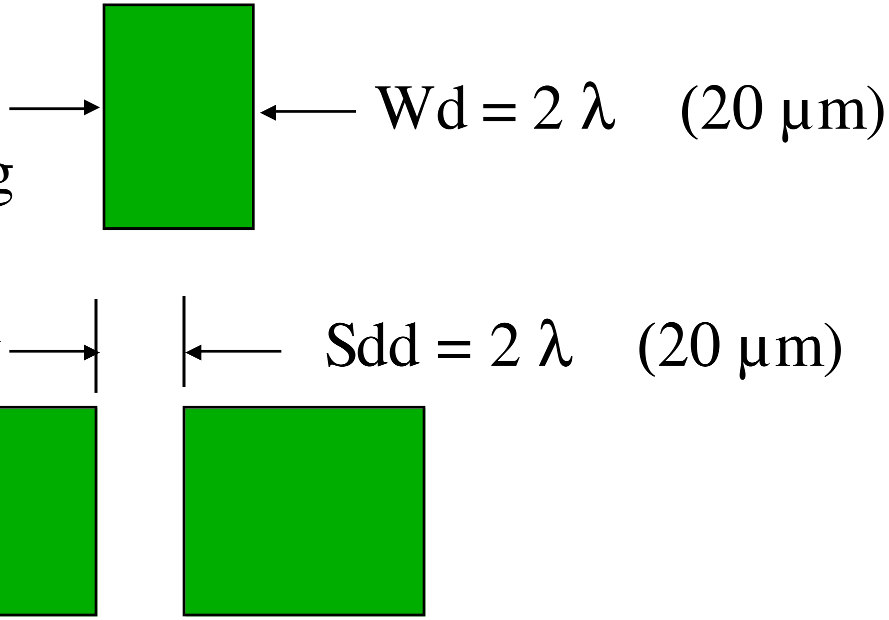
Wd = 2 λ

Rule 1.2 Minimum Spacing

Sdd = 2 λ

Rule 1.3 Extension beyond Contact cut

Edc = 2 λ



Wd = 2 λ (20 μm)

Sdd = 2 λ (20 μm)

■ 10 by 10 μm

RULES FOR DIFFUSION LAYER

Level 6 – Design Layer 6 – N+ Diffusion (Yellow)

Rule 1.1 Minimum Width

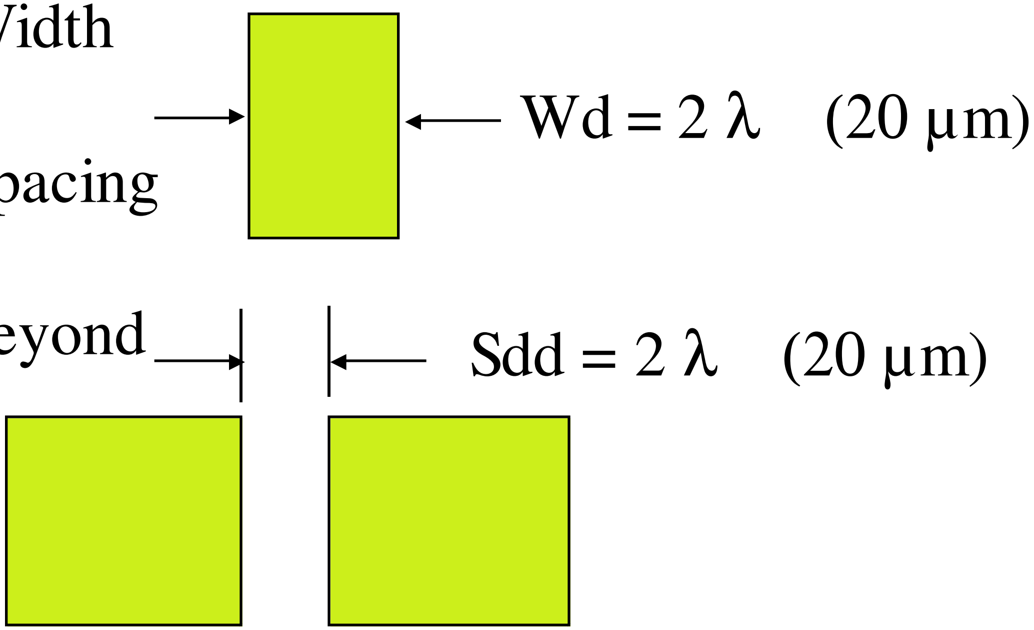
Wd = 2 λ

Rule 1.2 Minimum Spacing

Sdd = 2 λ

Rule 1.3 Extension beyond Contact cut

Edc = 2 λ



■ 10 by 10 µm

RULES FOR POLY LAYER

Level 2 – Design Layer 2 - Poly (Red)

Rule 2.1 Minimum Width

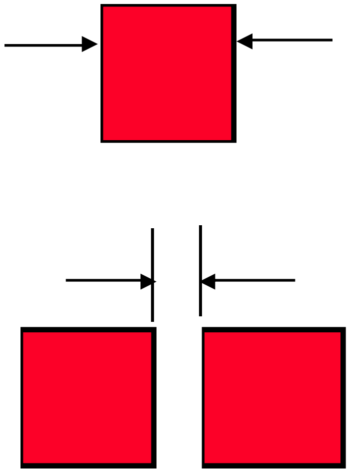
Wp = 2 λ

Rule 2.2 Minimum Spacing

Spp = 2 λ

Rule 2.3 Extension beyond Contact Cut

Epc = 2 λ



Wp = 2 λ (20 µm)

Spp = 1 λ (10 µm)

■ 10 by 10 µm

RULES FOR CONTACT CUT

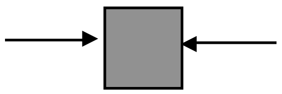
Level 3 – Design Layer 3 – Contact Cut (Gray)

Rule 3.1 Minimum Width

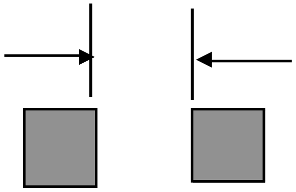
$W_c = 2\lambda$

Rule 3.2 Minimum Spacing

$S_{cc} = 2\lambda$



$W_c = 2\lambda$ (20 µm)



$S_{cc} = 2\lambda$ (20 µm)

■ 10 by 10 µm

RULES FOR METAL

Level 4 – Design Layer 4 - Metal (Blue)

Rule 4.1 Minimum Width

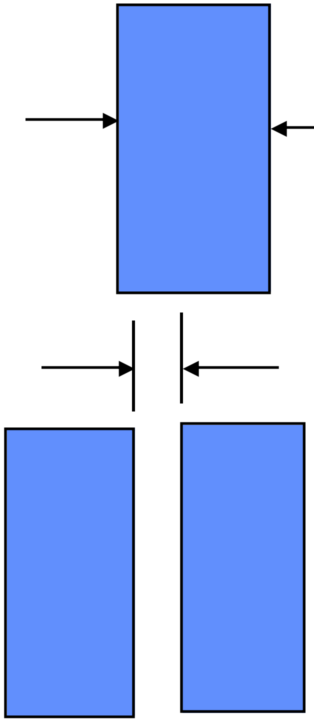
Wm = 2 λ

Rule 4.2 Minimum Spacing

Smm = 2 λ

Rule 4.3 Extension of Metal Beyond Contact Cut

Emc = 2 λ



Wm = 3 λ (30 µm)

Smm = 1 λ (10 µm)

■ 10 by 10 µm

RULES FOR DIAPHRAGM

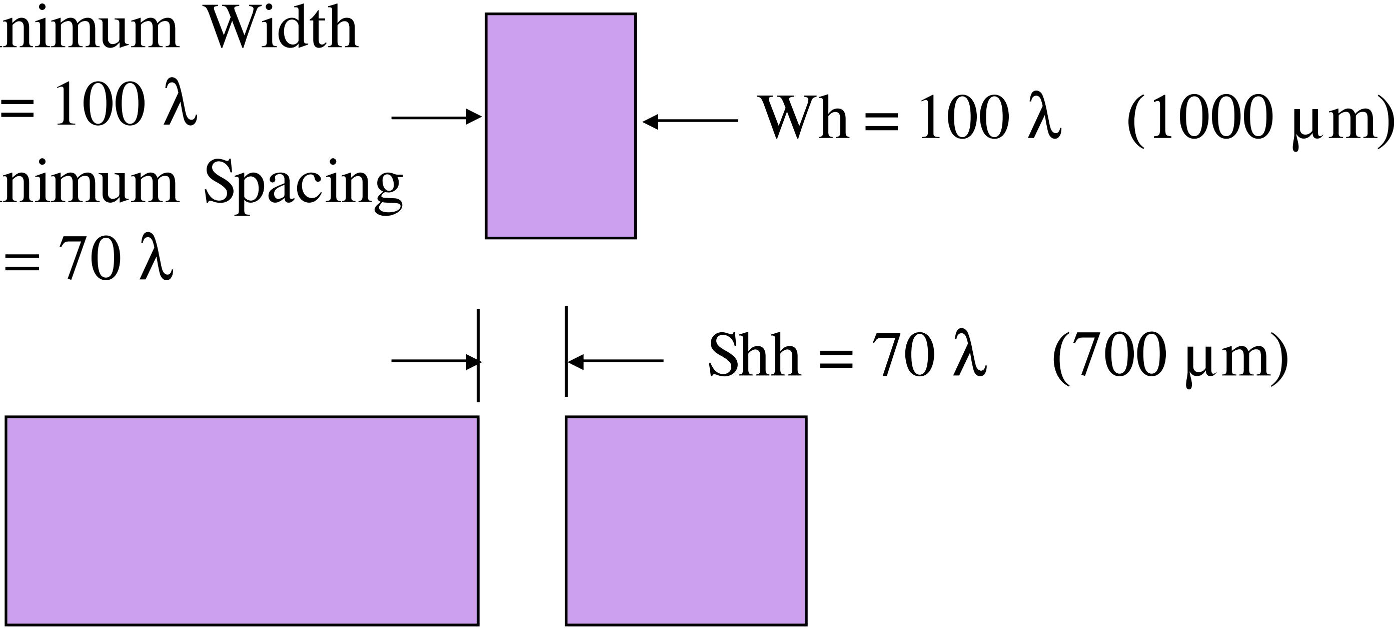
Level 6 – Design Layer 6 – Diaphragm (purple)

Rule 6.1 Minimum Width

Wh = 100 λ

Rule 6.2 Minimum Spacing

Shh = 70 λ



■ 10 by 10 µm

RULES FOR TOP VIA

Level 7 – Design Layer 7 – Top Via (White)

Rule 7.1 Minimum Width

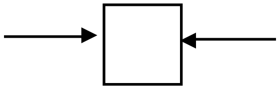
Wv= 2 λ

Rule 7.2 Minimum Spacing

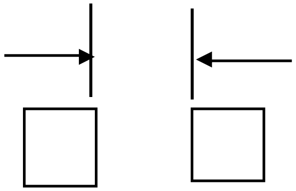
Svv = 2 λ

Rule 7.3 Minimum Extension of Metal beyond Top Via

Emv = 2 λ



Wv = 2 λ (20 µm)



Svv = 8 λ (80 µm)

■ 10 by 10 µm

RULES FOR THE POLY, METAL AND CONTACT CUT

Overlay (Extension)

Rule 2.3 Minimum Extension of poly beyond contact cut

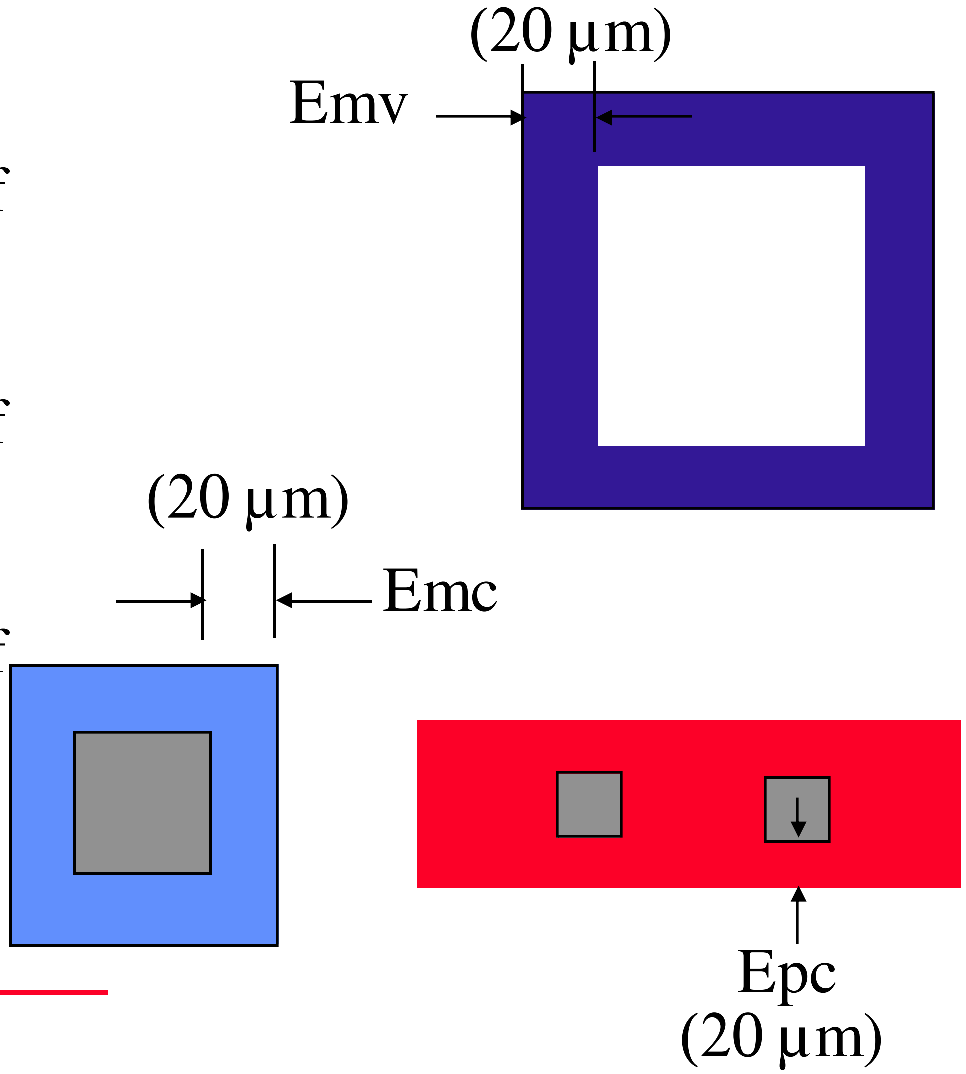
$Epc = 2\ \lambda$

Rule 4.3 Minimum Extension of Metal beyond contact cut

$Emc = 2\ \lambda$

Rule 7.3 Minimum Extension of Metal beyond Top Via

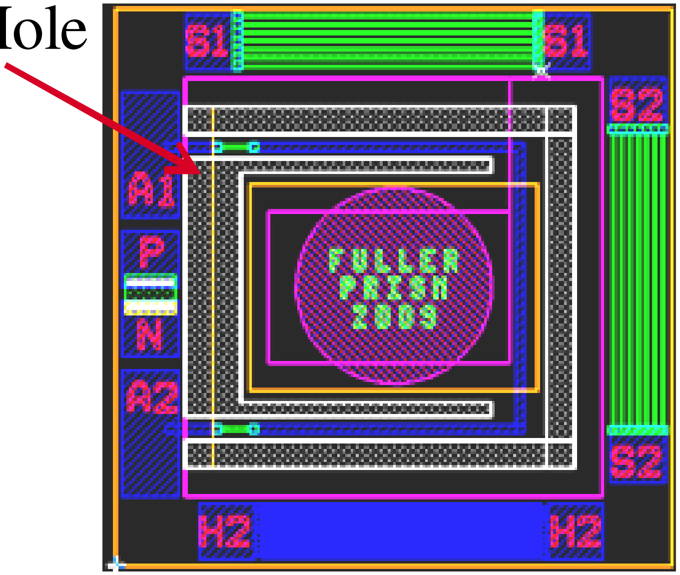
$Emv = 2\ \lambda$



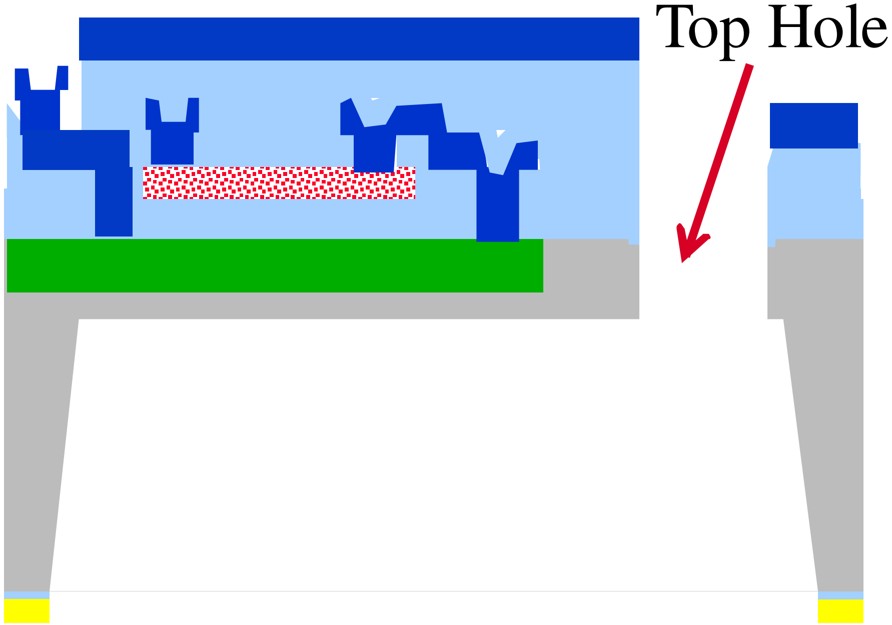
TOP HOLE DESIGN RULES

Top hole defines Silicon hole and also openings to metal pads. Silicon hole also needs to be defined with contact layer. Etch will remove oxide and Silicon around them but metal will protect etching of the pads. Contact to P+ diffusion should be made outside the top hole areas.

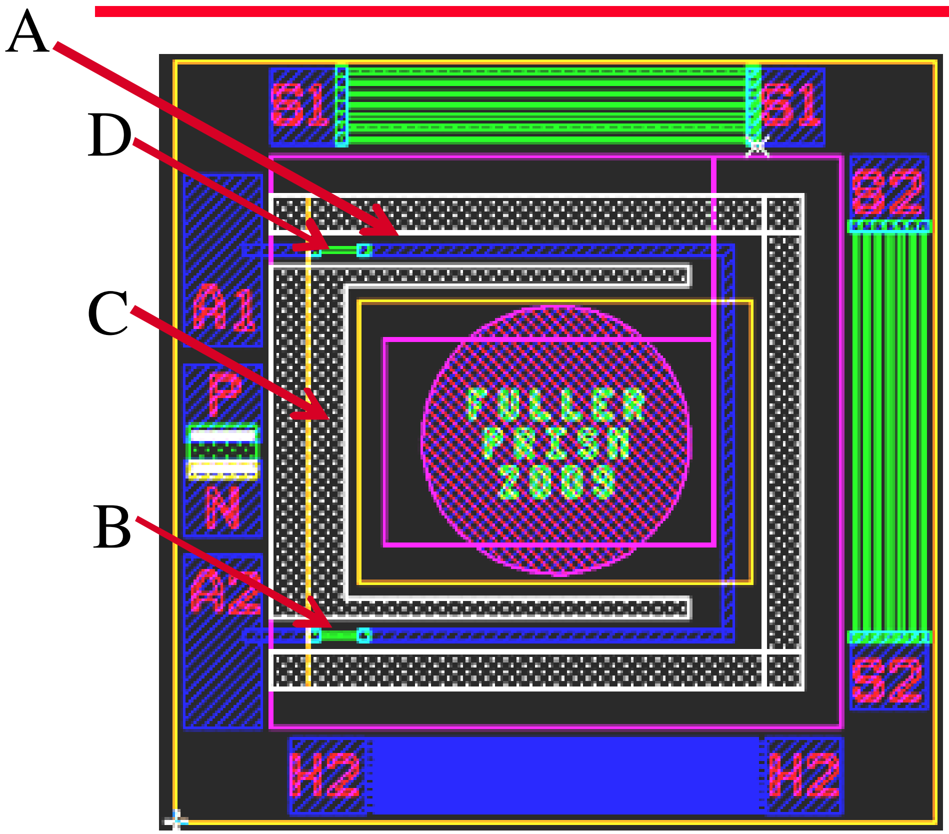
Top Hole

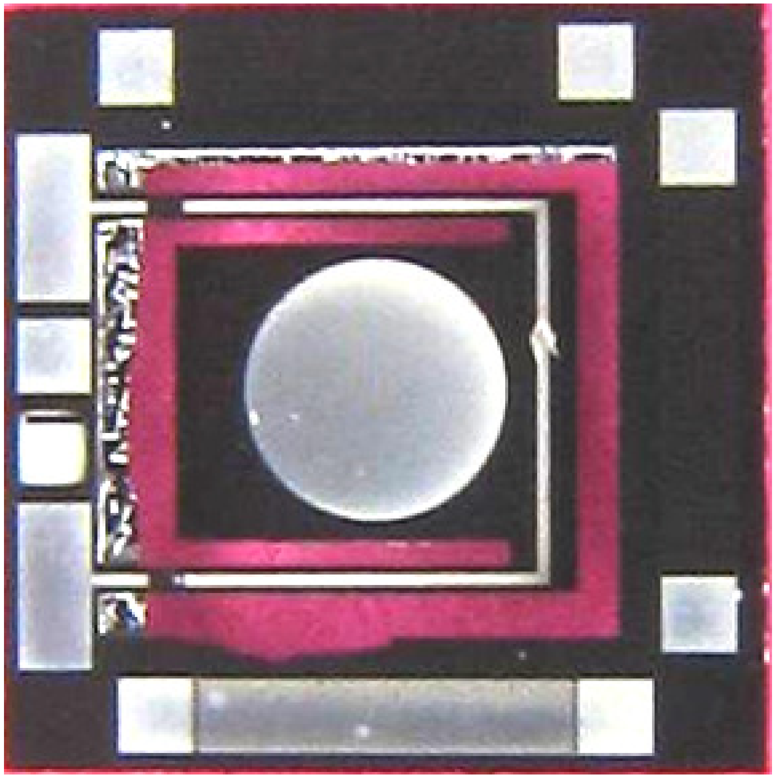


Top Hole



TOP HOLE DESIGN RULES





A. Distance from edge of top hole to metal line >50µm

B. Distance from edge of top hole to diffusion line >100µm

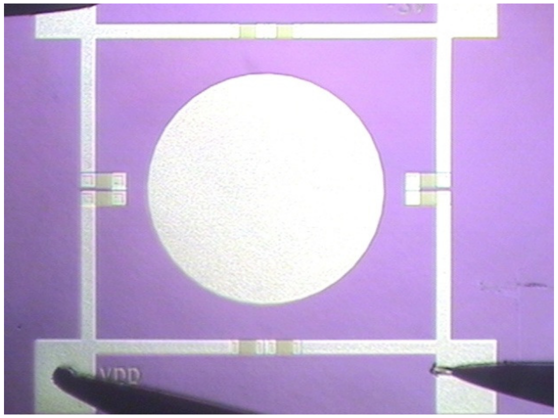
C. Distance from edge of top hole to edge of diaphragm >400µm

D. No top hole over diffusion/poly

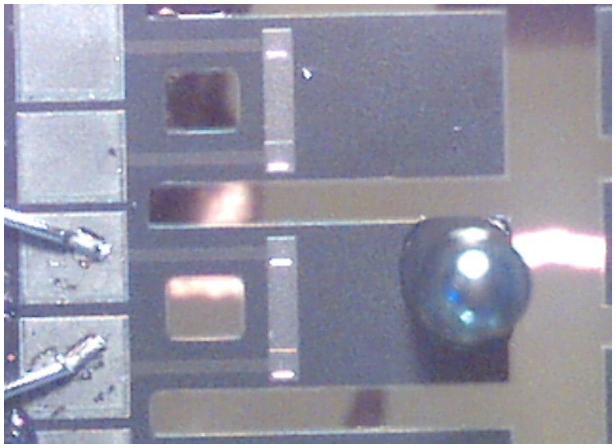
SOME POSSIBLE DEVICES

Pressure Sensor, diffused resistors or poly resistors
Microphone
Speaker – diaphragm with coil on it
Accelerometer – beam or mass on diaphragm
Diaphragm Actuator with coil or magnet with resistors for sensing and feedback
Thermally actuated membrane or beam
Optical pyrometer with thermocouples on diaphragm
Micro mirror with moving surfaces
Heater on diaphragm either poly or diffused resistor plus temp sensor
Heater plus interdigitated chemical sensor
Gas flow sensor single resistor anemometer
Gas flow sensor with heater and two resistors
PN junction temperature sensors

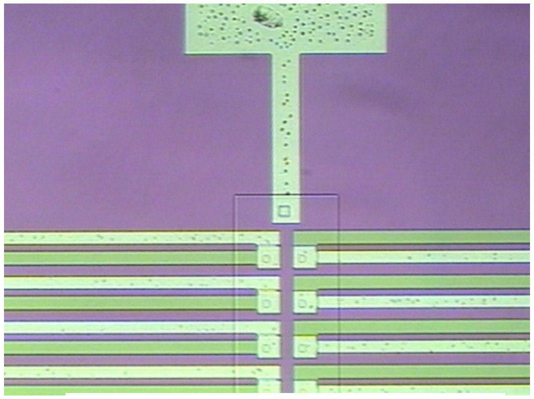
SOME EXAMPLES OF DEVICES



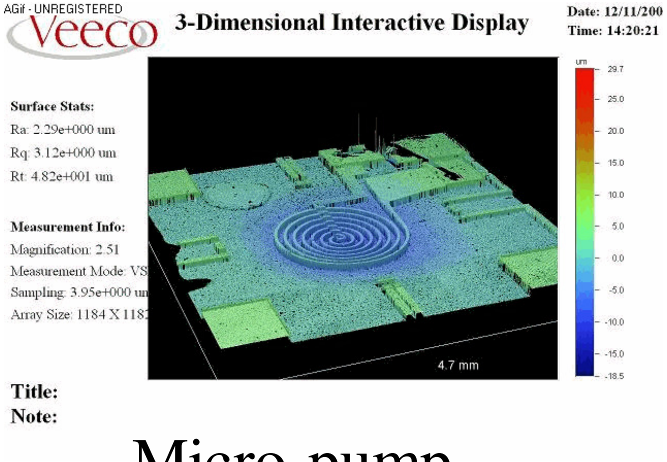
Pressure sensor



Accelerometer



Thermocouples and Heater



3-Dimensional Interactive Display

Date: 12/11/200
Time: 14:20:21

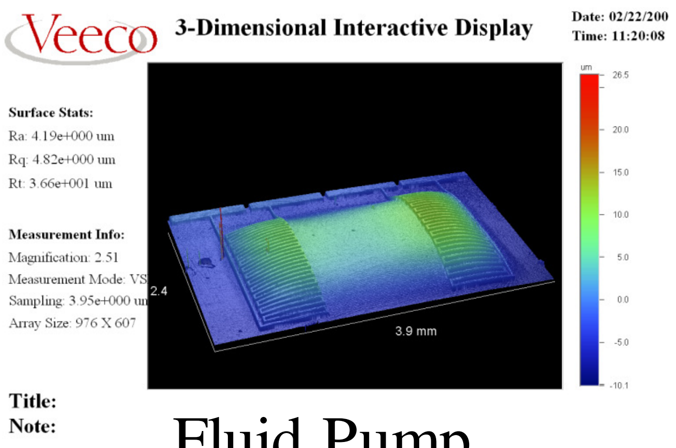
Surface Stats:
Ra: 2.29e+000 um
Rq: 3.12e+000 um
Rt: 4.82e+001 um

Measurement Info:
Magnification: 2.51
Measurement Mode: VS
Sampling: 3.95e+000 u
Array Size: 1184 X 118

Title:
Note:

Micro-pump

SOME EXAMPLES OF DEVICES


Veeco 3-Dimensional Interactive Display

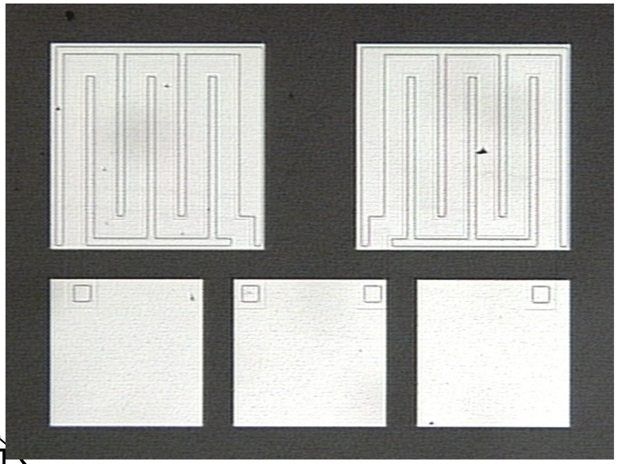
Date: 02/22/200
Time: 11:20:08

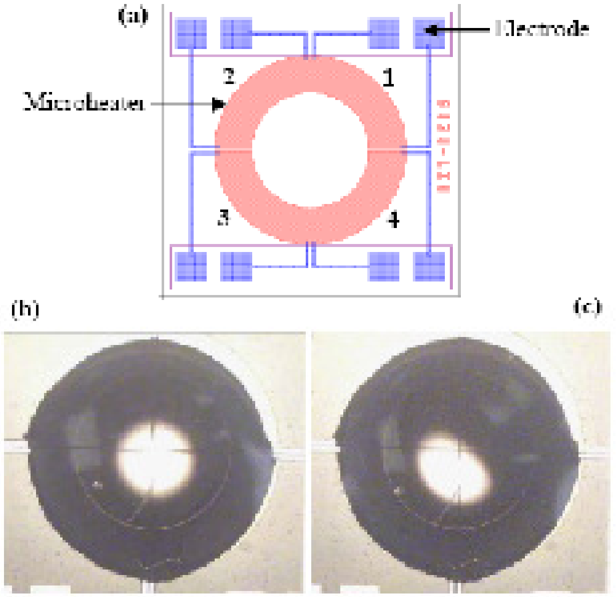
Surface Stats:
Ra: 4.19e+000 um
Rq: 4.82e+000 um
Rt: 3.66e+001 um

Measurement Info:
Magnification: 2.51
Measurement Mode: VS
Sampling: 3.95e+000 u
Array Size: 976 X 607

Title:
Note:

Fluid Pump





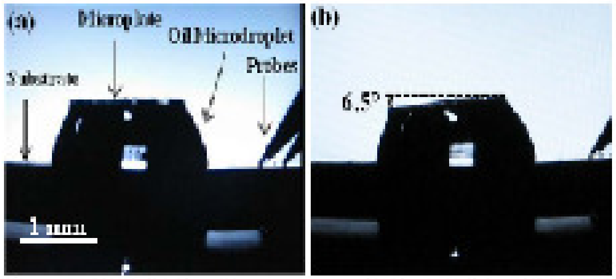
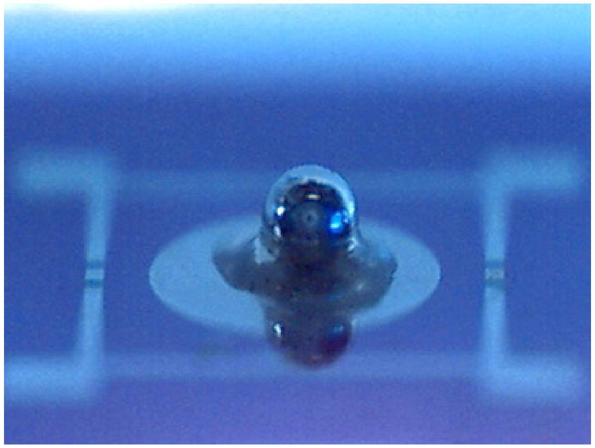


Figure 7: (a) Microplate on top of the oil droplet @ 0V. (b) Microplate tilted 6.5° when a 30 V actuation voltage was applied to the microheater at right.

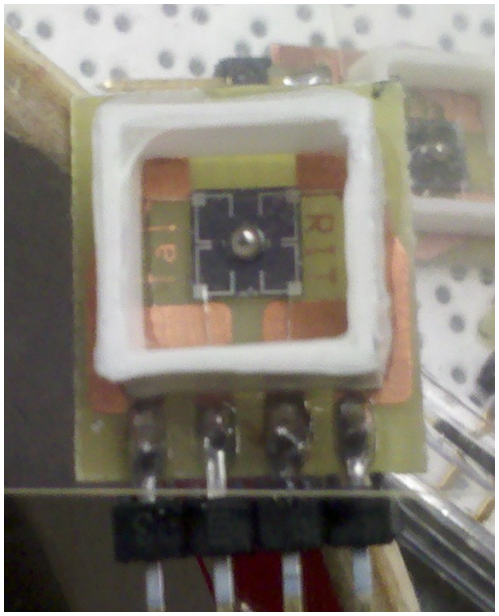
2-D Moving Mirror

SOME EXAMPLE OF DEVICES

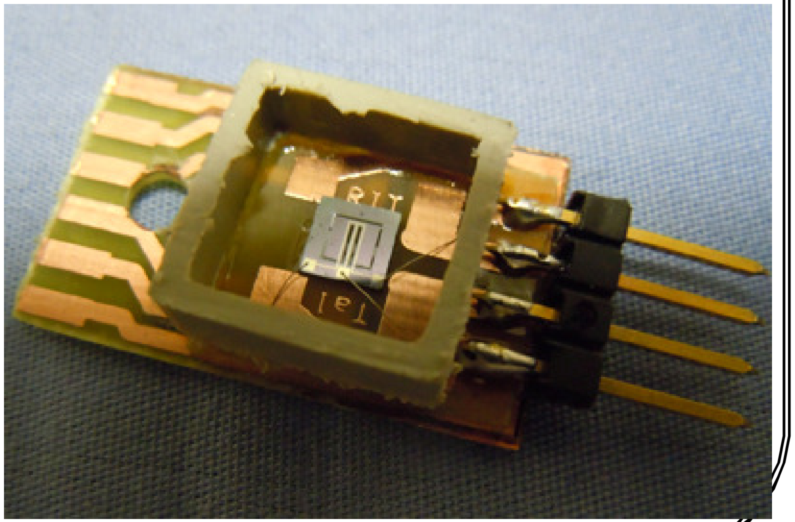


Accelerometer

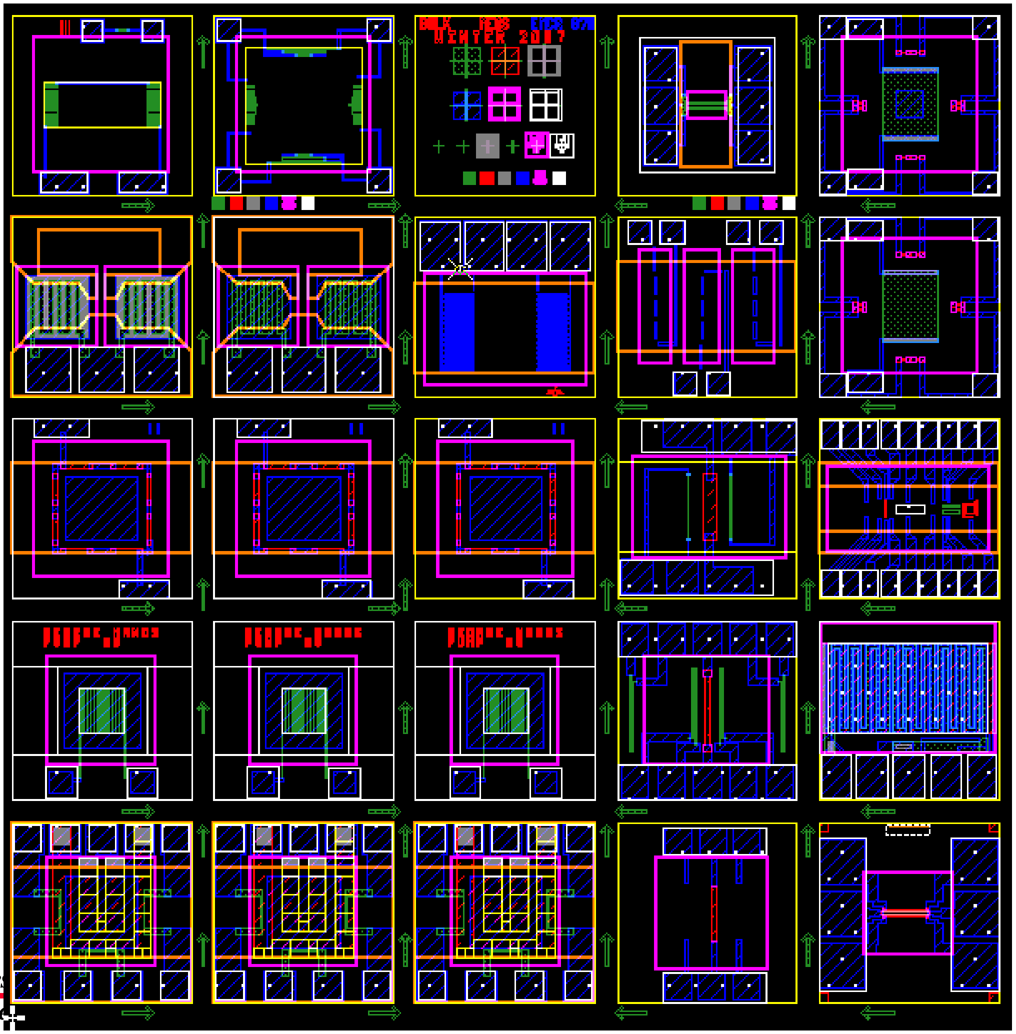
Magnetic Proximity Sensor



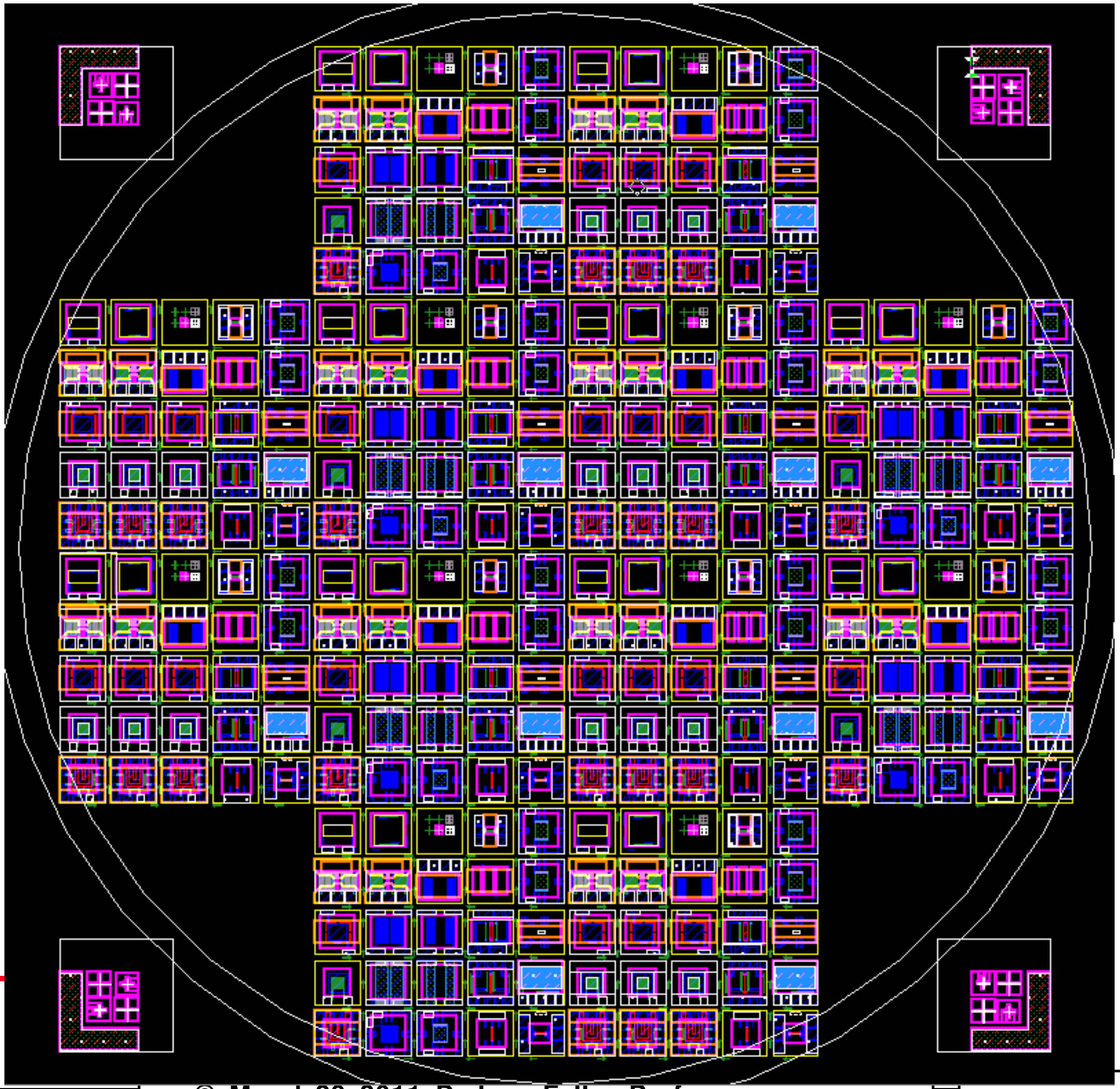
Packaged Accelerometer



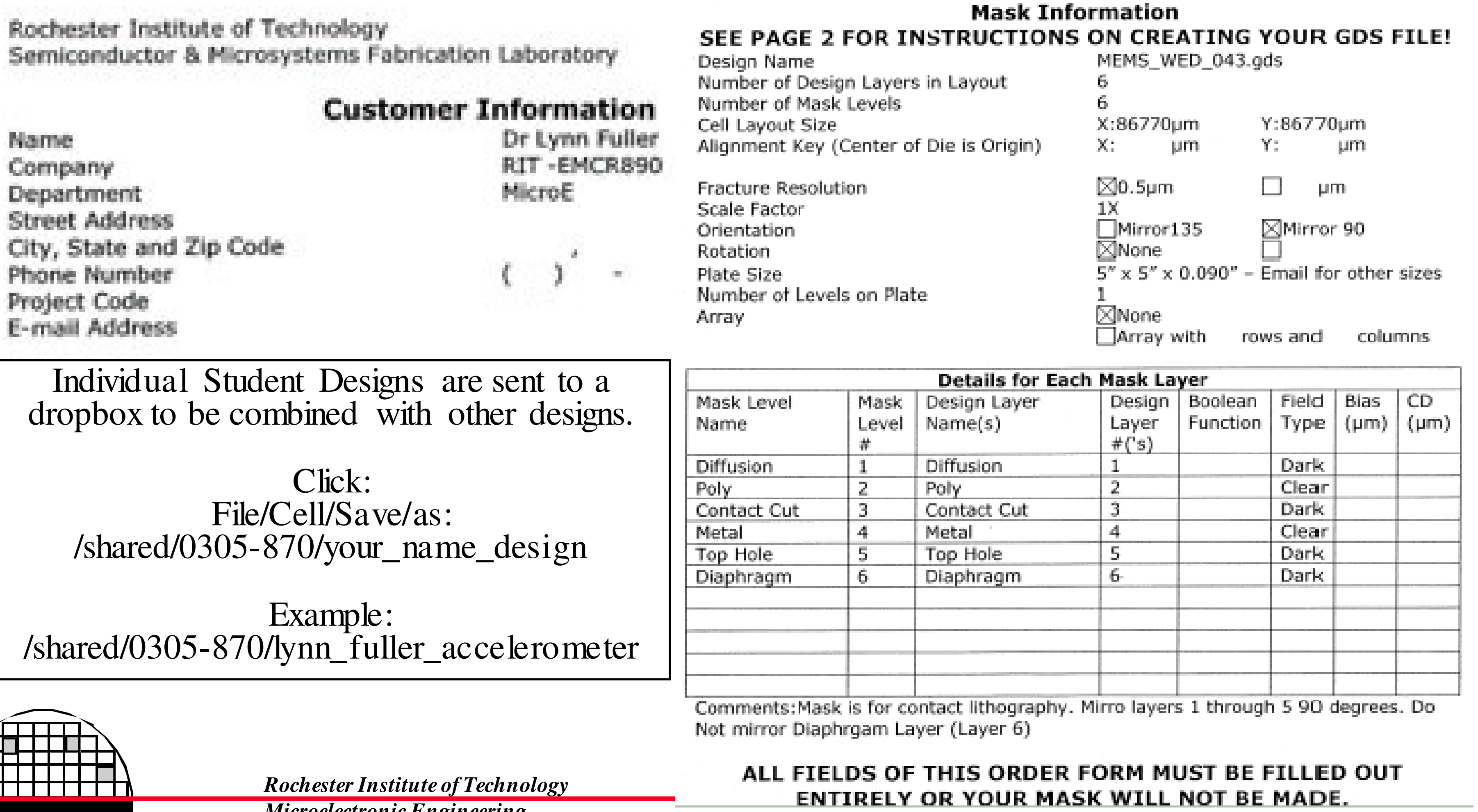
20072 MEMS MULTICHIP PROJECT DESIGN



20072 MULTI CHIP PROJECT WAFER LAYOUT



MASK ORDER FORM



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Customer Information

Name	Dr Lynn Fuller
Company	RIT -EMCR890
Department	MicroE
Street Address	
City, State and Zip Code	,
Phone Number	( ) -
Project Code	
E-mail Address	

Mask Information

SEE PAGE 2 FOR INSTRUCTIONS ON CREATING YOUR GDS FILE!

Design Name	MEMS_WED_043.gds	
Number of Design Layers in Layout	6	
Number of Mask Levels	6	
Cell Layout Size	X:86770µm	Y:86770µm
Alignment Key (Center of Die is Origin)	X: µm	Y: µm
Fracture Resolution	☒0.5µm	☐ µm
Scale Factor	1X	
Orientation	☐Mirror135	☒Mirror 90
Rotation	☒None	☐
Plate Size	5" x 5" x 0.090" - Email for other sizes	
Number of Levels on Plate	1	
Array	☒None ☐Array with rows and columns	

Details for Each Mask Layer

Mask Level Name	Mask Level #	Design Layer Name(s)	Design Layer #('s)	Boolean Function	Field Type	Bias (µm)	CD (µm)
Diffusion	1	Diffusion	1		Dark		
Poly	2	Poly	2		Clear		
Contact Cut	3	Contact Cut	3		Dark		
Metal	4	Metal	4		Clear		
Top Hole	5	Top Hole	5		Dark		
Diaphragm	6	Diaphragm	6		Dark		

Comments:Mask is for contact lithography. Mirro layers 1 through 5 90 degrees. Do Not mirror Diaphrgam Layer (Layer 6)

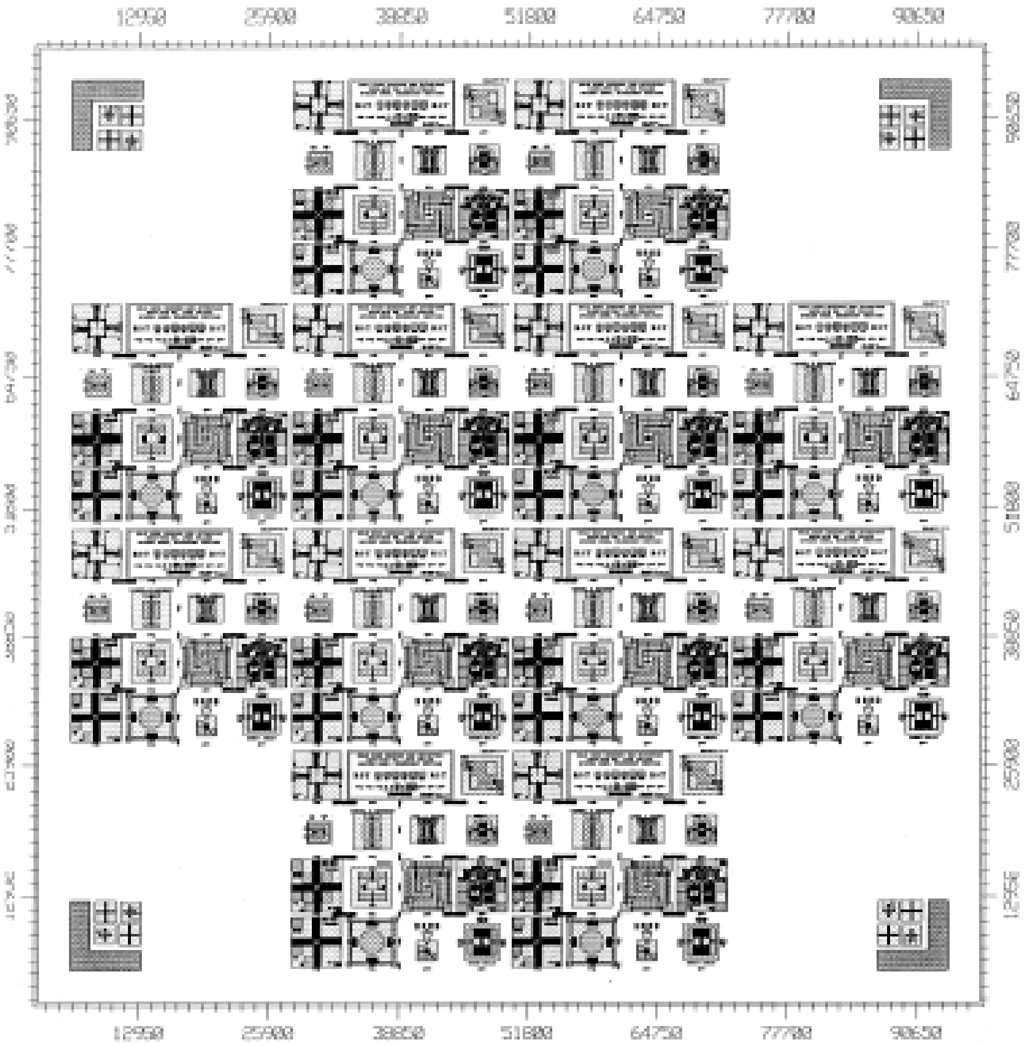
ALL FIELDS OF THIS ORDER FORM MUST BE FILLED OUT ENTIRELY OR YOUR MASK WILL NOT BE MADE.

Individual Student Designs are sent to a dropbox to be combined with other designs.

Click:
File/Cell/Save/as:
/shared/0305-870/your_name_design

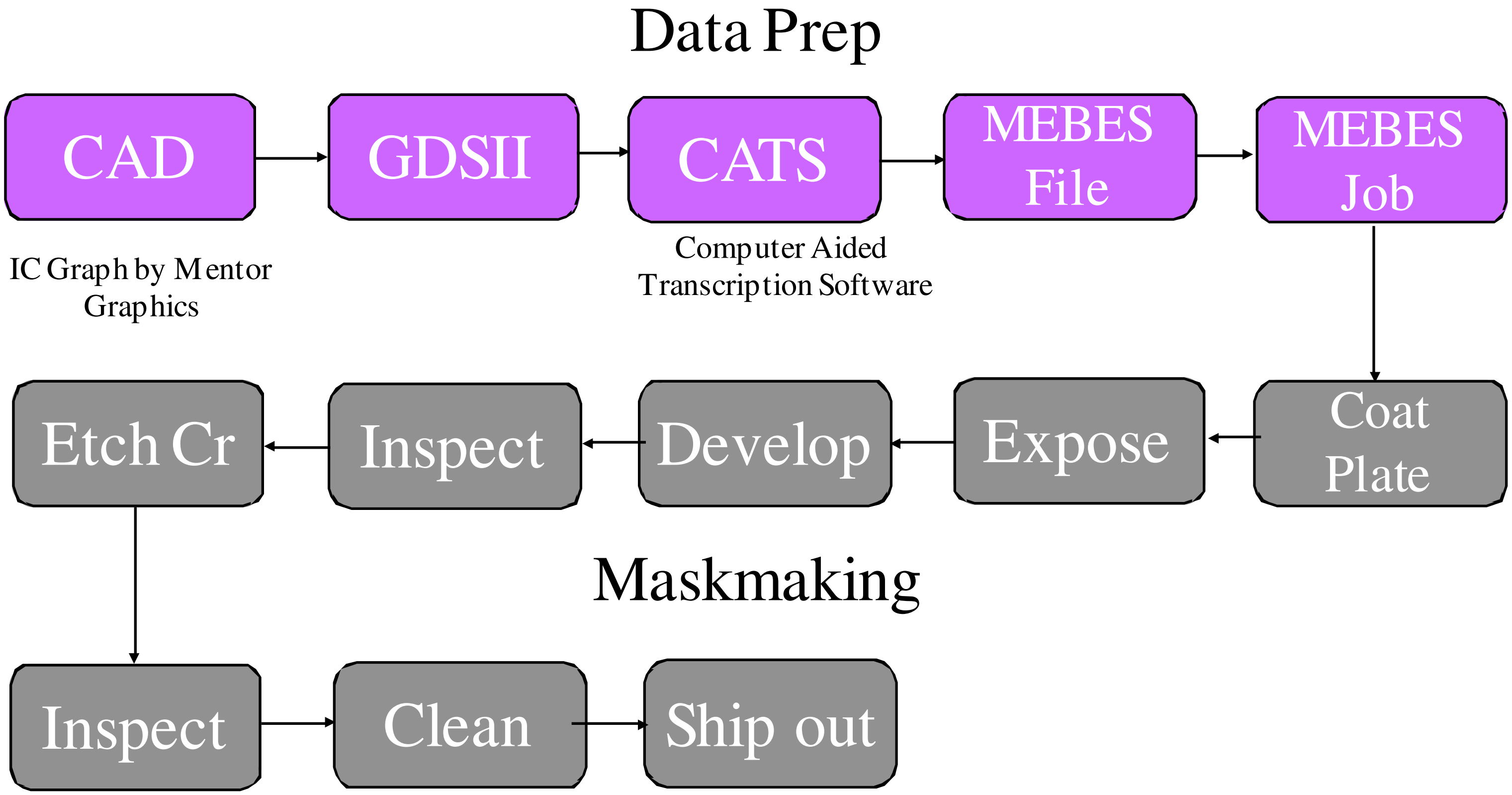
Example:
/shared/0305-870/lynn_fuller_accelerometer

WEDNESDAY LAB SECTION 1X ARRAY



Roc
Mic

MASK PROCESS FLOW



Data Prep

CAD → GDSII → CATS → MEBES File → MEBES Job

IC Graph by Mentor Graphics

Computer Aided Transcription Software

Coat Plate → Expose → Develop → Inspect → Etch Cr

Maskmaking

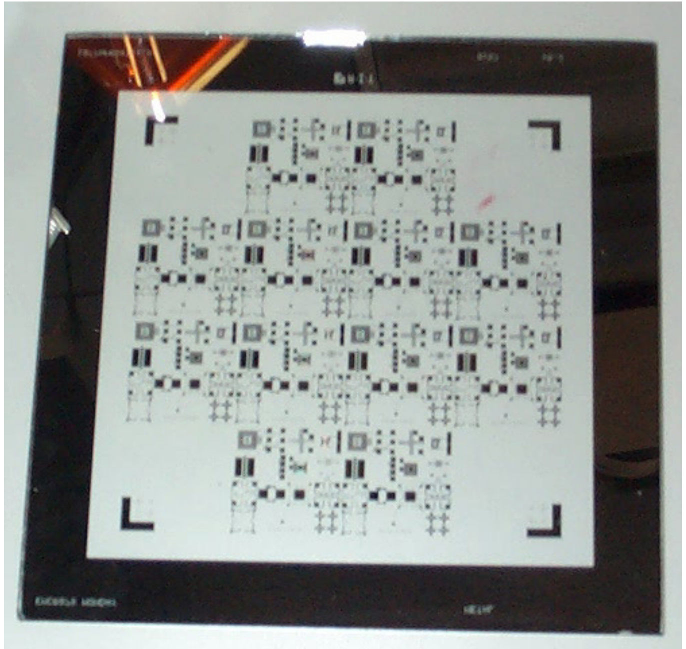
Inspect → Clean → Ship out

This process can take weeks and cost between $1000 and $20,000 for each mask depending on the design complexity.

MEBES - Manufacturing Electron Beam Exposure System

MASKS

Single Clear Field Mask



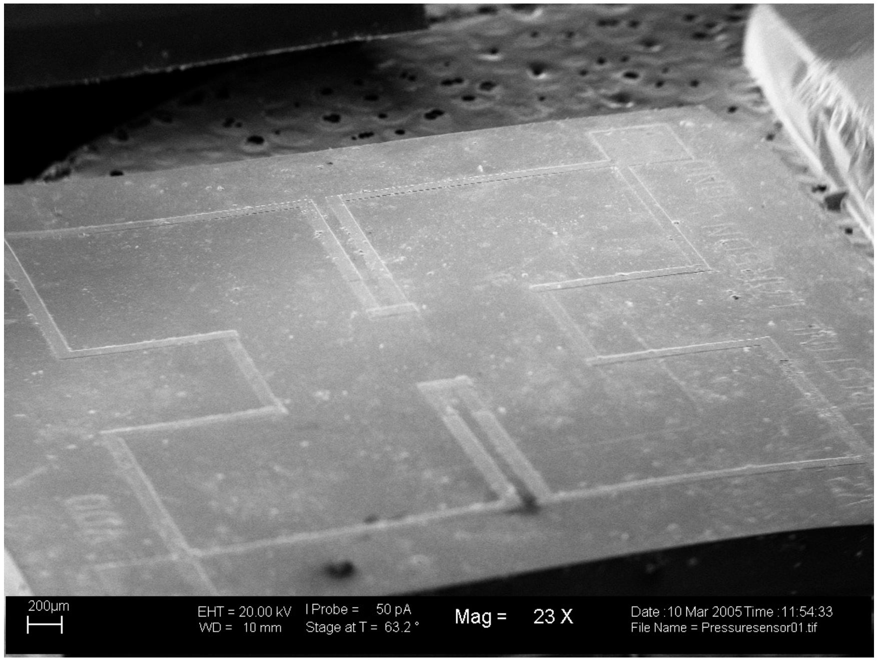
Mask Set

BULK MEMS PROCESS FLOW

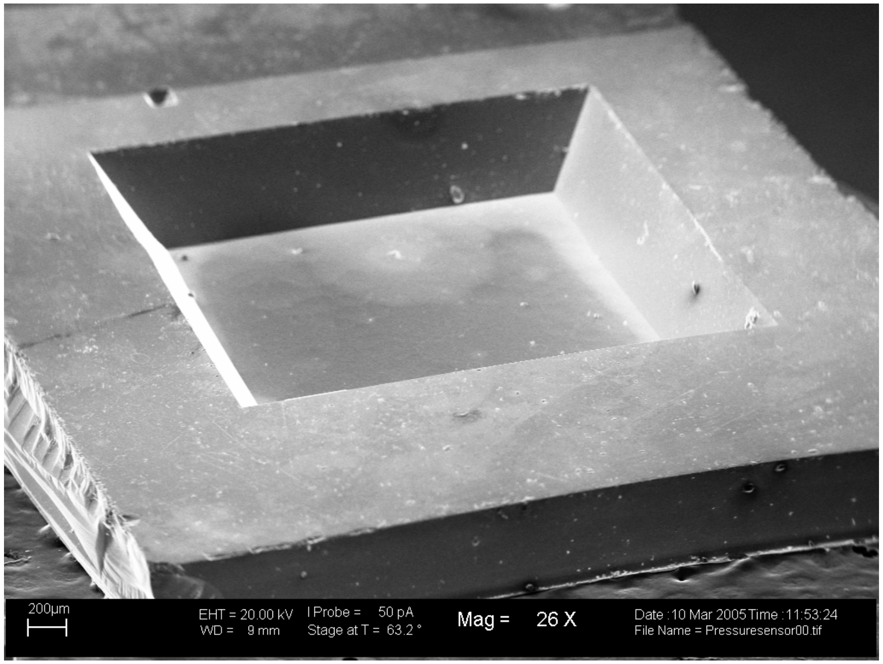
1. Obtain qty 10, 4” n-type wafers
2. CMP back side
3. CMP Clean
4. RCA Clean
5. Grow masking oxide 5000 Å, Recipe 350
6. Photo 1: P++ diffusion
7. Etch Oxide, 12 min. Rinse, SRD
8. Strip Resist
9. Spin-on Glass, Borofilm 100, include dummy
10. Dopant Diffusion Recipe 110
11. Etch SOG and Masking Oxide, 20min BOE
12. Four Point Probe Dummy Wafer
13. RCA Clean
14. Grow 500 Å pad oxide, Recipe 250
15. Deposit 1500 Å Nitride
16. Photo 2: for backside diaphragm
17. Spin coat Resist on front side of wafer
18. Etch oxynitride, 1 min. dip in BOE, Rinse, SRD
19. Plasma Etch Nitride on back of wafer, Lam-490
20. Wet etch of pad oxide, Rinse, SRD
21. Strip Resist both sides
22. Etch Diaphragm in KOH, ~8 hours
23. Decontamination Clean
24. RCA Clean
25. Hot Phosphoric Acid Etch of Nitride
26. BOE etch of pad oxide
27. Grow 5000Å oxide
28. Deposit 6000 Å poly LPCVD
29. Spin on Glass, N-250
30. Poly Diffusion, Recipe 120
31. Etch SOG
32. 4 pt Probe
33. Photo 3, Poly
34. Etch poly, LAM490
35. Strip resist
36. RCA Clean
37. Oxidize Poly Recipe 250
38. Deposit 1μm LTO
39. Photo 4, Contact Cut
40. Etch in BOE, Rinse, SRD
41. Strip Resist
42. RCA Clean, include extra HF
43. Deposit Aluminum, 10,000Å
44. Photo 5, Metal
45. Etch Aluminum, Wet Etch
46. Strip Resist
47. Deposit 1μm LTO
48. Photo 6, Via
49. Etch Oxide in BOE, Rinse, SRD
50. Strip Resist
51. Deposit Aluminum, 10,000Å
52. Photo 7, Metal
53. Etch Aluminum, Wet Etch
54. Strip Resist
55. Deposit 1μm LTO
56. Deposit Aluminum, 10,000Å
57. Photo 8, Top Hole
58. Top hole aluminum etch
59. Diaphragm thinning option
60. Top hole Silicon etch
61. Test

3-15-07

PRESSURE SENSOR SEM PICTURE



Front



Back

USING THE VLSI LAB WORKSTATIONS AND MENTOR GRAPHICS CAD TOOLS

Usually the workstation screen will be blank, press any key to view a login window.

Login: username
Password: *********

The screen background will change and the control panel will appear. Click the left mouse button on the terminal icon. A window will appear that says Shell-Konsole on the top and has a Unix prompt inside. Type the command **ls** at the prompt to see a list of directories and files, the account should be empty.

Type **ic** <RET>, it will take a few seconds, then maximize the IC Station window by clicking the left mouse button on the large square in the upper right corner of the IC Station window.

VLSI DESIGN LAB

USING THE HP WORKSTATIONS AND MENTOR GRAPHICS CAD TOOLS - PROCESS AND GRID

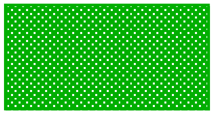
In the session menu palette on the right hand side of the screen, under Cell, select Create, using the lift mouse button. For cell name type name_device. Also set the process to the mems_bulk process by typing /shared/0305-870/mems_bulk_092 in the process field and click on return OK. In the gray area under the banner at the top of the screen, the process should now read mems_bulk. Select other>show layer palette, click/drag on layers 1 to 7 then press select. Layers colors and shading should appear in upper right corner.

A large window with a black background and white dots should appear. We can now check the grid settings. In the top banner choose Other > Window > Set Grid. Set the Snap to 10 for both x and y, minor=1, major=10, then click on OK

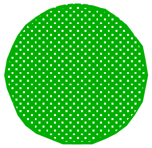
The cursor position is given at the top center of the window. The layer being used and the number of items selected is shown at the top right. The 12 gray buttons which correspond to the F1-F8 and 4 white buttons allow multiple functions. For example push F2 to (Unselect All). To get the next function listed below that (Unselect Area) push shift and F2. To get the function listed on the bottom for the F2 key (Move) press the CTRL key and the F2 key.

USING THE HP WORKSTATIONS AND MENTOR GRAPHICS CAD TOOLS - DRAWING

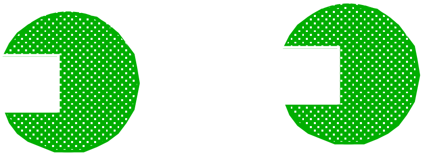
Select easy edit, Select Shape, Select Options and see the layer names, colors and shading pattern. Draw boxes by click and drag of mouse. Unselect by pressing F2 function key. The Notch command is useful to change the size of a selected box or merge rectangular shapes into more complex objects. The following command will draw a 3000 µm by 3000 µm box with level 5 color/shading. $add_shape([[0,0],[3000,3000]],5)



Draw circles by typing $set_location_mode(@arc) return. The following command will draw a 100µm radius circle centered at (0,0) using 300 straight line segments.
$add_shape($get_circle([0,0],[100,0],300),3)
To reset to rectangles type $set_location_mode(@line) return.



Select objects by clicking or by click and drag. Selected objects will appear to have a bright outline. Selected objects can be moved (Move), copied (Copy), deleted (Del) or notched (Notc). To unselect objects press F2.



USING THE HP WORKSTATIONS AND MENTOR GRAPHICS CAD TOOLS - OTHER

ZOOM IN OUT: pressing the + or - sign on right key pad will zoom in or out. Also pressing shift + F8 will zoom so that all objects are in the view area. Select view then area and click and drag a rectangle will zoom so that the objects in the rectangle are in the view area.

MOVING VIEW CENTER: pressing the middle mouse button will center the view around the pointer.

LASER PRINT OUTPUT: Select File and Print, OK. This gives a laser printer output of entire cell. Select printer **prec10**, clear width, len, pages, scale by using backspace so nothing is in those boxes. Say OK.

PRINT PART OF LAYOUT: first create a panel. Under objects, select add a panel, name it and click on rectangle symbol. Then use the left mouse button to drag a rectangle around the objects you want in the panel to be printed. Then select File and Print and enter panel name, click on print set up, printer is **prec10**, clear width, len, pages, scale by using backspace so nothing is in those boxes. Say OK.

USING THE HP WORKSTATIONS AND MENTOR GRAPHICS CAD TOOLS - OTHER

ADDING TEXT: Type $add_device(“$pgtext”) select the layer, enter the text, place the object on the layout and increase or decrease its size by selecting objects>scale…

SETTING CELL ORIGIN: under CONTEXT

COPY A CELL FROM A STUDENTS ACCOUNT TO COURSE DROPBOX:
Individual Student Designs are sent to a dropbox to be combined with other designs. Click: File/Cell/Save/as: /shared/0305-870/your_name_design

Example: /shared/0305-870/lynn_fuller_accelerometer

DRAWING SPIRALS

From MGC pull down menu select userware>load… and select file “spiral”. Once this file has been successfully loaded and an active sheet is open, type spiral() in the dialog box. Enter values for radius_incr and angle_incr (try 1 and 0.3). To change the width of your spiral line change the number 10 from the line in the file ($add_path(points,”1”,@internal,10,@center,@extended,@nokeep). Source Path: /home/rgm3104/spiral

```
//In IC Station. From MGG pull donw menu select userware>load... and
select file "spiral". Once this file has been succefuly loaded and an
active sheet is open, type spiral() in the dialog box. Enter values for
radius_incr and angle_incr, I'm not sure what these do, but 1 and 0.3
worked for me. To change the width of your spiral line - which is set to
10um in this case - change the number 10 from this line in the program
below $add_path(points,"1", @internal,10,@center,@extended,@nokeep);
//  Source path: /home/rgm3104/spiral

function spiral(radius_incr : number,
                angle_incr : number,
                init_rad : ic_line)
{
        local radius;
        local MAX_VERT=2040;

        local deltx, delty;

        local initx=init_rad[0][0], inity=init_rad[0][1];

    deltx=init_rad[1][0]-init_rad[0][0];
    delty=init_rad[1][1]-init_rad[0][1];

        radius=sqrt((deltx*deltx)+(delty*delty));

        local rad=0;
        local ang=0;
        local points=[[initx,inity]];
        local i;
        for (i=0;i<MAX_VERT-1;i=i+1) {
                if (rad>=radius) break;
                local cart=cartesian(rad,ang);
                cart[0]=initx+cart[0];
                cart[1]=inity+cart[1];
                points=$create_vector(length(points)+1,points);
                points[length(points)-1]=cart;
                rad=rad+radius_incr;
                ang=ang+angle_incr;
        }
        $writes_file(1,"num vert is: ",length(points),"\n");
        $add_path(points,"1", @internal,10,@center,@extended,@nokeep);
}

function spiral_prompt()
{
        $create_prompt("user_ic", @spiral,"Spiral",
                $prompt_arg(@radius_incr,"Radius Increments: "),
                $prompt_arg(@angle_incr, "Angle Increments: "),
                $prompt_arg(@init_rad,"Enter a line for initial point and
radius"),
                $prompt_dynamic(@init_rad, "($prompt_for_ic_line())")
        );
}

function cartesian(rad : number, angle : number)
{
        local ret_val=[0,0];
        ret_val[0]=cos(angle)*rad;
        ret_val[1]=sin(angle)*rad;
        return ret_val;
}
```

REFERENCES

1. Process Development for 3 D Silicon Microstructures, with Application to Mechanical Sensor Devices, Eric Peeters, Katholieke Universiteit Leuven, March 1994.]
2. S.K. Clark and K.D. Wise, "Pressure Sensitivity in Anisotropically Etched Thin-Diaphragm Pressure Sensors", IEEE Transactions on Electron Devices, Vol. ED-26, pp 1887-1896, 1979.

HOMEWORK – BULK MEMS DESIGN

1. Where do design rules come from? What are they for?
2. Why do all individual student designs have to use the same layout layer number for multichip project designs.
3. What are masks, what are they used for, and how are they made?
4. What does clear field and dark field mask mean? What determines if the mask should be clear field or dark field?
5. How much do masks cost?