ME 487

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Chapter 1

ME 487

The lab safety training is already up and I have to do that before the first lab.

You'll make a pressure sensor, and then a microfluidic mixer (because mixing small fluids is hard).

THERE WILL BE POP QUIZZES IN LECTURE

1.1 LAB POLICY

- **NO SHORTS, CONTACTS, OPEN TOED SHOES**
- Don't touch anything unless told so
- If you do anything stupid you get kicked out.

1.2 Importance

MEMS are important because they take advantage of forces that scale dramatically at small scales

- Surface tension scales with l
- Fluid/electrostatic forces scale with l^2
- weight/inertia forces scale with l^3
- electromagnetic forces scale with l^4

So at very small scales, these forces act very differently than in macro-scale systems. You can almost completely ignore gravity.

1.2.1 Cantilever

Deflection under self weight goes down dramatically with l^2.

Resonant frequency **increases** with l^{-1}.

1.2.2 Fabrication Scaling

- Devices are on a single substrate, and you can make thousands of devices on a single substrate.
- We can take infrastructure/technology from the semiconductor industry.

1.2.3 Function Integration

Both electrical and mechanical functions can be obtained with the same materials and processes.

Projectors use a MEM that has a mirror, tilting mechanism, and electronic controller all on 1 substrate.

1.2.4 Material Saving

Because MEMS are on the atomic scale, you use close to nothing on material saving. There is functionally 0 material cost.

1.3 Difficulties

- Really small (10^6)
- Only very very specific materials actually work in lithography
- All tools are only planar- we can only edit from the top/bottom of the wafer.
- You need very specific/expensive facilities and materials.

1.4 Typical Process

1. Deposition

   You put a target material onto a substrate

2. Lithography

   You put a photoresisting material onto that target, and you use lasers to get rid of material to leave a pattern.

3. Etching

   You get rid of the target material with lasers, and all the target material under the photoresist is untouched.

   You then remove the photoresist material and then you're left with just the target material in just the pattern you wish.

1.4.1 MUMPs (Multi-User MEMS Processes) Sequence

This is a 7 layer process of depositing, adding a photoresist, and etching.

This esseentially allows a company to make multiple different MEMS blueprints on a single wafer.

Often used by fab-less companies. They buy a small bit of a wafer from a fab company and have that company etch a specific blueprint onto that small portion of wafer.

1.4.2 Finish Fabrication

- Singulation: Cut the large wafer into little dies such that each individual die has 1 MEM.
- Packaging:

  Bond the functional pieces of the MEM with a wire so that it can work in a larger system.
- Encapsulation

  seal the MEM so it becomes a functional black box with wires for input/output.

Chapter 2

Cleanroom Procedure

Something something something review.

We're usually going to be working in the $\sim 5\mu m$ range for our MEMS building.

2.1 Wafer Contamination

If you leave your wafer in the cleanroom uncovered, it will eventually get contaminated with dust particles. The amount of time it takes for your device to get contaminated is probabilistic. A more clean cleanroom will mean the chances your device gets contaminated in a certain amount of time decreases.

As we consider smaller and smaller dust particles, they move more and more randomly due to the random motion of air particles (Cunningham Correction Factor). Particles move at a speed dependent on some large convoluted equation.

Possible contaminants include dust particles, organic films, and atoms/ions.

2.1.1 Humidity

Fluid condensation is bad.

Water can contaminate your device, and as the water evaporates, the surface tension will warp your device (cantilever).

You can calculate the forces caused by the surface tension of water stuck in your cantilever.

2.2 Cleanroom Itself

You have to wear a whole bunch of silly clothes

The yellow room is for photolithography.

The white room is for deposition and etching.

2.2.1 Chase

A part of the cleanroom only available to staff.

New device will be brought in through the chase.

Chapter 3

Chemicals

All sorts of chemicals and they're all flammable and carcinogenic so don't touch anything or you'll die.

- Solvents
- Photoresists (Carcinogen)
- Developers (Weak base)
- Strippers (acetone)
- Etching (Acids)

3.1 Materials Safety Data Sheet (MSDS)

It gives you a bunch of information about certain chemicals

- Chemical breakdown
- Methods of exposure
- Effects/risks of exposure
- other
- other

16 different important bits of information on every MSDS.

There is a physical binder and a search engine that gives you the MSDS to every chemical in the cleanroom.

3.2 NFPA Diamond

It's the square with 4 parts that tells you everything about a certain chemical in a container.

Yellow is for reactivity, red is for flammability, blue is for health hazards, white is for miscellaneous.

White: OXY, ACID, ALK, COR, W-, RAD

3.3 PPE

You need certain equipment BEYOND THE CLEANROOM GOWN to work with certain chemicals.

HF spills have to be treated with special care.

3.3.1 Do's and Dont's

Do

- change gloves whenever dirty/broken
- Use fresh gloves
- use cleanroom paper
- remove rings and bracelets

Chapter 4

Lithography

Writing stuff on stone by using an insoluble material on top.

You can then put an acid on top and the resist on top will not be dissolved, but the rock will be dissolved.

4.0.1 Process (Etch)

1. Prepare surface and apply photoresist
2. Pre-bake oven
3. aligner exposure (with mask)
4. develop, rinse, and dry
5. Post-bake oven
6. Inspect and measure
7. Etch and Deposit
8. Strip the photoresist and clean
9. Deposit or grow new layer
10. repeat

Etching is putting down deposition material and then putting the photoresist on top and in a certain pattern and then removing all material **not** under the photoresist.

4.0.2 Lift-off

You put the photoresist on and get rid of the unwanted resist, **then** you put on the deposition material, and then the material that is on top of the photoresist gets removed.

4.0.3 Issues

Photoresists etch at various rates, so you need a tall photoresist layer to make sure that the photoresist doesn't completely etch away before your unwanted material is fully gone.

4.1 Wafer Cleaning

Degrease the wafer with acetone, alcohol (IPA), de-ionized (DI) water, dry with N_2 gas.

4.1.1 Standard Clean 1 (SC1, RCA1)

DI water, ammonium hydroxide, hydrogen peroxide

Removes light organic material.

4.1.2 Standard Clean 2 (SC2, RCA2)

DI water, HCl, hydrogen peroxide.

Good for removing metal ions.

Pirhana solution = sulfuric acid + hydrogen peroxide. very very harsh etch. Must be done in a fume hood!!!!! Reactive mixture must be allowed to deactivate. Only really used if you're trying to salvage a wafer.

Surface tension determines how far into a crevass a solvent will go.

4.1.3 Other Cleaning

Ultrasonic Cleaning - use sound in the 20-400 kHz range to dislodge large particles ($> 2\mu m$)

Megasonic cleaners use even faster waves (800-2000 kHz) to dislodge smaller particles ($< 0.5\mu m$).

Cryogenic Cleaning - immerse your substrate into liquid nitrogen to make your wafer (and debris) very brittle, which should break apart debris.

Supercritical cleaning/drying - Immerse in ethanol or methanol. Supercritical CO2 dissolves the solvent. When pressure is lowered the gas changes.

4.2 Wafer Priming

You want a very hydrophobic surface for best adhesion. You also want to minimize humidity.

You can use a number of methods for priming

- Oxygen plasma descum
- Adhesion Promoter AP8000 (chemical)
- Increase soft bake
- Sputter the surface to induce micro-roughness.

4.3 Details Of Photolithography

1. Surface preparation
2. Spin coating
3. Alignment and Exposure
4. Post-exposure bake
5. Develop, clean, and dry
6. Inspection
7. Descum and Hard Bake
8. Resist Stripping (Removing the PR)

4.3.1 Photoresist

PR's consist of 3 main materials

- Polymer (resin)
- sensitizer
- Solvent

You want your PR to be as flat as possible so that you are at minimal risk of under-exposure or over-exposure.

4.3.2 Spin Coating

You just use centrifugal forces.

edge beading is what happens at the edge of your wafer that comes from excess PR at the edge of the wafer coming back into the wafer once it is done spinning.

The equation for spin coating is given by

$$T = \frac{KC^\beta \eta^\gamma}{\omega^\alpha}$$

- T = thickness
- K = calibration constant
- C = polymer concentration
- η = intrinsic viscosity
- ω = angular speed (rpm)
- α, β, γ = empirically determined parameters

Features on the wafer should be no more than 20% of the resist thickness, otherwise the resist may not have good coverage.

To estimate the dispense volume, you just do basic geometry

$$V = \pi r^2 T$$

4.3.3 Other Methods of PR Deposition

- Spray coating
- Electrostatic Spraying
- Meniscus Coating
- Electrodeposition
- Roller Coating
- Silkscreen Pirnting
- Dip Coating
- Curtain Coating
- Extrusion Coating

4.4 Soft Baking

Depends on the type and the thickness of the PR. It is also called pre-bake or pre-exposure bake. Hotplates are used in the 60C to 110C range.

Pre-baking is important because it

- Relieves stresses in the film
- Removes solvents
- Promotes adhesion

Too much heat can degrade photosensitivity!!

PR must be soft-baked so that it does not stick to your mask during alignment.

4.5 Exposure

Optical transfer of the pattern on the mask to the PR.

The light wavelength of our exposure is mainly in the UV range because we need visible light to see.

Lasers are monochromatic and coherent.

PR's have a required "dose" of light to successfully be removed from the wafer.

4.6 Mask

It's the device that blocks light at certain locations so that the PR is untouched underneath it. There are multiple types of masks

Masks are made of optically flat glass coated with a patterned absorber layer which blocks the light.

- lightfield mask

  exposed almost everywhere

- darkfield mask

  exposed only in features.

- Binary Mask

  either completely exposed or completely blocked

- Greyscale mask

  transparency varies so you can deposit material of varying heights with only a single layer of PR.

- Phase Shift Mask

  Work like holograms and odulate the phase-shift of the light beam to create interference patterns in the PR. Requires a coherent light-source for exposure.

4.6.1 Mask Materials

- Chrome is opaque to both visible and UV light
- iron oxide is clear to visible light but opaque to UV
- emulsion based materials are transparent

  Soda Lime glass, BK-7, Quartz, CaF_2

The emulsion based materials have various cutoff wavelengths, and you would use different mask materials depending on both your PR and your exposure wavelength.

Mask production is another lithography step.

4.6.2 Exposure Tools

- Contact mask: put the mask on the wafer directly

  Fast, cheap, and simple, but the wafer has to be specifically made to withstand contact, there's no magnification, and the mask is the same size as the wafer.

- Proximity: put the mask as close as you can without touching

  Fast, and no-contact, but slightly more complex, the separation leads to diffraction blur, and the mask needs to be the same size as the wafer (expensive).

- Projection: use lenses to be able to accurately place the light without proximity.

  Masks are easier, laser is more expensive.

Projection is useful because the mask does not have to be the same size as the pattern because the lens will de-magnify the light.

The modulation transfer function is the function that determines the type of feature sizes that can be put into a system.

4.6.3 Projection Lithography

You have to worry about both resolution and depth of focus.

Chapter 5

SKIPPED OPTICS LECTURE

Chapter 6

Polymers

6.1 Crosslinking

This is what happens when a polymer changes into an insoluble product due to light exposure.

This is for negative photoresists

6.2 Scission

Polymers separate under light exposure and actually become soluble.

This is for positive photoresists

6.2.1 Examples of Positive PR

- PMMA

  sensitive at 220nm and useful with DUV but not mercury

- DNQ resists

  Have a DNQ ester and a resin

  useful with mercury lamp lines

6.3 Pros and Cons

Positive PR's are better for resolving isolated holes and trenches

Negative PR's are better for resolving isolated lines.

Positive PR leaves PR everywhere except the illuminated parts

Negative PR leaves PR only on the illuminated parts and not anywhere else.

In order to use PR, you put you material **where there is no photoresist** and then the PR removes all the deposited material on top of it.

6.3.1 Permanent Resists

These are PR's that become permanent components of the device. Thicker layers are achievable. They use strong adhesion, which makes removal difficult.

6.3.2 Dry Resists

A film is directly laminated onto a surface. No liquids are used. Available thickness from $25\mu m$ to $100\mu m$. It conforms to surfaces of different topologies, and is developed in sodium carbonate solutions.

6.3.3 Image Reversal Resists

You can use both heat and UV to make the PR act as both a positive PR and a negative PR.

6.4 Overexposure

You use too much light and part of the PR that was meant to be not touched is touched.

6.4.1 Positive

Too much PR has been removed

6.4.2 Negative

Too much PR is solidified on the wafer.

6.4.3 Liftoff

Positive photoresists are better for liftoff when overexposed because the PR forms a concave structure that makes sure the deposition material is definitely disconnected.

6.5 Underexposure

The opposite of overexposure.

Negative PR is better when you underexpose.

6.6 PR Resolution and Contrast

Certain resists only change a certain amount depending on the dosage of light.

The sensitivity = resist contrast = the slope of resist removed over dosage

$$\gamma_p = \frac{1}{\log(D_p) - \log\left(D_p^0\right)} = \left(\log\left(\frac{D_p}{D_p^0}\right)\right)^{-1}$$

Having a PR with less contrast is useful if you have 2 masks.

6.7 Developers

- MIF (Metal Ion Free) Developesr
- Inorganic (metal ion based) Developer

Do not mix these two developers

6.8 Choosing a PR

Dependent on wavelength, feature size, thickness, positive/negative, lift-off, chemical/plasma resistance, removal, developer, stripper.

6.8.1 Multi-layer Resists

These are used when you have resolution issues but still need a very thick layer.

A multi-layer resist could also be used if there are features already in the wafer. You use 1 layer to cover all your features and then use a second layer for your actual pattern.

The resist thickness should be $5\times$ as big as the largest feature.

6.8.2 LIGA

It's some German word.

Essentially you use a very thick PR to make a mold, and then you plate the PR mold with metal electroplating.

6.8.3 Lift-Off Resist

Basically you put a resist on top of an overexposed resist so you can get the nice concavity while still having a straight line for the deposition process.It's some German word.

6.8.4 Post-Exposure Treatment

Heavily Dependent on Resist. baking, radiation, reactive gas, vacuum, time.

6.8.5 Stripping

There's all sorts of ways to get PR's off of your wafer.