STRUCTURAL ANALYSIS OF TSVs

HUGO BENDER

**CHRIS DRIJBOOMS, PATRICIA VAN MARCKE,
JEF GEYPEN, OLIVIER RICHARD, PAOLA FAVIA**

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OUTLINE

Introduction : 3D device stacking

FIB analysis

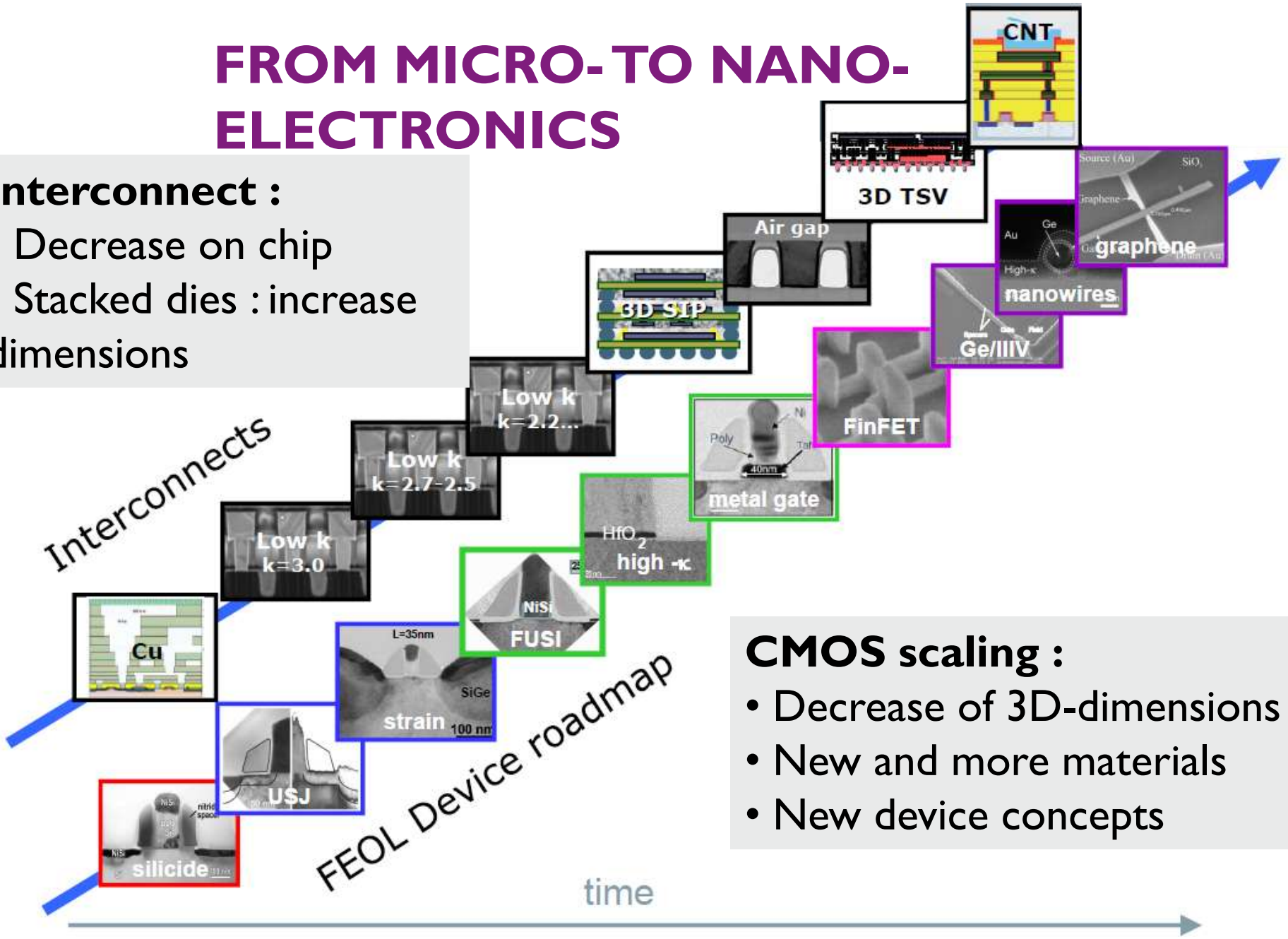
- Polish and FIB/SEM
- Standard FIB/SEM
- Alternative configurations for FIB/SEM

- Slice&view and 3D volume reconstruction

FROM MICRO-TO NANO-ELECTRONICS

Interconnect :

- Decrease on chip
- Stacked dies : increase dimensions



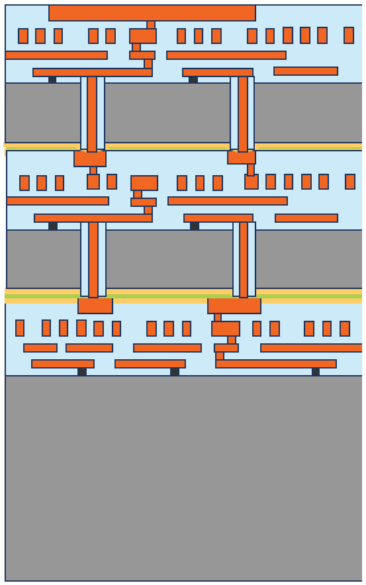
CMOS scaling :

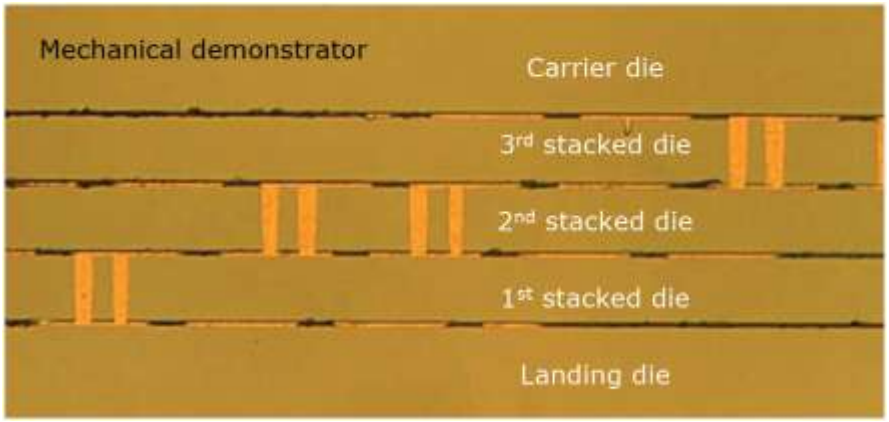
- Decrease of 3D-dimensions
- New and more materials
- New device concepts

STACKED DEVICES

3D-Stacked IC

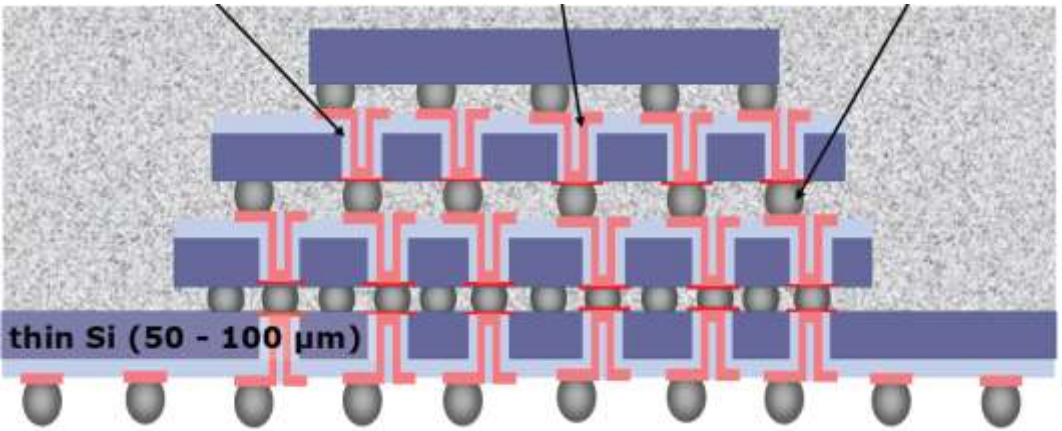
Si : 50-100 µm



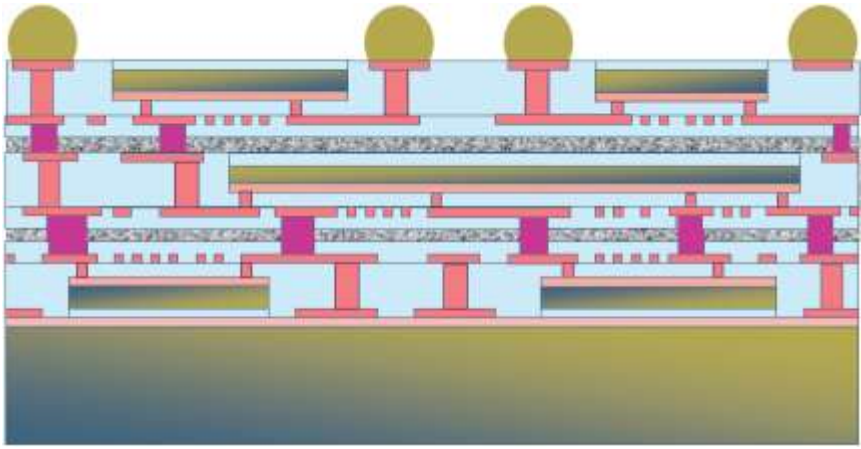


3D-WaferLevelPackaging

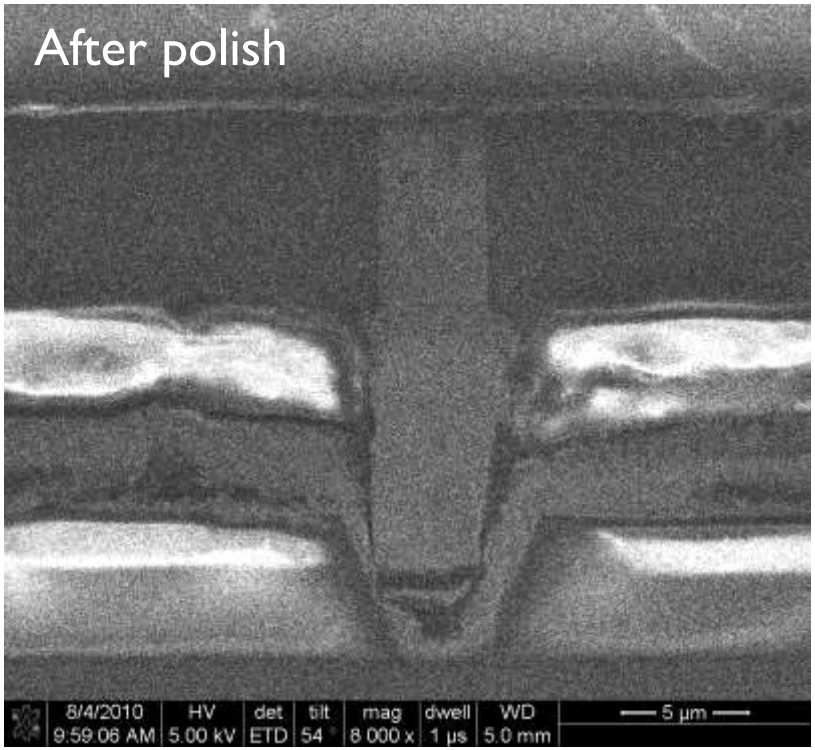
Through silicon via + microbumps



Embedded dies

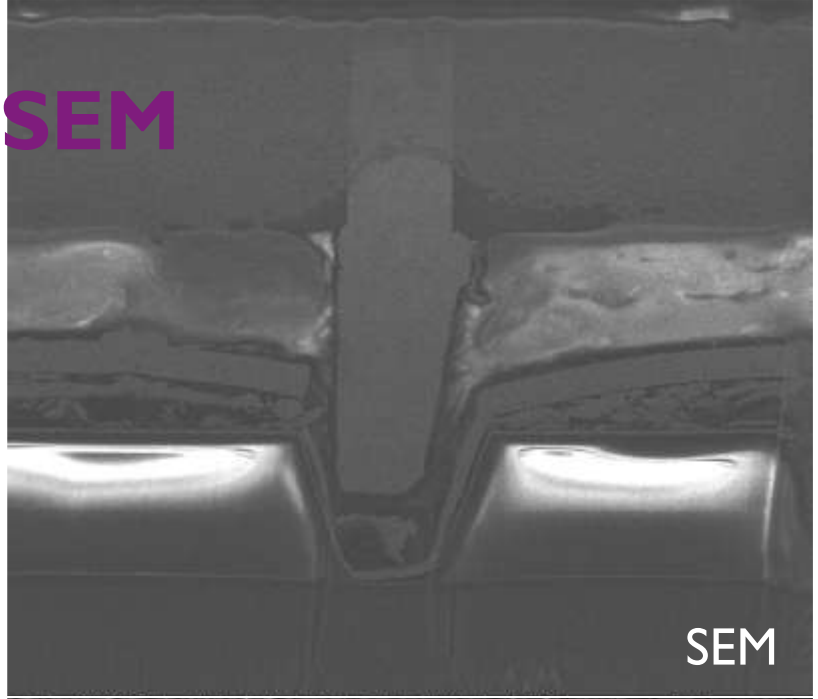


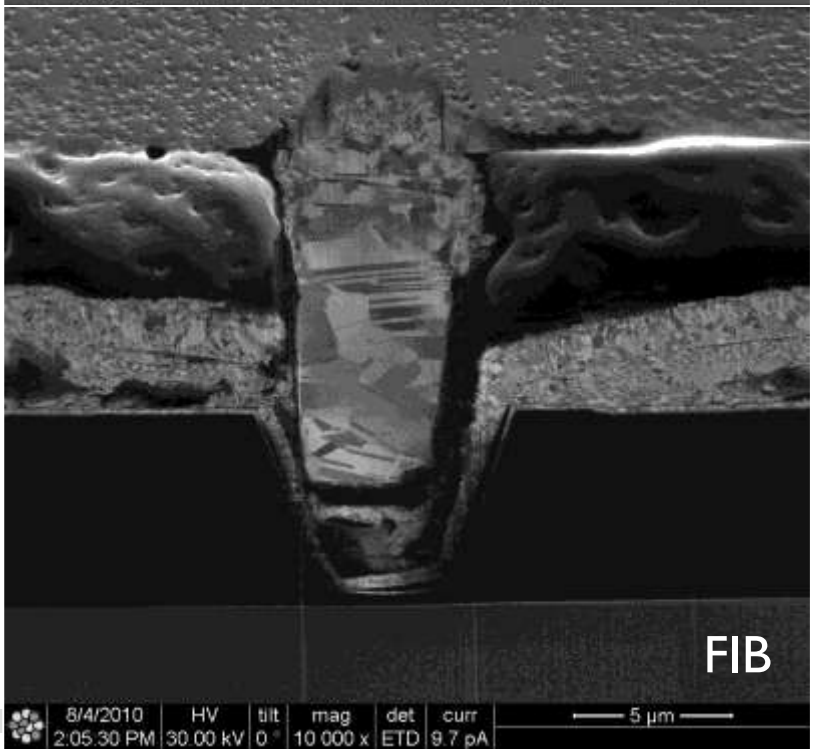
POLISH AND FIB/SEM



Problems :

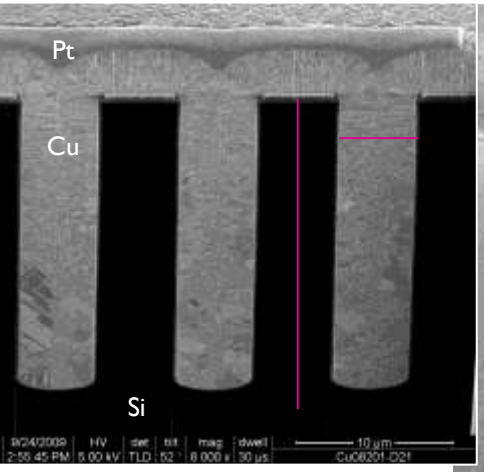
- epoxy above : thickness and charging
- polished face not vertical
- position through the TSV unclear
- no FIB slicing through the full structure possible





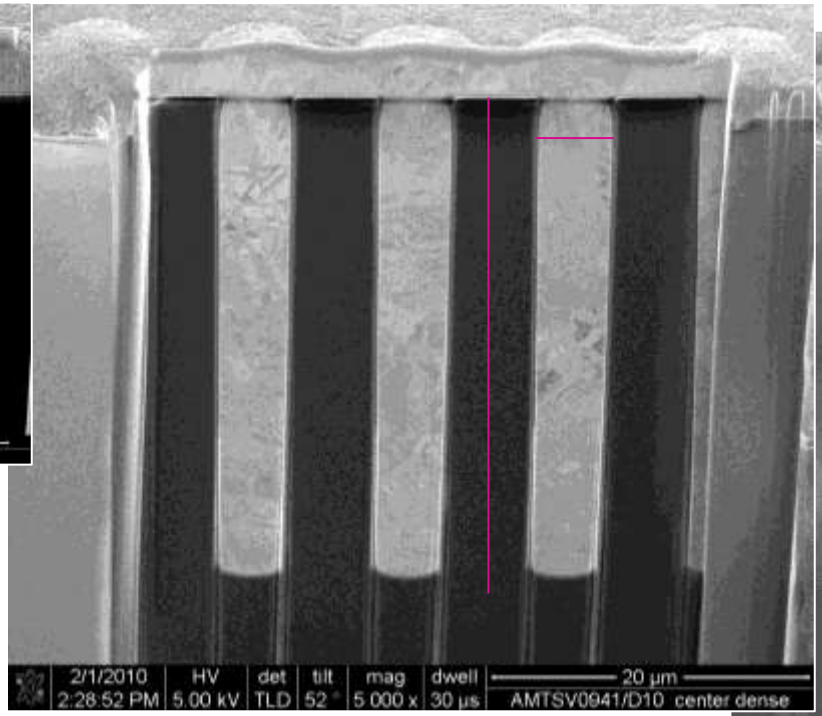
3D-SIC – Through Silicon Vias (TSV)

5x25 µm

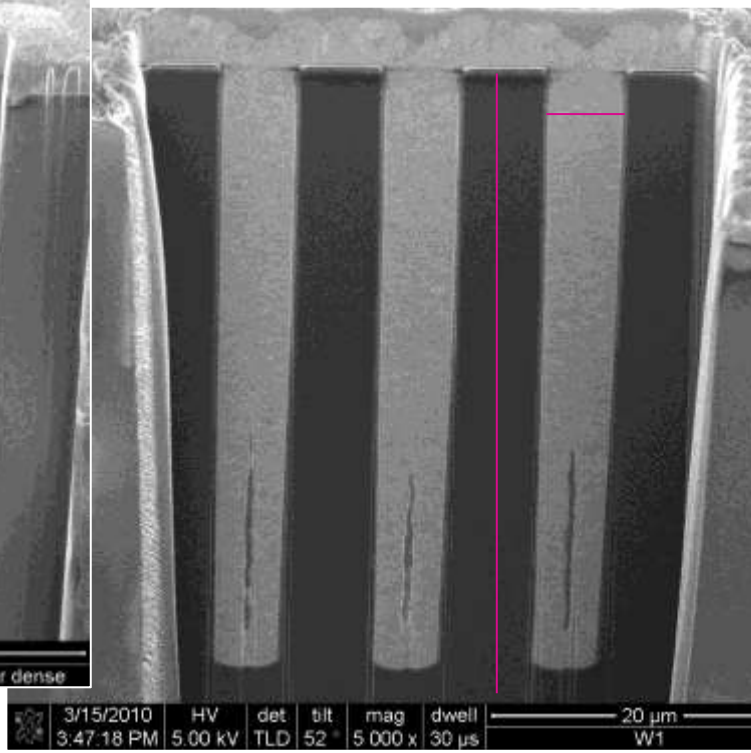


FIB/SEM

5x40 µm



5x50 µm



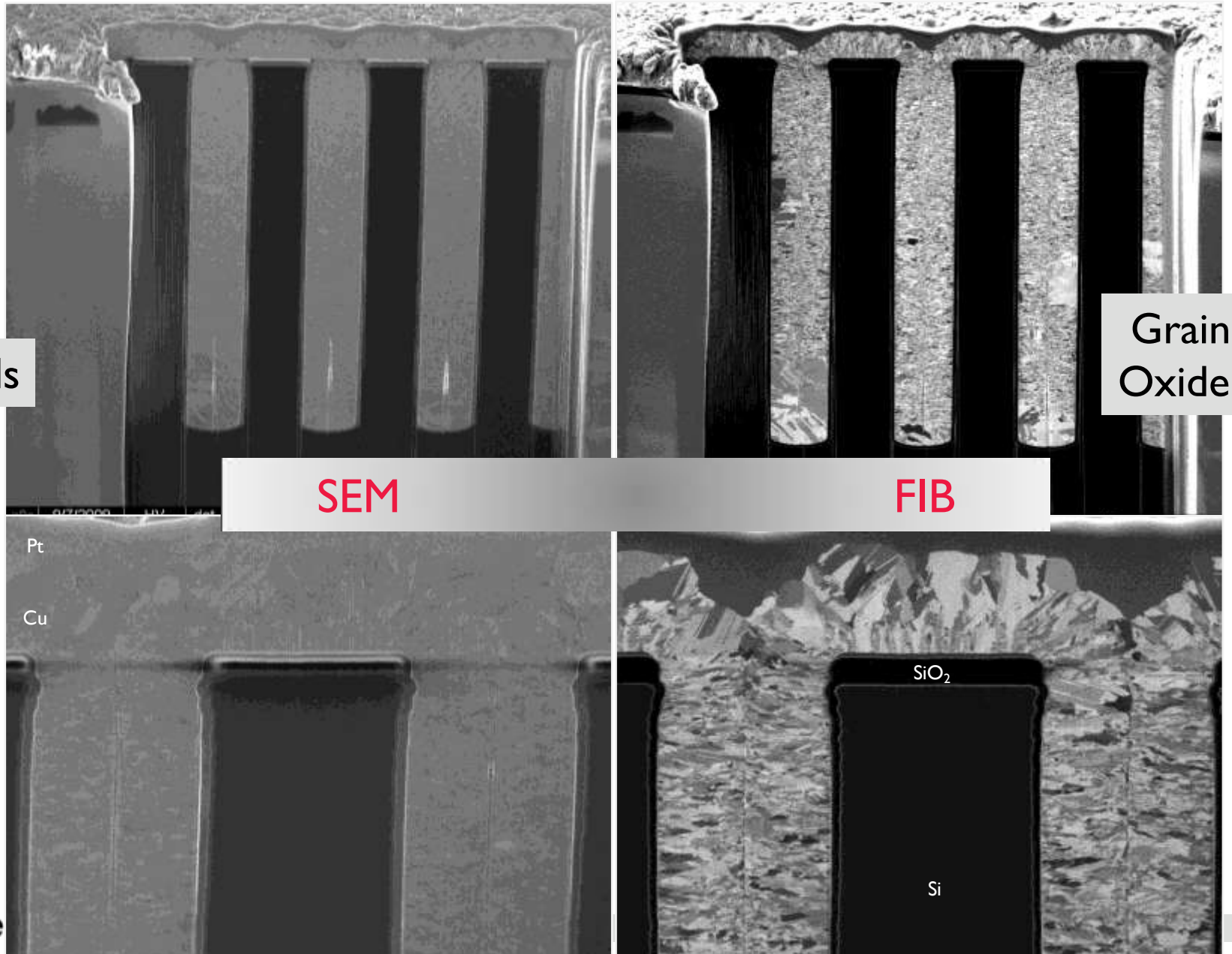
Interests :

- **Cu filling (small voids)**
- **grain size**
- barrier
- oxide liner

Analysis challenges :

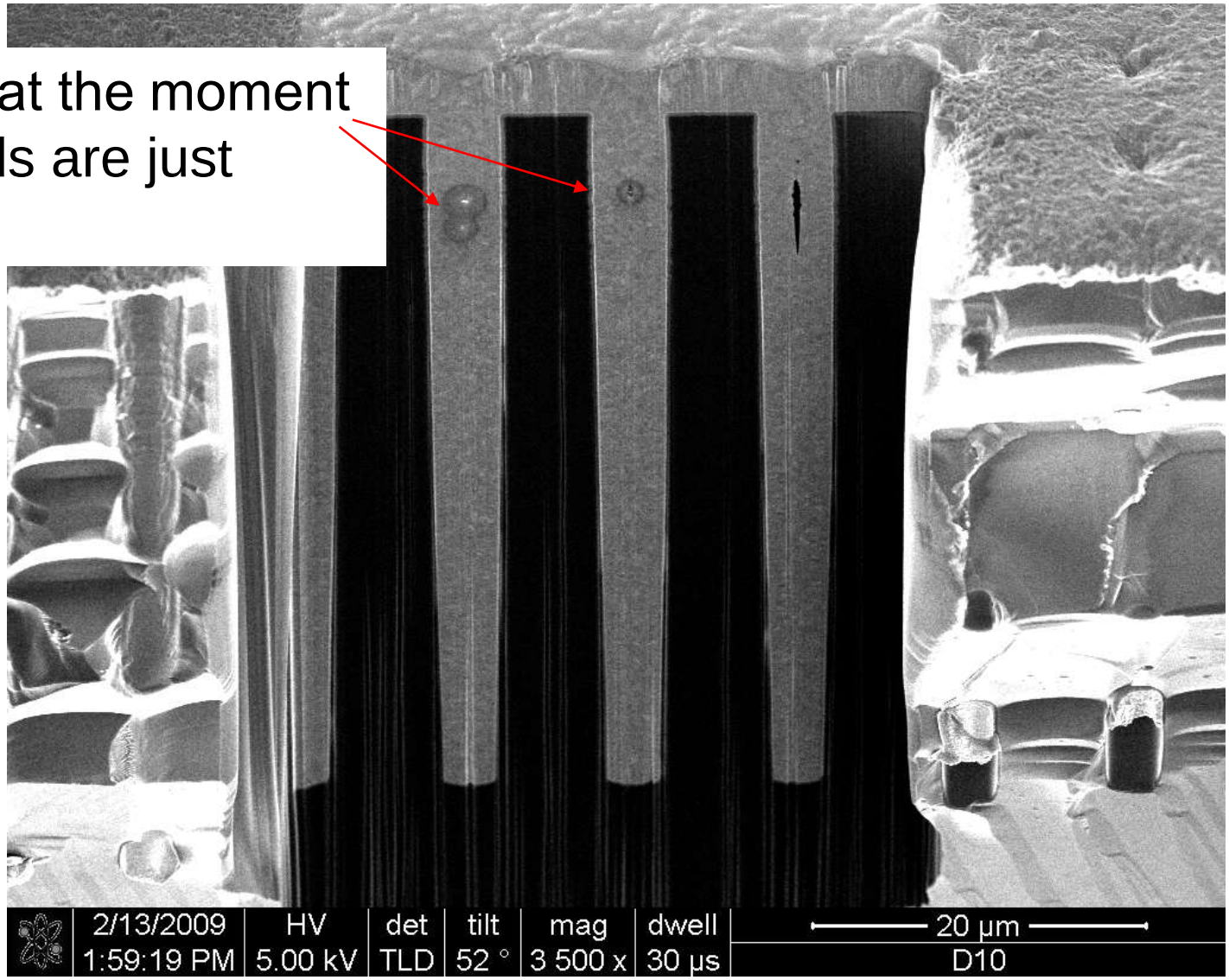
- **dimensions vs required resolution**
- depth of focus & contrast at bottom
- 3D analysis
- curtaining
- **analysis time**

TSV - IMAGING MODE

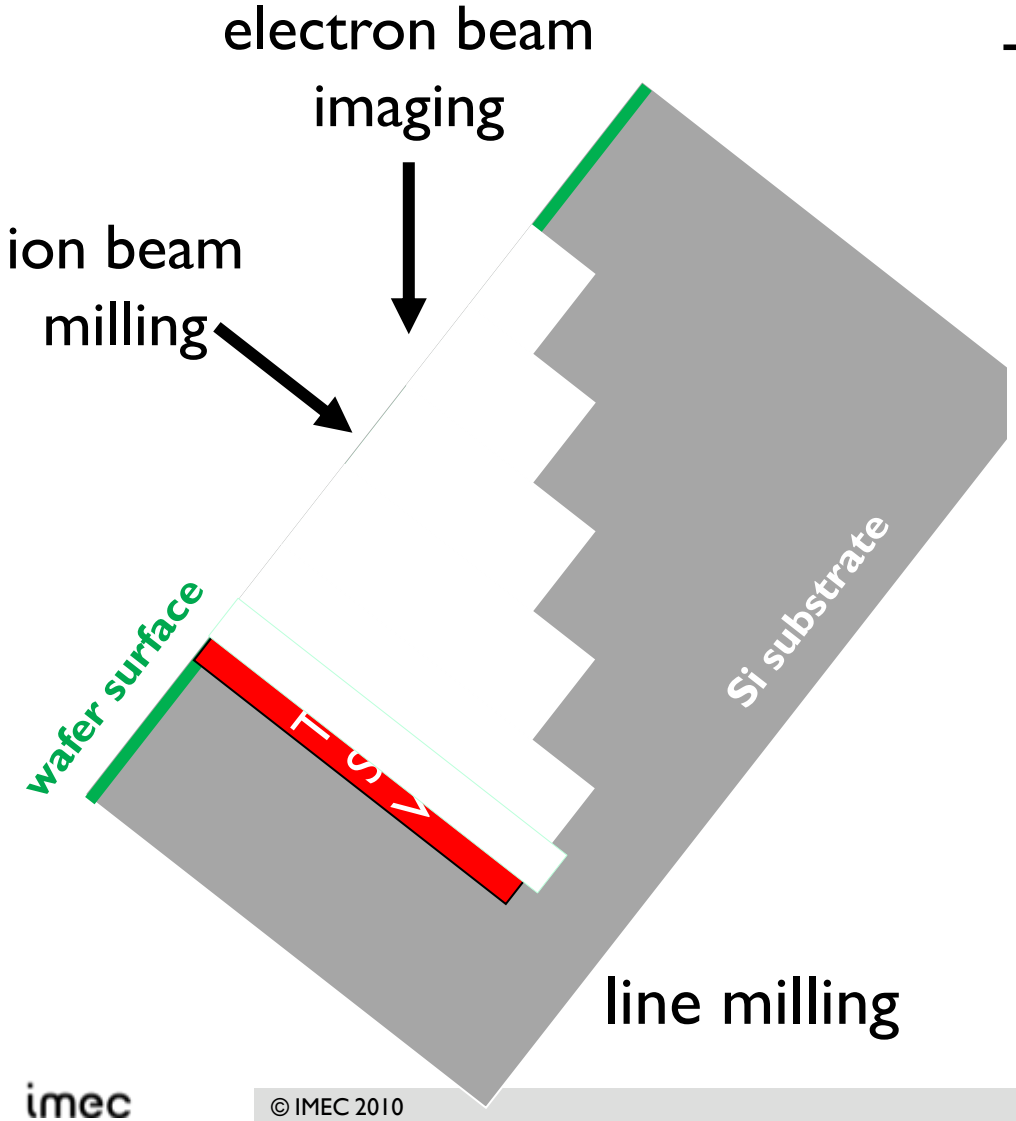


CHEMICALS IN VOIDS

"liquid" at the moment the voids are just opened



STANDARD FIB PROCEDURE



TSV : height h, diameter Φ

milling strategy :

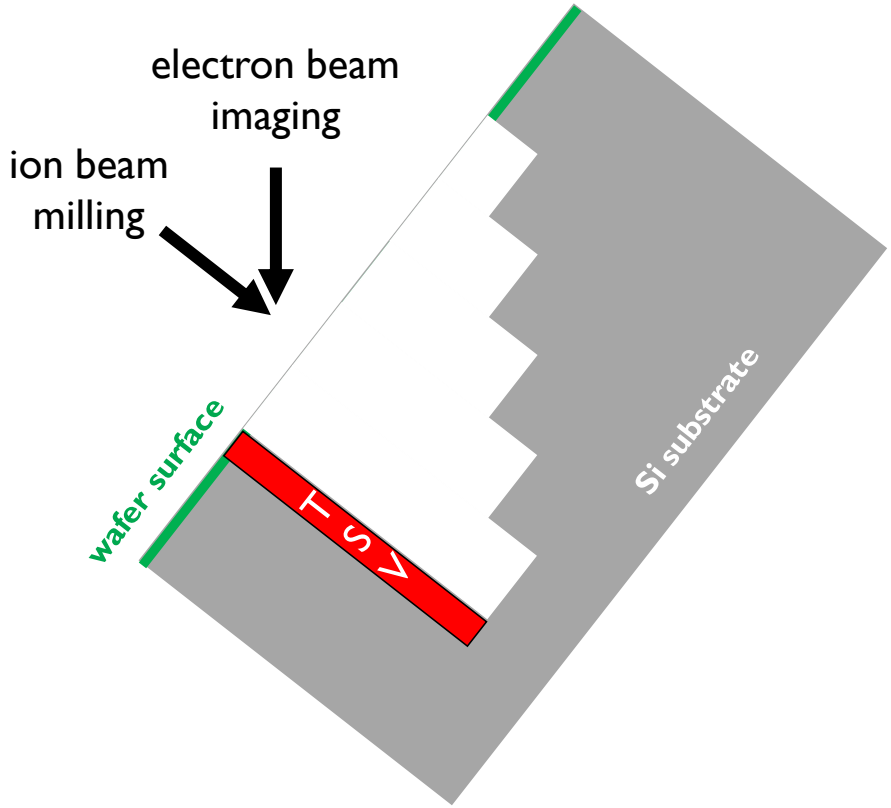
- stair case with high beam current

$$volume = \frac{d^2 w}{2\tan(38^\circ)}$$

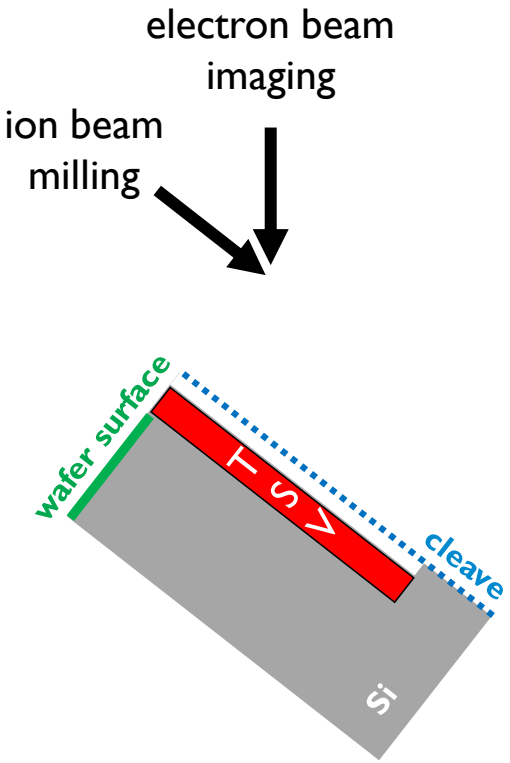
- clean : line milling with lower beam current "slice and view"

ALTERNATIVE MILLING PROCEDURES

standard



cleave
mill sidewall

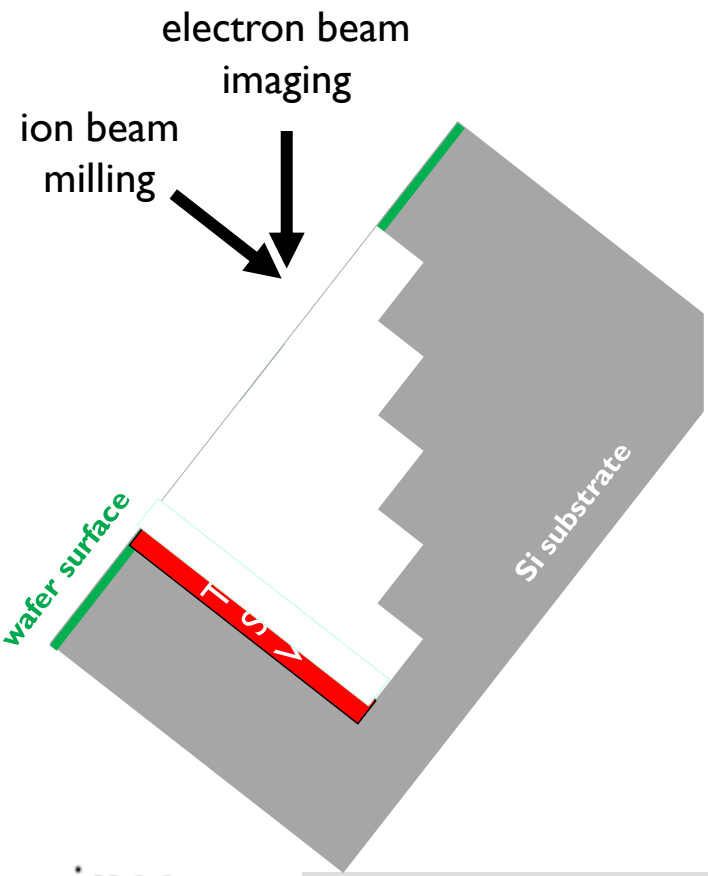


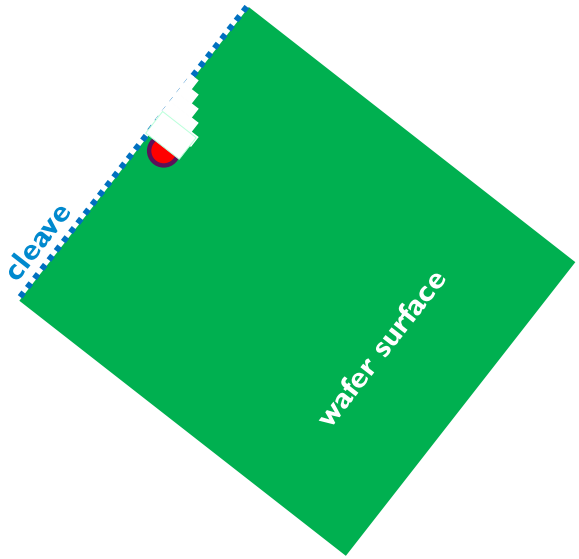
ALTERNATIVE MILLING PROCEDURES

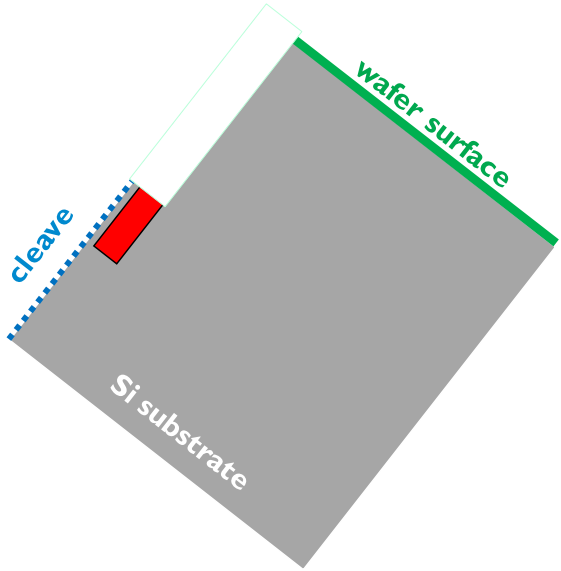
standard

cleave
mount on edge
mill classical way

cleave
mount on edge
only clean mill

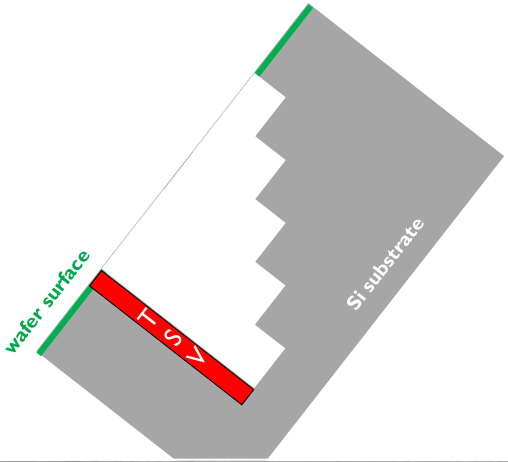


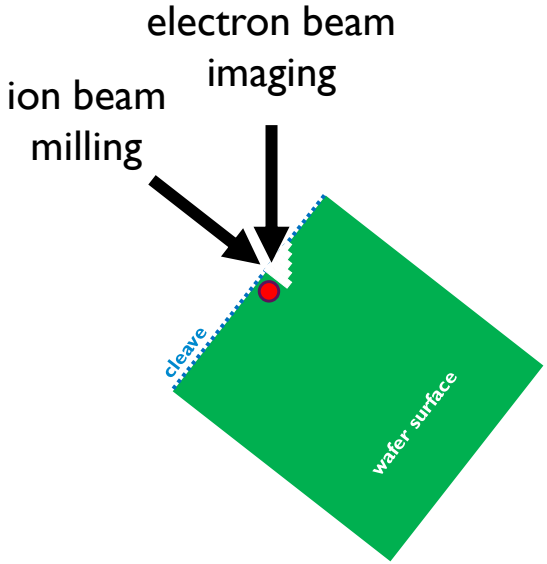


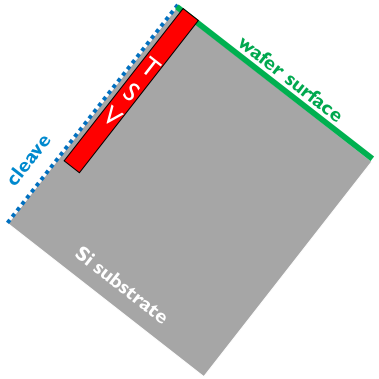


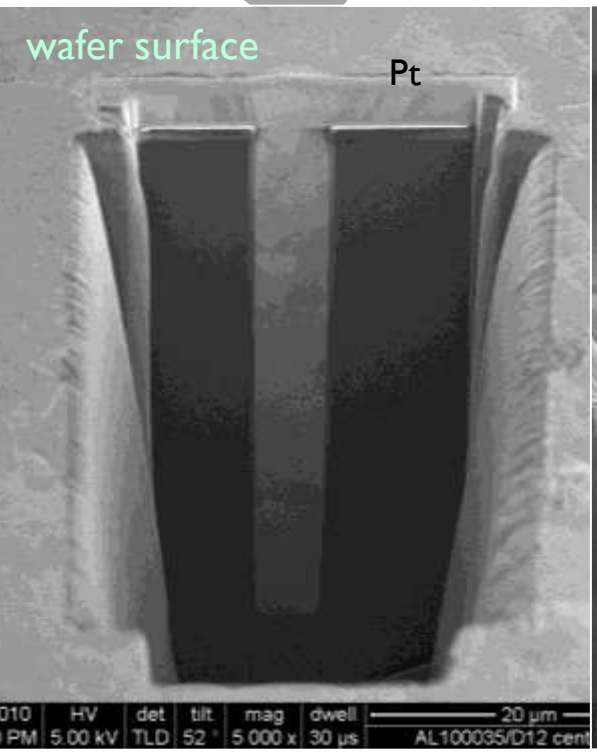
line milling

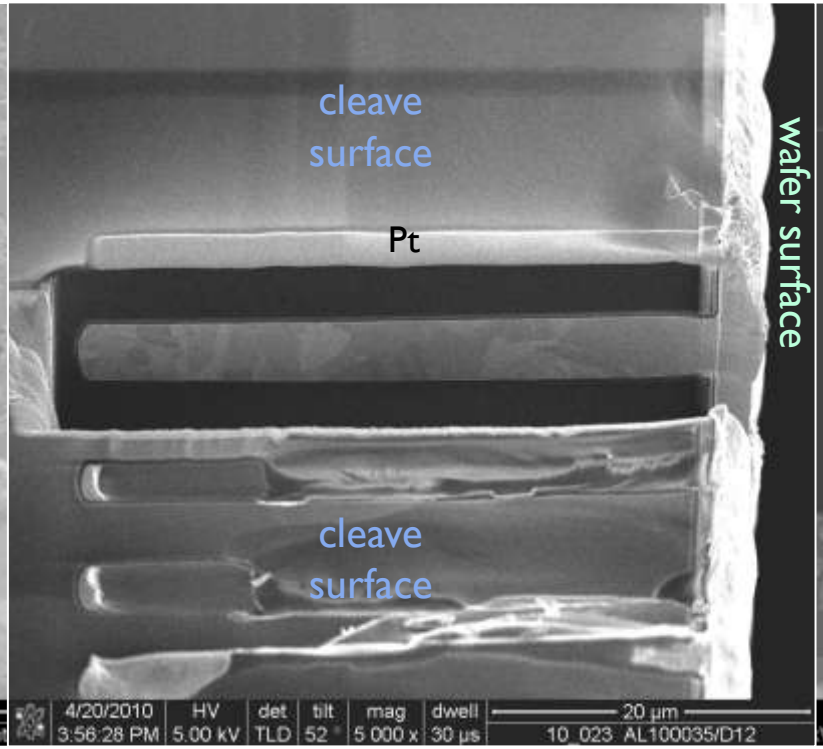
TSV



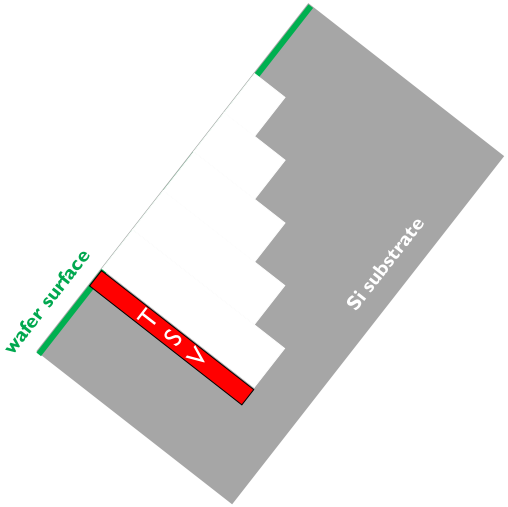


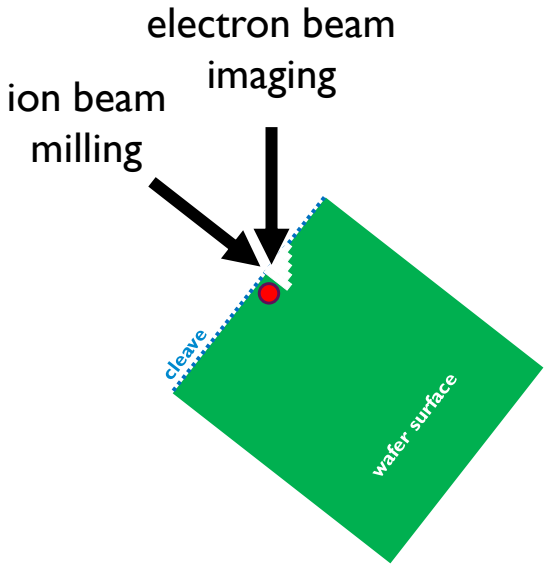


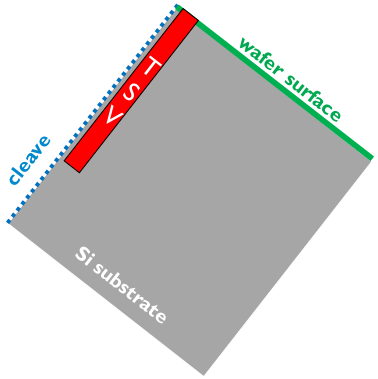


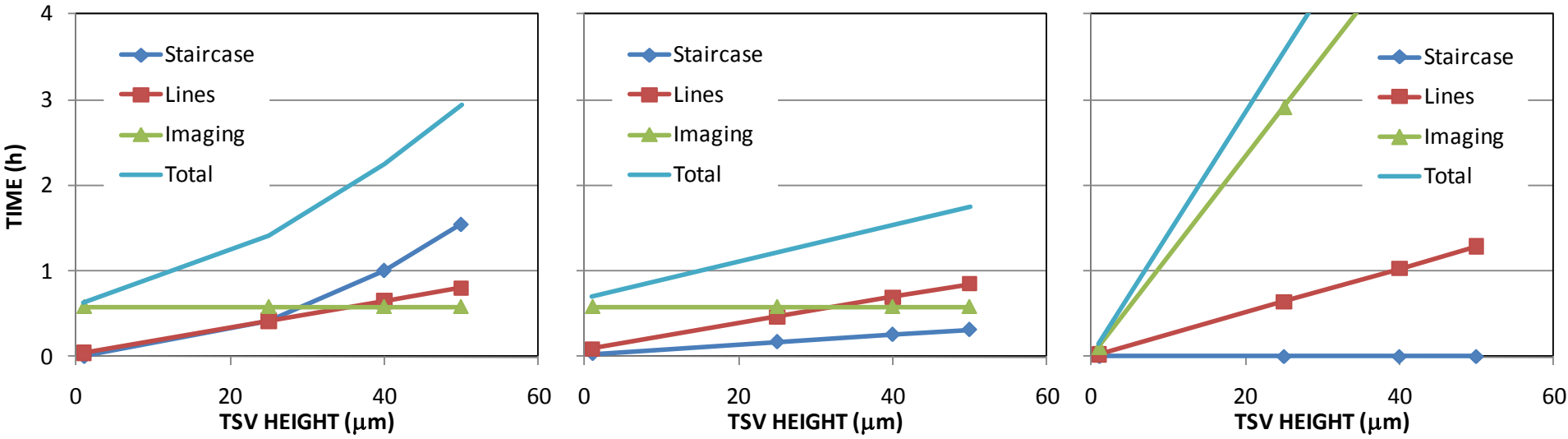


TSV



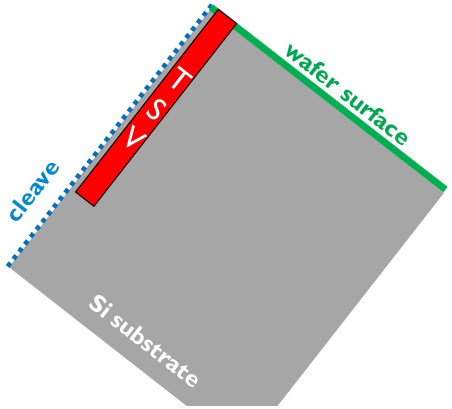


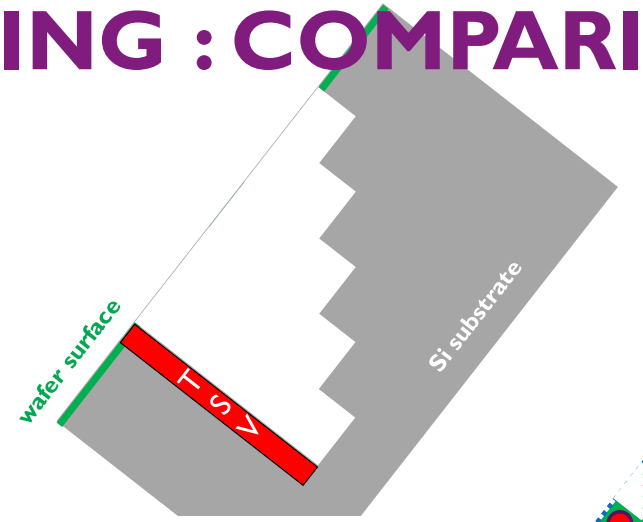


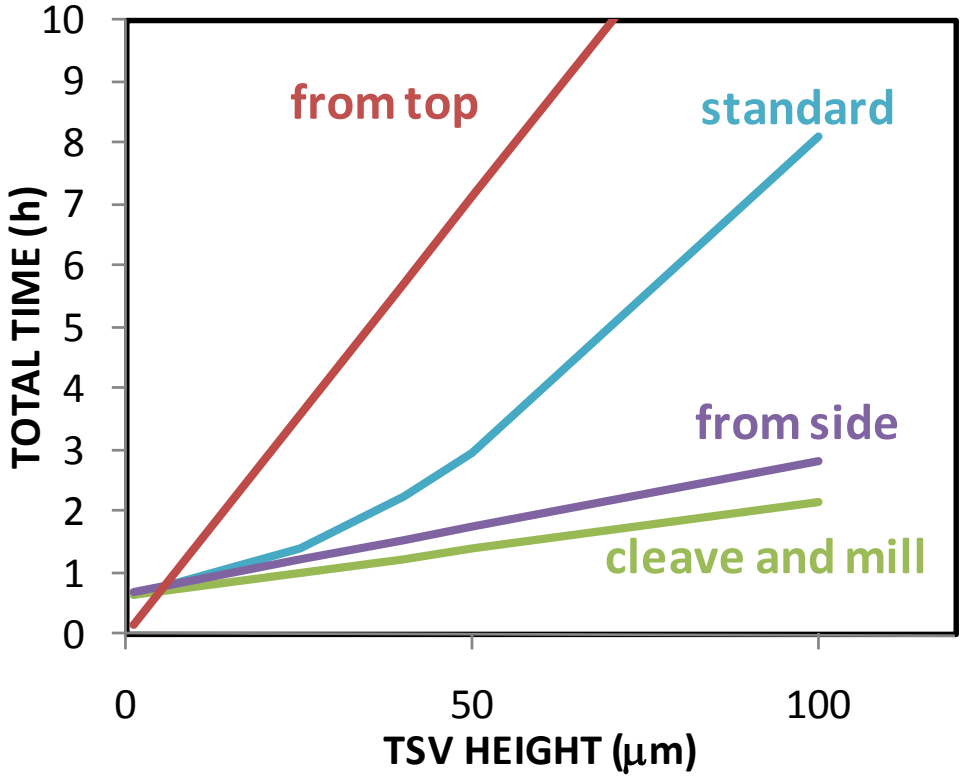


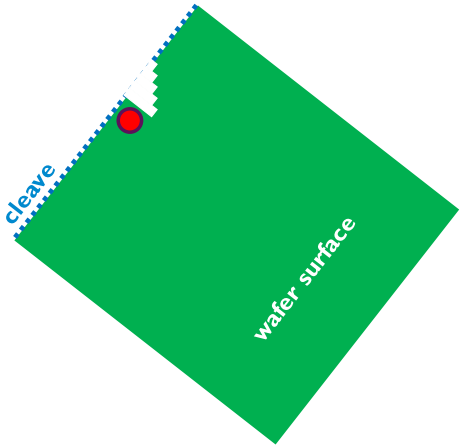
Assuming :
d = h+2µm for standard and cleave and mill ; d = ϕ+5µm for mount on edge
w = ϕ+5µm or h+5µm for from the side
Staircase with 21 nA, slices with 2.7 nA double mill rate starting 1µm before and milling till end
Imaging at 30 µs/pixel = 0.5 min, 0.2 min switching e⁻<>ion

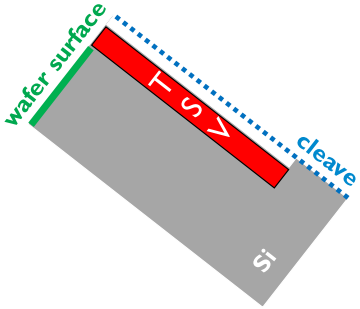
TSV MILLING : COMPARISON





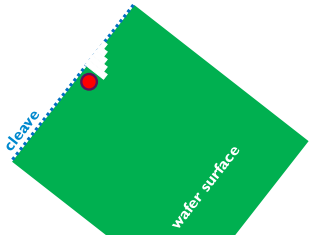


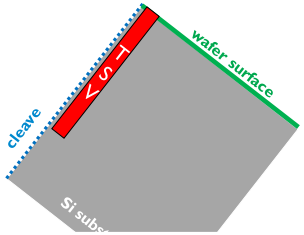


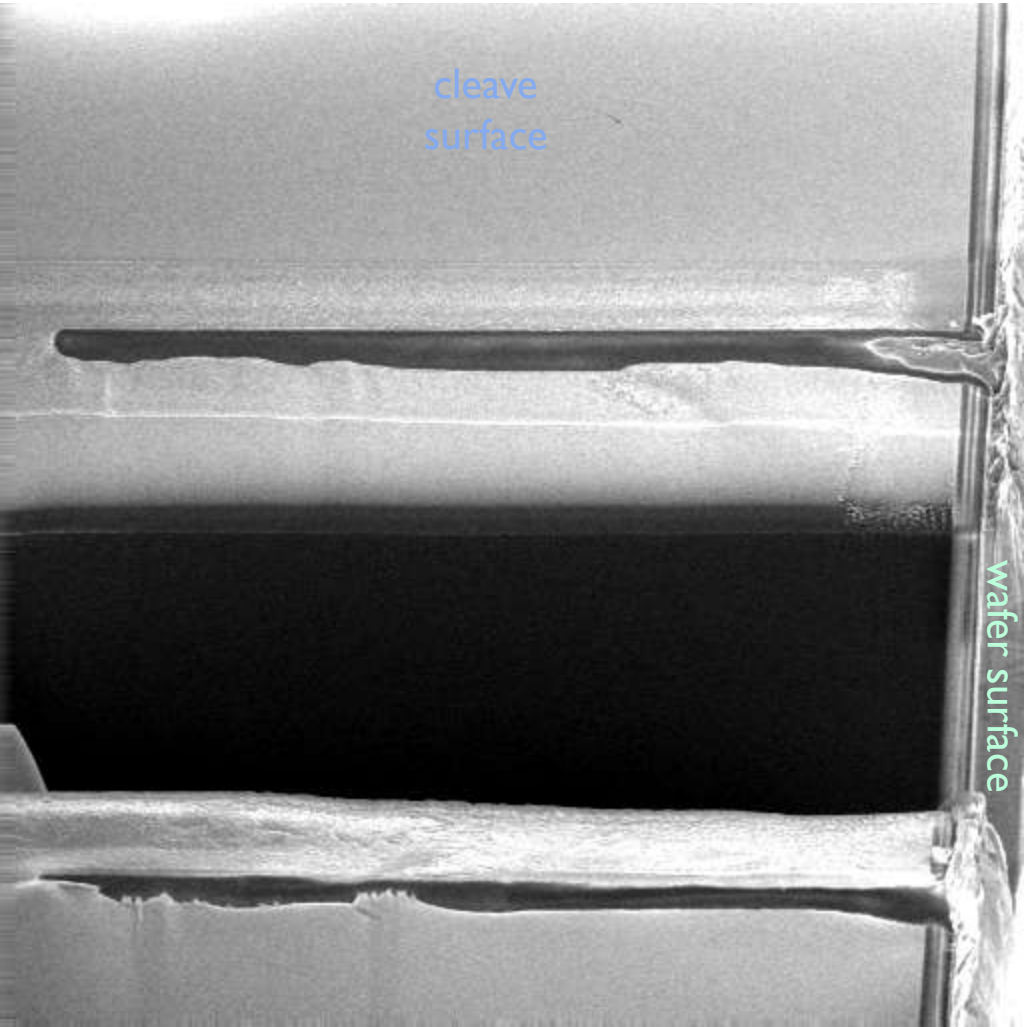


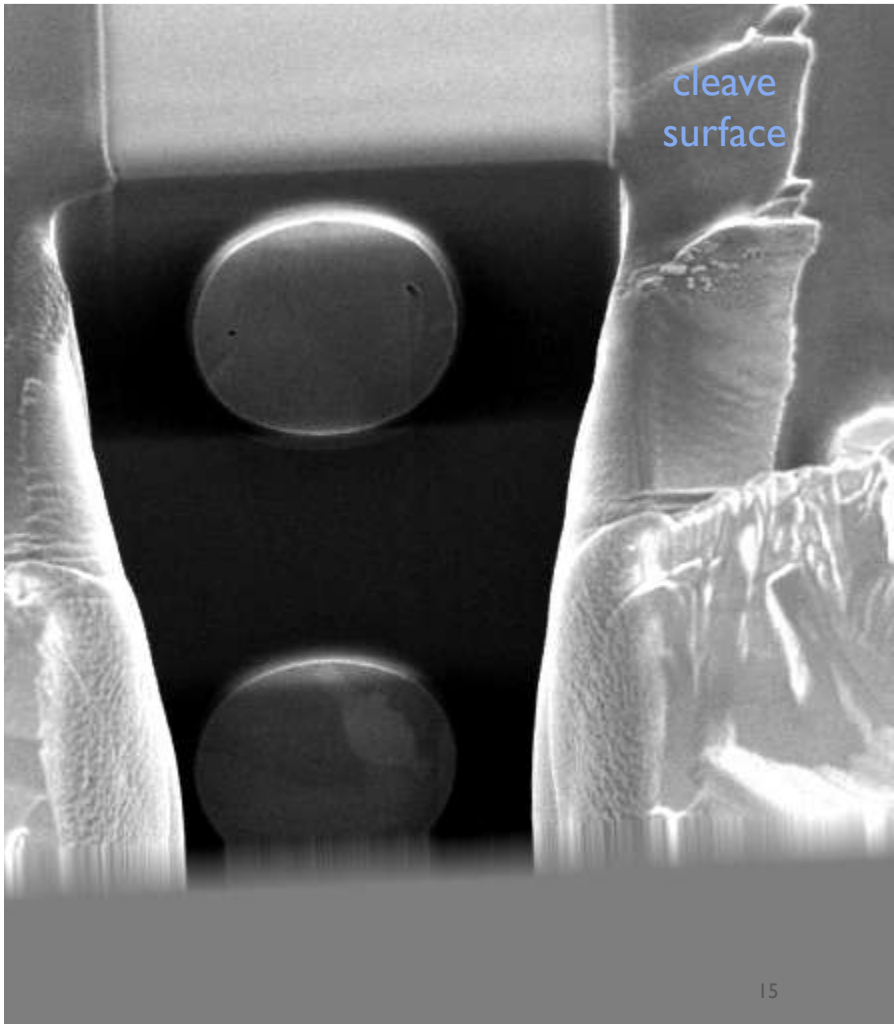
3D FIB SLICE & VIEW

Results of manual slice&view !

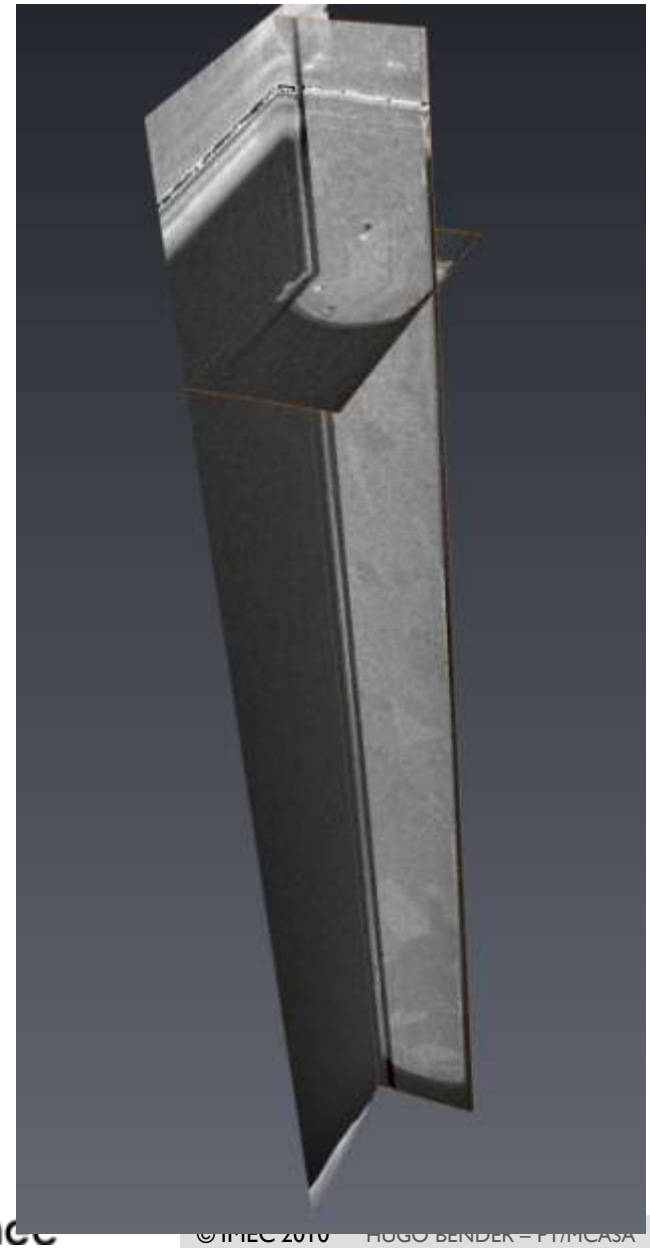


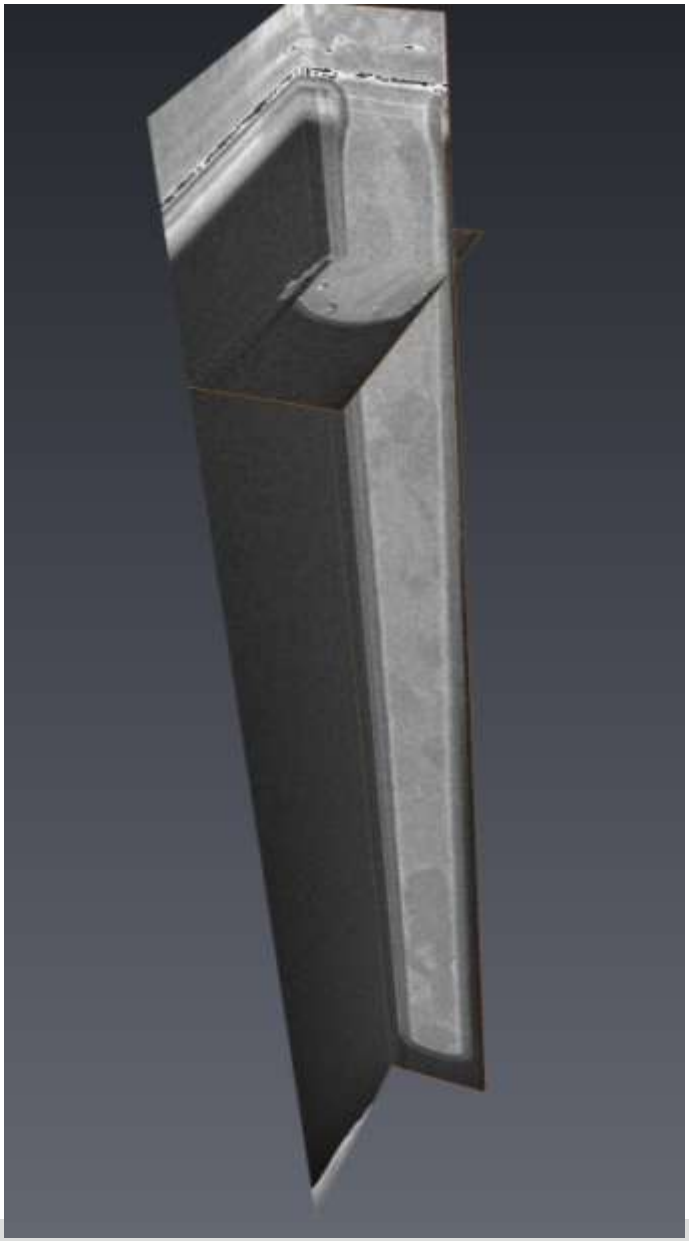


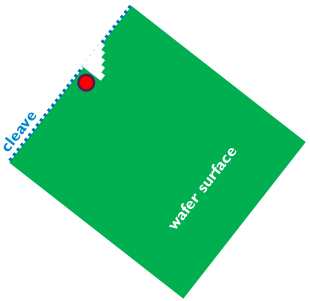




MILL FROM SIDE

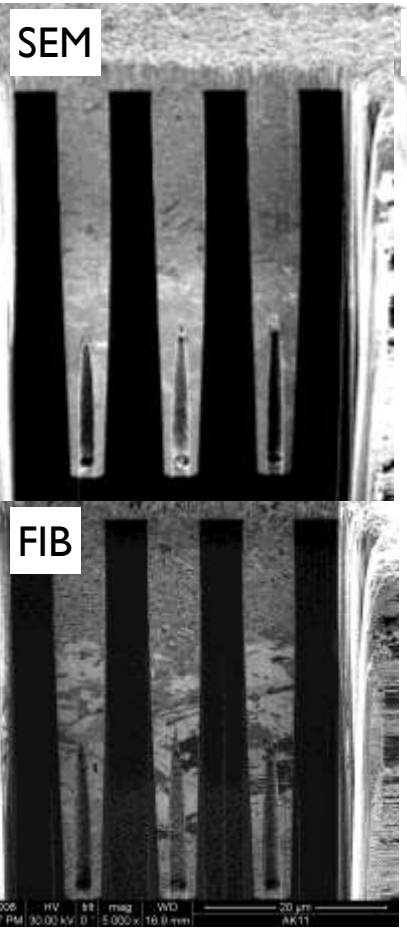






Xe PLASMA FIB

Demo results
No system available !
Also : single beam



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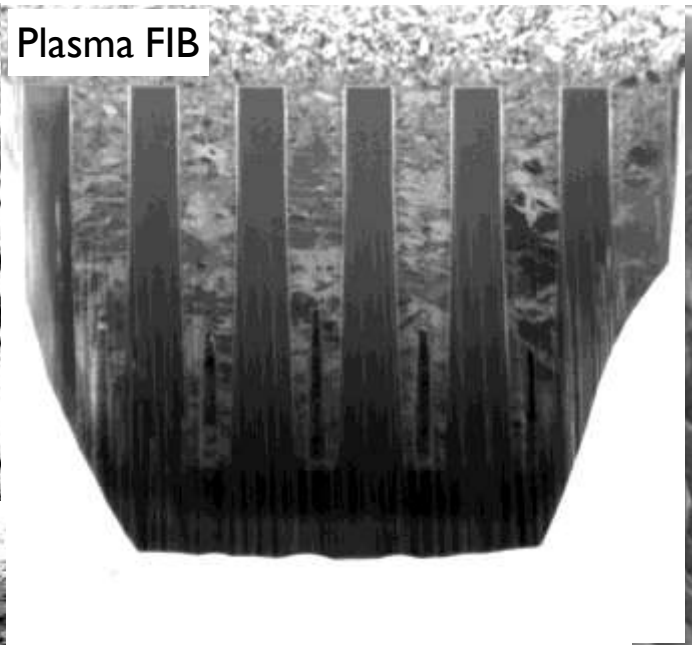
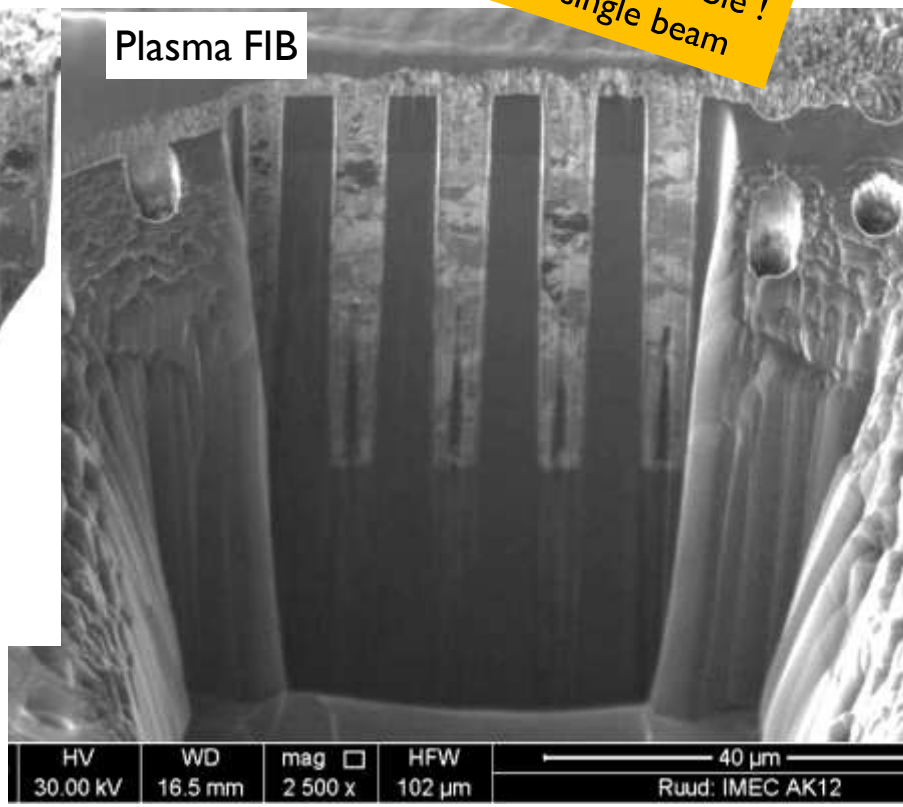


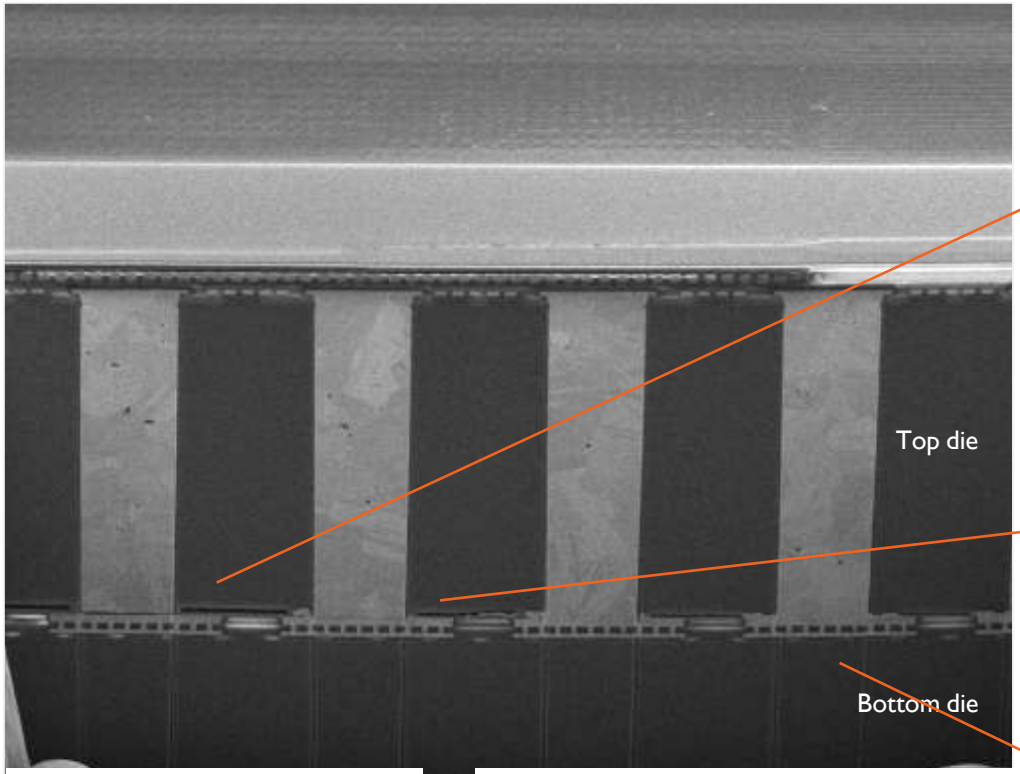
Oregon Physics
Noel Smith

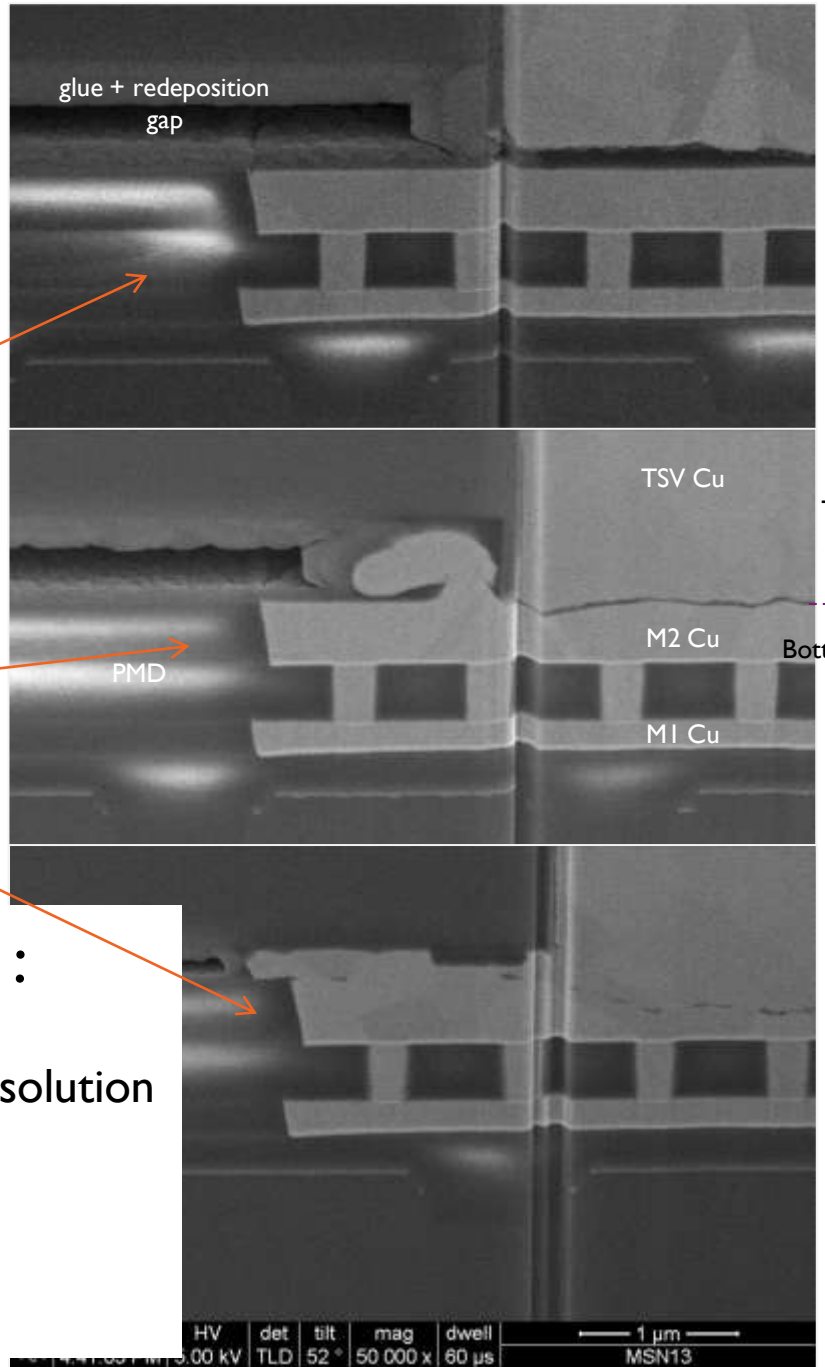


FEI
Ruud Schampers

Ga-FIB 20-40 nA → Xe-plasma source >500-1000 nA

BONDED DIES





Interests :

- **bonding quality**
- Cu filling (voids)
- grain size
- barrier
- oxide liner

Analysis challenges :

- **no cleaving possible**
- dimensions vs required resolution
- depth of focus
- 3D analysis
- curtaining
- analysis time

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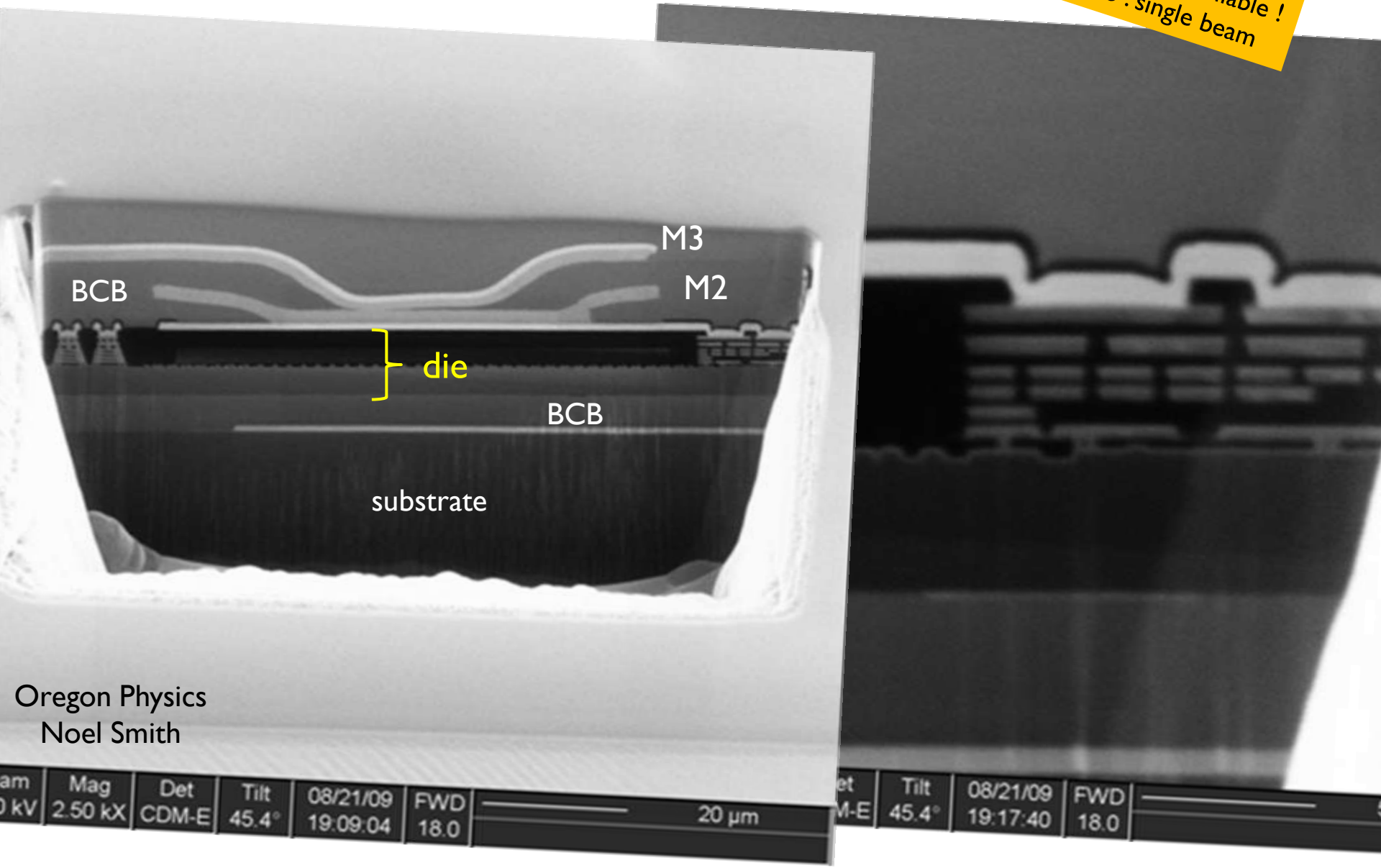
EMBEDDED DIE – PLASMA

Demo results
No system available !
Also : single beam



TSV OPTIONS FOR CROSS-SECTIONAL INSPECTION

	Embed & polish	Standard DB-FIB mill	Cleave & DB-FIB mill	Mill from the side	Plasma-FIB
Speed	Slow	Slow	Medium	Medium	Fast
Typical for 50 µm TSV	8 h	6-8 h	3-4 h	3-4 h	1 h
Area	Large	>30x50 μm^2	>30x50 μm^2	>50x10 μm^2	>100x100 μm^2
Quality	Polishing artefacts Void filling	SEM for voids FIB for grains Curtaining	SEM for voids FIB for grains Curtaining	SEM for voids FIB for grains Less curtaining	FIB only Curtaining
3D	~	Slice and view	Slice and view	Slice and view	Slice and tilt
Bonded dies	(Yes)	Yes	No	No	Yes
Difficulty	Patient operator	Mature	Mature	Mature	System in development

CONCLUSION

- 3D-FIB on large structures is very time consuming
- Cleaving reduces time (if possible, but still >4h)

- Automated slice&view has problem of resolution vs total overview (no simple intermediate zooming possible)
- Manual slice and view generally needed (actually always applied)

- Outlook / dreams
  - Higher beam current FIB systems : will be mainly beneficial for the large volume milling
  - Higher milling rates : higher energy ? Other beams ?
  - Plasma-FIB : unclear when it will become available

Acknowledgement
Demo's : Oregon Physics, FEI, Hitachi

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