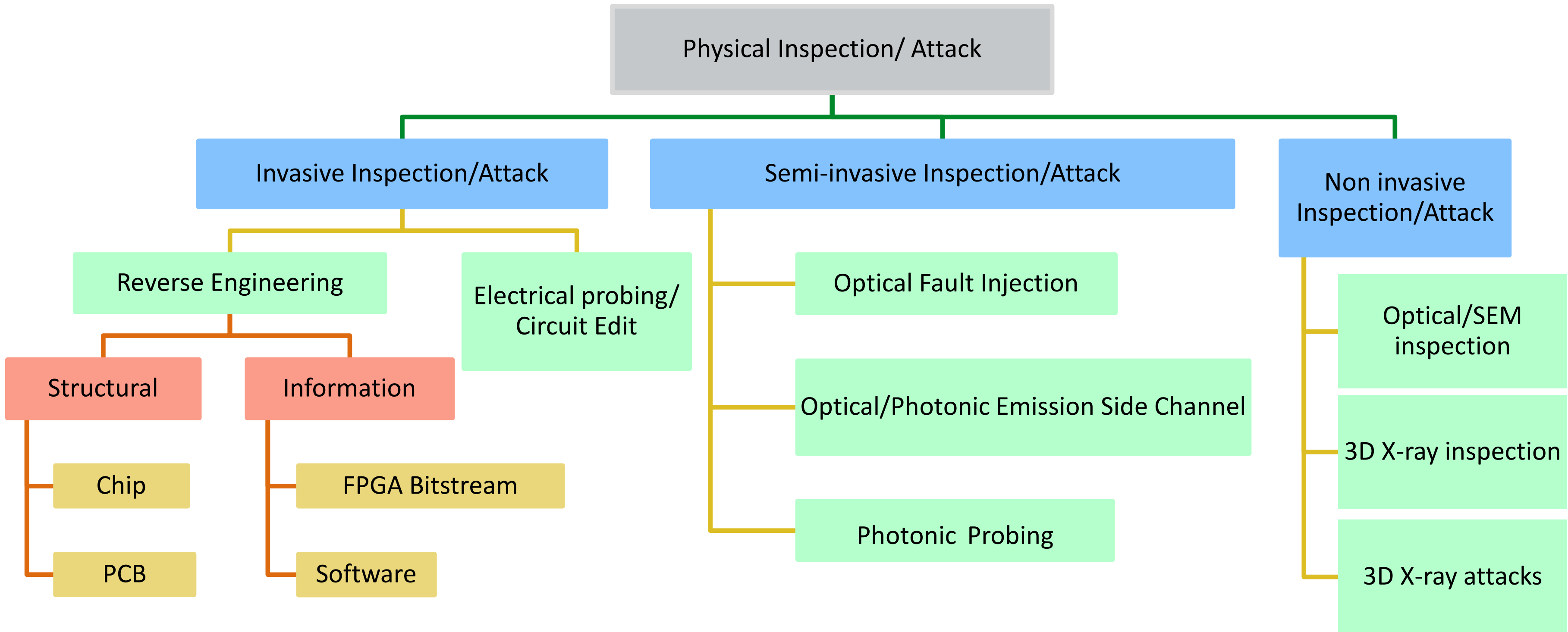
Sample Preparation and Delayering

Navid Asadi

Physical Inspection and AttacKs on ElectronicS (PHIKS)

Physical Inspection/Attack



- Physical access to the chip is required
  - Non-Invasive Attack: Observe and manipulating device without any physical harm
  - Invasive Attack: Complete deprocessing of the chip to extract information
  - Semi-invasive Attack: Removing package keeping the chip structure intact

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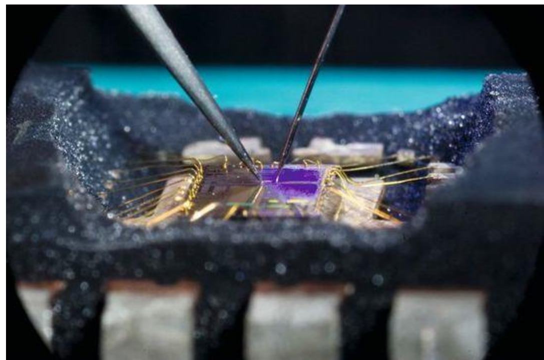
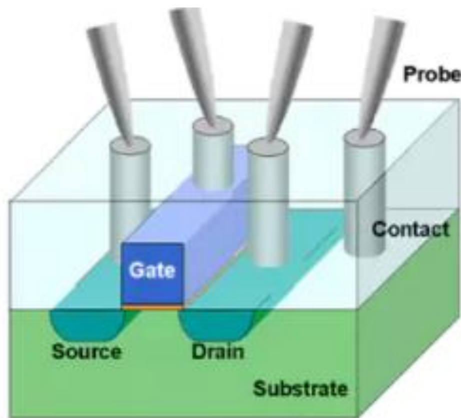
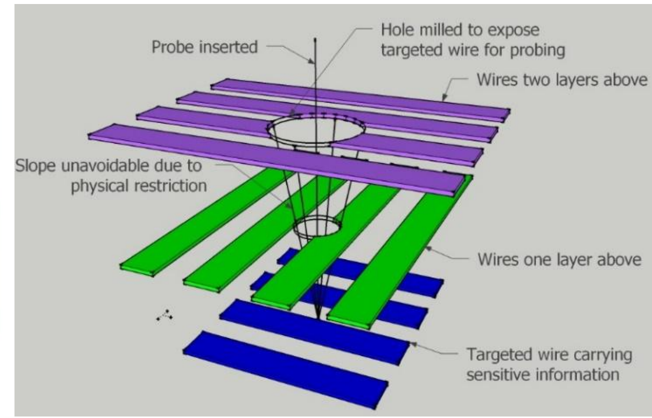
Probing Attacks

- **Probing**: circumvent encryption by probing at signal wires to extract security sensitive information

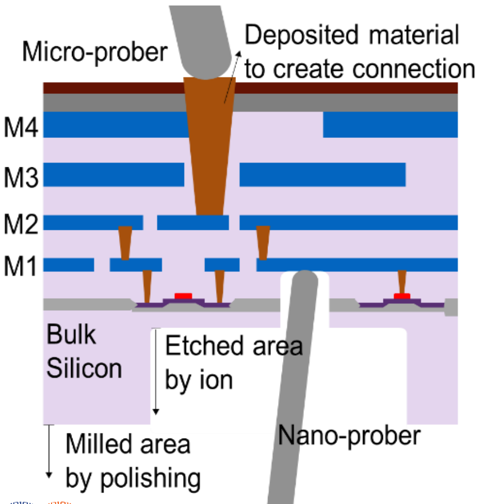


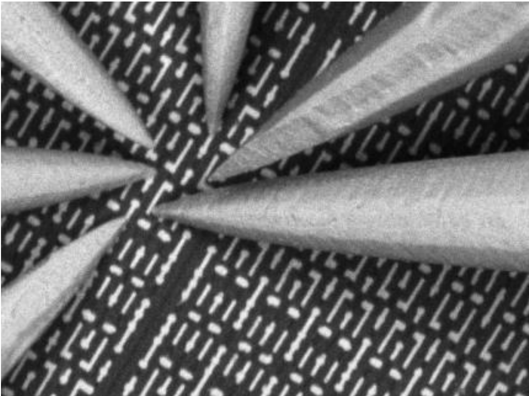
Wet etching

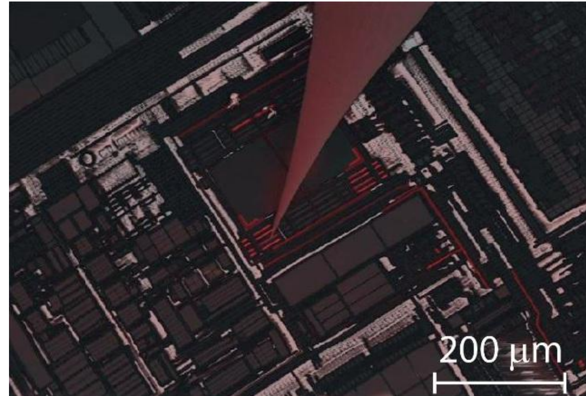




Electrical Probing from frontside







Nanoprobing

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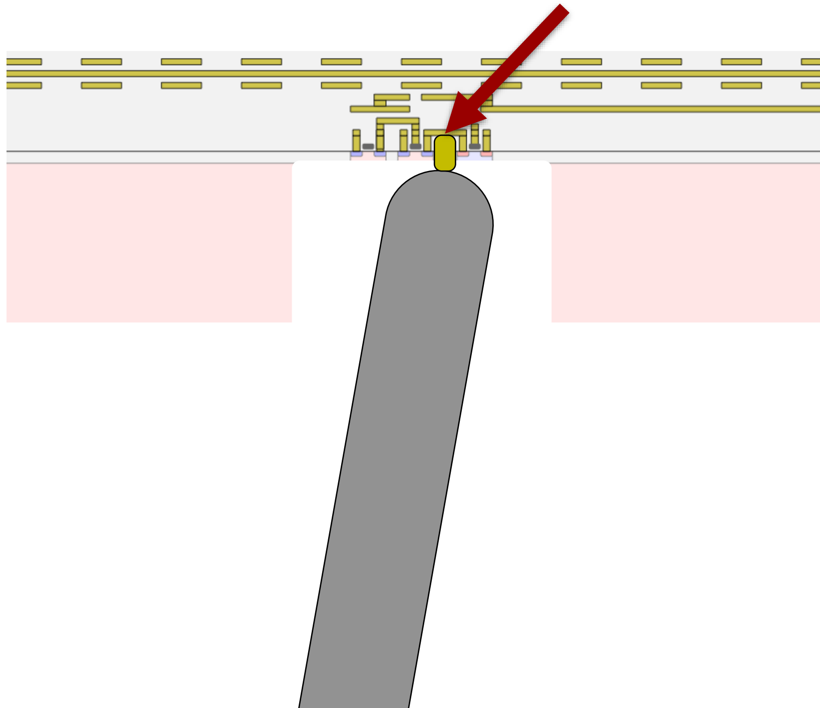
Backside Probing



- Bulk substrate is mechanically thinned to approximately 25µm
- FIB trench is milled at approximate location of the target signals
- A smaller trench exposes the target traces
- Metal can be deposited to make contacting the circuit with the probing needle easier

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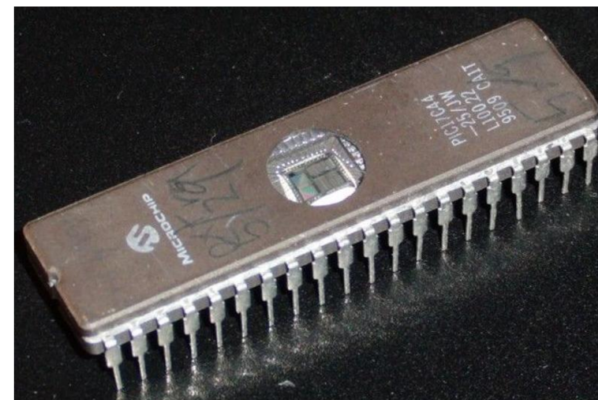
Packing and De-packing

Packaging Classification

1. Material
   - Ceramic
     - Expensive
     - Still used in some chips
   - Plastic
2. Packaging
   - Wire bond vs flip chip

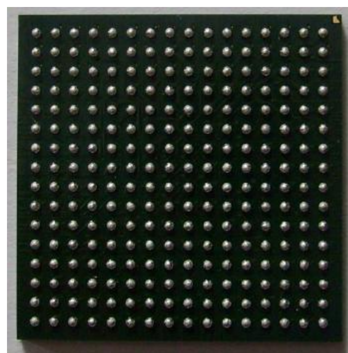
Plastic



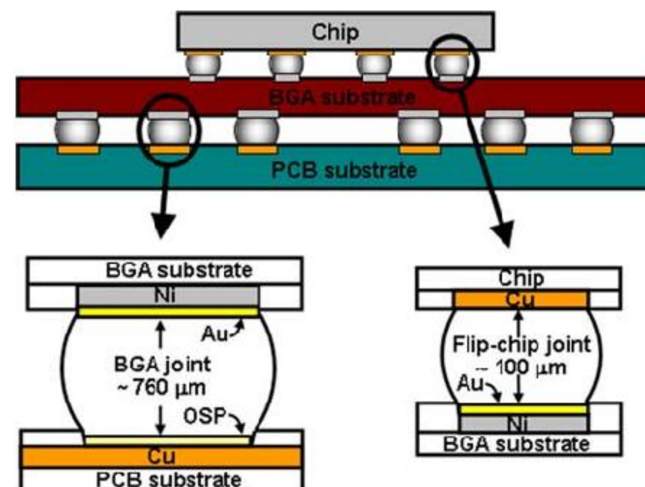
Ceramic

De-packing Classification

1. Selective
   - Plasma/reactive ion etching (RIE)
   - Wet chemical etching
2. Non-selective
   - Mechanical cutting and grinding, Laser ablation



BGA



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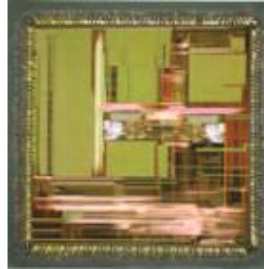
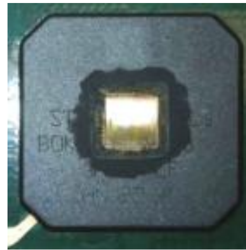
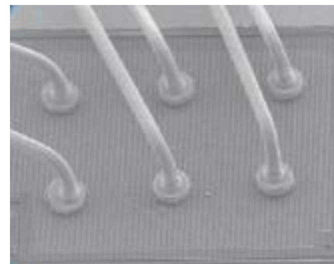
De-packing

- Acid etching (bare die)
  - Temperature control
  - Sulfuric acid
  - Nitric Acid
  - Mixed acid
  - Rinse acid
- Bond wire protect
  - Maintain integrity of sensitive components







- Mechanical
  - Grinding
  - Polishing

- [Laser etching](#)

- Plasma etching
  - Microwaved gas is inciting chemical radicals for isotropic etching
  - The gas mass flow controls the etching rate
  - Can protect silver or copper bod wires

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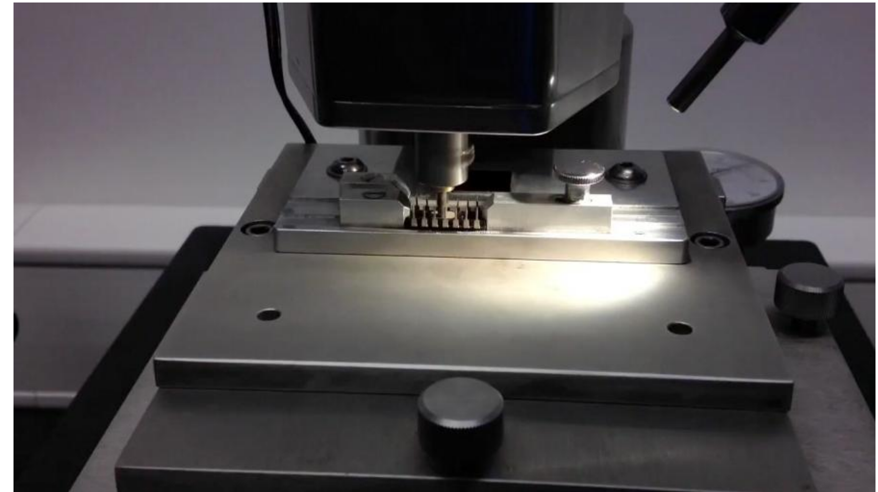
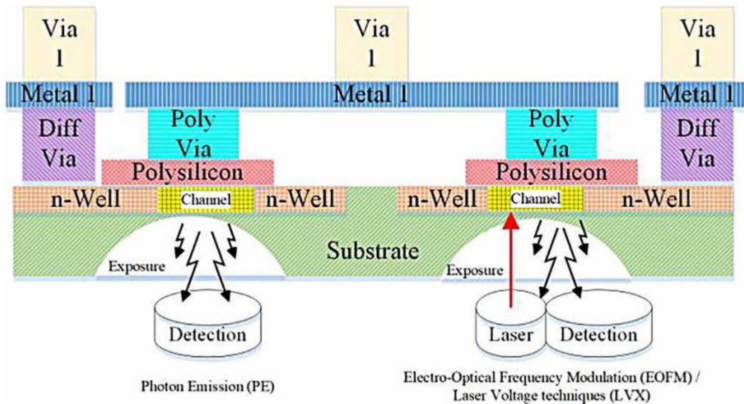
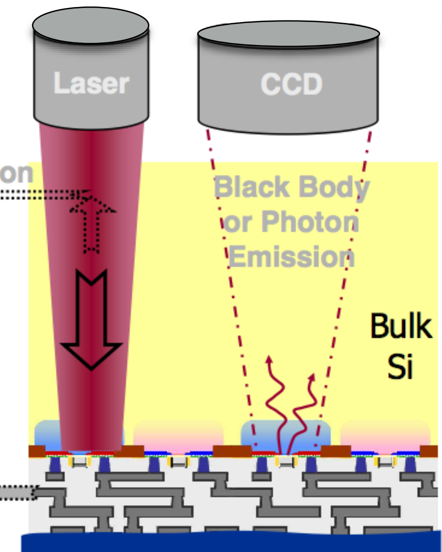
Photonic Inspection/Attack

- Extracting assets through decapsulation and photonic emission
- Frontside and Backside attack
- Tools
  - Depackaging tool
  - Laser/NIR light source required
  - Laser scanning microscope





- Photon Emission
- Rise and Fall Events of Digital Signal Pattern
- Modulation of reflected light by device operation: Contactless Probing
- Laser Stimulated Current or Voltage Sources: Delay / Fault Injection



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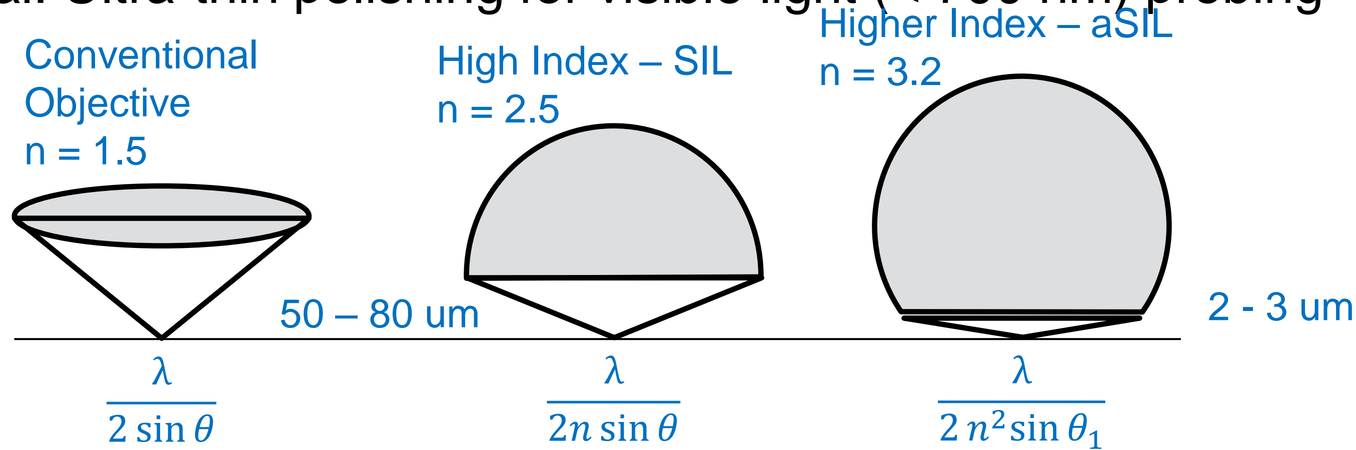
The Drive for Ultra Thin

- The role of optical debug tools in the advancement of semiconductor products & technology is one of the most underappreciated contributors.
  - Role in yield enhancement, design debug, & failure analysis
- The implementation of Silicon Immersion Lenses SIL push to higher NAs, to achieve higher resolutions, the depth of focus becomes very narrow.
  - A SIL is a fixed focal length lens, the silicon thickness must be tightly controlled.
- Goal: Ultra-thin polishing for visible light (< 700 nm) probing



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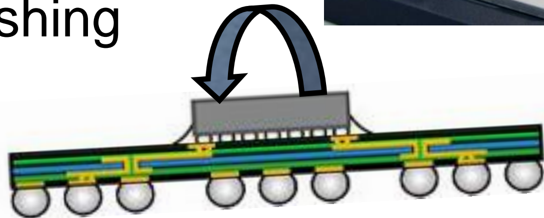
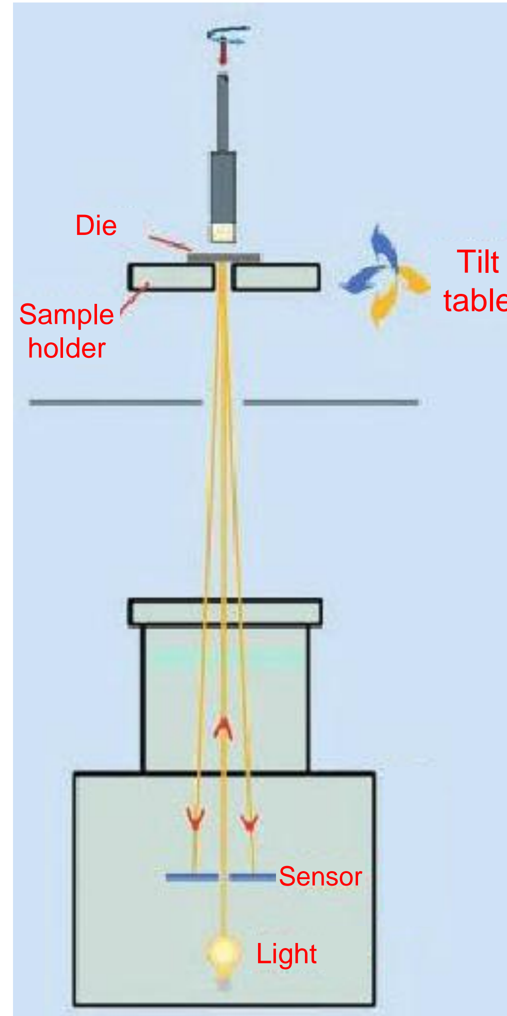
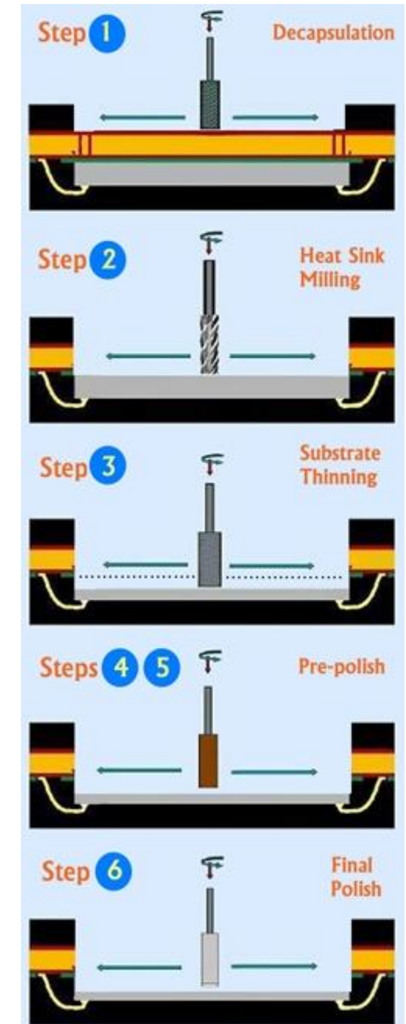
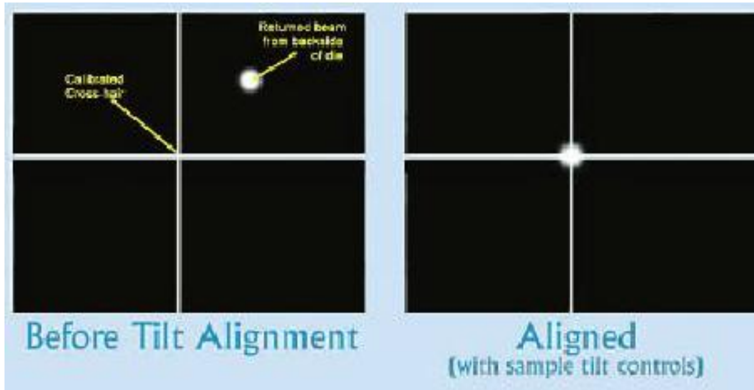
Back Side Thinning

- Ultratech ASAP
- Sample tilt correction is required to improve the planarity during polishing





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PEM Image Examples

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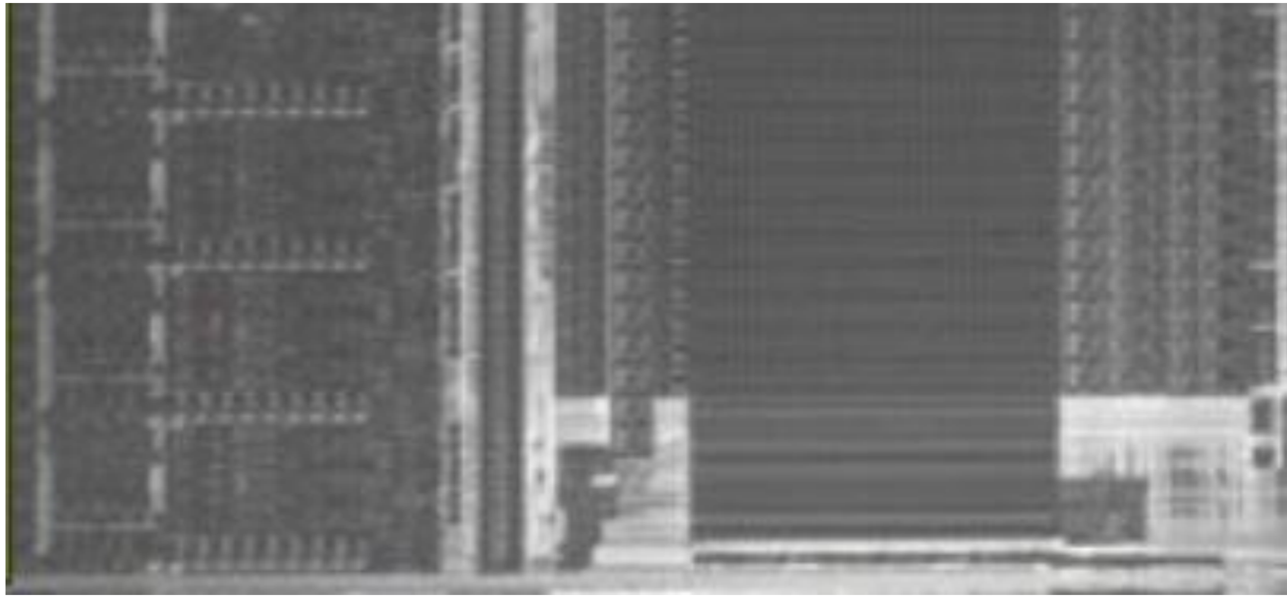
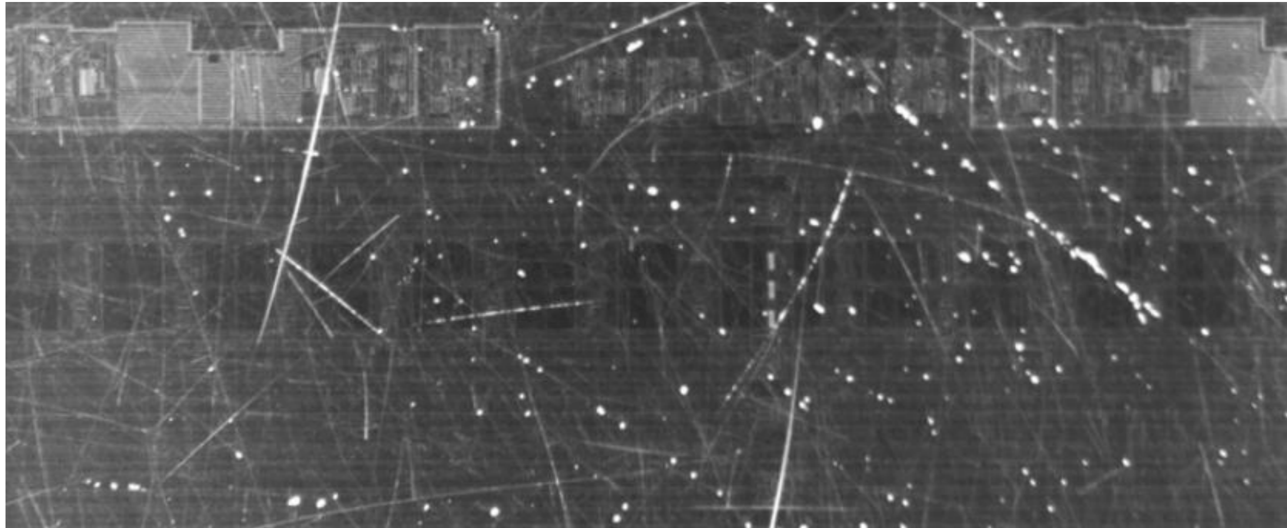
Fine polished



Scratches left which can scatter the photon emissions



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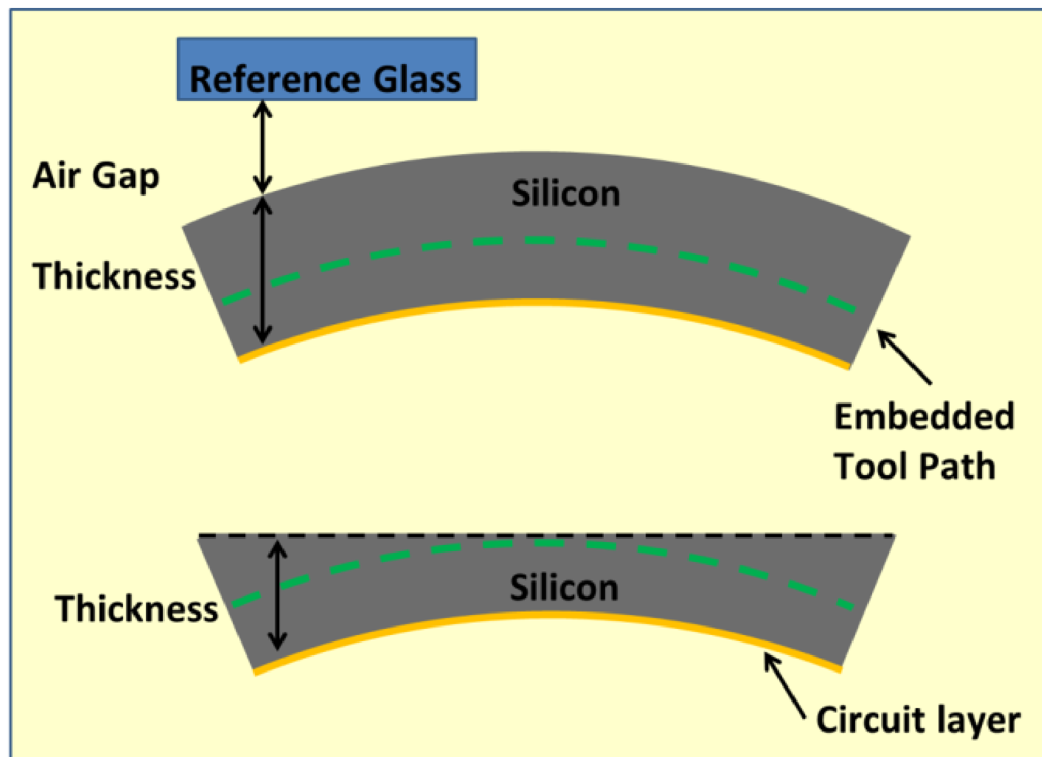
The Challenge of Non-Ideal Samples

- The temperature coefficient of expansion difference between the die and the package.
- In general, the shape of the sample is not stationary since the bending strength of the die changes as it gets thinner



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Dynamic Sample Challenges

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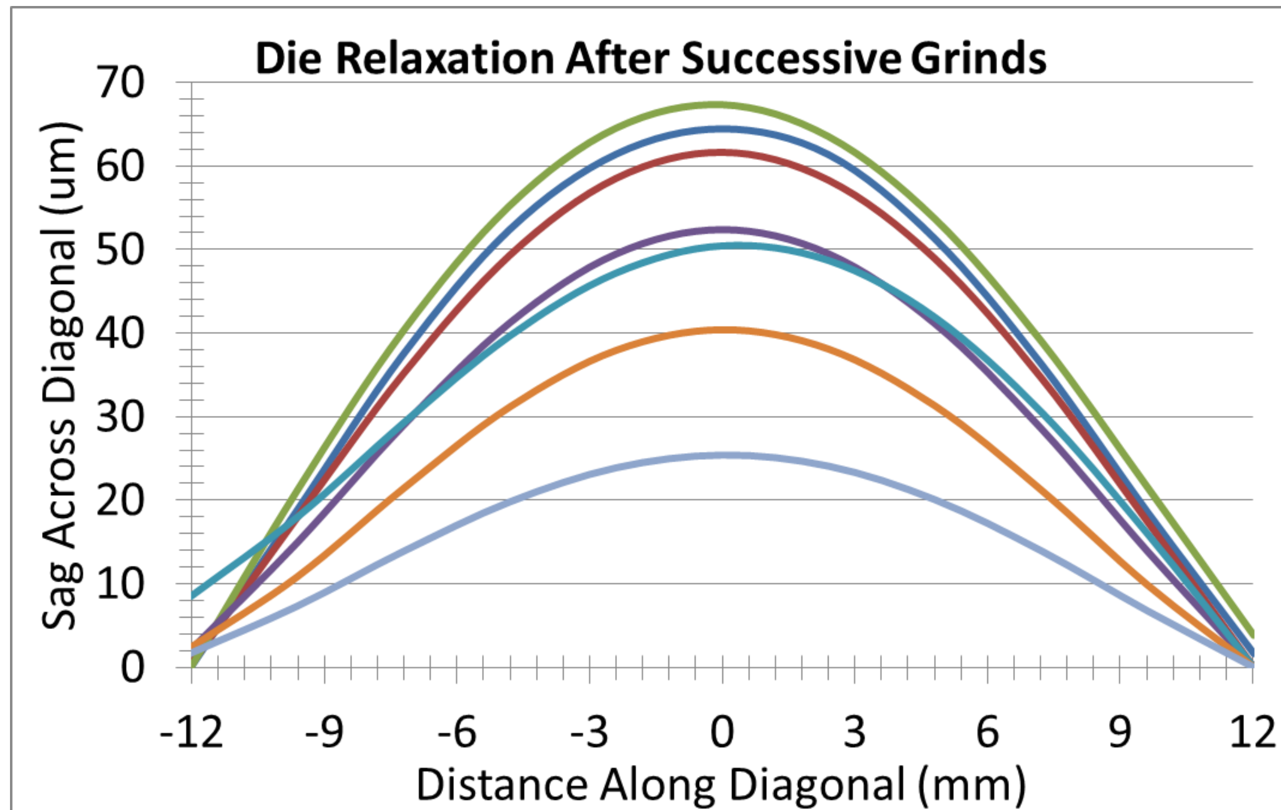
- Surface profile of one die as it is thinned.
- The sag relaxes ~45 um, from 70 um at full thickness to ~ 25 um when thinned to ~ 10 um.



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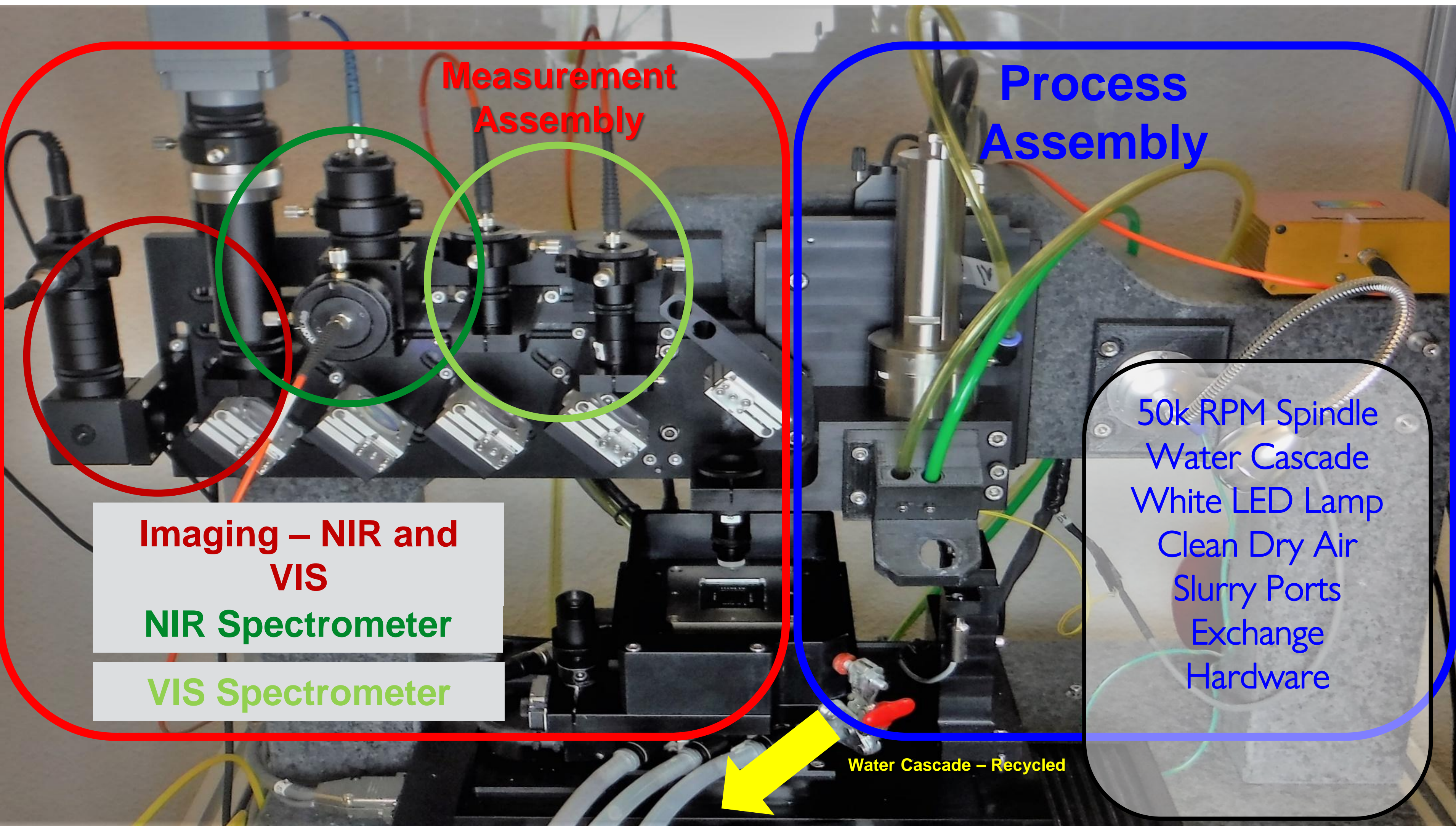
Approach to Extreme Thinning

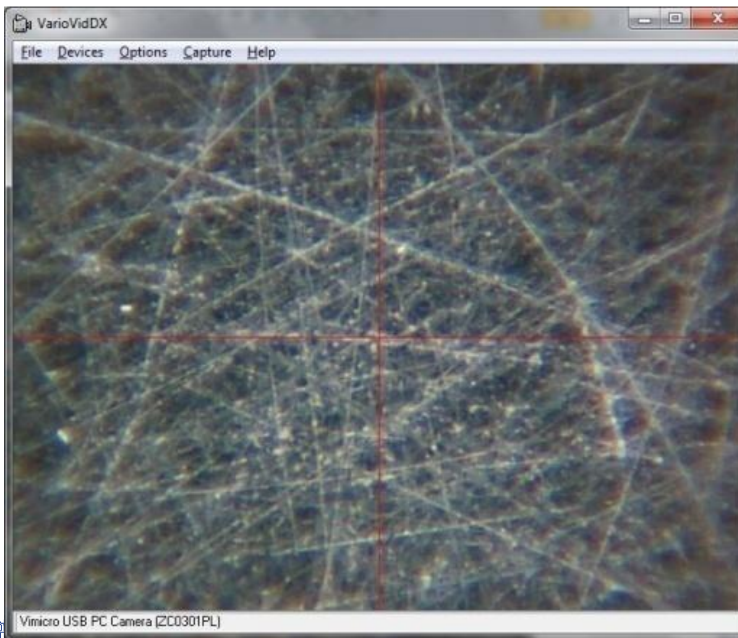


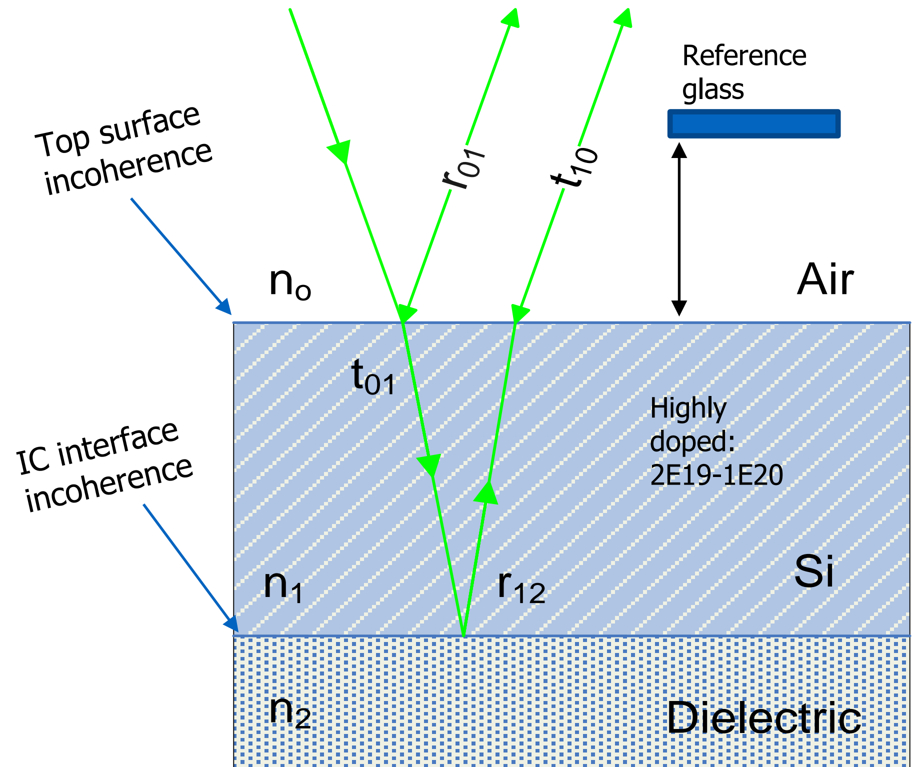
Laser Reflectance Spectroscopy (LRS)

A key element to the silicon removal process is the determination of the remaining silicon thickness.

Measurements from highly incoherent surfaces such as the ground silicon surface and the embedded circuit layer.

15 um polished surface





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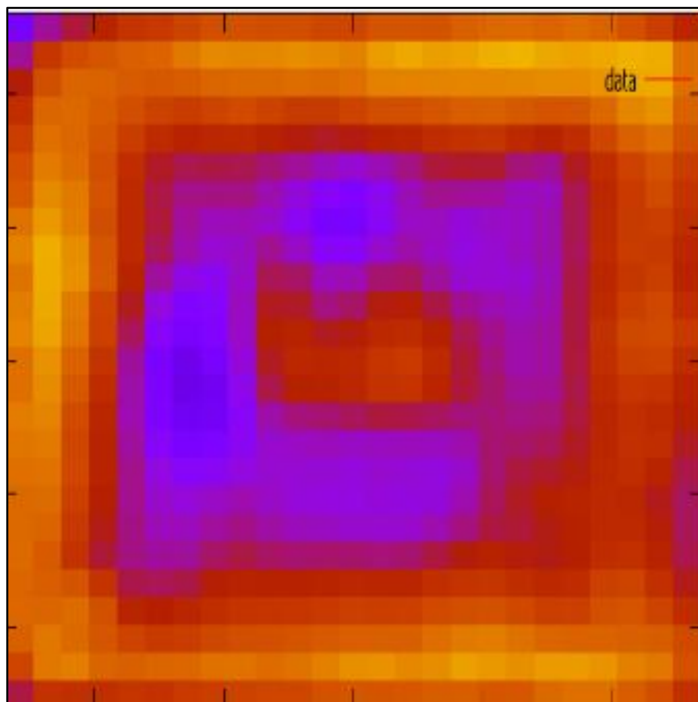
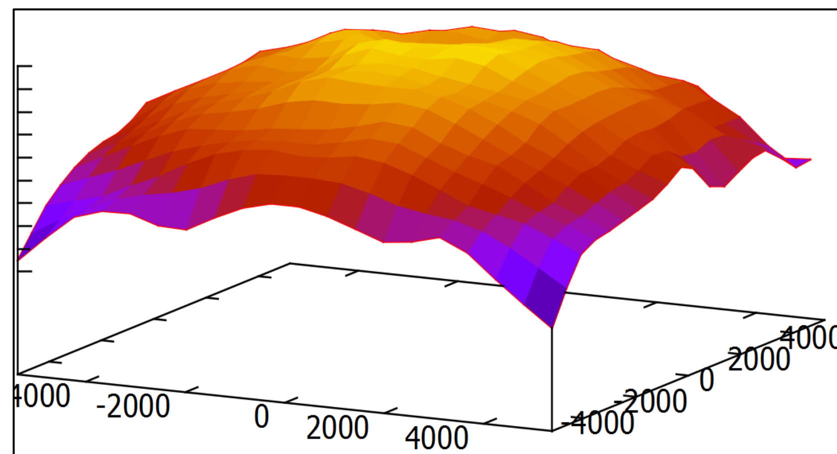
Mapping of the Silicon Thickness

Create a profile map of the silicon substrate to guide the grind process.





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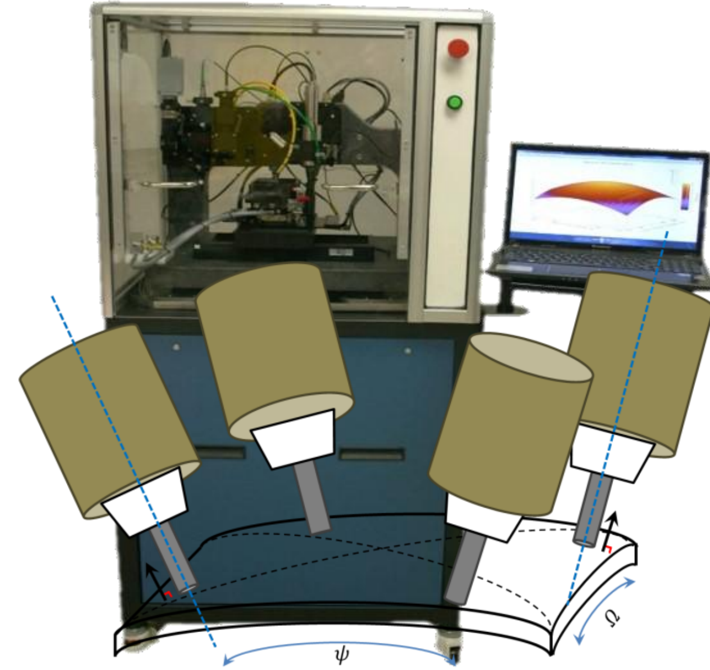
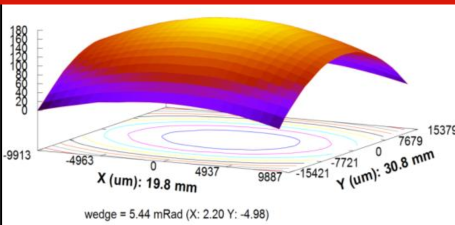
Automated Backside Thinning with VarioMill™

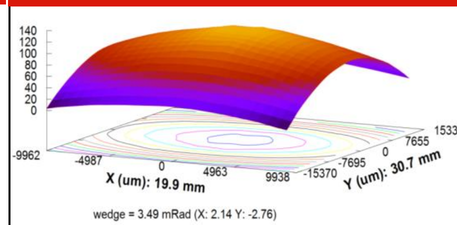
- Adaptive 5-axis CNC Tool for Grinding and Polishing of Advanced Package Integrated Circuits
  - Prep for Circuit Edit, Failure Analysis
- *In Situ* Measurement enables Adaptive Capability
- Tool exchanger provides step-down grinding and multi-tool applications
  - Single Step Polishing
- Adaptive shape and thickness measurement integrated into CNC tool, no external processes



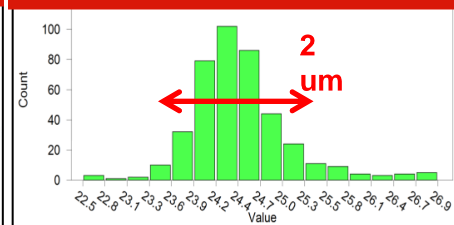
Silicon die 32 x 21 = 672 mm^2



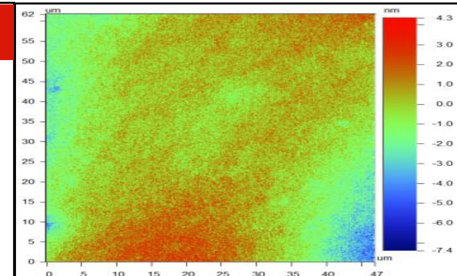
Die Relaxes ~ 55 um thinned



Thinned to 24 um RST



Final Polish < 3 nm RMS



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Back side Ultra thinned

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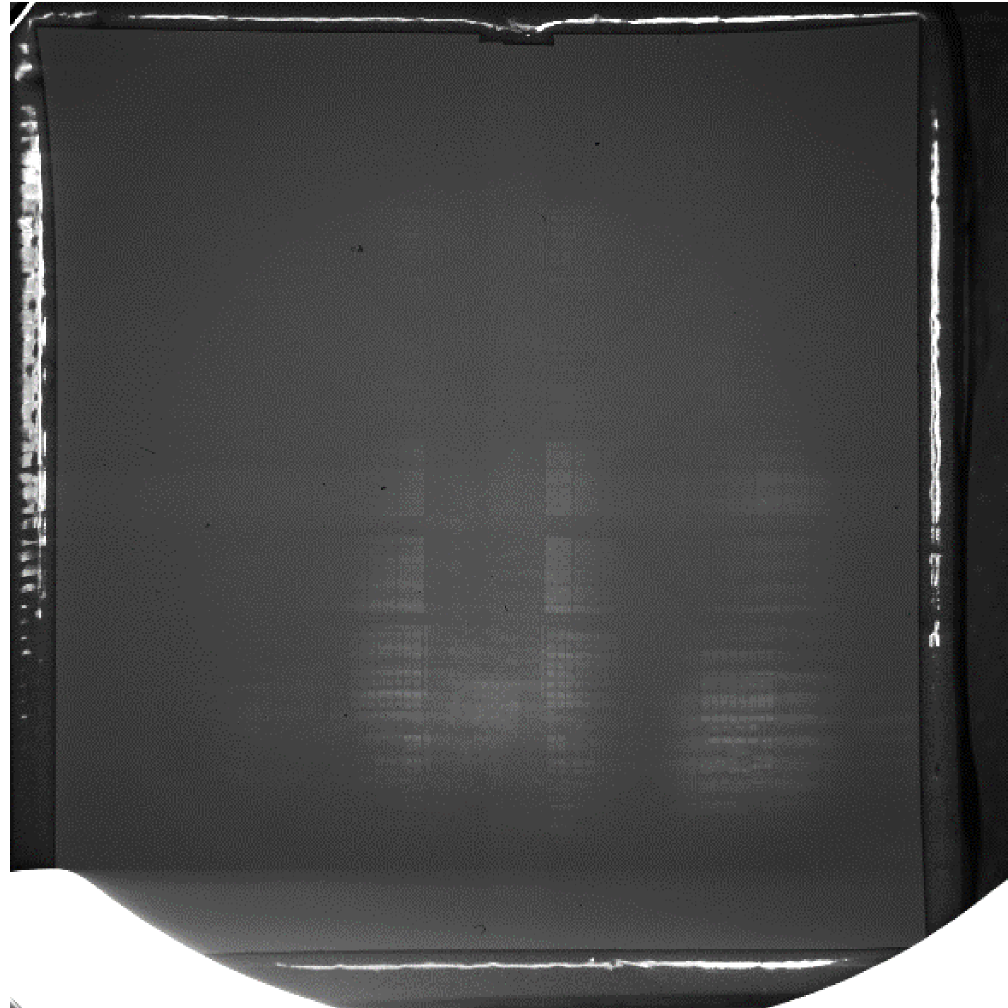

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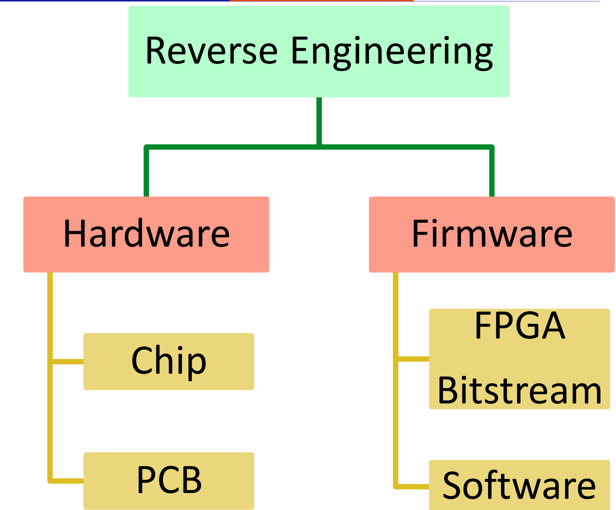
Reverse Engineering

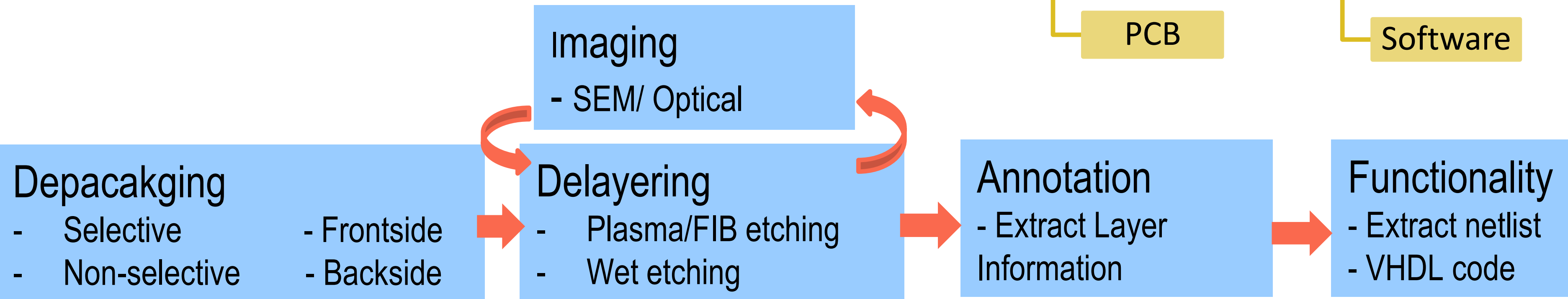
Primary Purpose of RE

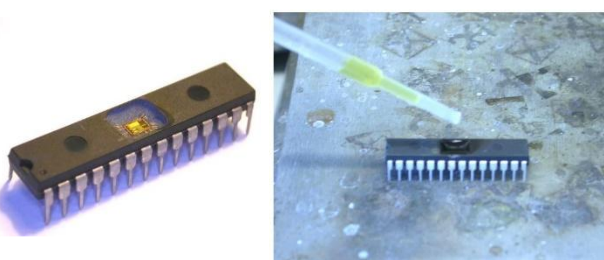
- ✓ Analyzing internal structure to extract netlist
- ✓ Extracting functionality or firmware

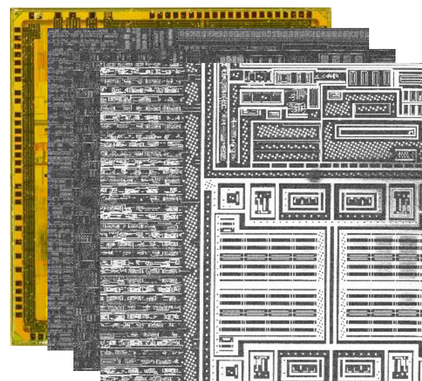
Chip Level RE

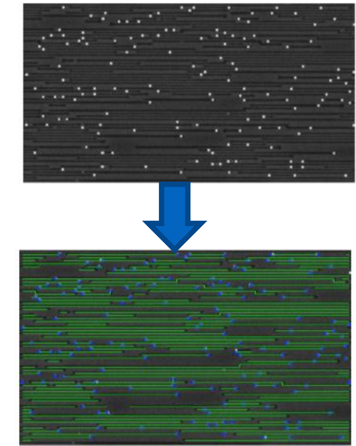
- ✓ 5 Steps for complete chip RE

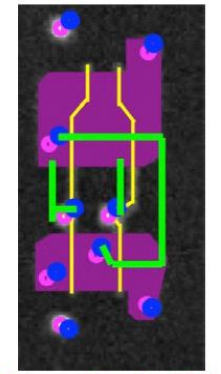












Extracted Standard Cells

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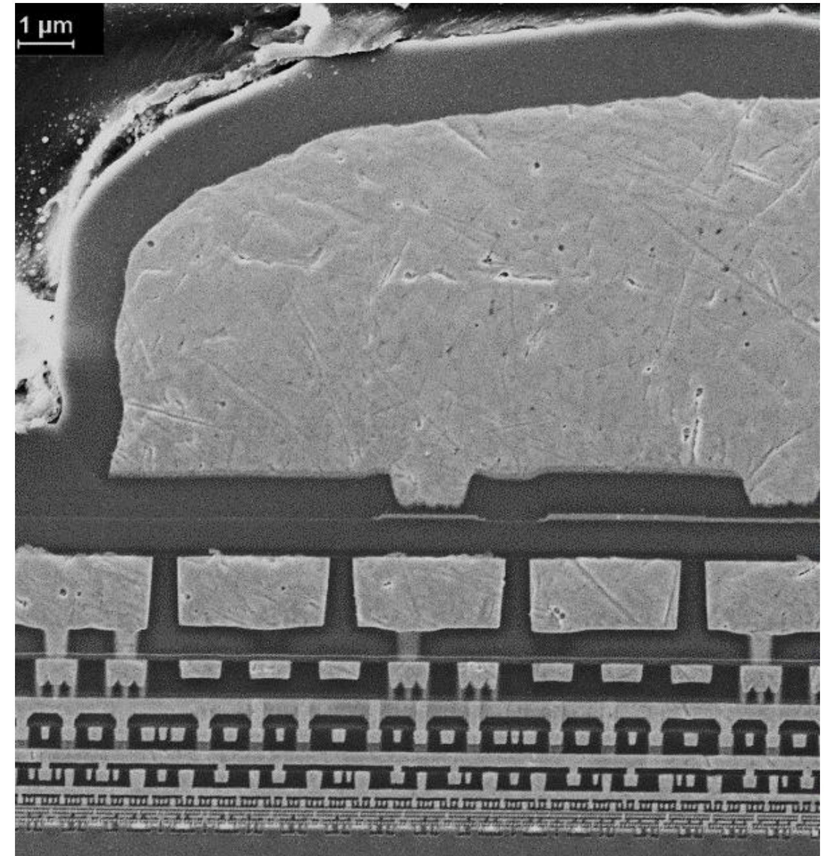
Delayering

Delayering is an important step to reverse engineering ICs

1. Wet Etching
2. Dry etching

Concerns for successful delayering

- Selectivity
- Etch rate
- Anisotropy (horizontal removal)
- Minimal damage to underlying layers
- Effective removal of reactants and products



Cross section of a 14 nm Intel skylake i7 cp.

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Wet Etching

- Acids, bases, oxidizers
- Can be very selective (1000:1)
- Can be very hard to control (rate, direction)
- Take advantage of device structure (etch stops)
- Many premixed off-the-shelf etchants available or can mix your own

Material	Chemistry
SiO2	HF:NH4OH:H20
Al	HCl, H3PO4, NaOH
Cu	H2O2:H2SO4
W	H2O2, H2O2:H2SO4
Au	HCl:HNO3, KI
Ti	H2O2:H2SO4, HF:HNO3
	many more and many variations...

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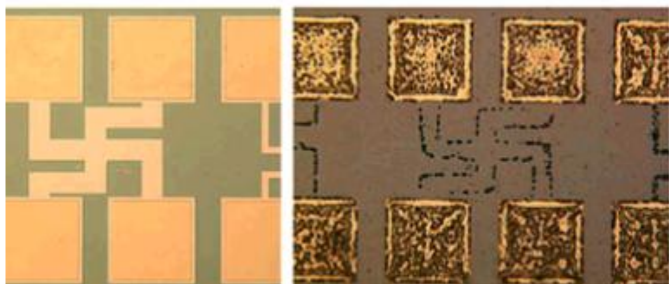
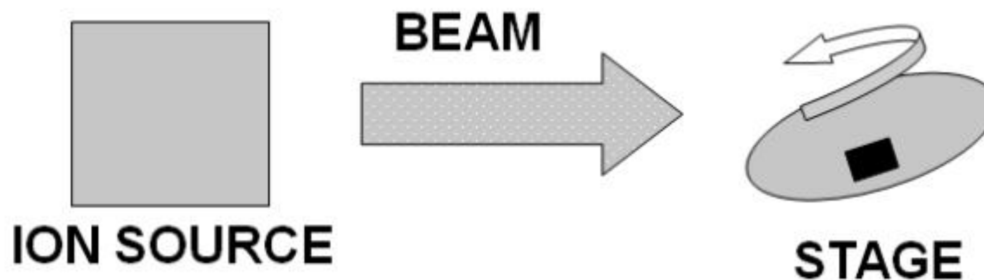
Advanced Etching

- Laser
- Ion beam milling





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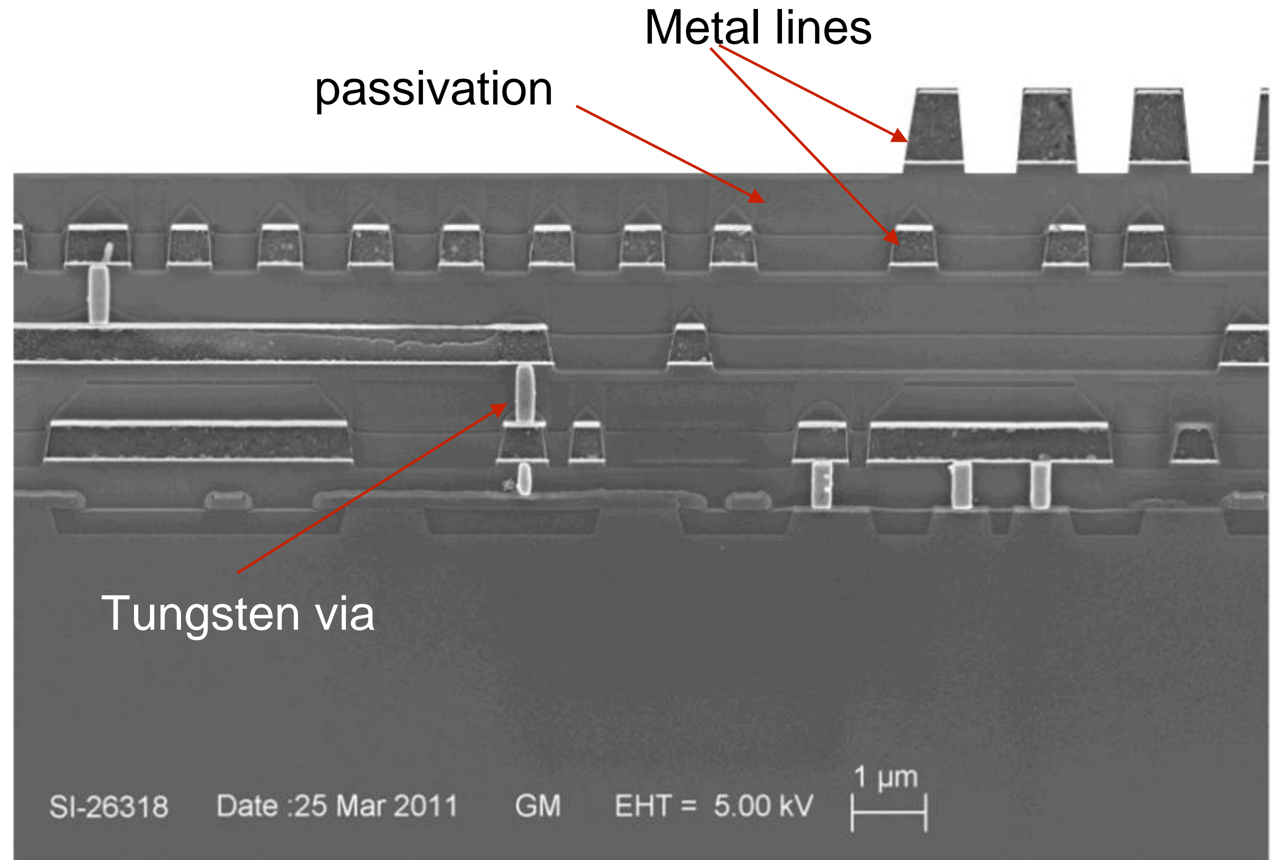
Delayering – Case study

1. Dry Plasma etch to remove passivation and see the metal layers
2. Wet etch to remove aluminum
3. Polishing to remove the barrier
4. Dry plasma etch to expose the next metal layer
5. Wet etch that removes Al but does not attack the tungsten via



DRY ETCH PASSIVATION (NITRIDE, OXIDE) - RIE:CF4/CHF3/O2

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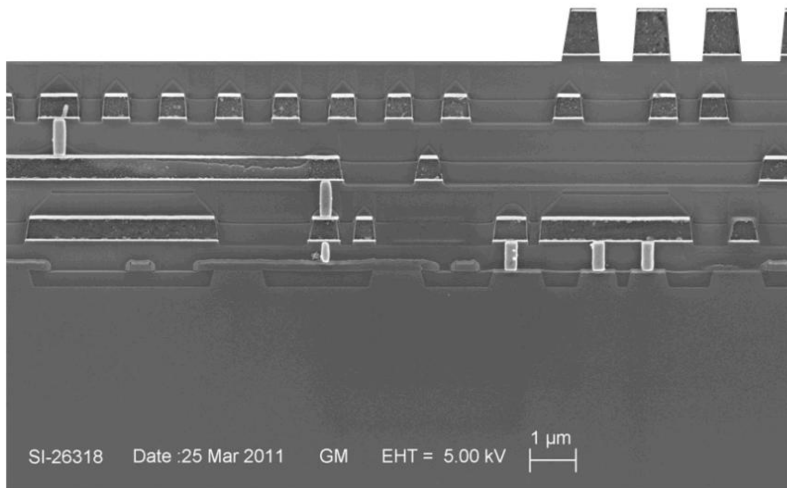
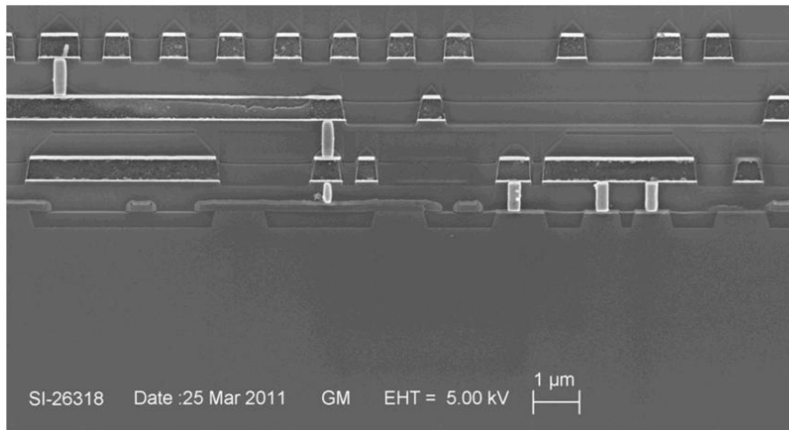
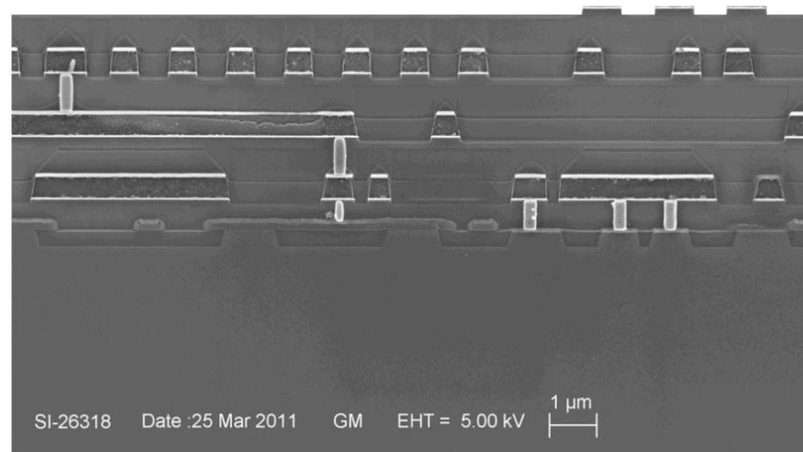
Delayering – Case study



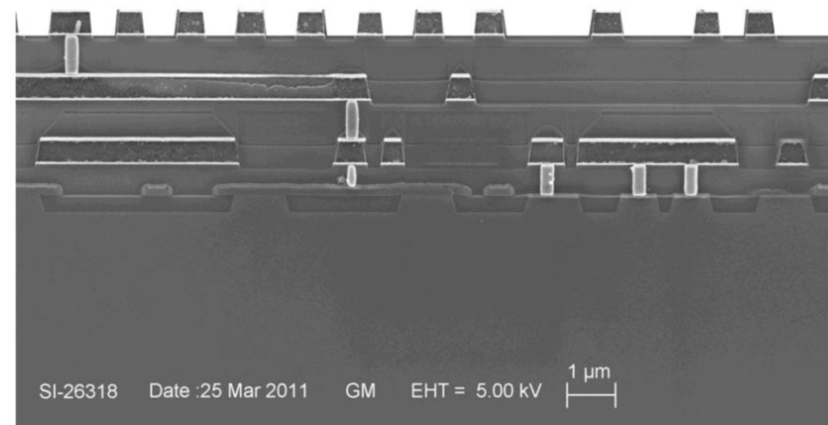
DRY ETCH PASSIVATION (NITRIDE, OXIDE) - RIE:CF4/CHF3/O2



POLISH M4 BARRIER - Silica Slurry



WET ETCH M4 - NaOH



DRY ETCH IMD3 - RIE:CF4/CHF3/O2

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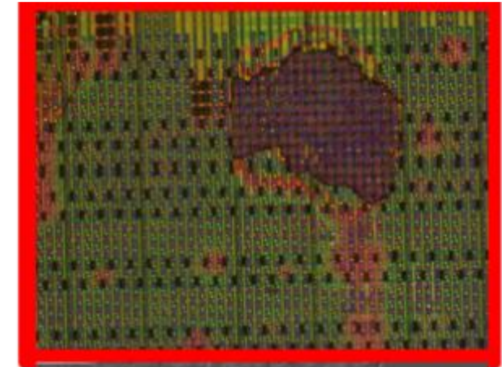
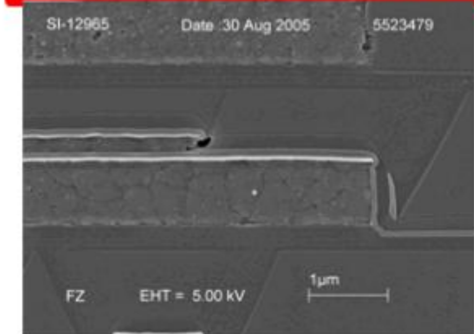
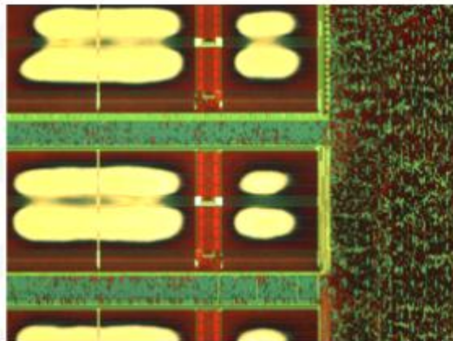
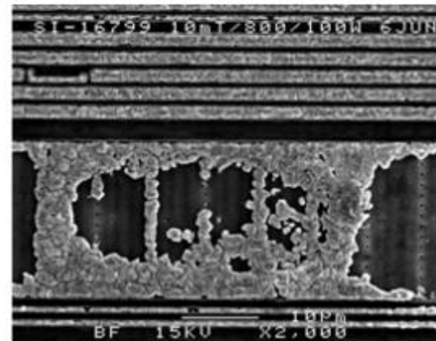
Challenges

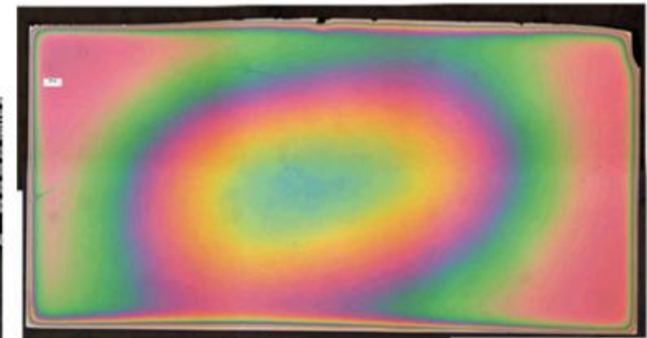
- Delamination
- Thin layers, half layers
- Planarity
- Material removal rates
  - Metal removal (grain boundaries)
- Pattern density
- Die size (thickness, length, width)
- Not enough parts











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PFIB Delayering

Chamber View

SEM HV: 5.0 kV | WD: 25.00 mm | FERA3 TESCAN
View field: 20.1 mm | Det: SE | 5 mm
SEM MAG: 41 x | Date(m/d/y): 02/13/17 | FICS University of Florida

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Readings and Videos

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- https://www.youtube.com/watch?v=tnY7UVyaFiQ&list=PLe7niMUMEviOyD05aEA08lWVau_sDEScH&index=11&t=0s
- https://www.youtube.com/watch?v=oQzF-di-JQo

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