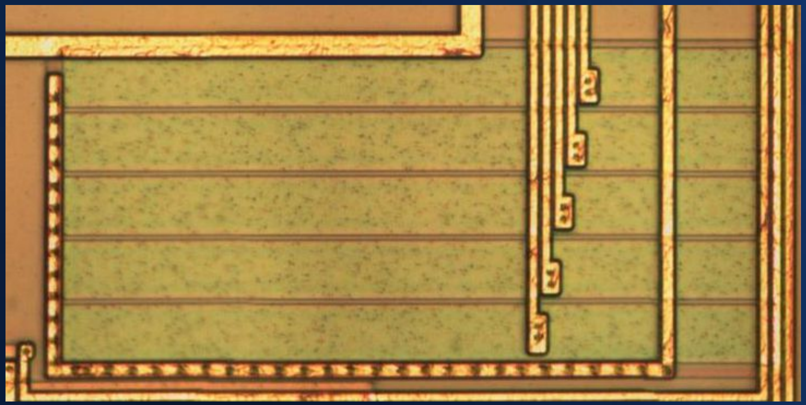
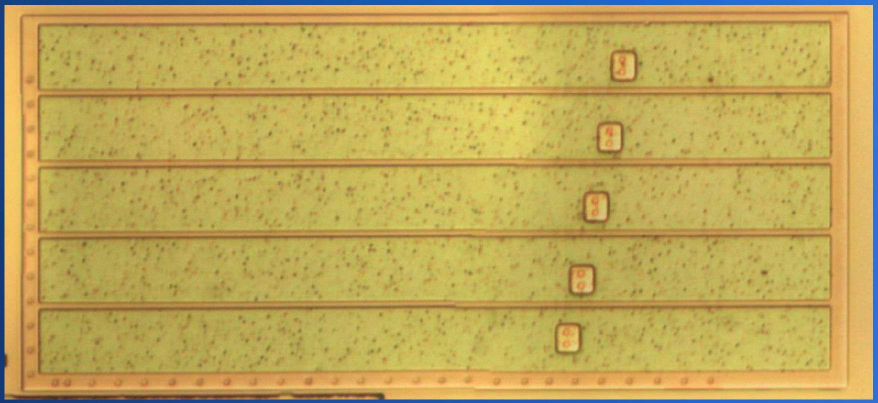
CSCI 4974 / 6974
Hardware Reverse Engineering

Lecture 6: Deprocessing

What is deprocessing?

- Reversing the manufacturing process to reveal features made early on
- Based on, but not identical to, fab processing
- Inherently destructive to sample





Types of deprocessing

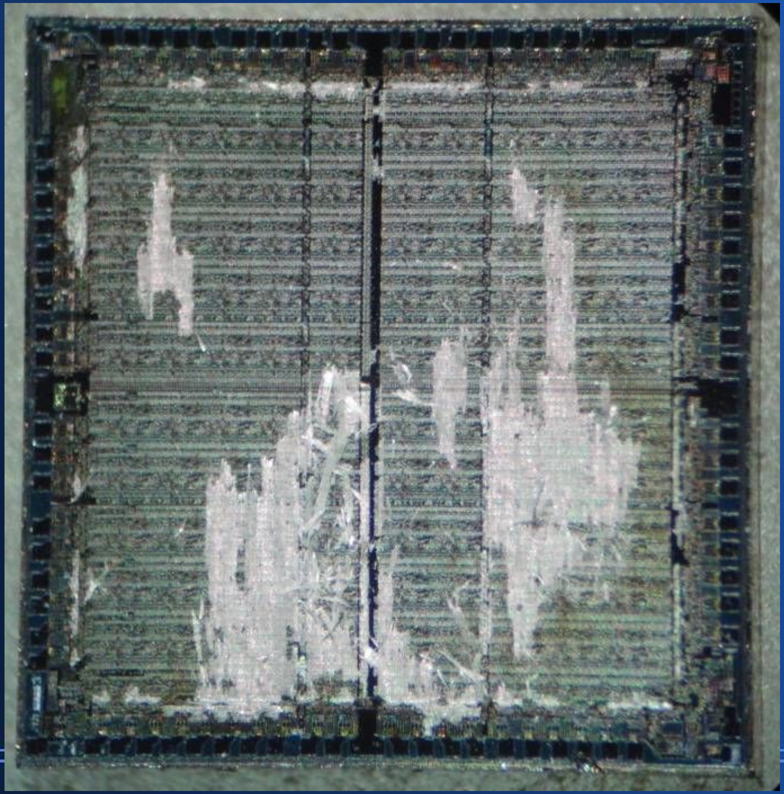
- Material removal
  - Selective
  - Non-selective
- Staining

Wet etching

- Submerge sample in tank of corrosive liquid
- Make sure all etchant is gone after!
  - Etchant residue on surface can cause further damage to sample after removal from tank
- Generally isotropic
- Sonication/stirring may help uniformity
- Lots of processes: http://siliconpr0n.org/wiki/doku.php?id=delayer:wet

Wet etching

- Surface must be extremely clean beforehand
  - Dirt/package residue on surface will mask etch



HF wet etch

- Target: SiO_2
  - $SiO_2 + 4HF \Rightarrow SiF_4\ (g) + 2H_2O$
  - $SiO_2 + 6HF \Rightarrow H_2SiF_6\ (aq) + 2\ H_2O$
  - Will also damage Al, but not poly or Cu
- Will undercut wires if overetched
- Poor choice for deep etches (hard to control)

HF toxicity

- Handle with extreme care!
- Emits toxic vapors
- Weakly acidic (does not cause immediate pain)
- Fluorine toxicity is the real problem
  - Removes Ca^{+} from cells, eats bones
  - Clogs things with insoluble CaF

HF wet etch

- Removal of oxide
  - Exposing poly on 1-metal chips
  - Stripping dies to active layer
  - Removing ILD after CMP so wires stick up
- Ingredient in Dash etch (covered later today)

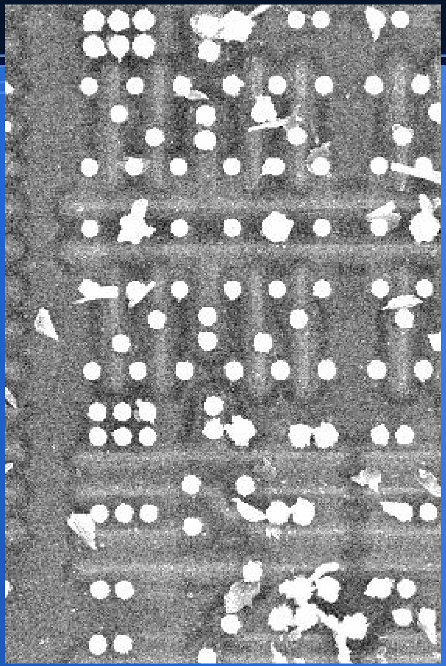
HF wet etch

- Use a pH buffer (BOE) to improve evenness
  - Also reduces damage to metal
- Do not use glass labware!
- Use dedicated plastic labware
  - Keep free of metal ions (will leave residue)
  - Keep free of oxidizers (will damage Si)
- Stirring OK, do not use ultrasound
  - Will rip wires and oxide chunks off

Stress induced ILD cracking

- Not sure of cause, could be many things
- Overheating during decap
- Etching too fast
- Mechanical shock

Metal fluoride crystals



- Caused by HF eating metal
- Difficult to remove
- Workarounds
  - Use BOE to reduce metal damage
  - Remove metal before etching with HF

Wet etching for metal

- Aluminum
  - 65% phosphoric acid @ 50C
- Copper
  - 6 parts 3% H_2O_2 + 1 part concentrated HCl
- Tungsten
  - HCl
- Tables of etch rates and mixtures published in fab journals / textbooks

Wet etching for silicon nitride

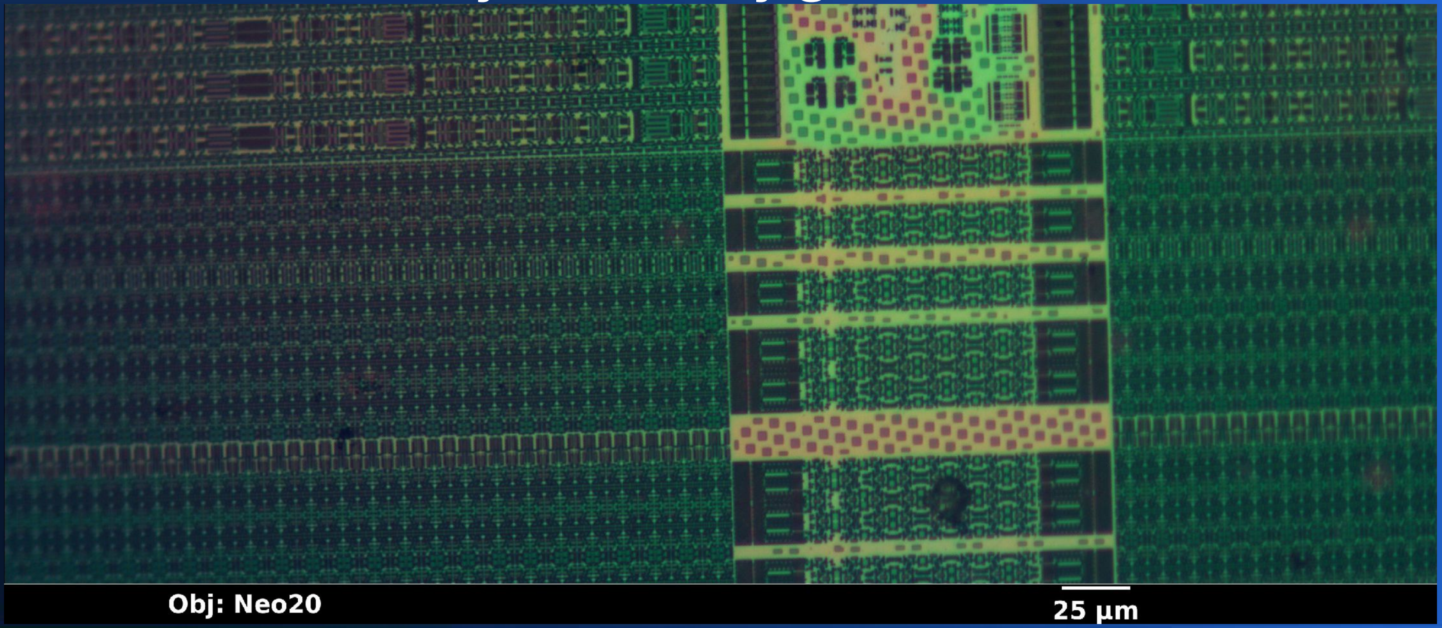
- Phosphoric acid
  - 10:1 selectivity vs oxide
  - 4x faster than HF on nitride
  - But eats most metals
  - May be useful for thinning overglass
- HF
  - Doesn't attack metal as fast
  - Will attack ILD

Wet etching for barriers

- TiN [Beck's Failure Analysis]
  - 9 parts 30% H_2O_2
  - 2 parts 35% NH_4OH
  - Etch ~3 min at 50-55C
  - Can self-heat, may need water bath

CMP for deprocessing

- Gives very good results for planarized devices
- Requires extremely level mounting of sample
  - Can use adjustable jigs to correct for tilt

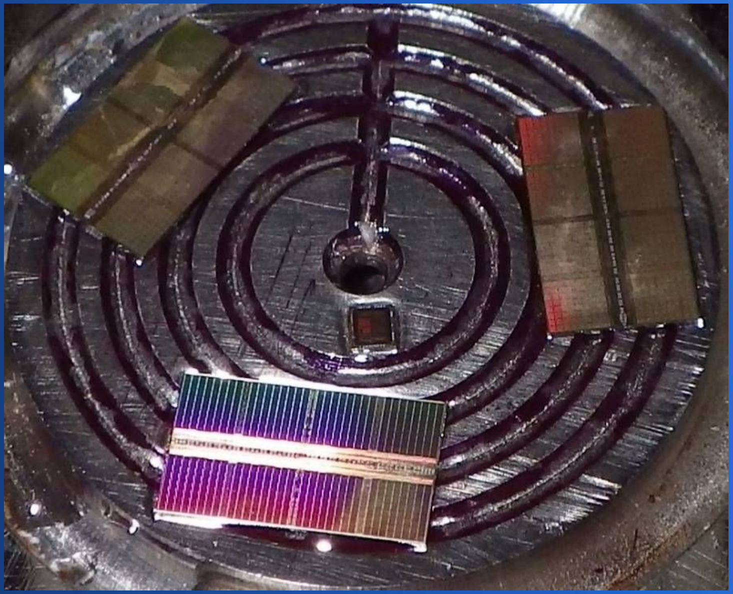


Lapping fixtures

- Center slides in and out for adjusting depth
- Tripod jigs have adjustable tilt
  - More expensive, but can get flatter results
- Conditioning pads around rim
  - Fluffs up pad
  - Evens out slurry layer

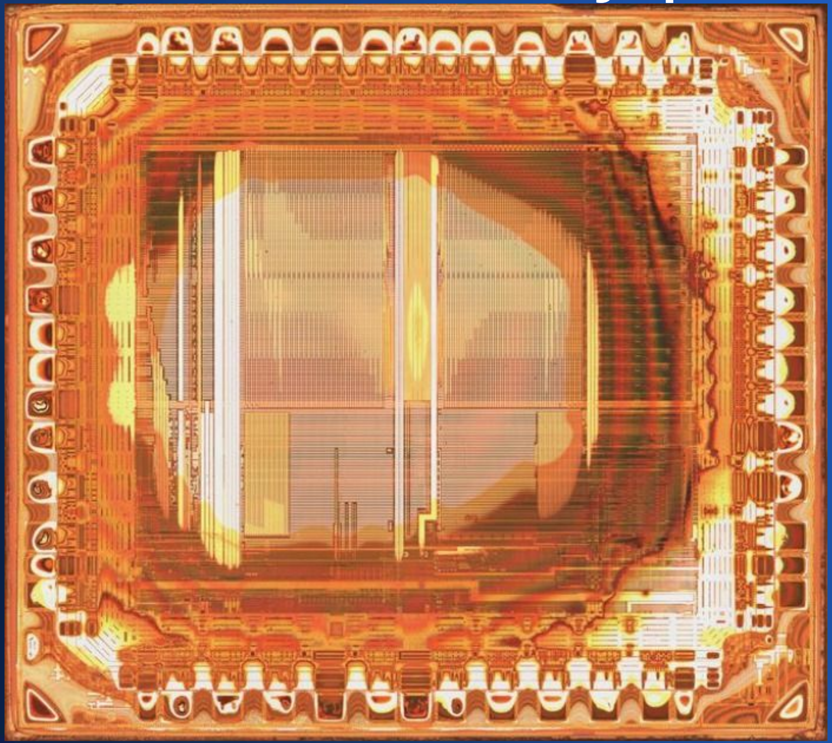
Sample mounting

- Mount die in lapping jig with wax
- Place sacrificial dies around sample
  - Thickness matching is critical
- Die surface must be clean
  - Particles scratch!
- Do not mount die at center (rings)

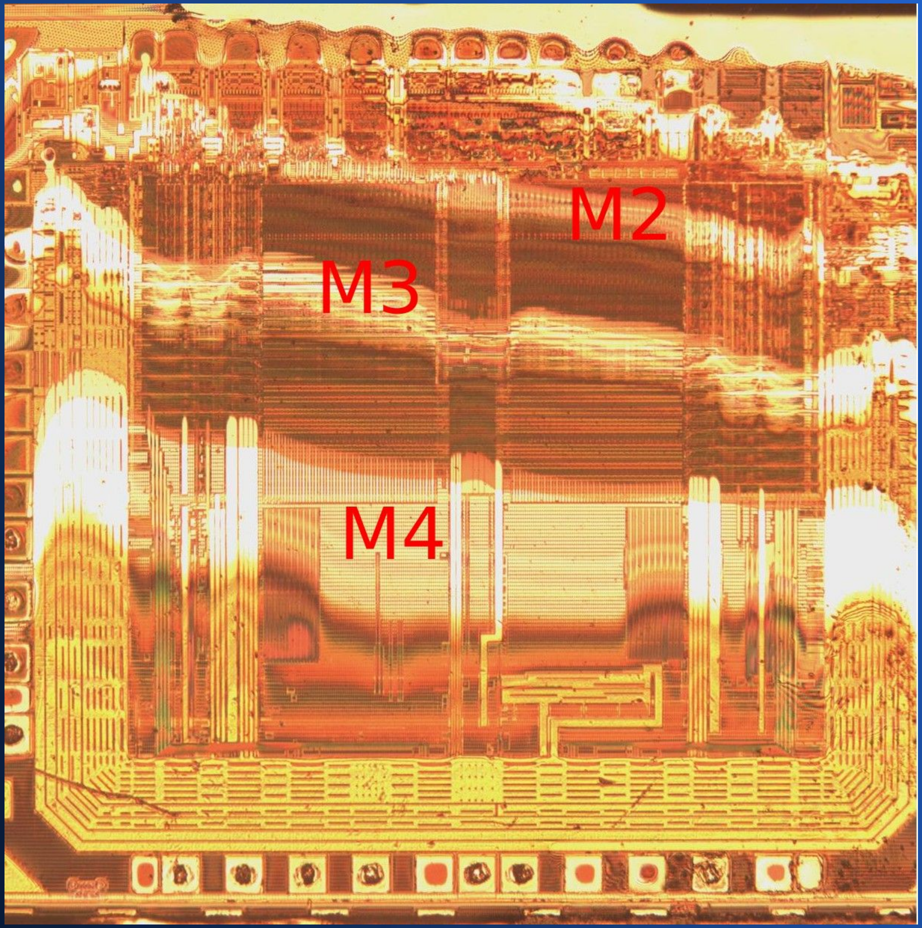


Edge rounding

- Sacrificial dies help correct with this
- Boundary condition caused by pad elasticity



Tilted sample



Hand polishing

- Slide polishing fixture by hand over fixed pad
- A bit cheaper
- Takes a long time, not recommended

Machine polishing

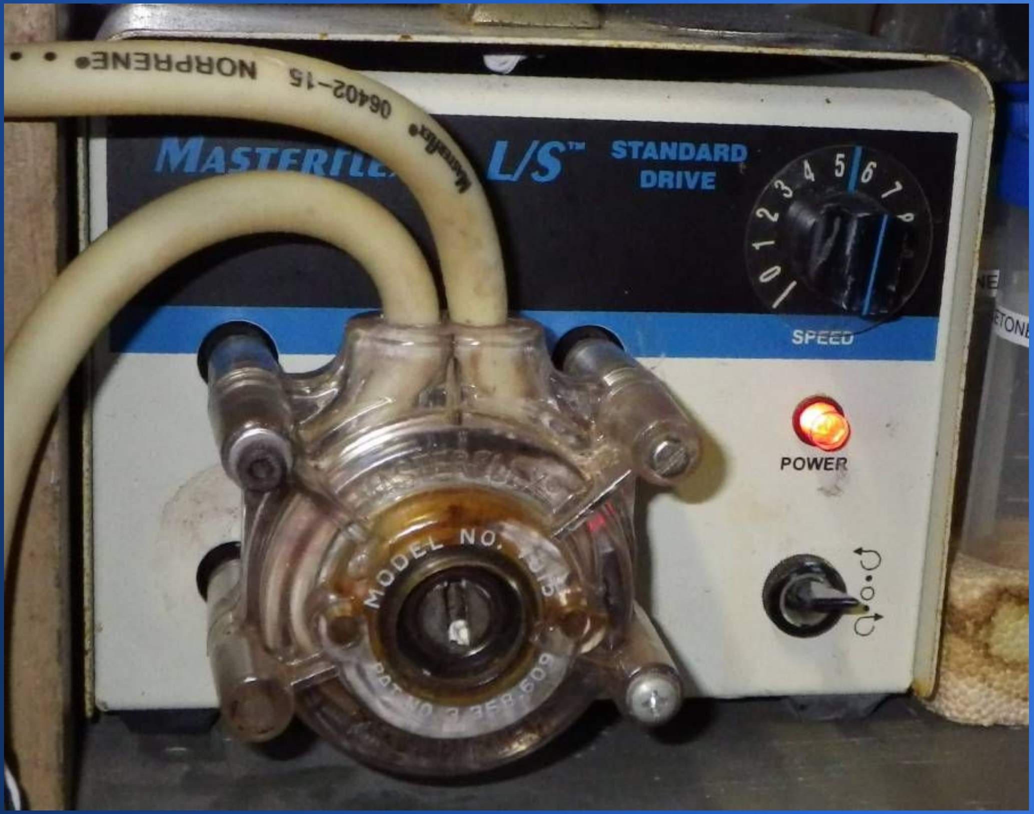
- Polishing pad is mounted on spinning surface
- Drip abrasive suspention on pad
- Press mounted sample against spinning pad and move around
- Moving jig helps uniformity
  - Do not rotate about sample!

Machine polishing with finger

- Doesn't require a jig
- Press die against spinning pad with finger
- Dangerous to both operator and sample
    - Not recommended!

Slurry pumping

- Slurry is corrosive and abrasive
- How do you pump it?
- Peristalstic pump!



Other notes

- Keep pads clean, do not allow abrasive slurry to dry up on pad
  - Colloidal silica likes to clump and crystallize
- Maintain uniform, low flow rate on slurry drops
  - See http://siliconpr0n.org/wiki/doku.php?id=delayer:lapping

RIE for delayering

- Same RIE systems used for fab can be used for deprocessing!
- Selectivity may not be as good, but less chance of undercutting
- Requires more expensive infrastructure and plumbing for toxic gases

RIE for delayering

- Copper
  - Impossible, no useful gaseous compounds
- Aluminum
  - Cl or Cl-based gases
  - Very selective against Si/SiO2

RIE for delayering

- SiO2
  - CF_4
  - Also attacks Si :(

Dash etch

- Used to reveal doping
  - Figuring out tricky gates with weird sizing
  - Reading implant-based ROMs
- Pre-requisite: Strip off metal, poly, and oxide
  - Etching too long may damage ROMs
  - ROMs are weak implants and very sensitive!

Dash etch

- 3 parts 65% HNO_3 (oxidizer)
- 1 part 48% HF (oxide etch)
- 10-12 parts glacial acetic acid (diluent)

John McMaster variant

- Adjusted from original to use dilute HF
  - May be easier to get hold of
  - Less HF fumes during mixing
  - Slightly safer to handle, but still toxic/corrosive
- 3 parts 65% HNO_3
- 4 parts 12% HF
- 8 parts acetic acid

Dash etch

- Based on a common isotropic silicon etch
  - $2HNO_3 \Rightarrow NO_2 + NO + H2O + 2O$ [1]
  - Si + 2O => SiO2
  - HF then etches SiO2
  - Acetic acid is just there to dilute and slow the reaction to a manageable rate

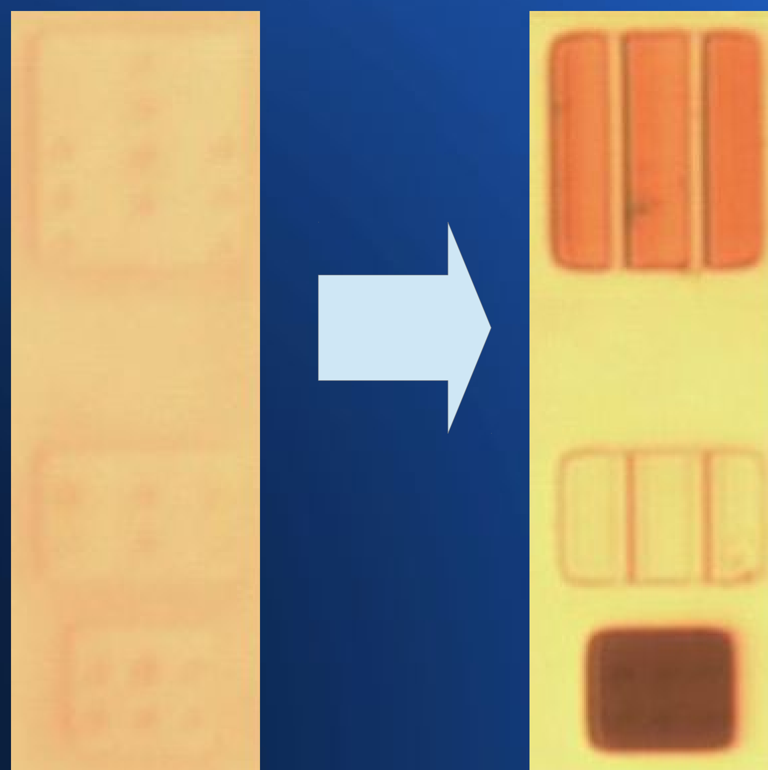
[1] http://cecs.anu.edu.au/files/posters09/448853800000000101.pdf

Dash etch

- Oxidation rate is weakly dopant-dependent
- Set up an equilibrium, dopants tip it
  - Undoped Si: Etch rate ≈ oxidation rate
  - N-type: Etching dominates
  - P-type: Oxidation dominates
- End result: P-type areas grow oxide
- Typical process times: 5-15 sec
  - May need to dilute / etch less for deep sub-µm
  - http://siliconpr0n.org/wiki/doku.php?id=delayer:dash

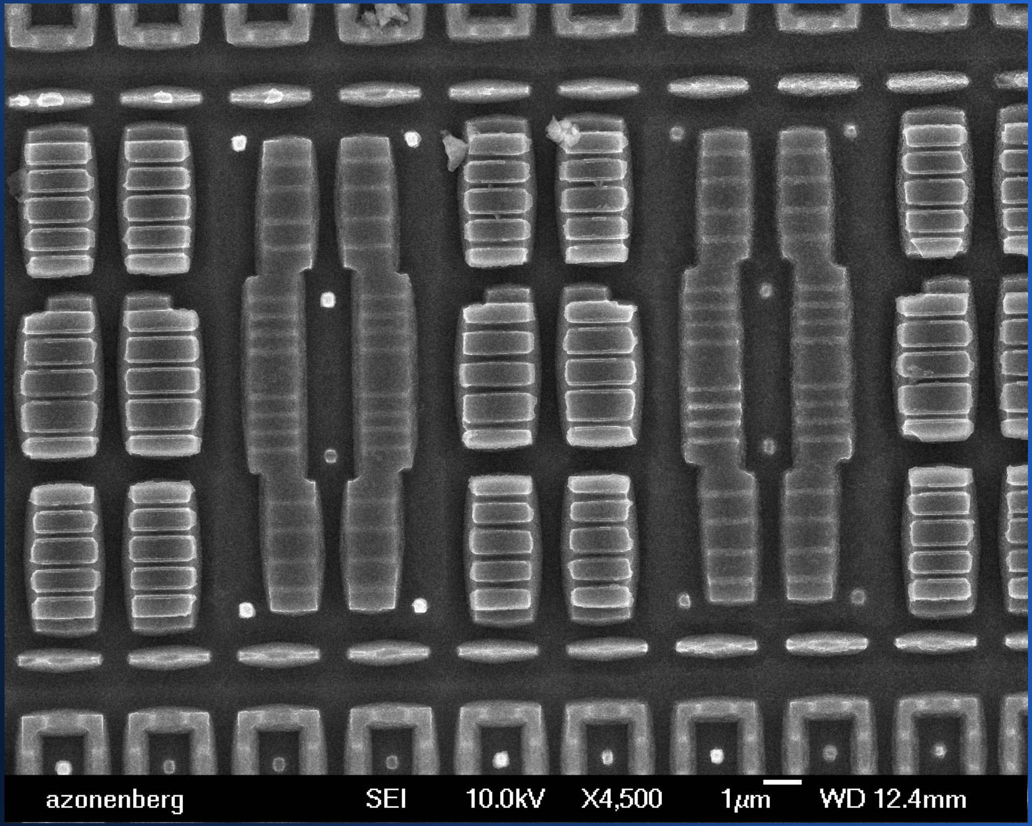
Dash etch results

- Oxide causes thin film interference colors

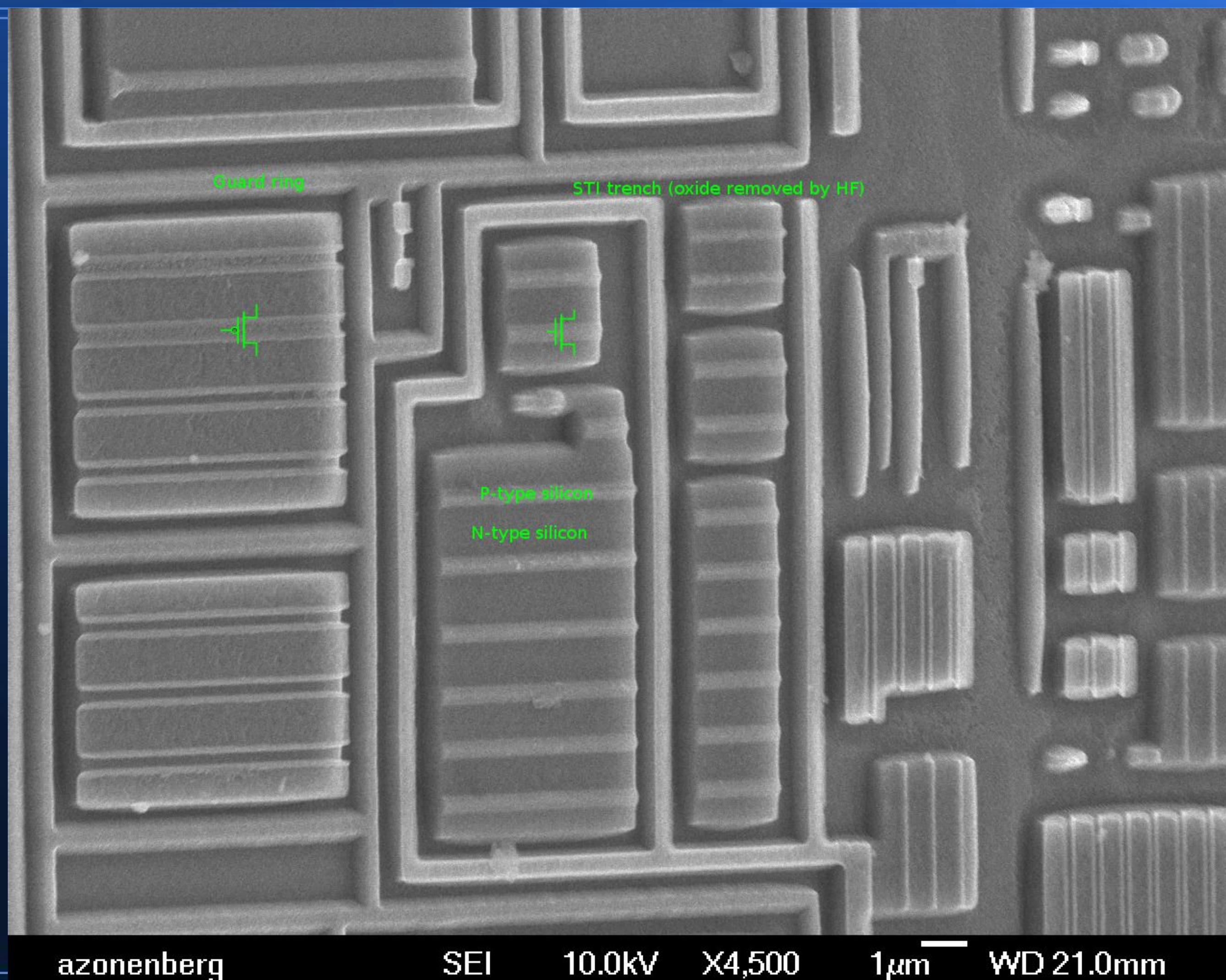


Dash etch results

- Topography is directly visible under SEM

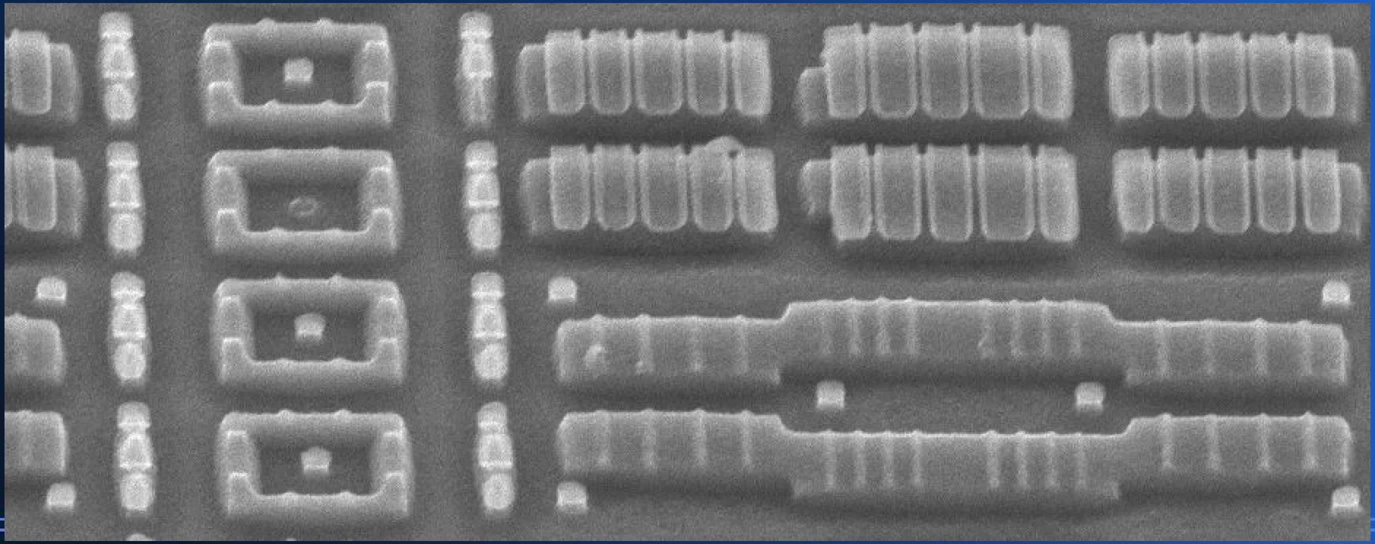


Dash etch results



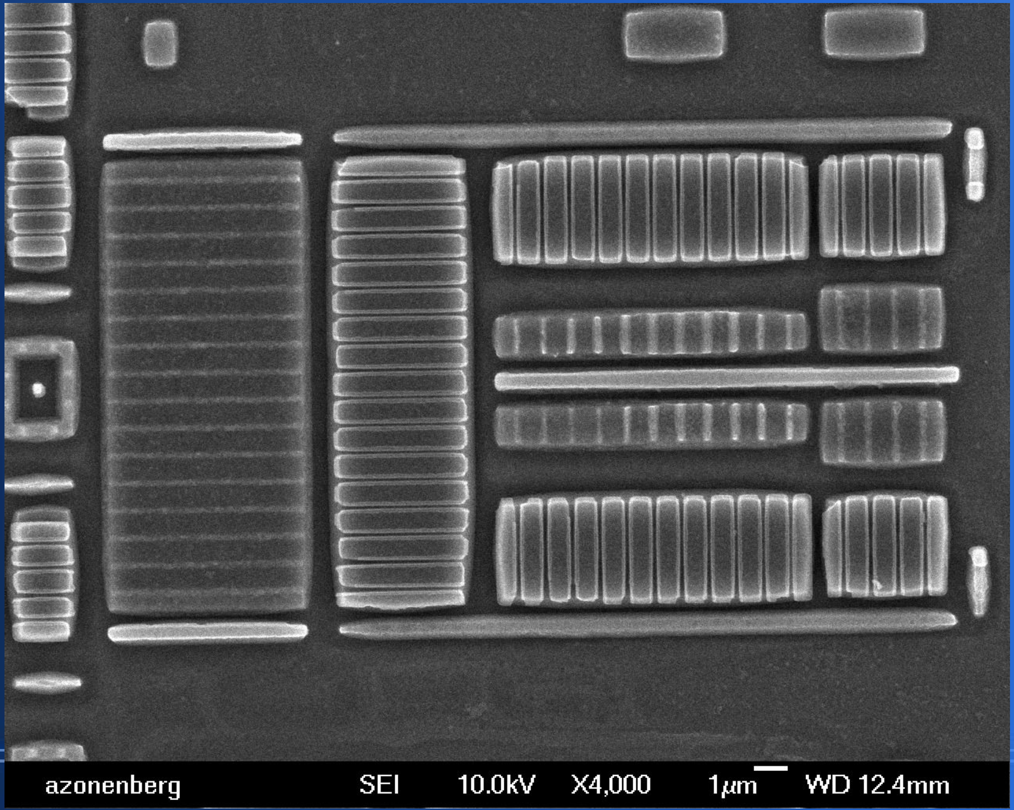
Dash etch results

- Use short stain times for deep submicron
  - Faint coloration starts at ~75 nm oxide
  - May be too much for < 250 nm nodes!
- Example of slight over-stain on 180 nm



Dash etch

- Example of unusual doping (XC2C32A ZIA)
- NMOS at left is larger than PMOS!



Questions?

- TA: Andrew Zonenberg <azonenberg@drawersteak.com>
- Image credit: Some images CC-BY from:
  - John McMaster <JohnDMcMaster@gmail.com>
- See also: “Etch rates for micromachining processing, pt 2”