



Non-Gallium Applications for Circuit Edit and Failure Analysis

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Contents

- Non-gallium technologies
- Xe⁺ plasma FIB
 - Cross sectioning
 - Reducing curtaining
 - Si trenching
 - Metal deposition

Non-Gallium Technologies

- Plasma Source
 - Xe⁺, Ar⁺, O⁺
- SEM
- Light ion microscopes
 - He⁺, Ne⁺
- Mass-filtered alloy source FIBs

Non-Gallium Technologies

•Plasma Source

- Xe⁺, Ar⁺, O⁺

- SEM

- Light ion microscopes

- He⁺, Ne⁺

- Mass-filtered alloy

- source FIBs

- Long source lifetime

- High current

- Different ions are possible

- Deposition yields higher than Ga⁺

- Lower resolution than Ga⁺

- Metal depositions (electrical)

Other Technologies

- Plasma Source

- Xe⁺, Ar⁺, O⁺

- **SEM**

- Light ion microscopes

- He⁺, Ne⁺

- Mass-filtered alloy

source FIBs

- High resolution
- No mechanical damage
- Extreme chemical selectivity
- Extreme chemical selectivity
- Electrical invasiveness

Other Technologies

- Plasma Source

- Xe⁺, Ar⁺, O⁺

- SEM

- **Light ion microscopes**

- **He⁺, Ne⁺**

- Mass-filtered alloy

- source FIBs

- High resolution

- Very low mechanical damage

- High milling/deposition precision

- Very low current

- Source stability

- Bubbles

- Metal deposition (electrical)?

- Electrical invasiveness?

Other Technologies

- Plasma Source

 - Xe⁺, Ar⁺, O⁺

- SEM

- Light ion microscopes

 - He⁺, Ne⁺

- **Mass-filtered alloy**

- **source FIBs**

- Easy switching between ions

- Source lifetime

- Lower resolution than Ga⁺

- Metal deposition (electrical)?

- Electrical invasiveness?

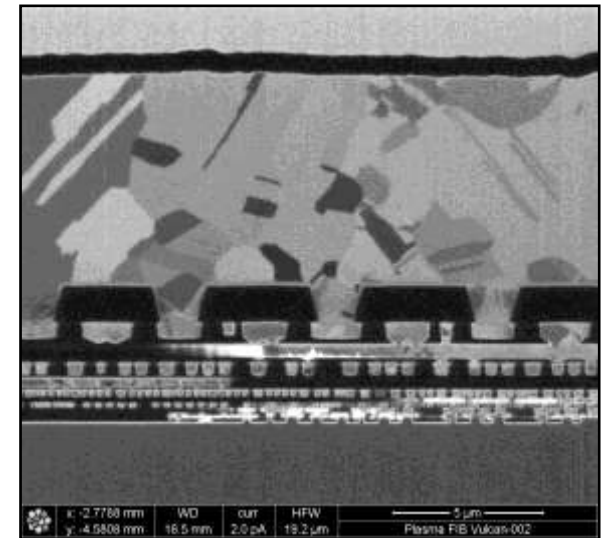
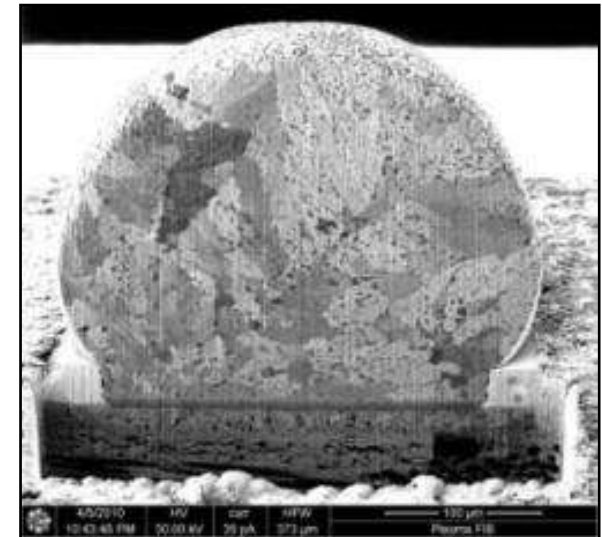
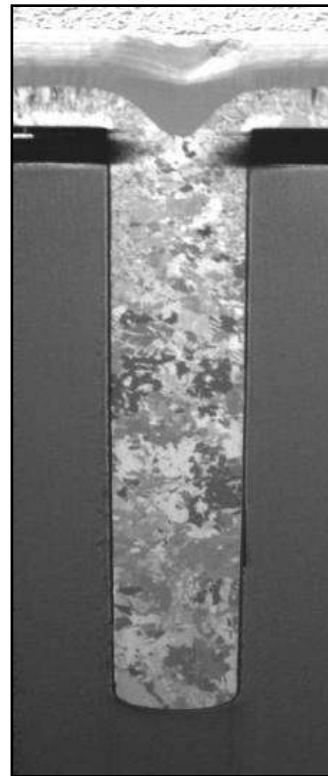
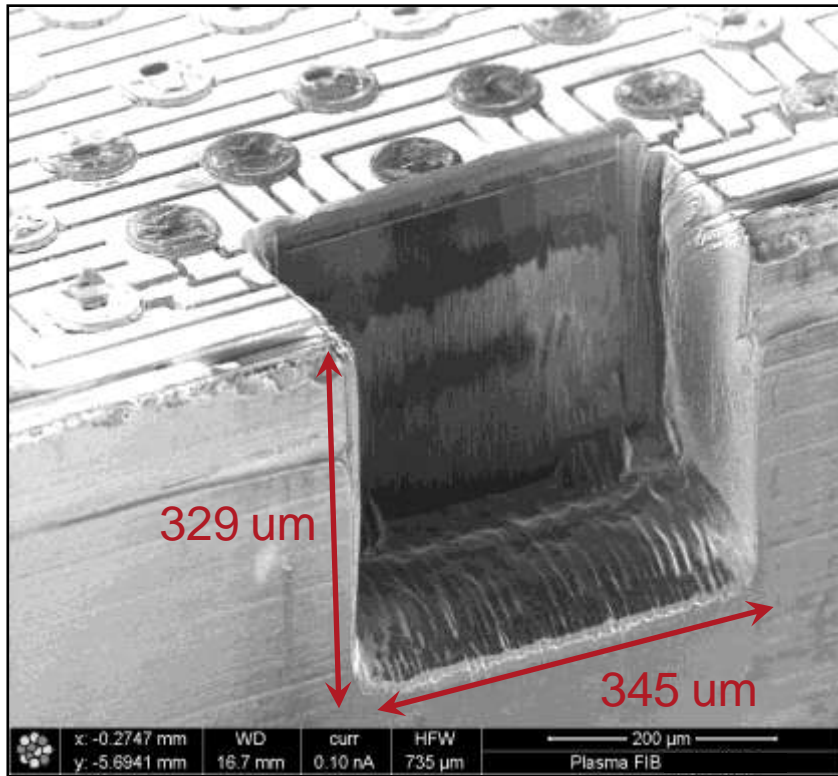
Comparing Ga with Other Technologies

Task	Ga	Plasma FIB	SEM	Light Ion Microscope	Alloy Source FIB
Cross Sectioning	Green	Green	Red	Yellow	Green ?
Si Trenching	Yellow	Green	Red	Red	Green ?
Metal Deposition (electrical)	Green	Yellow	Yellow	Yellow ?	Yellow ?
Metal Deposition (protective)	Yellow	Green	Yellow	Yellow ?	Green ?
Copper cutting	Green	Green	Red	Yellow ?	Green ?
Nanomachining	Yellow	Yellow	Yellow	Green	Green ?

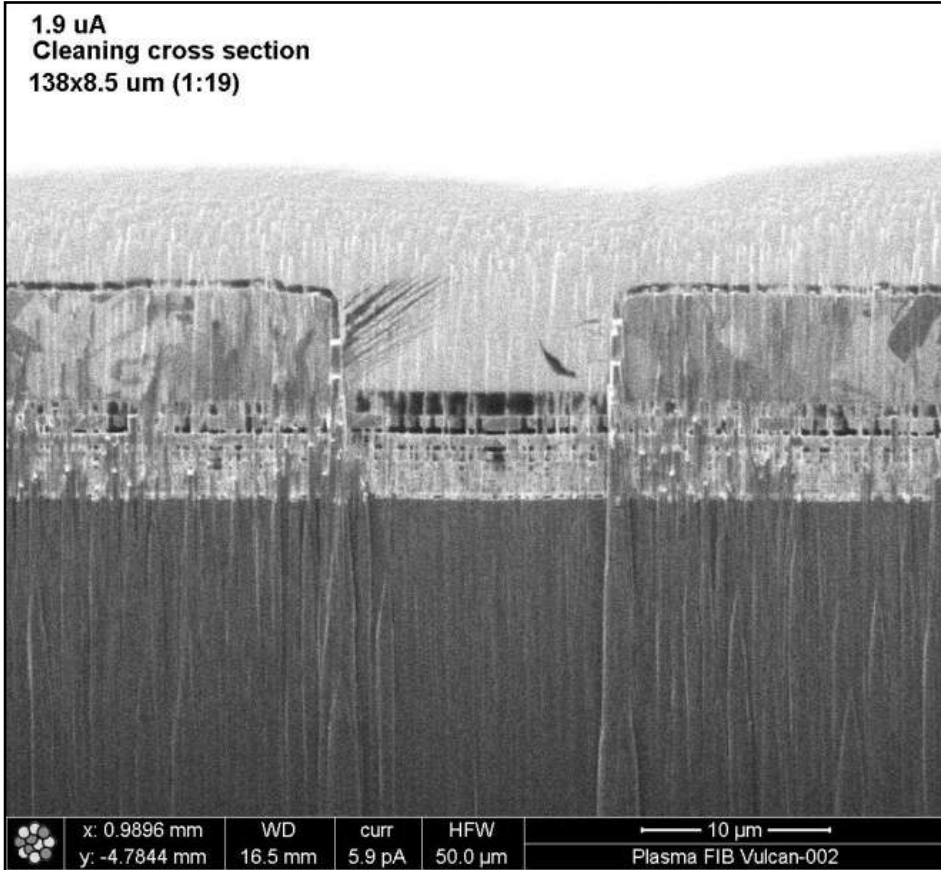
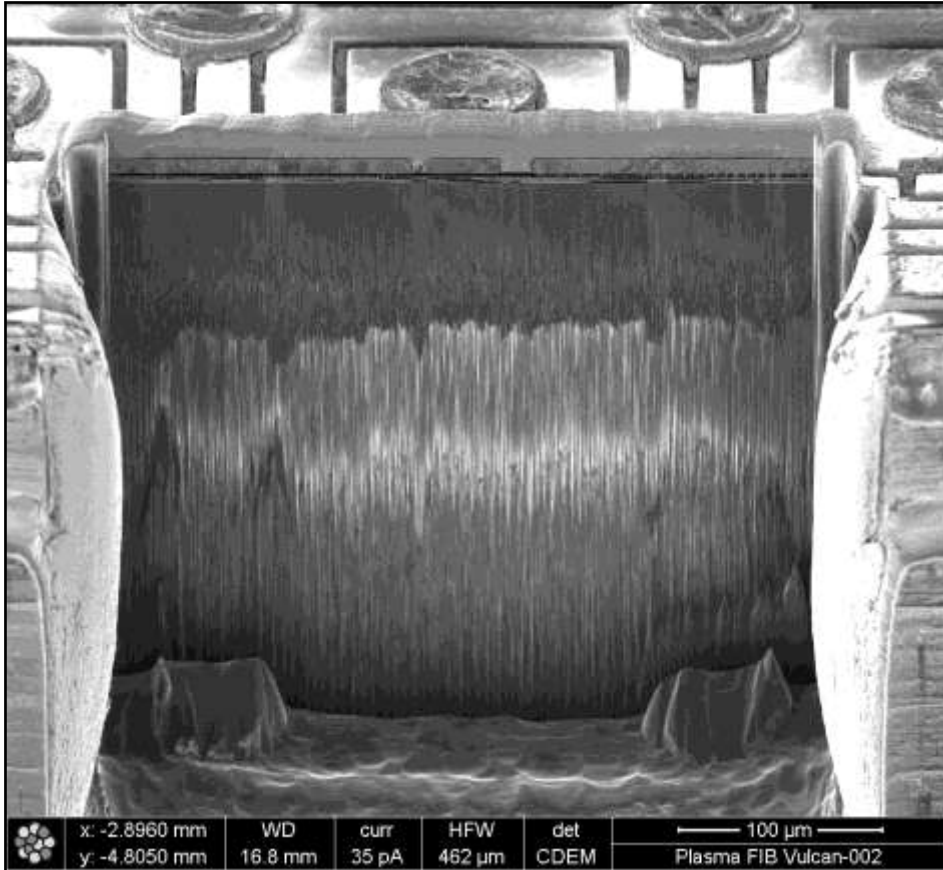
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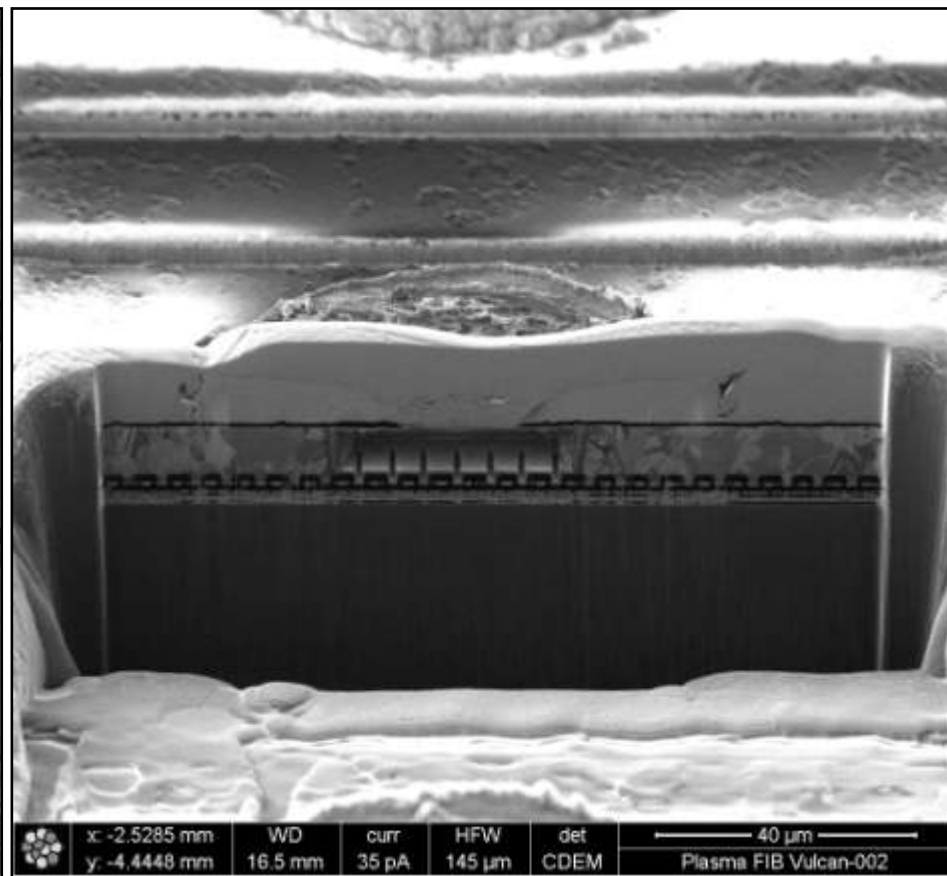
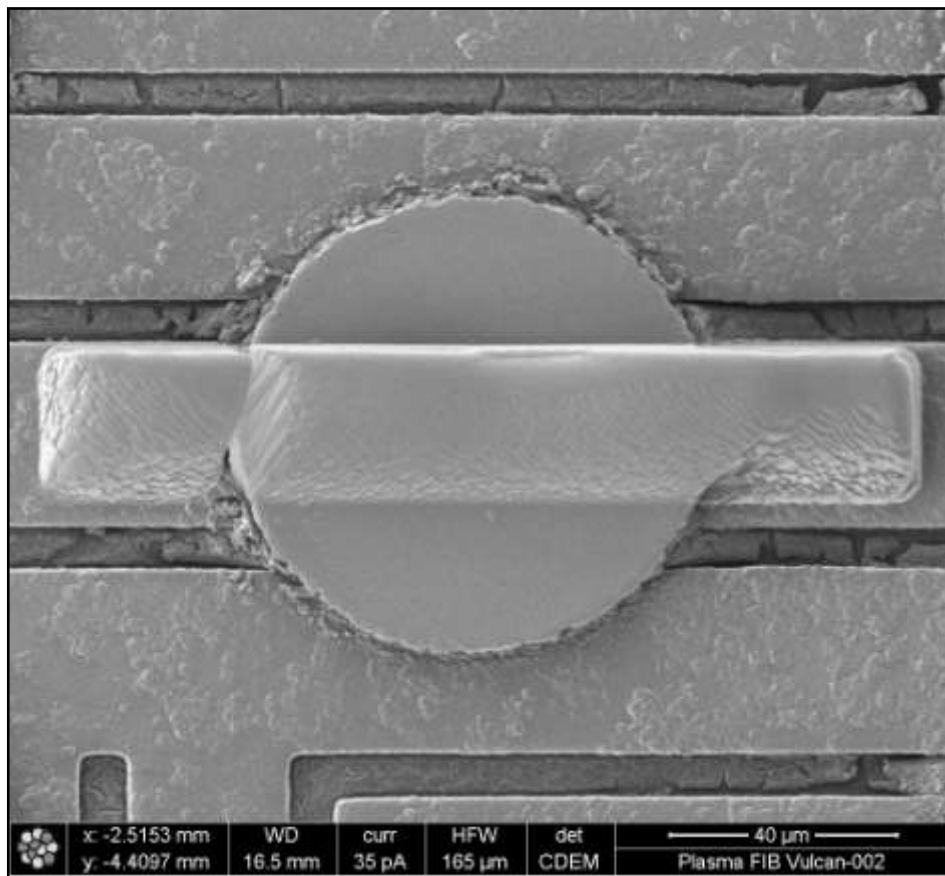
Plasma FIB Applications



How to Reduce Curtaining on Large X-Sections?

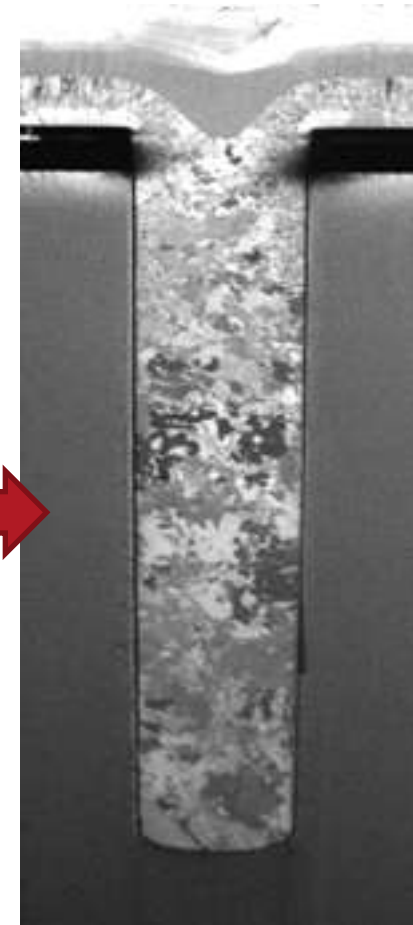
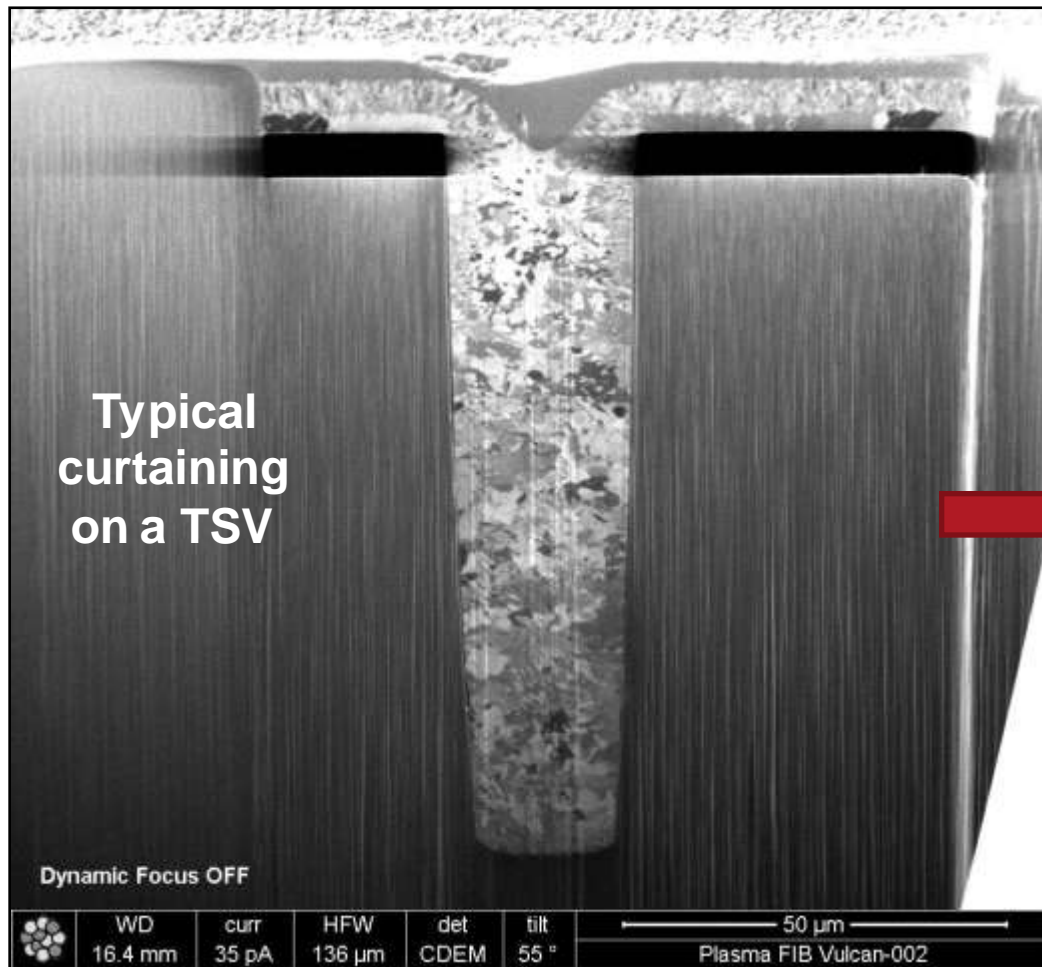


How to Reduce Curtaining on Large X-Sections?

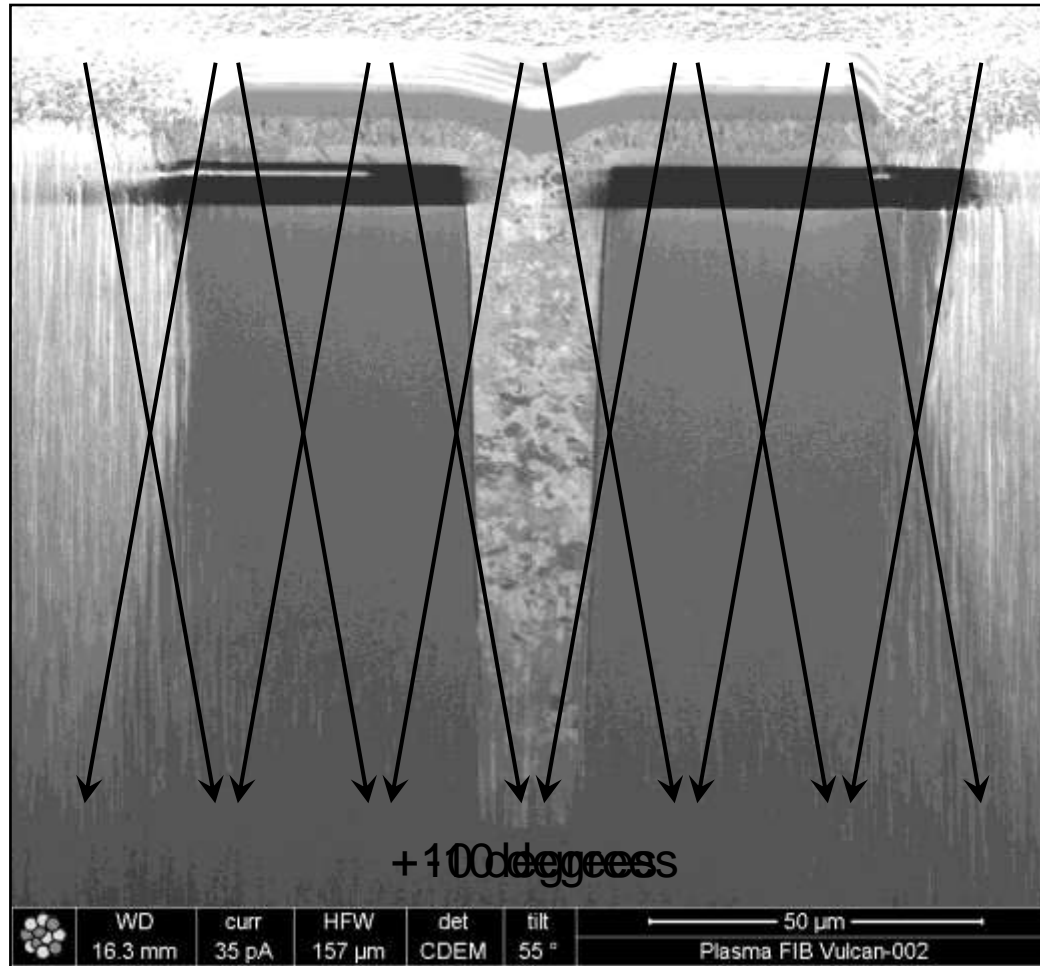


Sacrificial metal deposition

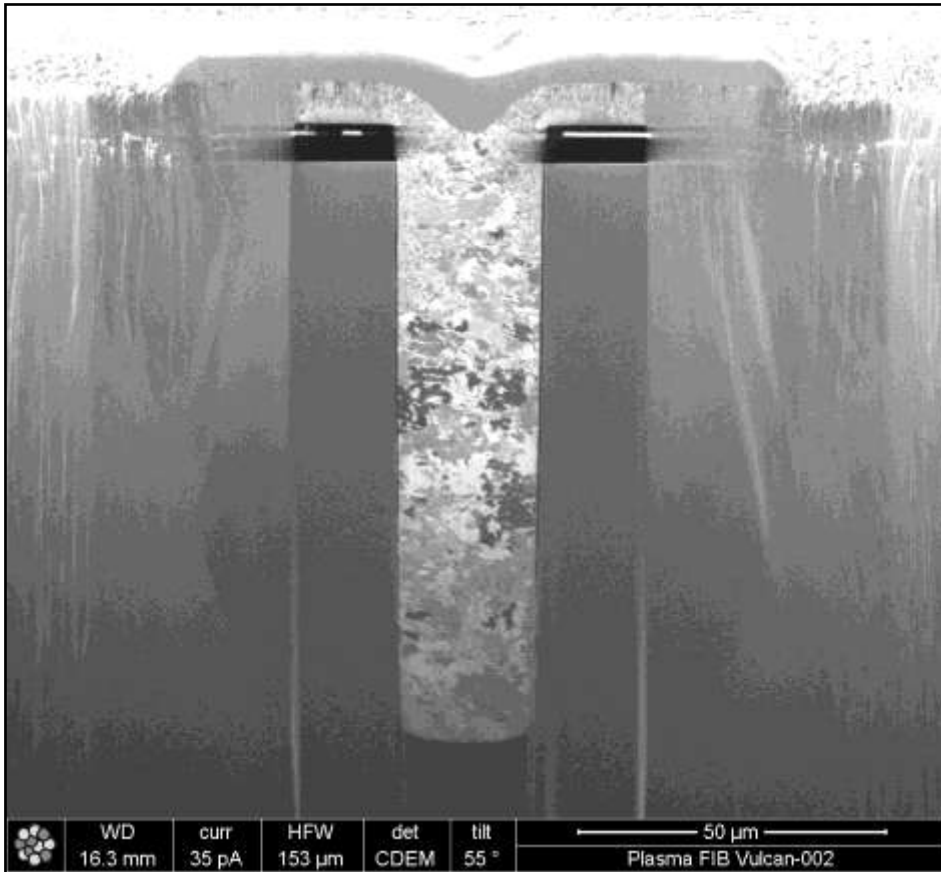
Reducing Curtaining



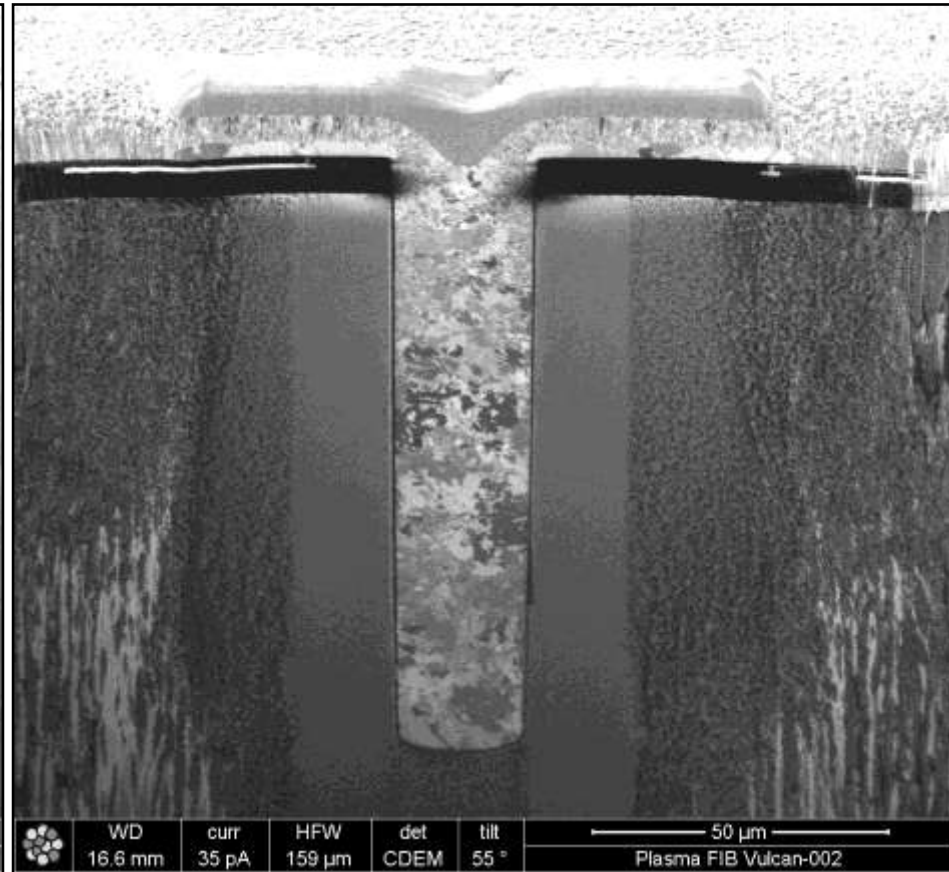
Reducing Curtaining with Tilted Milling



Reducing Curtaining with Tilted Milling

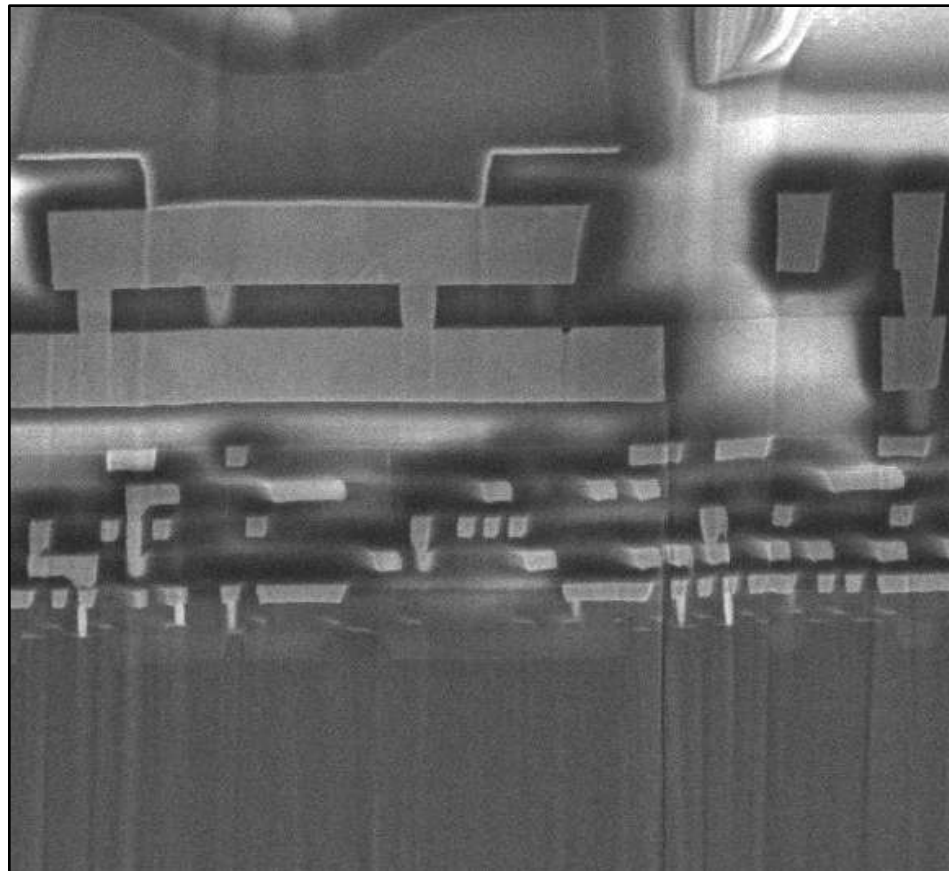


Tilted milling complete...

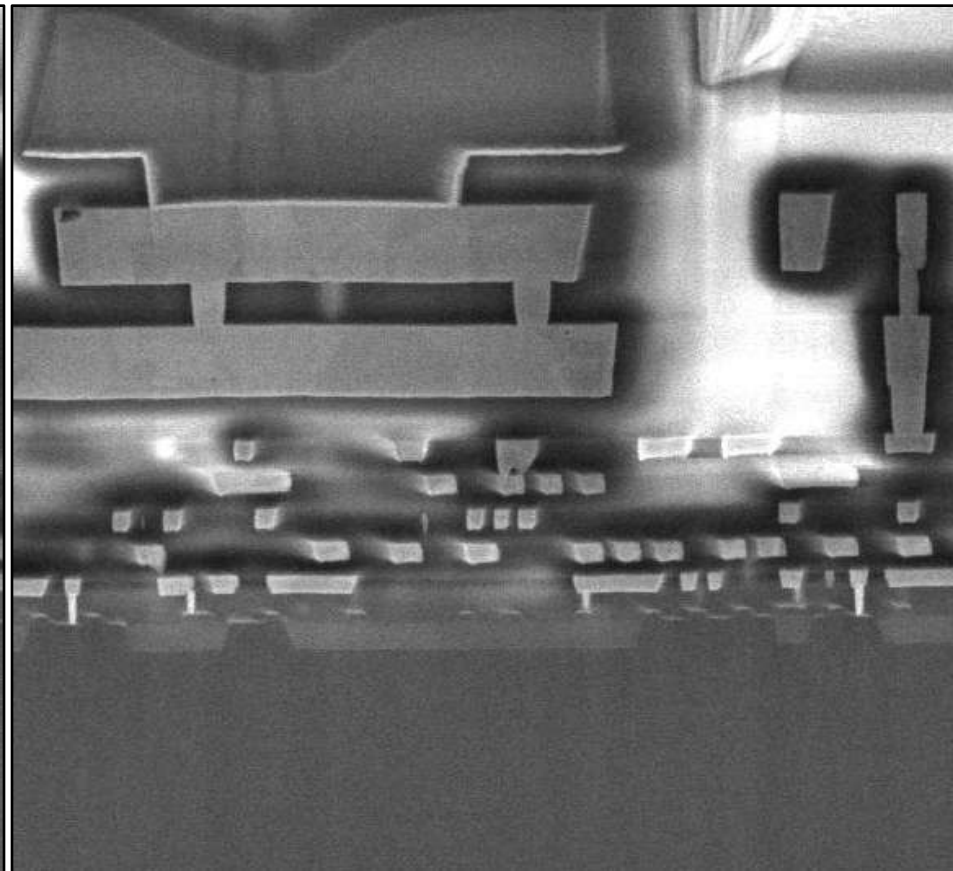


...and after a splash of XeF_2

Reducing Curtaining with Tilted Milling



After typical cleaning cross section

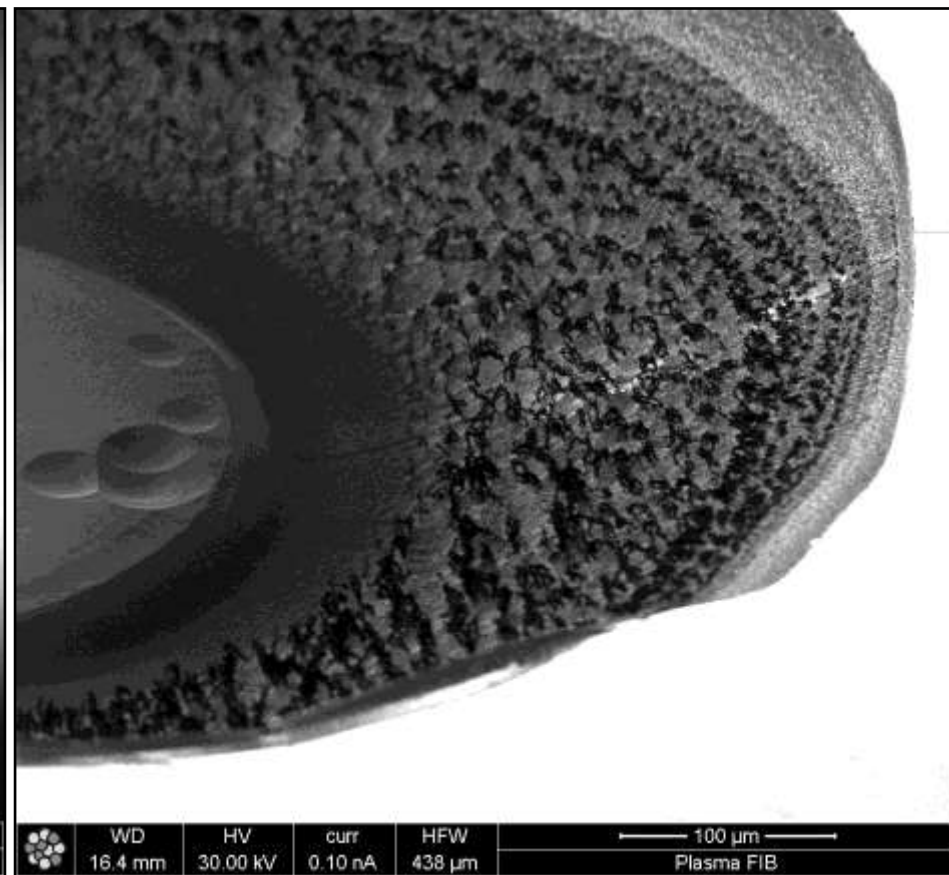
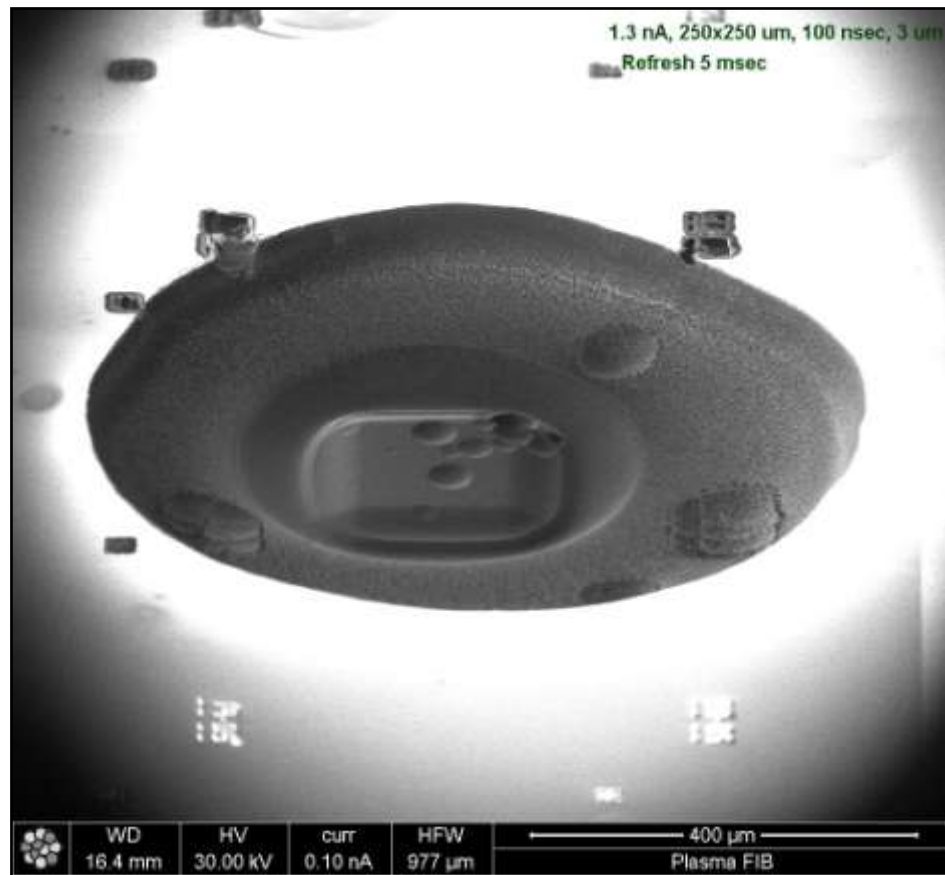


After tilted milling process

Contents

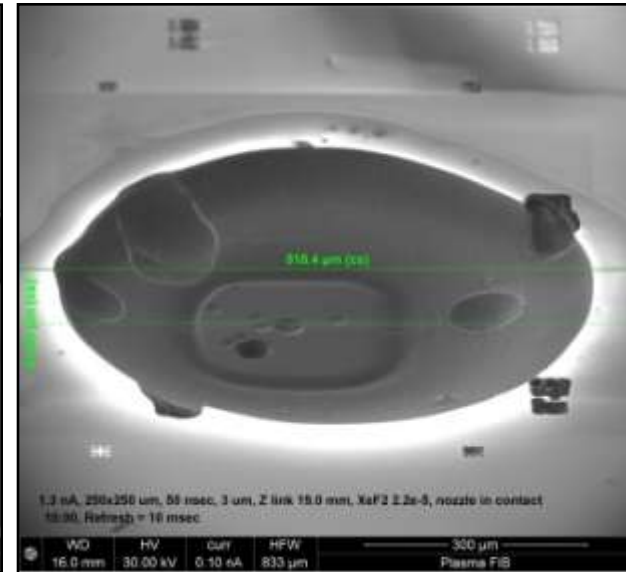
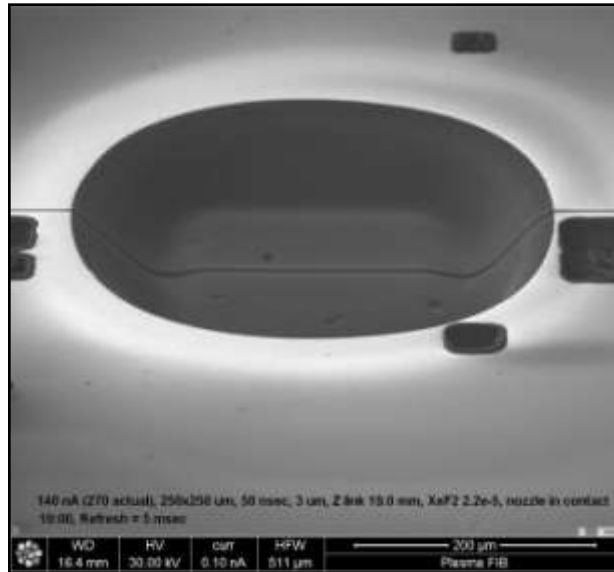
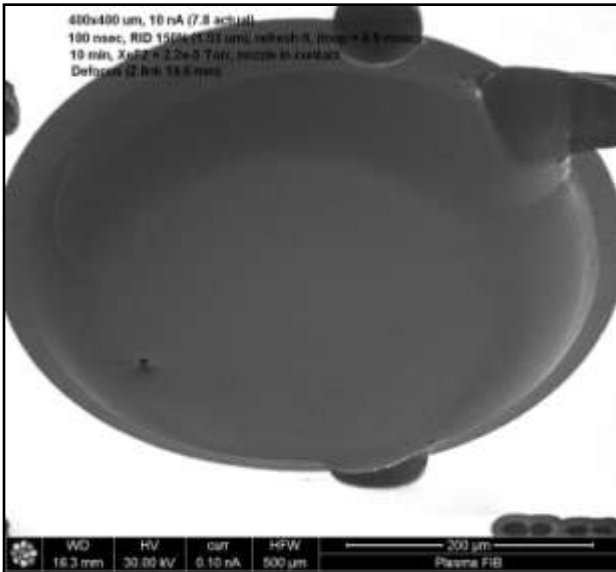
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XeF₂-Assisted Si Trenching



Gas depletion effects can be severe if the parameters are not optimized

Gas Depletion Effects



Gas enhanced



Gas depleted



XeF₂-Assisted Si Trenching

Successful trenching:

- Short dwell time (100 nsec)
- Large pixel spacing (-150%)
- Defocus
- High gas flux (2e-5 Torr w/ coax nozzle)

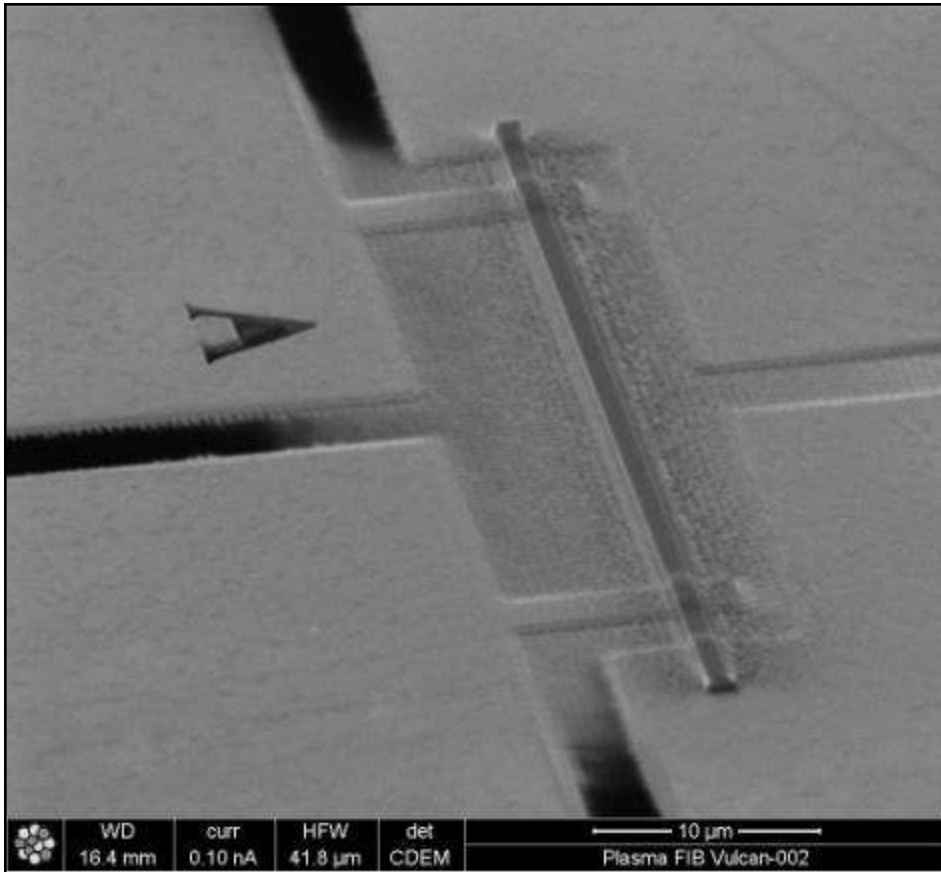
Best results so far:

- Enhancement factor = 45
- Milling speed = $1.42 \times 10^6 \mu\text{m}^3/\text{min} = 2.37 \times 10^4 \mu\text{m}^3/\text{sec}$
- Estimated time to mill full thickness sample (780 μm):
 - 250x250 ($4.9 \times 10^7 \mu\text{m}^3$) \approx 34 min
 - 400x400 ($1.25 \times 10^8 \mu\text{m}^3$) \approx 89 min

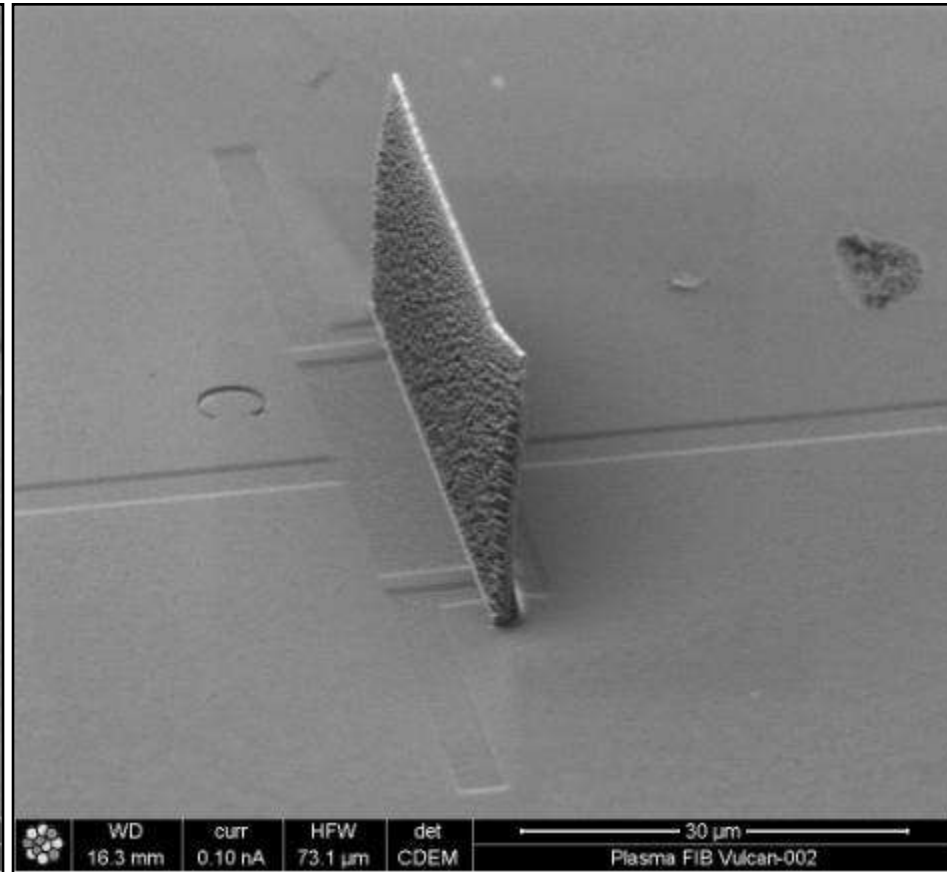
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Metal Deposition Yields

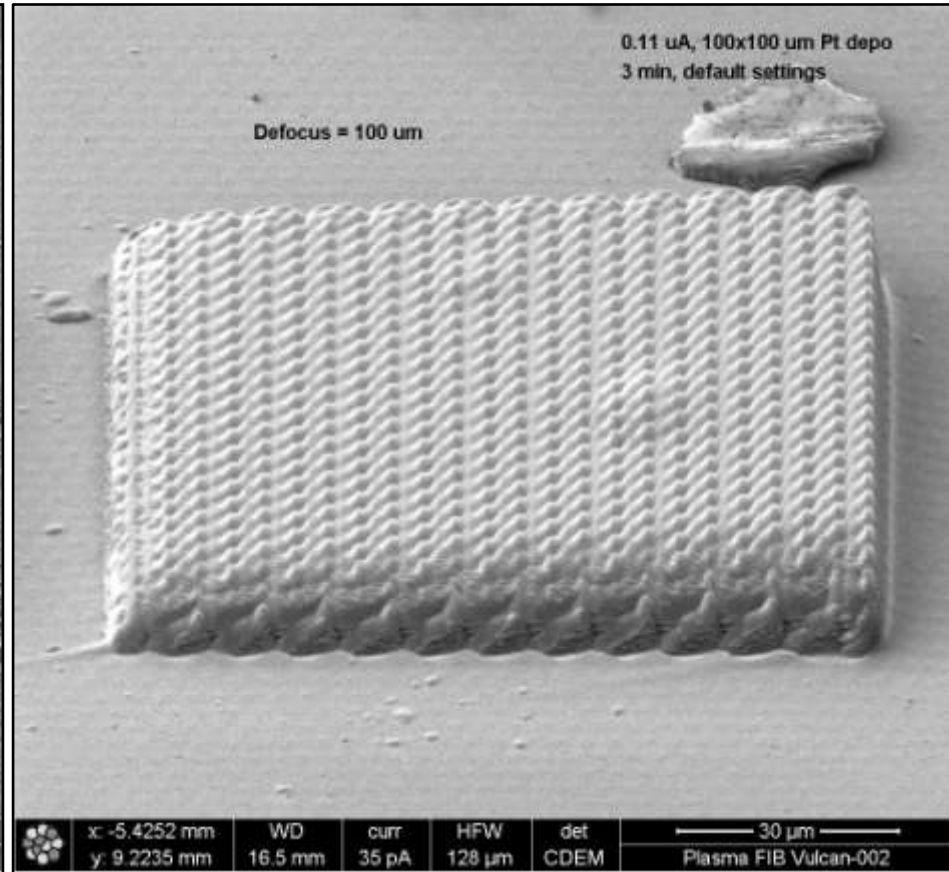
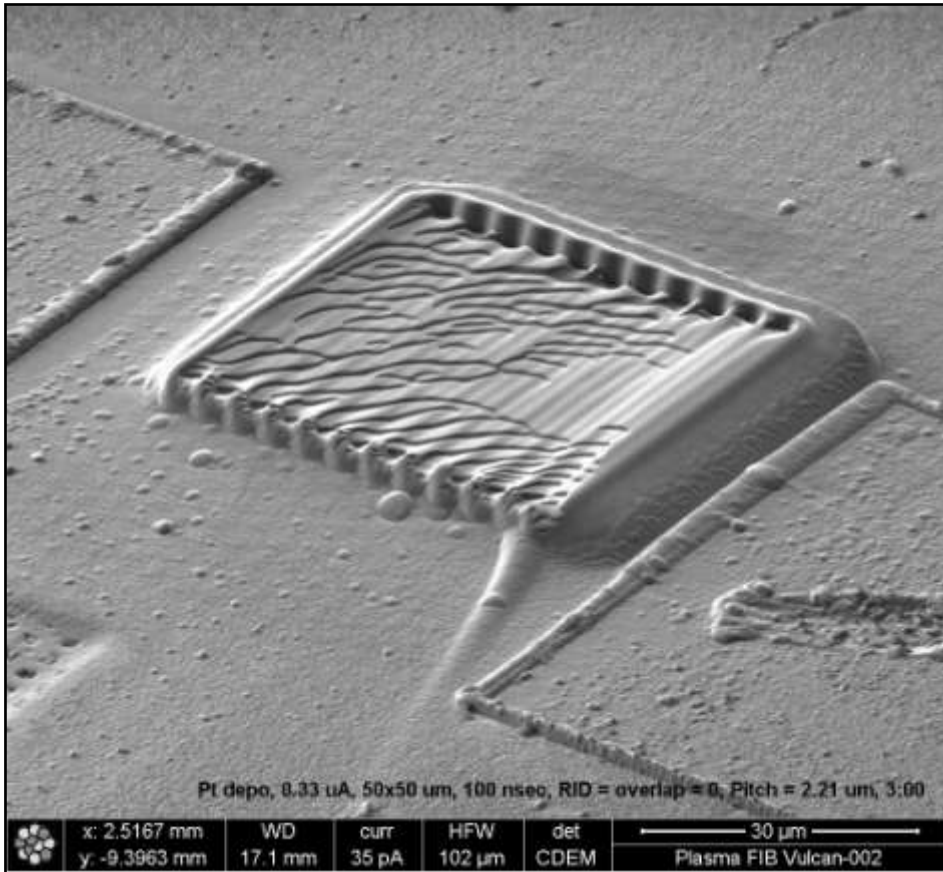


W Deposition,
dose of 2

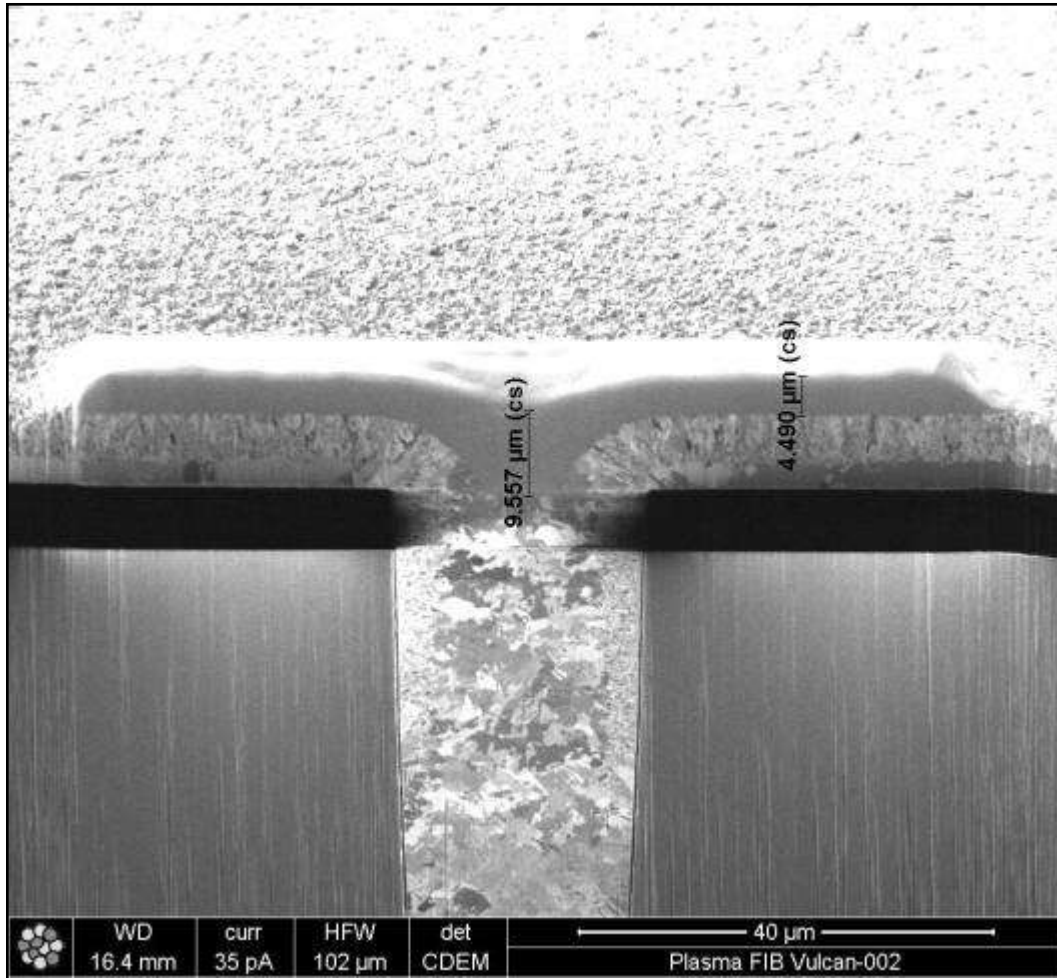


Pt Deposition,
dose of 2

Sacrificial Pt Depositions



Sacrificial Pt Depositions



- 150x25x7.5 μm in 3 min (62 nA)
- 156 $\mu\text{m}^3/\text{sec}$
- 2.52 $\mu\text{m}^3/\text{nC}^*$

* Ga $\sim 0.67 \mu\text{m}^3/\text{nC}$

Conclusions

- Many existing and emerging technologies, but... Ga is tough to beat
- Xe⁺ plasma FIB results:
 - Titled milling can reduce curtaining
 - Si trenching requires careful balance
 - Metal deposition is very fast
 - Good for sacrificial caps
 - Poor electrical performance