Solid State Sensors

Tour of a Microfabrication Lab

8/27/24

Microfabrication Lab Safety

- Dangerous chemicals and equipment used
- Safety is VERY important
  - Poisoning
  - Burns
  - Cuts
  - Electrocution
  - Irradiation
  - Death
- Chemical safety
  - Acids – severe burns
  - Toxic liquids and gases
  - Flammable liquids
  - Explosive potential
- Equipment safety
  - High voltage
  - UV / X-ray radiation
  - High pressure
  - High/low temperatures
  - Glassware (sharp if broken)
- Proper clothing required
  - Clean room suit
  - Protective gloves
  - Safety goggles

A Microlab when Safety is Ignored

Cleanliness

- Very important in microfabrication
- 100μm width human hair: 10μm device feature
- Class X cleanroom: less than X 0.5μm particles per cubic foot
  - Ex: Class 10,000: < 10,000 0.5μm particles per ft^3
- AU microlab:
  - Class 1000/2000 in open areas
  - Class 100/200 in photolithography room

Typical Cleanroom Clothing

Low particulate cleanroom suit

Protective gloves

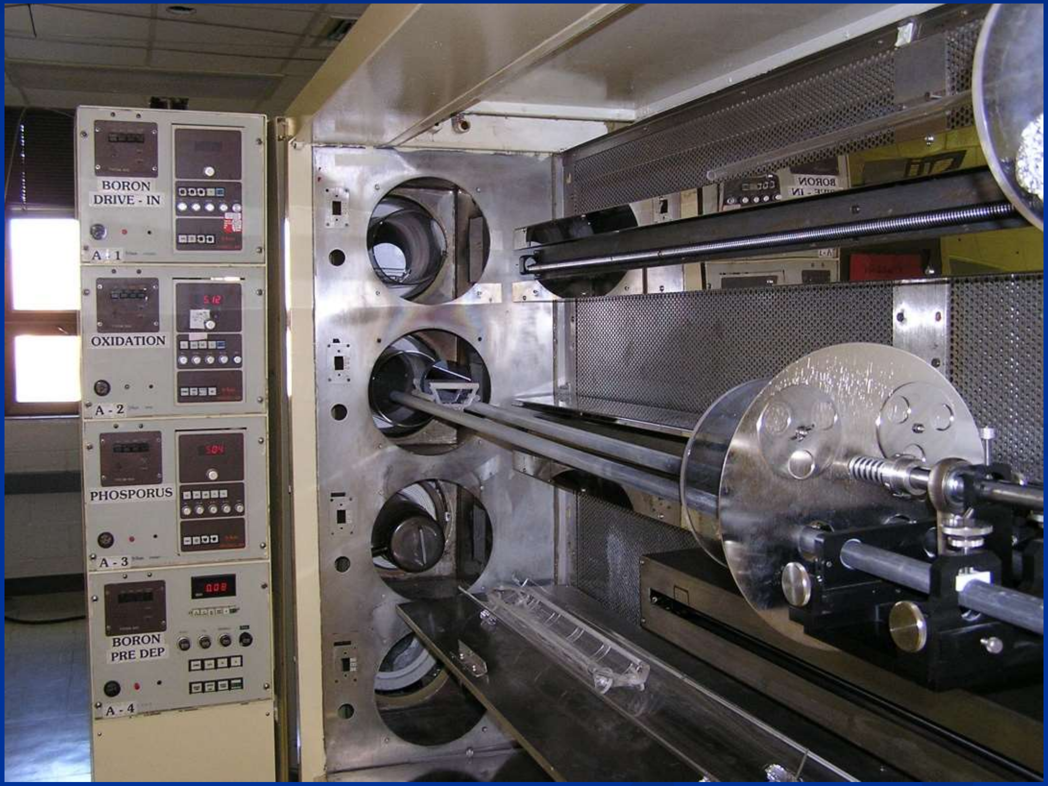
Hair net

Safety glasses required when working with chemicals

Booties

Oxidation and Diffusion Furnace

- For thermally growing Silicon Dioxide (SiO_2) on Si wafers
  - Uses an oxygen torch and a hydrogen torch
  - Oxidation process
- For diffusion doping of Si wafers
  - To make n-type or p-type regions
  - Such as piezoresistors



Oxidation and Diffusion Furnace

LPCVD System

- "Low Pressure Chemical Vapor Deposition"
- For growing a layer of polysilicon on a wafer
- Also for growing a layer of silicon nitride on a wafer
- Typically thin films, ≤ 5µm thick

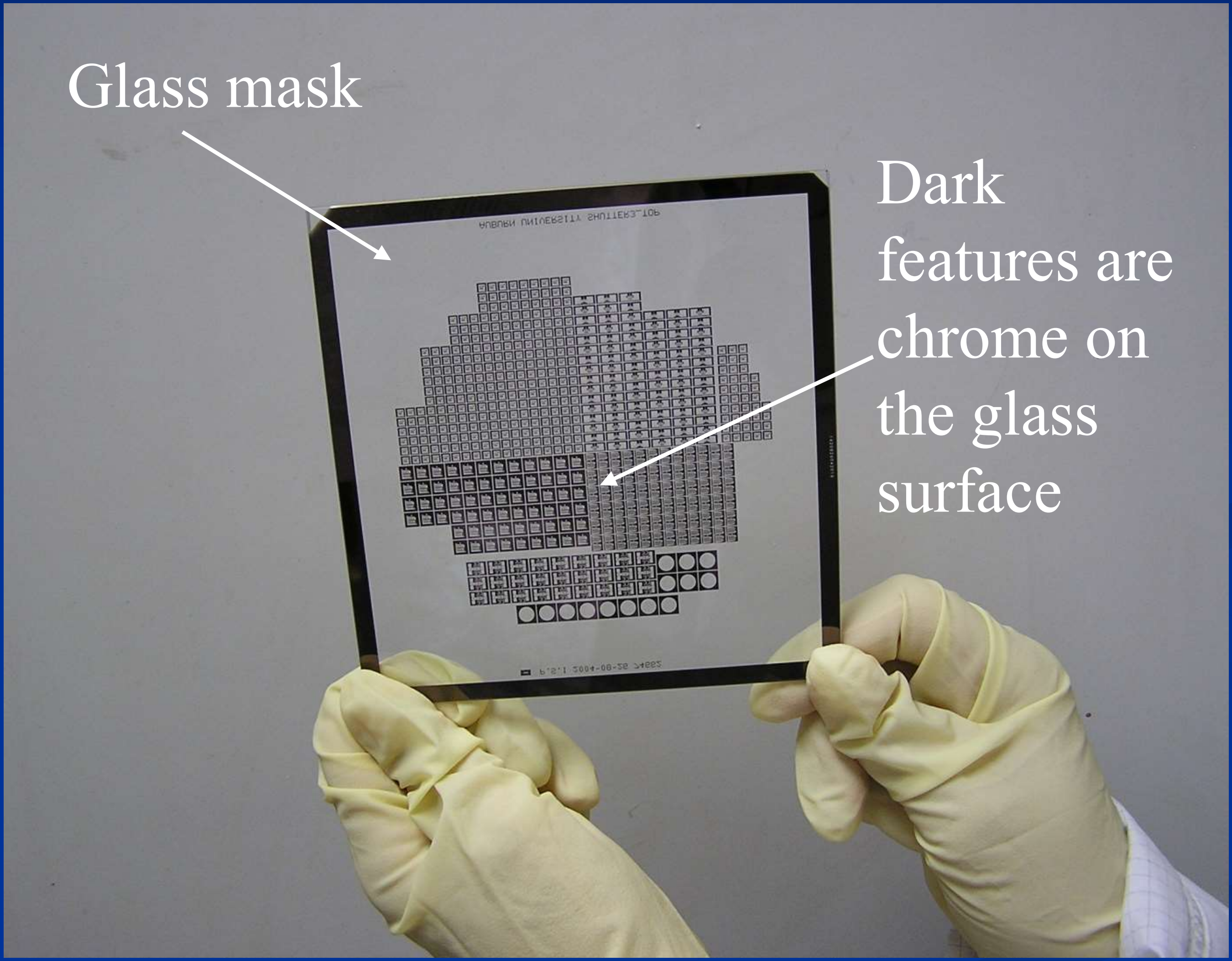
LPCVD System

PECVD System

- “Plasma Enhanced Chemical Vapor Deposition”
- Low temp Si dioxide (LTO) deposition
- Low temp silicon nitride (SiN) deposition
- Deposition of other conformal thin film coatings via plasma processing

PECVD System

Photograph of a Photolithography Mask



Glass mask

Dark features are chrome on the glass surface

Spinner for Applying Photoresist to a Wafer

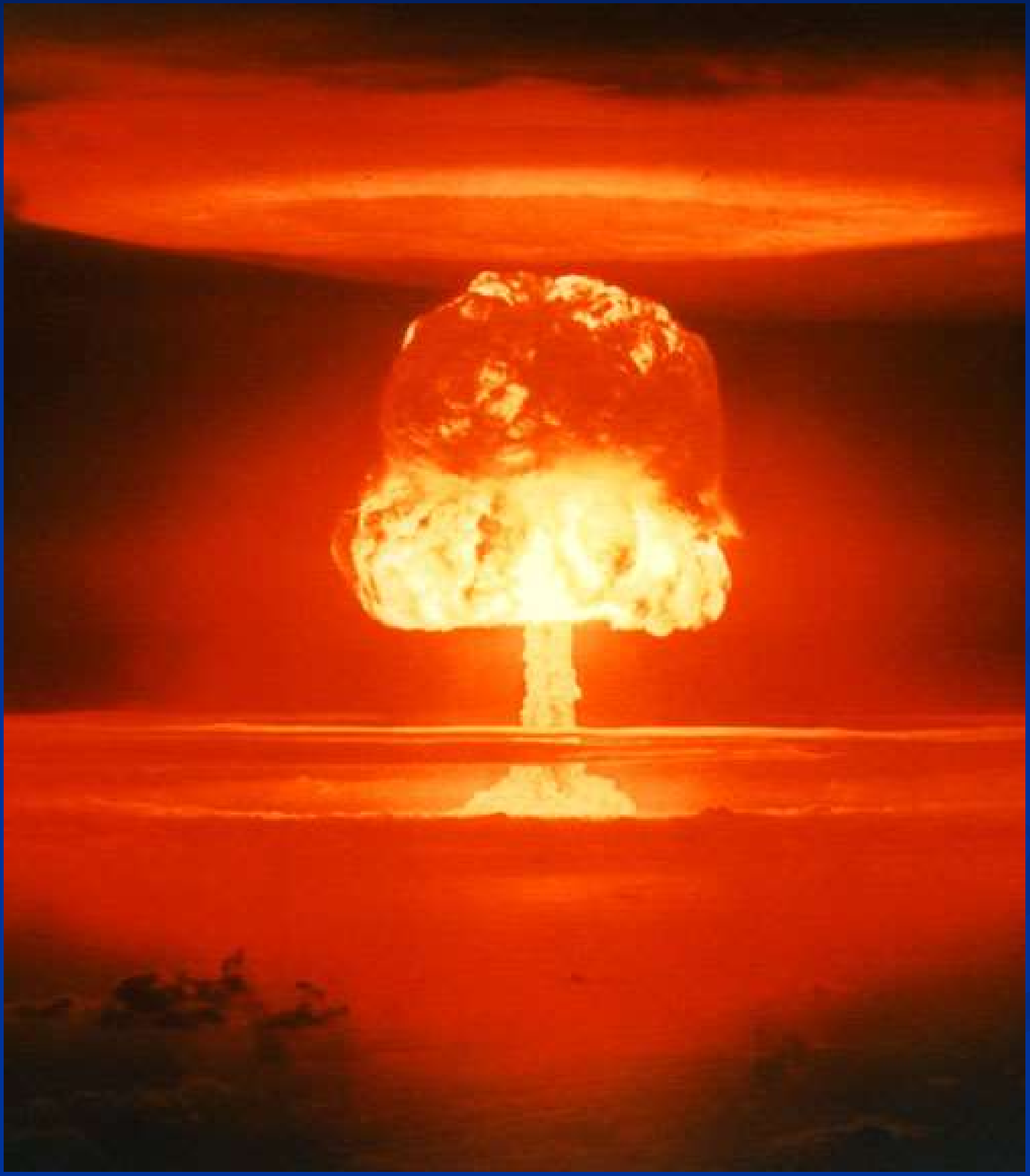
Photograph of a MA/BA6 Mask Aligner

Wet Chemical Processing

Vapors are pulled up and out of the lab through a ventilation hood

Acids and solvents processed separately

When Acids and Solvents Mix



Removing Used Photoresist

- Can be removed chemically using solvents such as acetone
- Can be removed by Ashing
  - An oxygen plasma treatment that burns organics off the surface

Matrix Asher

Sputtering and Electron Beam Deposition

- Has 2 electron beam guns and one sputtering gun
- Holds 1 sputter target and 7 E-beam targets
  - Can deposit 8 different materials without breaking vacuum
- With the 2 E-guns, can co-deposit 2 materials at the same time
  - Can deposit alloys on a substrate

Typical cleanroom suit

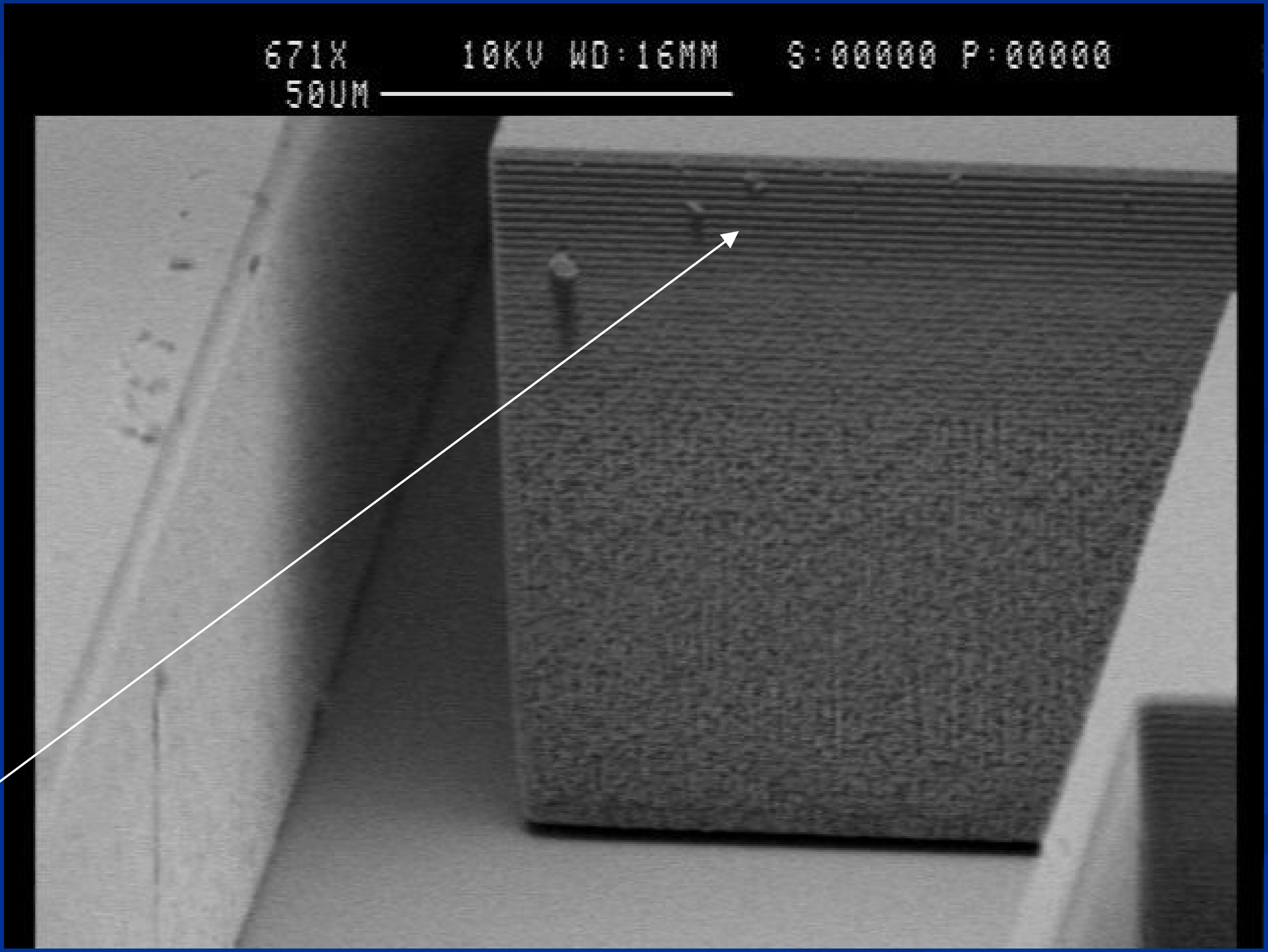
Mark 50

STS Advanced Silicon Etcher

- Bosch process DRIE etcher for Si wafers
- Holds 4” diameter wafers
- Can obtain a 10:1 aspect ratio when etching through a Si wafer
- Real “workhorse” for many MEMS fabrication projects

STS ASE Bosch Process Si DRIE Etcher

A Dry Etched Si Wall



Bosch dry etching process results in horizontal micro trenches on vertical surfaces

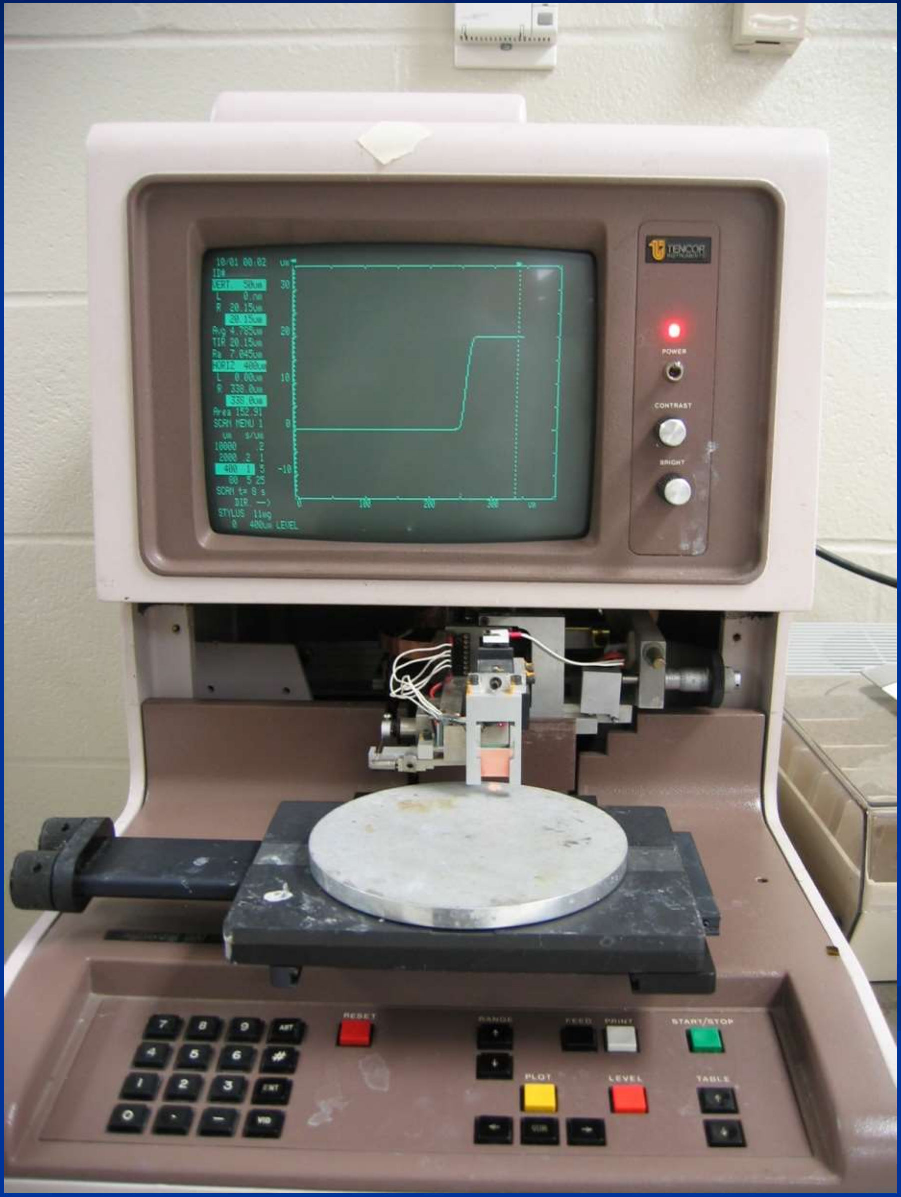
STS Advanced Oxide Etcher

- Non-Bosch process RIE system for non-Si materials:
  - Glass
  - Titanium thin films
  - plastics

STS AOE RIE Etcher

Profilometer

- Measures the depth of etched features
- Used along with RIE to determine when the desired etch depth has been reached

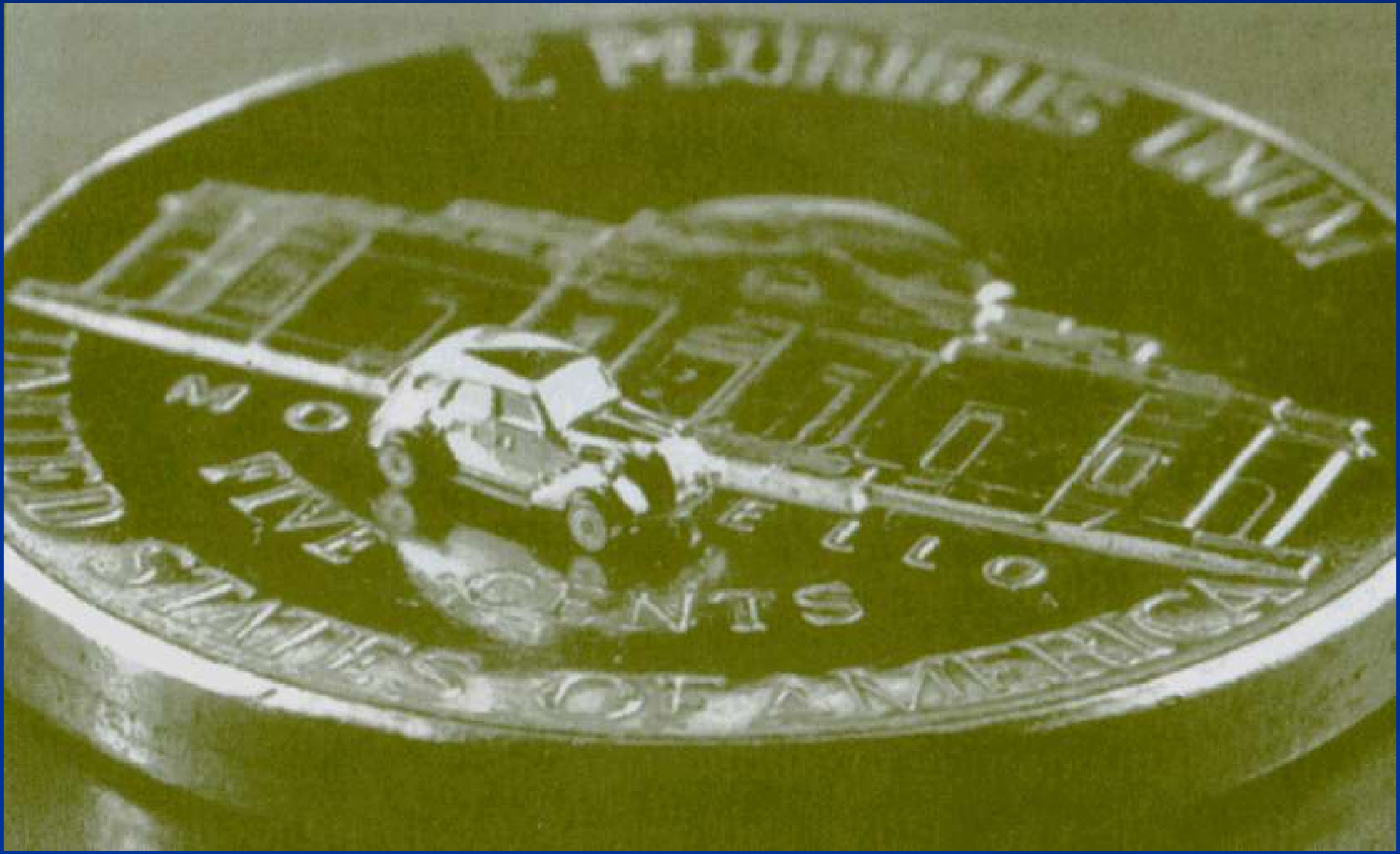


Electroplating System

- Electroplating used to grow metal micro-structures
- Cu, Ni, Au, Sn, etc. can be electroplated

Wafer Plating System

Plated Working Electric Car



Courtesy: Denso Corp

Polyimide Processing

- Polyimides are special plastics
- Wafers can be coated with polyimide layers
- The polyimide can then be cured in this special vacuum furnace

Polyimide Vacuum Curing Oven

Automated Dicing Saw

- Dices a wafer into die
- Uses a diamond saw blade
- Water cooled
- Wafer attached to a tape to hold die in place

Karl Suss Flipchip Bonder

Finished die are placed into position with a precision x, y, θ vacuum chuck, and heat is used to bond them into packages

Automatic Thermosonic Wire Bonder

- Die are wire bonded to package pads for electrical connections
- Gold wire bond wire is used (~25µm diameter)

Photo of Wire Bonds

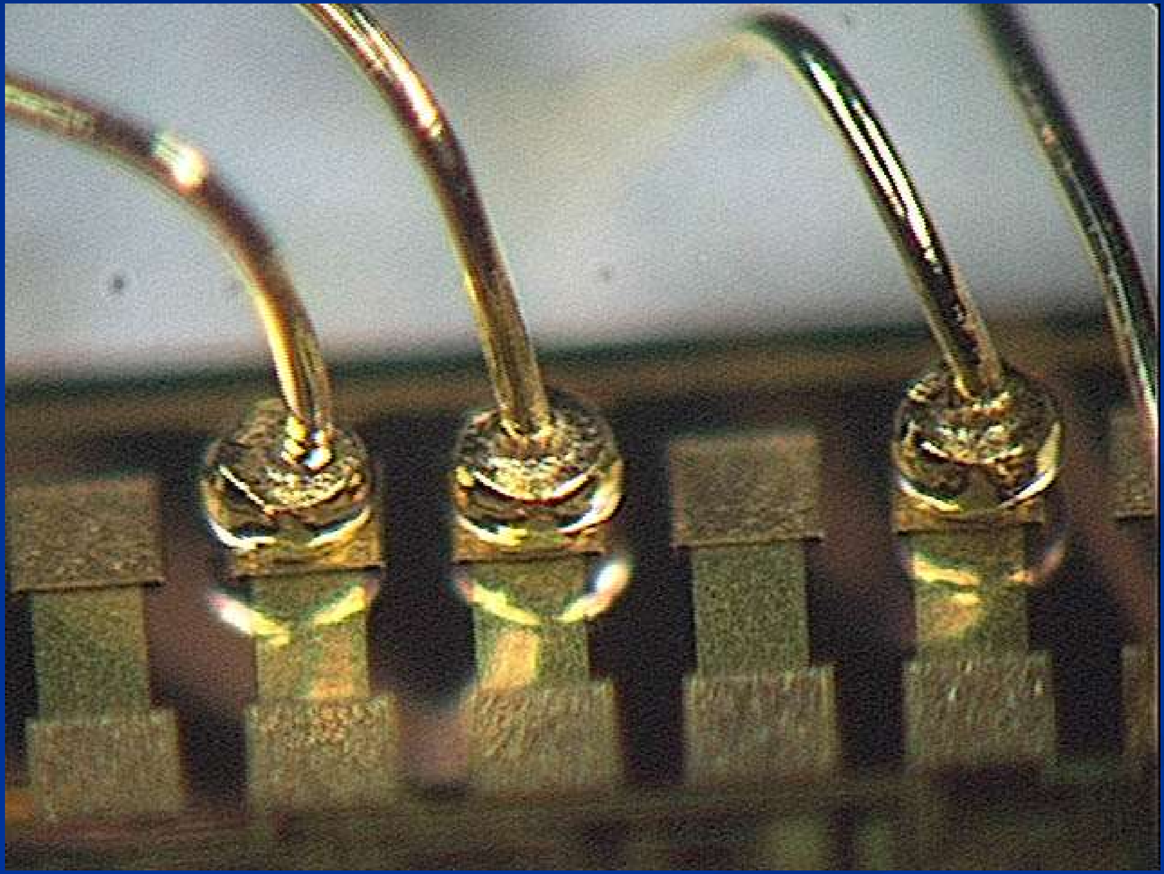


Photo of a Commercial Microfabrication Facility

ST Microelectronics

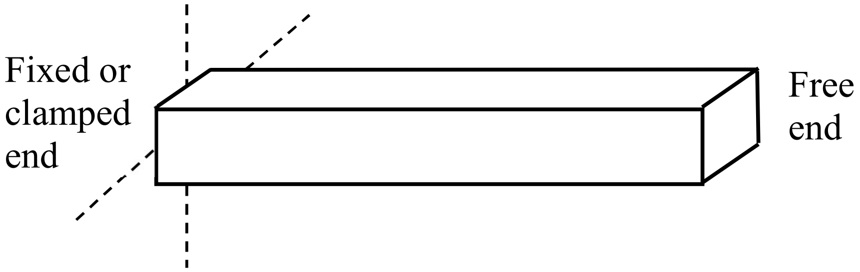
http://france3-regions.francetvinfo.fr/auvergne-rhone-alpes/pas-suppression-usines-france-annonce-st-microelectronics-sites-grenoble-crolles-sont-circonspects-862743.html

The End

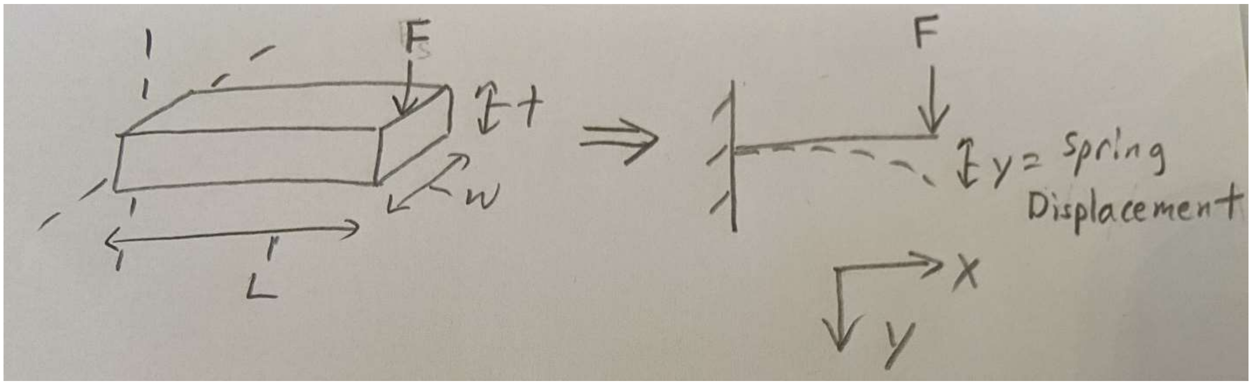
Lecture 8/27/24

Springs

Consider the simplest beam spring:



This type of beam is called a cantilever.



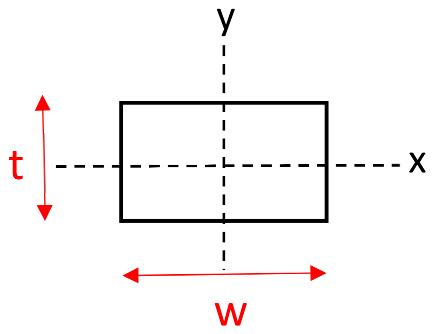
From Beam Theory:

$$y(x) = \frac{F}{6EI}(3x^2L - x^3)$$

At x = L : $y(L) = \frac{FL^3}{3EI}$

I is the 2nd moment of area or the moment of inertia.

For a rectangular cross-sectional beam, such as what we have:



$$I = I_z = \frac{wt^3}{12}$$

Definition

t (thickness): spring dimension in the direction of displacement.

w (width): spring dimension perpendicular to the direction of displacement.

Therefore: $y(L) = \frac{4FL^3}{wt^3E}$

Associated with a spring is spring force, F_s

$F_s = kd$, d = displacement, y(L)

k = spring constant, [k] = N/m

$k = \frac{F_s}{d} = \frac{Ewt^3}{4L^3}$ → spring geometry dependent

Observations about the spring constant

$k \propto w$ → if $w_{new} = 2w_{old}$: $k_{new} = 2k_{old}$

$k \propto t^3$ → if $t_{new} = 2t_{old}$: $k_{new} = 8k_{old}$

Lecture 8/27/24

$k \propto \frac{1}{L^3} \rightarrow$ if $L_{new} = 2L_{old}$: $k_{new} = \frac{k_{old}}{8}$

** A unit change in w has a <u>much smaller</u> effect on k than the same change in t or L. **

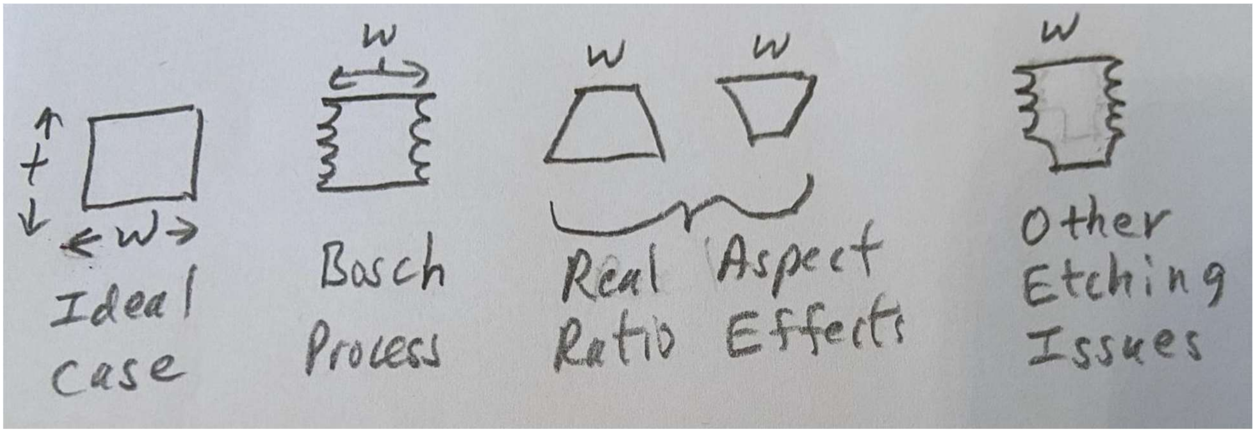
<u>Spring Fabrication Issues in the SOI Fabrication Process</u>

t → Device Layer thickness → very accurate

L → set by photolithography (L: usually large) → pretty accurate

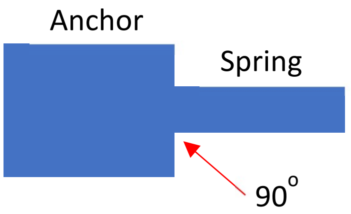
w → set by photolithography and etch process (w: usually small) → not very accurate

Cross-sectional drawings of spring elements:



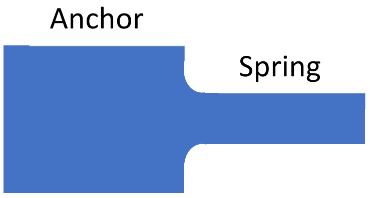
All of these non-ideal etching cases result in a non-ideal, non-constant w, resulting in the spring constant differing from the desired value. But since k is the least sensitive to changes in w, allowing w to be along the direction with the most variability minimizes the effects of fabrication tolerances on k.

Observe the anchor-spring attachment point below:



With the right angle turn at the spring-anchor attachment points, if this lines up with a Si crystal plane, it will be prone to micro cracks, which will propagate along that plane, resulting in the beam snapping off at the anchor wall.

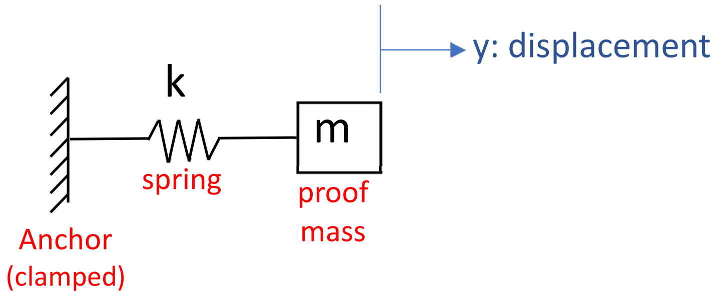
To mitigate this issue, round the corners at the spring-anchor attachment points:



Rounding the corners at the spring-anchor attachment points has minimal effect on the spring constant.

Modeling the Mass-Spring System Dynamically

Mechanical schematic diagram



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$F_I \equiv$ Inertial Force = ma

$a = \frac{d^2y}{dt^2} = \ddot{y}$ (Note: $\dot{y} = \frac{dy}{dt} \equiv$ velocity)

$F_s \equiv$ Spring Force = ky

At equilibrium: $F_I + F_s = 0$

$m\ddot{y} + ky = 0$ → 2nd order linear differential equation with constant coefficients.

Let's pull the proof mass a displacement = y_o and let it go.

At t = 0s → initial condition: $y(t)|_{t=0} = y_o$

To solve, let's assume a solution of: $y(t) = Acos(\omega t)$

$\therefore \ \dot{y}(t) = -A\omega\sin(\omega t)$

And $\ddot{y}(t) = -A\omega^2\cos(\omega t)$

So plugging into $m\ddot{y} + ky = 0$ yields:

$-mA\omega^2\cos(\omega t) + kAcos(\omega t) = 0$

Divide both sides by Acos(ωt), yielding:

$-m\omega^2 + k = 0$

Rearranging yields: $\omega = \sqrt{\frac{k}{m}} \equiv \omega_n \equiv$ natural frequency of the system

$\therefore y(t)|_{t=0} = y_o = Acos(\omega_n t)|_{t=0} = A$

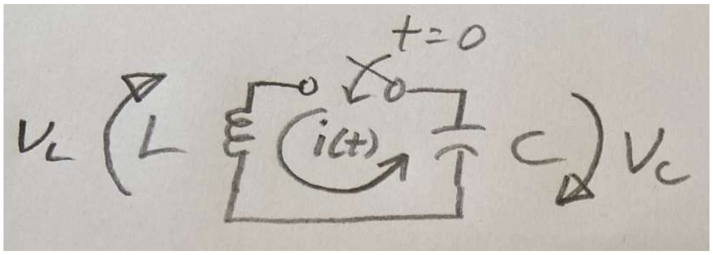
$\therefore\ y_o = A$

The solution is therefore: $y(t) = y_o \cos\left(\sqrt{\frac{k}{m}}\,t\right)$.

This mechanical system will oscillate forever with $f = \frac{\omega_n}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$ with an amplitude of y_o.

This system is lossless → all real systems have energy losses.

Analogous Electrical System



$V_L = L\frac{di}{dt}$ and $V_C = \frac{1}{C}\int_0^{\infty} i(t)dt$

At $t = 0^+$: $V_L + V_C = 0$

$\therefore\ L\frac{di}{dt} + \frac{1}{C}\int_0^{\infty} i(t)dt = 0$: An integro-differential equation

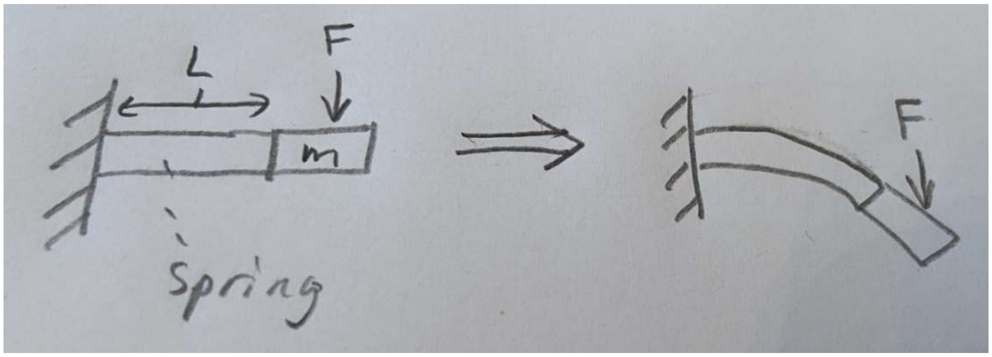
Therefore, differentiate both sides to realize a differential equation:

$L\ddot{i} + \frac{1}{C}i = 0$ → same form as: $m\ddot{y} + ky = 0$

Electrical – Mechanical System Equivalence

Electrical Parameters	**Mechanical Parameters**
L	m
1/C	k
R	mechanical losses

Other Spring (Suspension System) Considerations



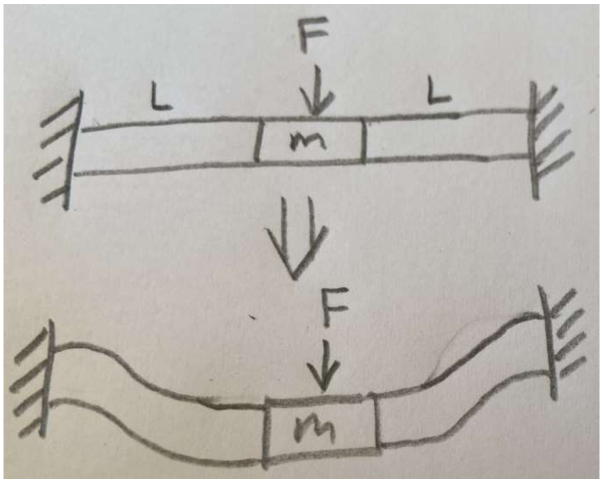
Observe that the proof mass has tilted while the spring has deformed due to the applied force, F.

This may or may not be desirable:

Capacitive detection: not desirable

Piezoresistive detection: OK

Consider this two-beam suspension system:



The proof mass, m, does not tilt now.

However, each spring element (beam) is now in tension AND is bent: this beam structure is now statically indeterminate (i.e. we cannot solve for the displacement with a simple beam equation). So, we must use a different approach.

Assume that the deflections are small compared to the spring length.

Therefore, use this approximation for the system spring constant:

$$k \approx \frac{N_{Leg}}{N_{Zig}} \frac{Ewt^3}{L^3}$$

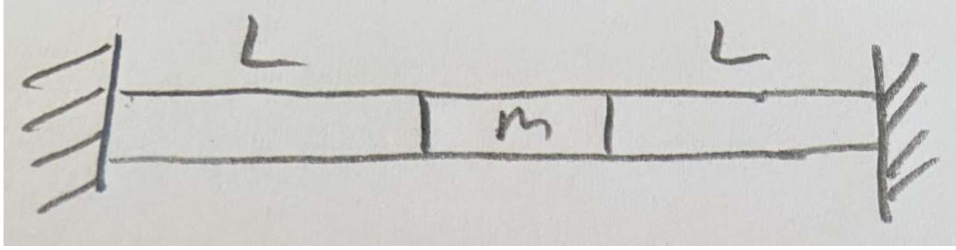
Where N_{Leg} = # Legs or spring elements

and N_{Zig} = # cutbacks (straight beam = 1, folded beam = 2, etc.)

Note: this CANNOT be used with the simple cantilever:

For the simple cantilever: $k = \frac{Ewt^3}{4L^3}$ → the multi-beam suspension system is stiffer.

Example multi-beam suspension system:



2 beams: $N_{Leg} = 2$, $N_{Zig} = 1$

Therefore $k \approx \frac{2Ewt^3}{L^3}$