Etching of SiLK - an Organic Low-k Material

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Outline

- **Principles of Etching SiLK**
  - **SiLK - Basic Material Properties**
  - **Chemistry for SiLK Etching**
  - **Process Characterization and Trends**
- **Etch Challenges and Solutions**
- **Etching Porous SiLK**
- **Summary**

Principles of Etching SiLK

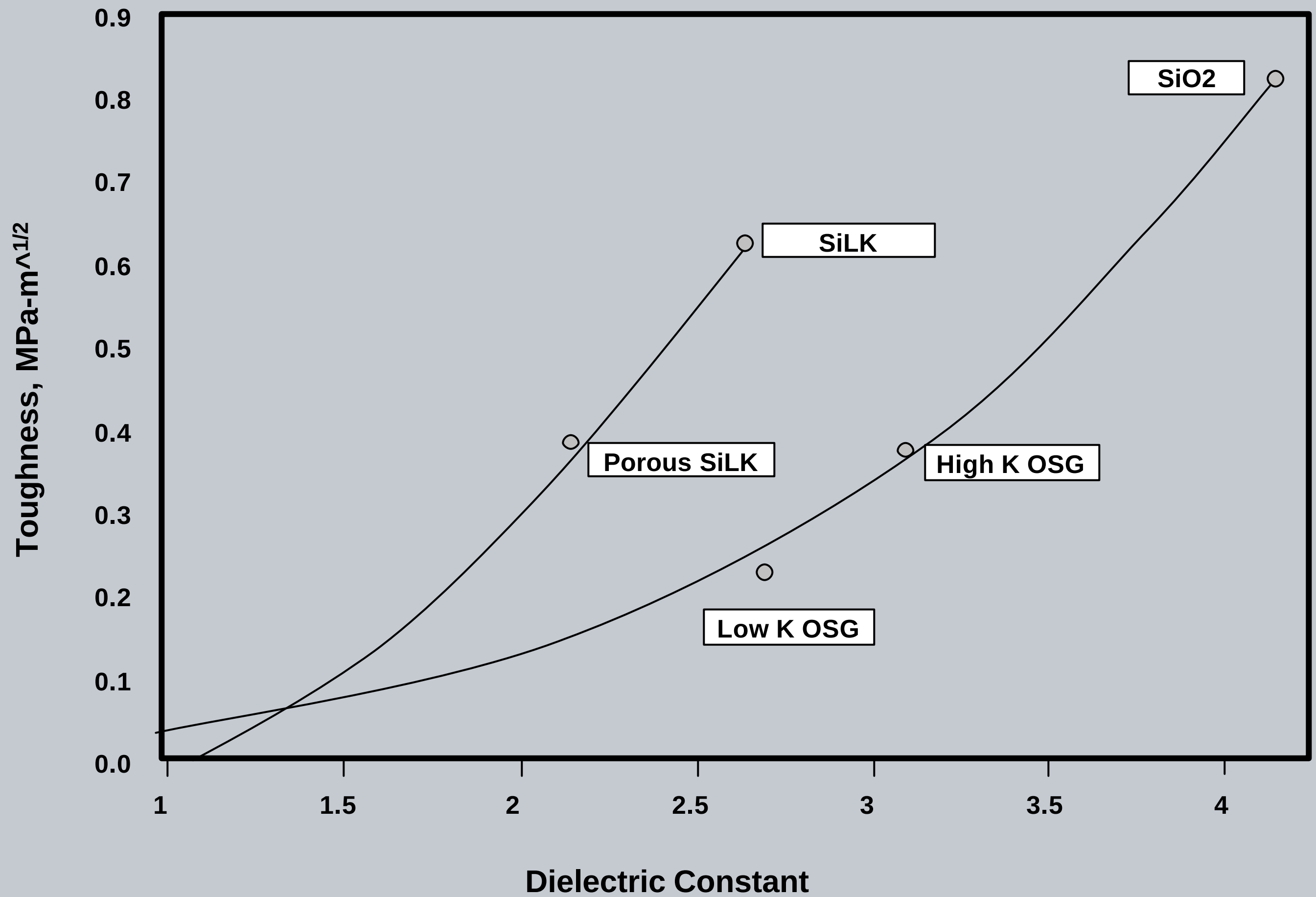
SiLK - Organic, Spin-on, Low-k Dielectric Film. Basic Material Properties

- **SiLK: Aromatic Hydrocarbon -- Pure Organic**
  - **No Fluorine, no Silicon -- C, H, O, ...**
- **K < 2.65**
- **Coat and Cure**
  - Coating is spin-on. Curing is needed.
  - SiLK J has 3.25% adhesion promoter which contains Si
  - Porous SiLK is based on SiLK I.

Process Step	SiLK I	SiLK J	Porous
Dispense Promoter	Yes	No	Yes
Bake Promoter @ 185C for 60 secs	Yes	No	Yes
Dispense SiLK	Yes	Yes	Yes
Bake SiLK @ 325C for 90 secs	Yes	Yes	Yes
Cure SiLK on hot plate or furnace	Yes	Yes	Yes
Adhesion Promoter	No	Yes	No

Ref. *Scott Cummings - Dow Chemical ; PEUG March 2001*

SiLK Properties:
Dielectric Constant and Resistance to Stress



Ref. *Scott Cummings - Dow Chemical ; PEUG March 2001*

SiLK Etch ---- Reaction of SiLK with H_2, O_2, N_2

- **SiLK** + $\mathbf{H_2}$ ➡ C_2H_2, C_2H_4, ***$C_3H_2^+$**,** H_2O, OH^+, ...

  ($C_xH_yO_z$) + $\mathbf{O_2}$ ➡ CO_2, CO, H_2O, OH^+, …

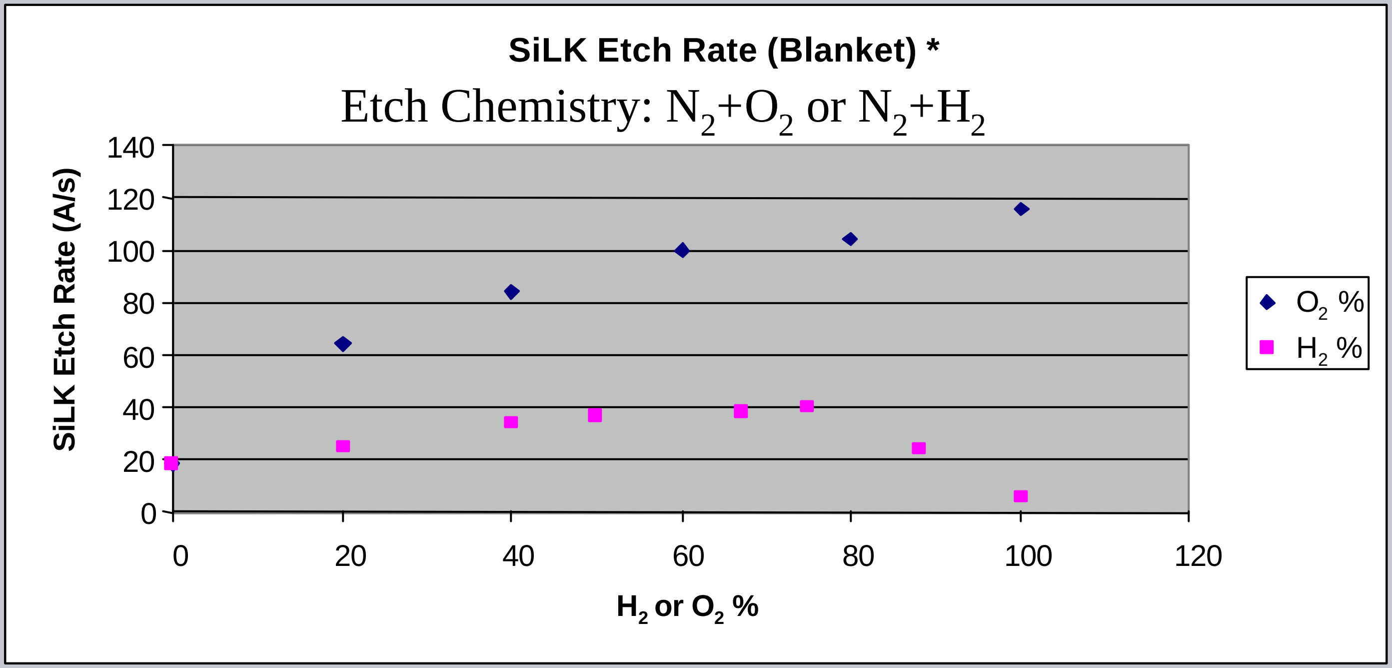
  + $\mathbf{N_2}$ ➡ ***$C_3H_2N^+$**,** CO, NO, NCO, NH^+.

  ⬇ ⬆

  Graphitized SiLK (*Carbon Skeleton*)

* **Polymer Precursors**: Large Molecules or Radicals or Ions formed & decomposed, … yielding less or non-volatile products.

Chemistry for SiLK Etch - SiLK Etch Rate (Blanket)*



- Conclusions:

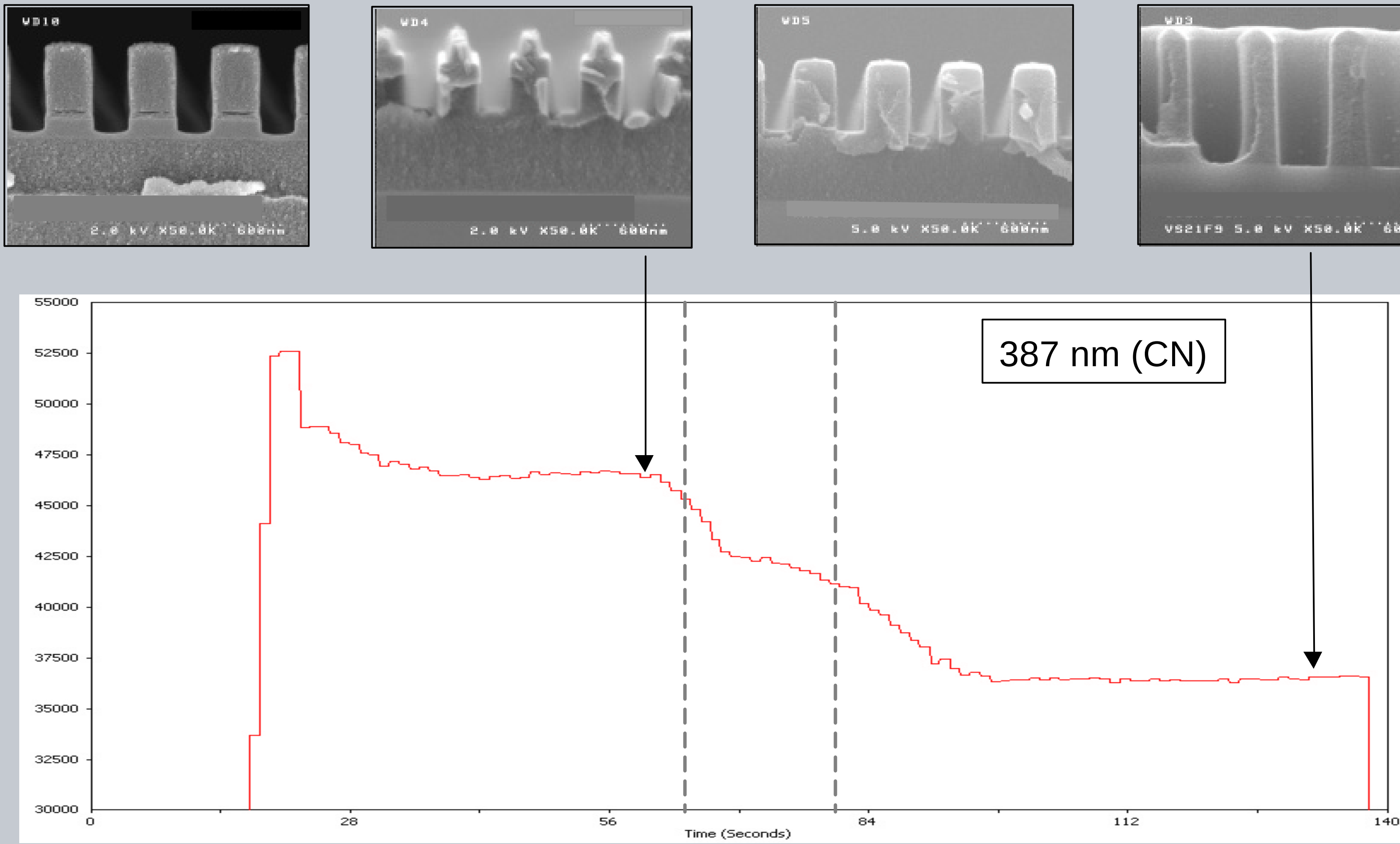
  1). N_2: More physical etching (compared to H_2)

  2). H_2: More chemical Etching

  3). O_2: Chemical and Physical Etching (ER: O_2>N_2>H_2)

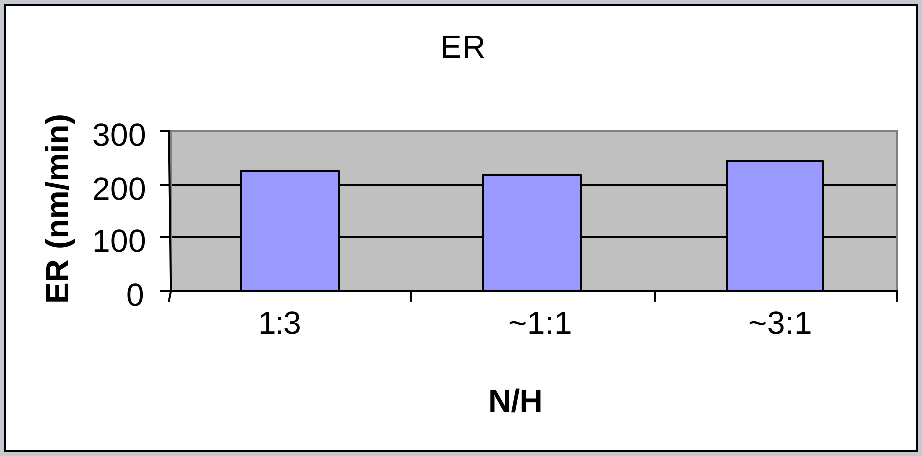
* Ref: D.Fuard, et al., J. Vac Sci. & Technology., B19 (2001)447

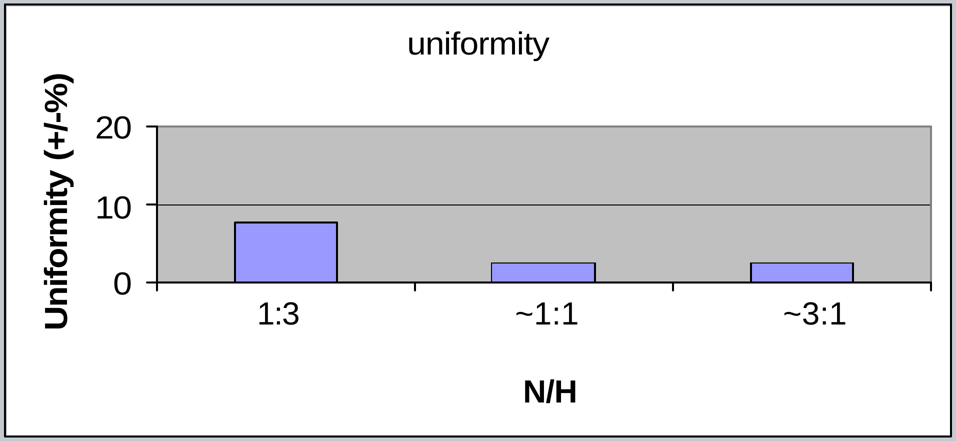
Process Characterization - Plasma Optical Signal Detection during SiLK Etch



N/H Trends - SiLK Via

ER and Uniformity: Wide Process Window for SiLK Etch

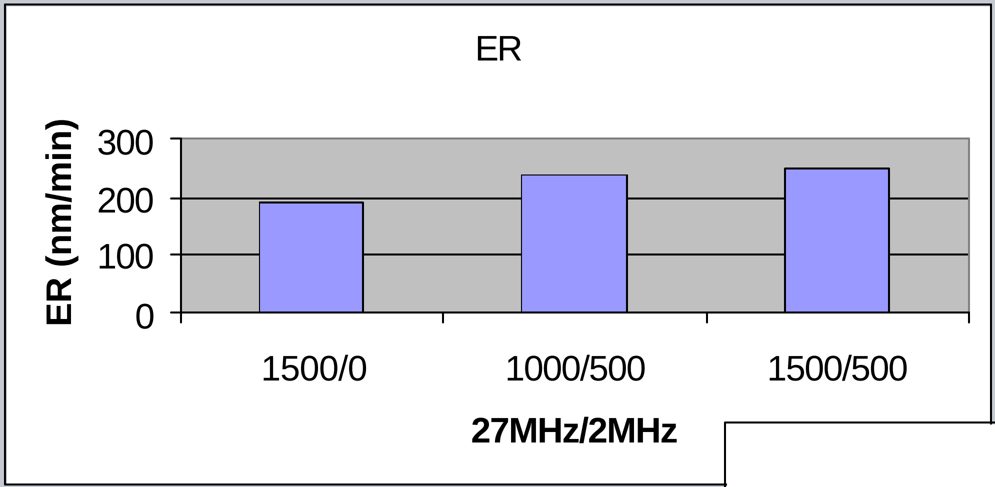


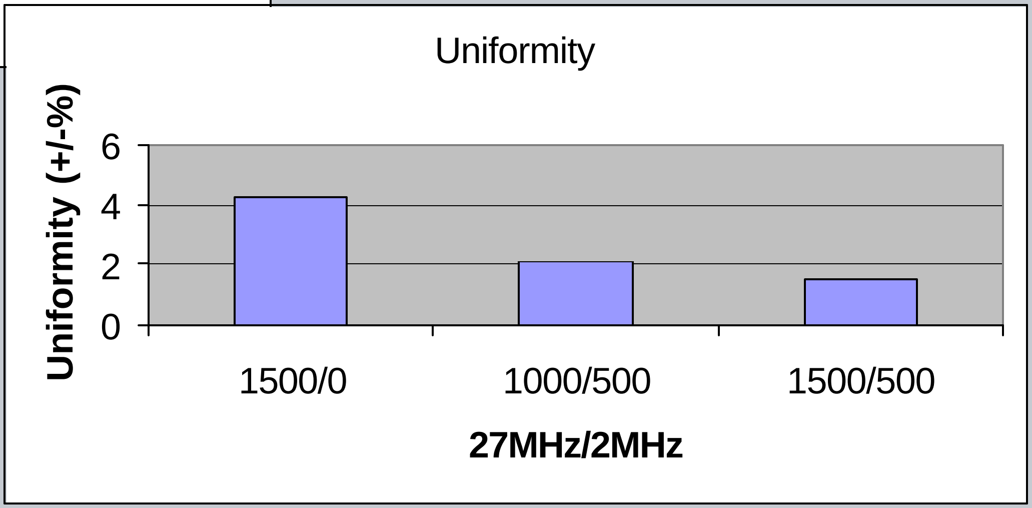


Increasing N/H ratio and/or total flow does not strongly influence ER but improves ER uniformity

N/H Trends - SiLK Via

ER and Uniformity: Effect of Generator Power





Higher 27/2 RF power ratio and higher total power increases ER and improves uniformity

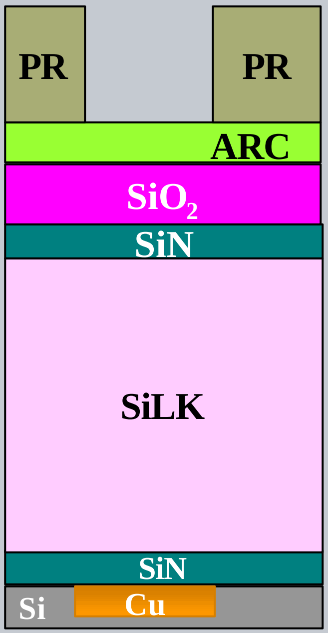
Etch Challenges and Solutions

- *Single Damascene*
- *Dual Damascene*

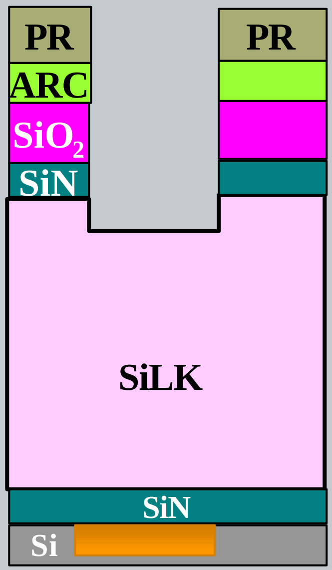
- *Integration Schemes*
- *Process Challenges*
- *Lam Solutions for Integrated SiLK Etch*

Dual-HM SiLK Single Damascene Trench Etch

Pre-etch Structure

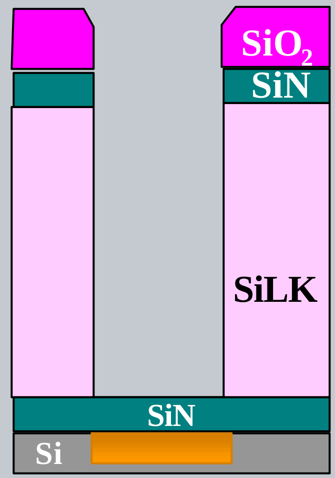


1. ARC/Mask Open



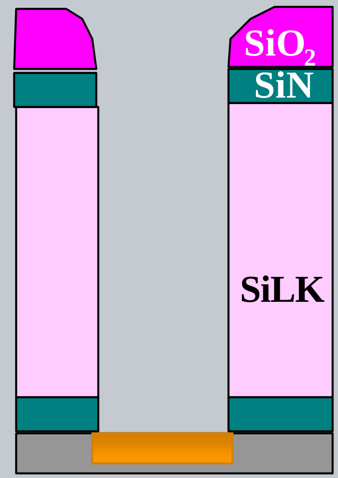
- **CD Bias <10*nm***

2. SiLK Trench Etch



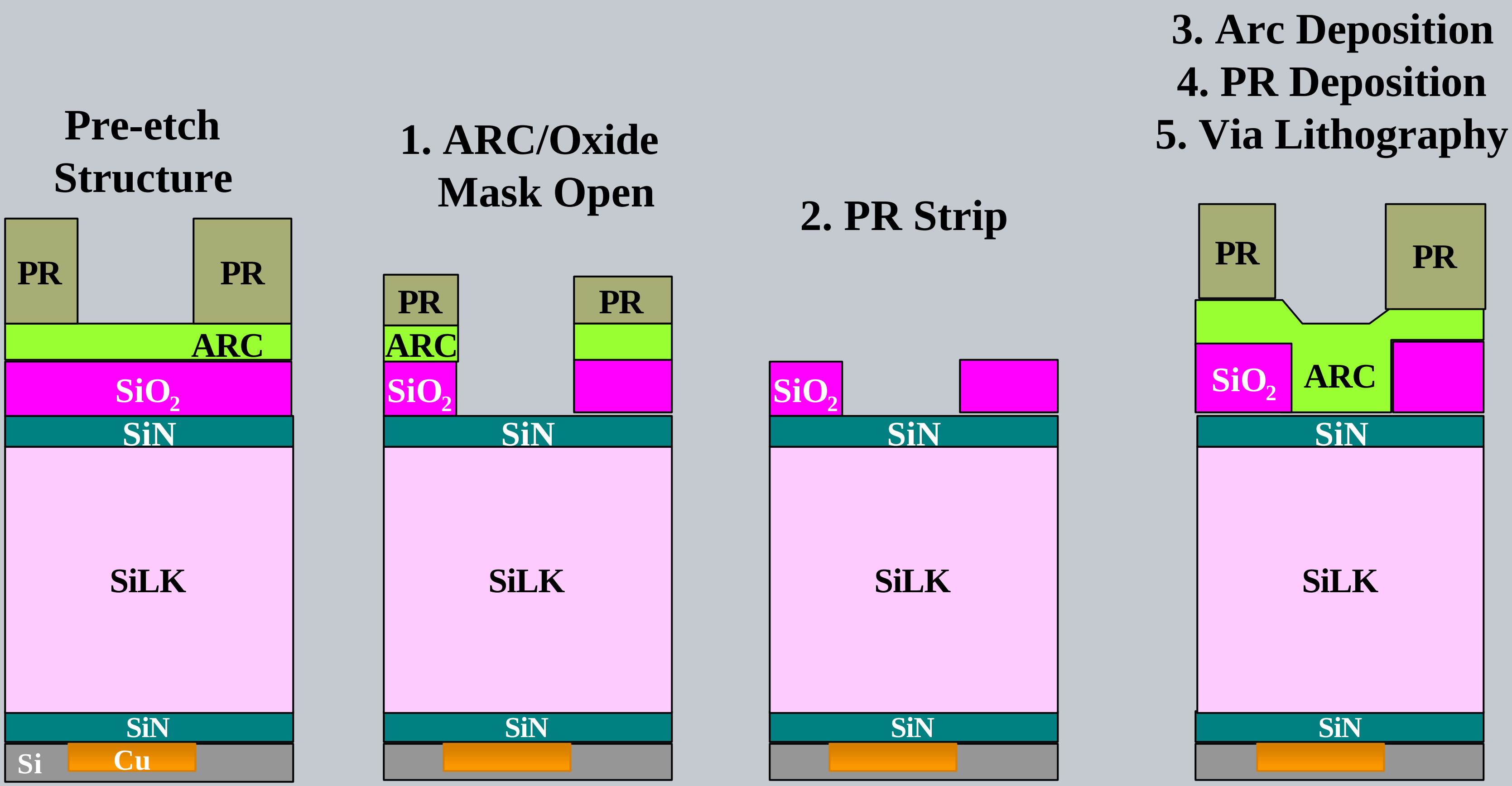
- **No bowing**

3. Barrier Open



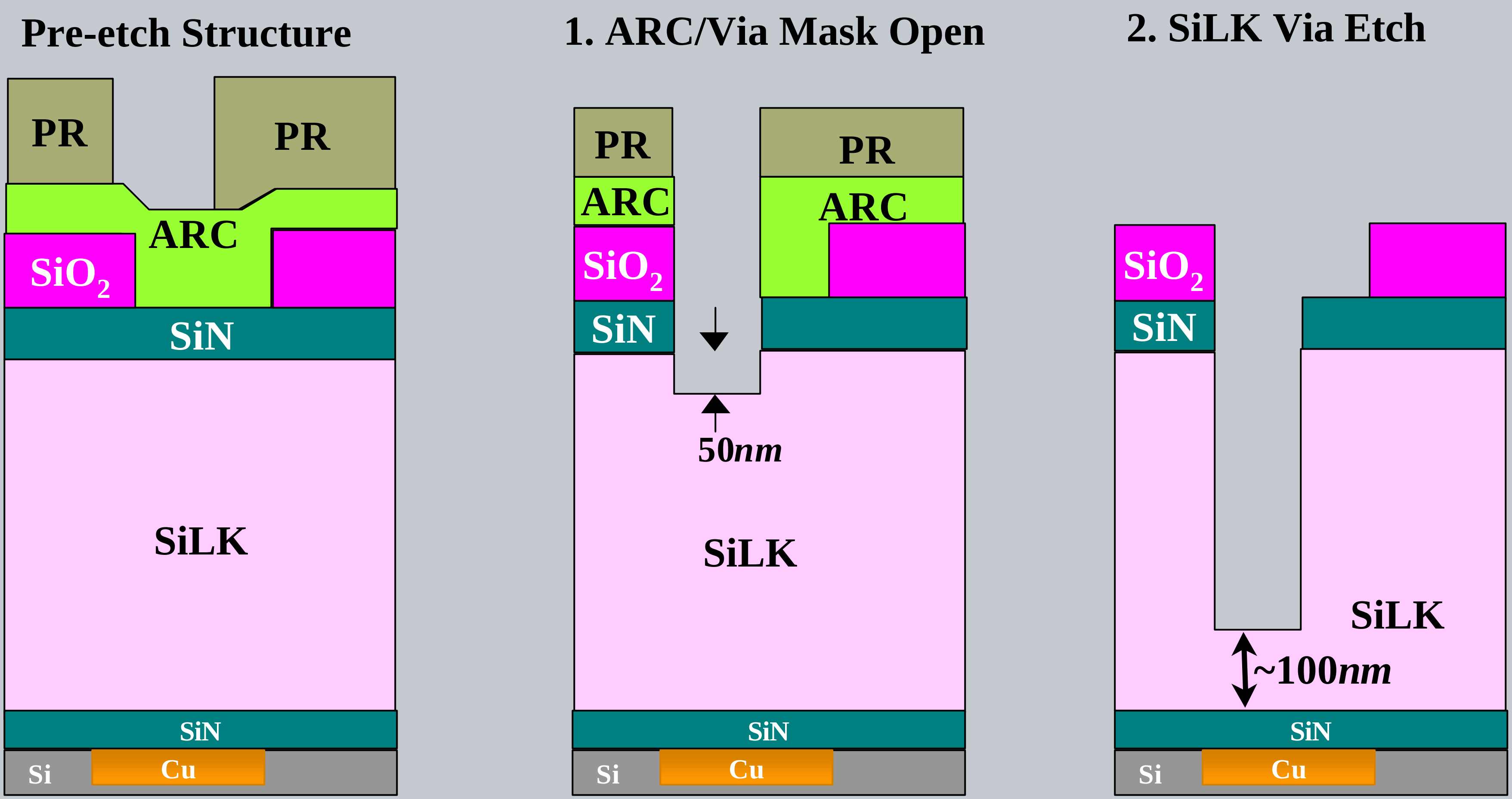
- **Low Facet and Mask Erosion**
- **No undercut**

Dual-Hard Mask SiLK Etch - Trench pattern definition for DD scheme



- CD Bias <10*nm*
- CD Bias <10*nm*
- Ready for DD

Dual Hard Mask DD SiLK Etch without Stop Layer

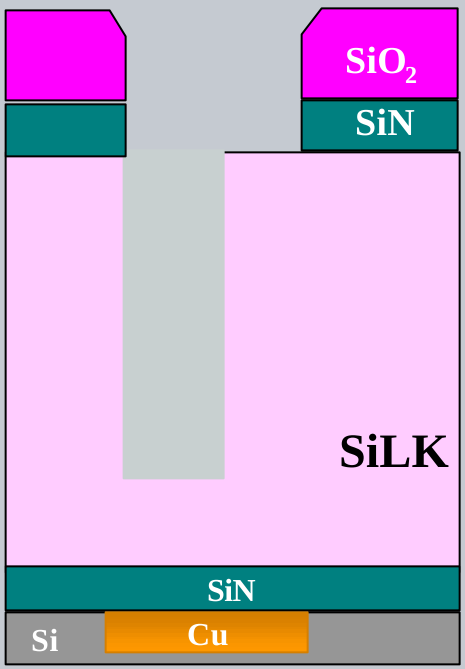


- CD Bias<10*nm*

- No bowing

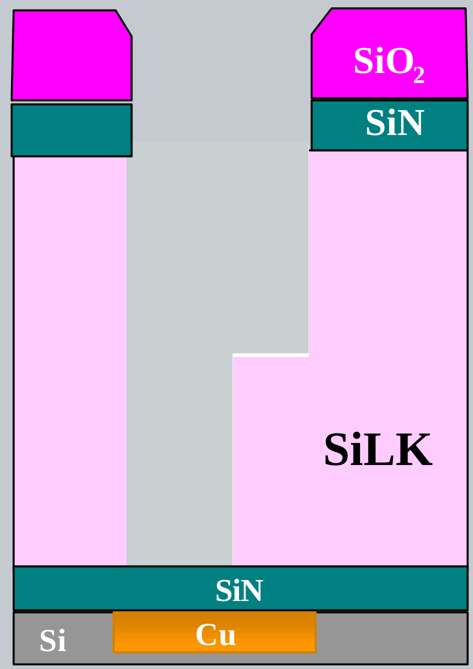
Dual Hardmask DD SiLK Etch without Stop Layer - continued

3. Trench Mask Open



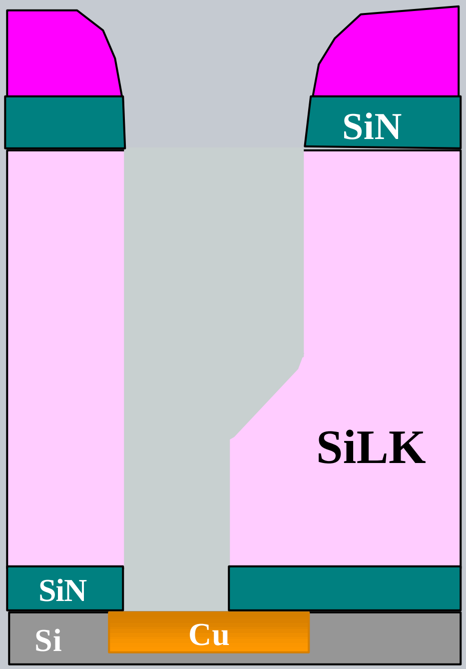
- *Minimal mask facet*
- *No mask undercut*

4. SiLK Trench Etch



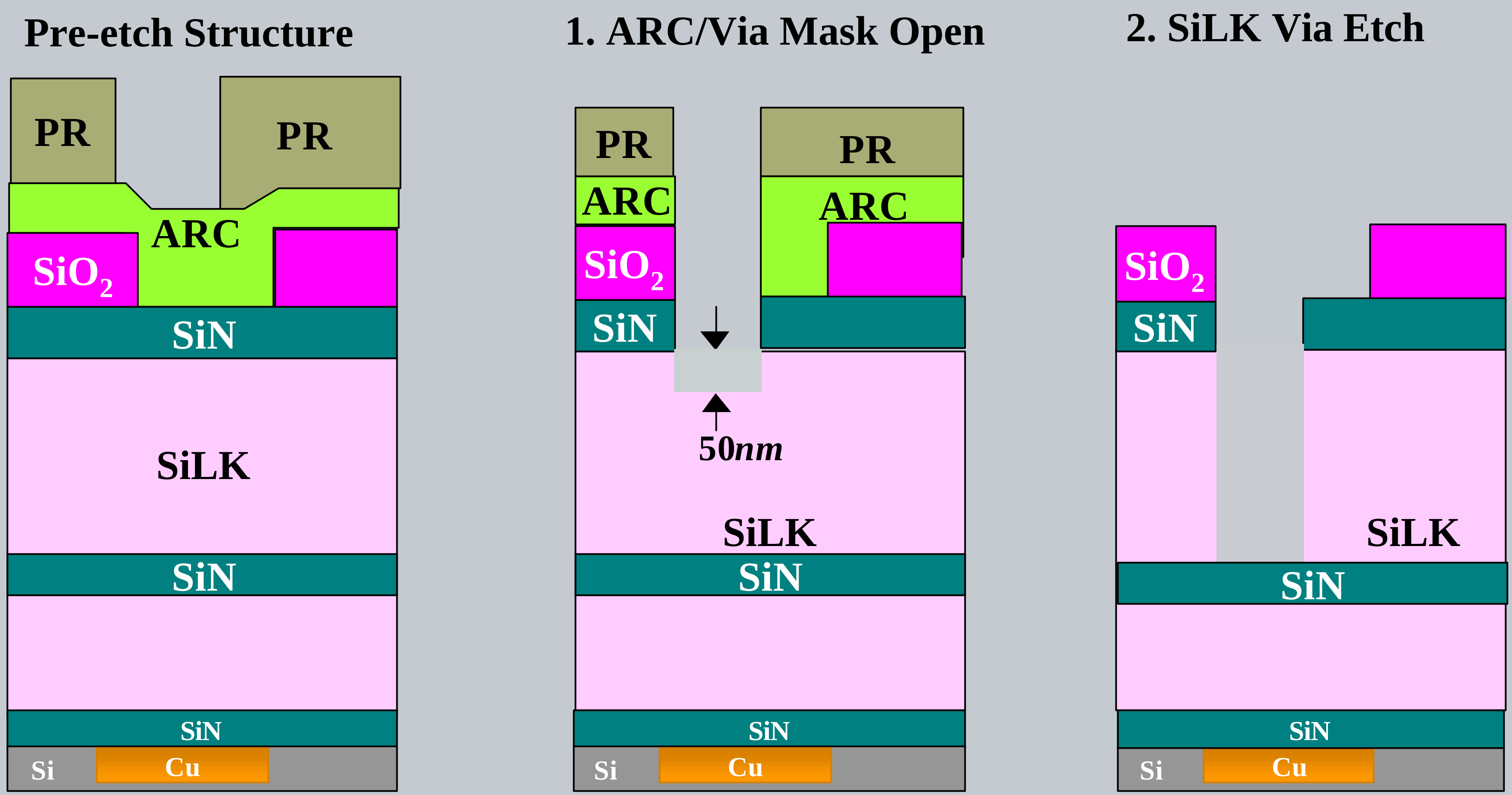
- *No microtrenching*
- *No residues*

5. Finish Etch



- *Minimal mask facet*
- *No mask undercut*

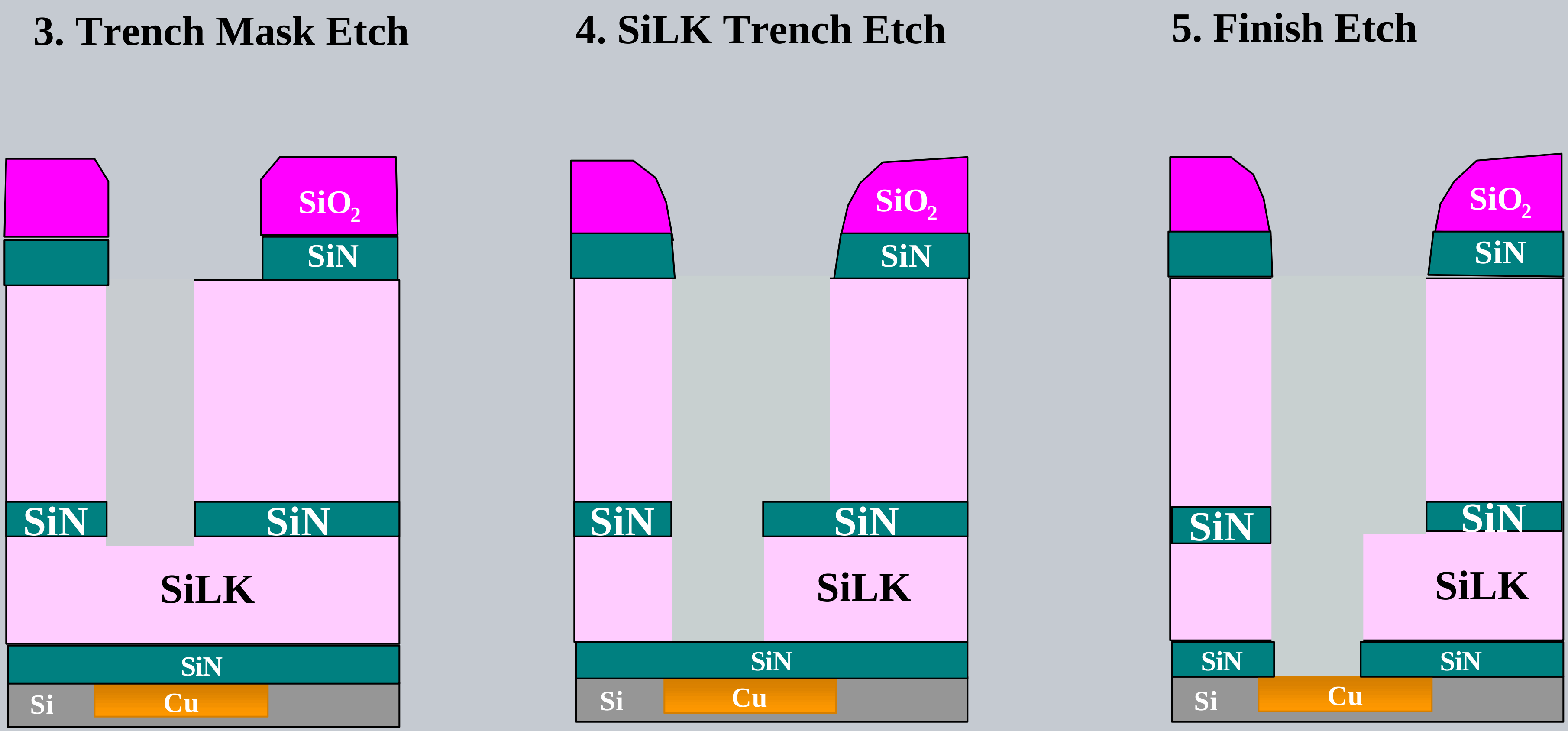
Dual Hardmask DD SiLK Etch Steps with Stop Layer



- *CD Bias<10nm*
- *No bowing*

Dual Hardmask DD SiLK Etch Steps with Stop Layer

-continued



- *Minimal mask facet*
- *No mask undercut*

- *No microtrenching*
- *No residues*

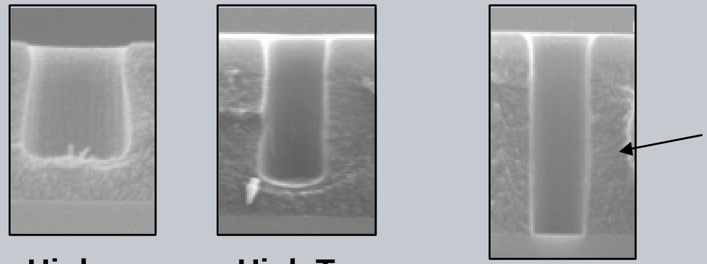
- *Minimal mask facet*
- *No mask undercut*

Other possible SiLK DD Integration Schemes:

- **Self Aligned**
- **Trench First Via Last**
- **Via First Trench Last**

Etching Challenges and Solutions

- **CD/Profile control**
  - Pressure -- change in process regime
  - Pressure -- Neutral/ion ratio
  - Temperature -- sticking coefficient
  - Additives -- Polymer precursors

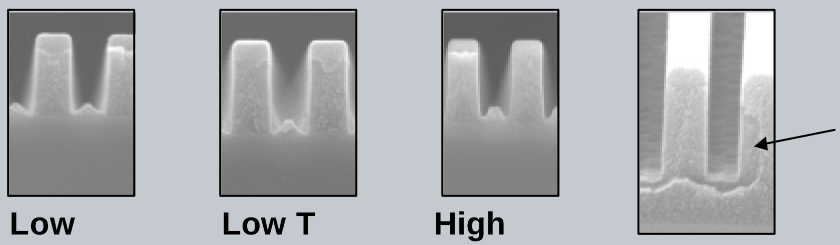


High Press.

High T

Optimized:
Vertical profile with good CD and facet control

- **Microtrenching**
  - Bias power
  - Pressure
  - Temperature
  - Polymer addition



Low Pressure

Low T

High CHxFy & high Pressure

Optimized:

Vertical profile with no bowing, no residue , and no microtrenching.

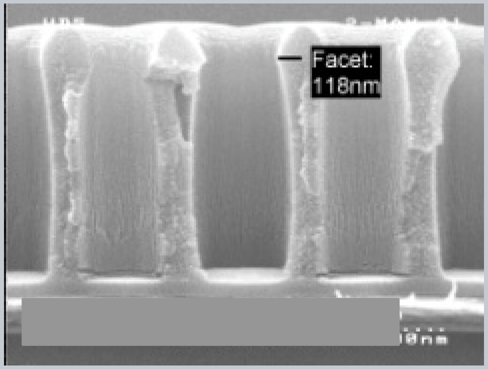
Etching Challenges and Solutions:

Facet:

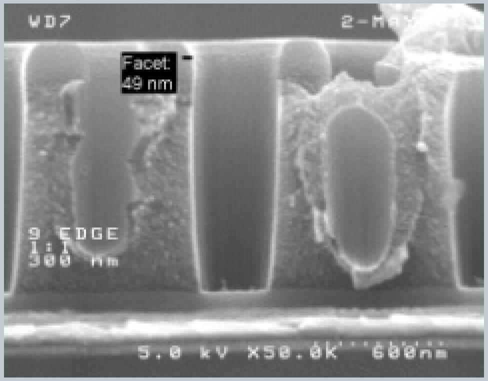
Knobs:

2 MHz Power (W)

ESC Temperature



500 W (2 MHz) / 40 °C



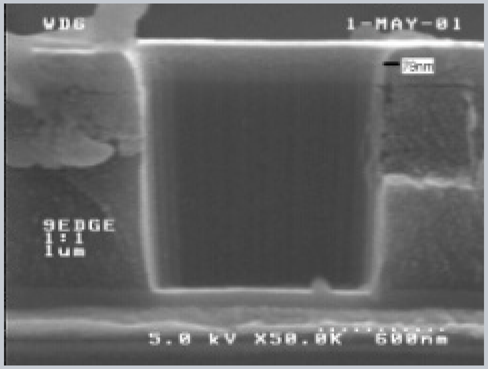
0 W (2 MHz) / 0 °C

Via CD:

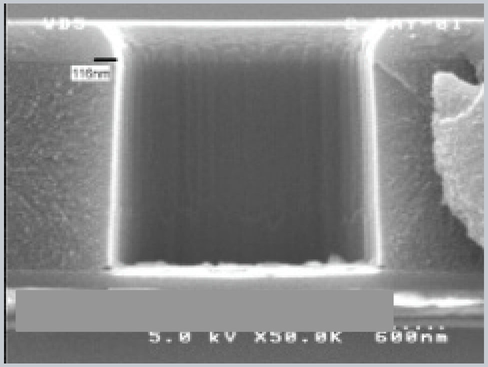
Knobs:

2 MHz Power (W)

ESC Temperature



0 W (2 MHz)/0 °C



500 W (2 MHz)/40 °C

Dual HM SiLK Etch

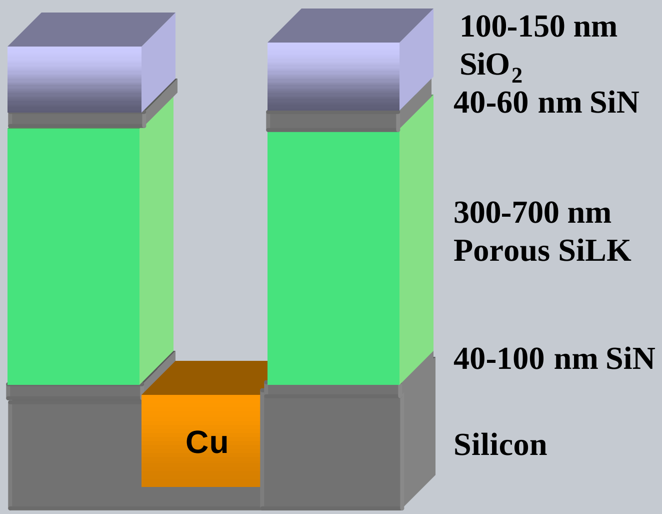
- **Etch Performance**
  - **Vertical profile**
  - **Minimum HM facet**
  - **Residue-free**
  - **No under cut, no bow**
  - **Flat and smooth trench etch front**
  - **No residue/ grass/ pitting, no microtrenching**
  - **Etch rate**
  - **Good profile (No bowing)**
  - **Maintain critical dimensions (CD)...**

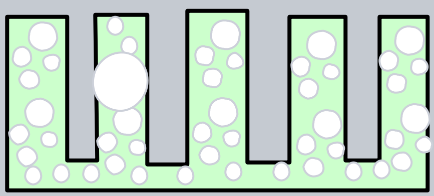
Etching of Porous SiLK

Porous Low-k Etch Integration: Similar Integration Schemes as Non-Porous Materials

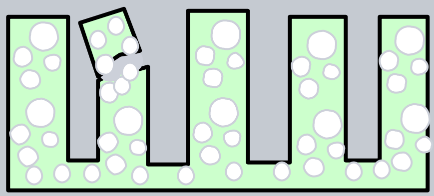
Typical Film Stack for DD Porous or Non-porous SiLK:

SD Trench Post-Etch

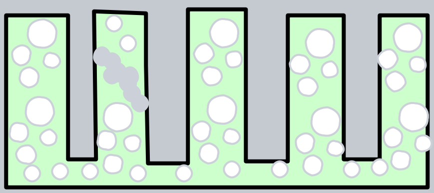




Not very large pores for protection against shorts



Uniform Pore Distribution for mechanical integrity and performance

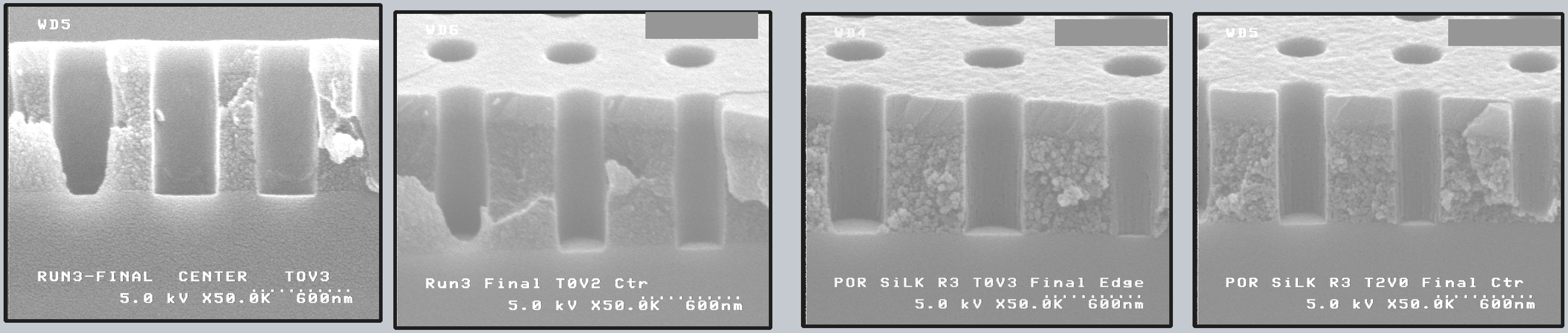


Closed Pores. Channels can trap chemicals

Ref. *Scott Cummings - Dow Chemical ; PEUG March 2001*

Dense and Porous SiLK Etch - SD Via Comparison

SiLK	Porous SiLK

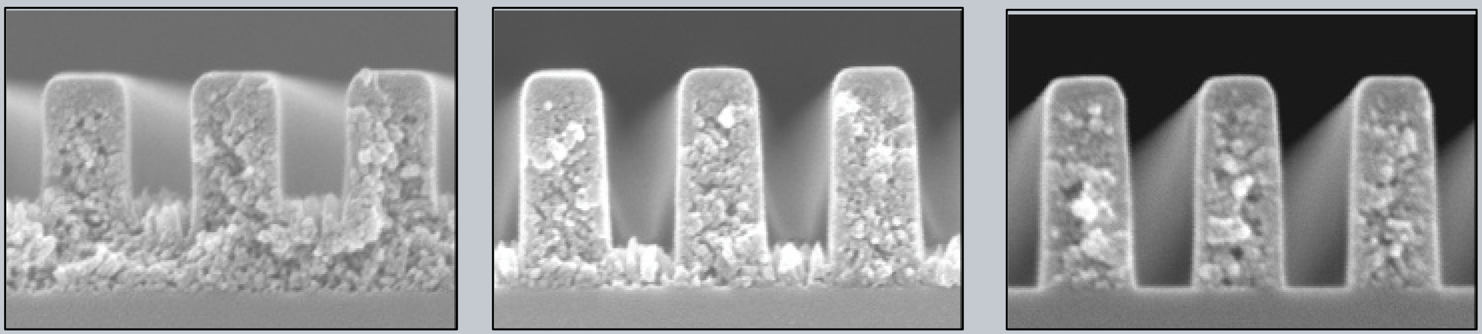


- **Similar results obtained using the same process**
- **10 to 30% higher etch rate for porous SiLK**

Single Damascene processing with porous materials

Etch front roughness is eliminated when encountering a stop layer

Etch Front Progression



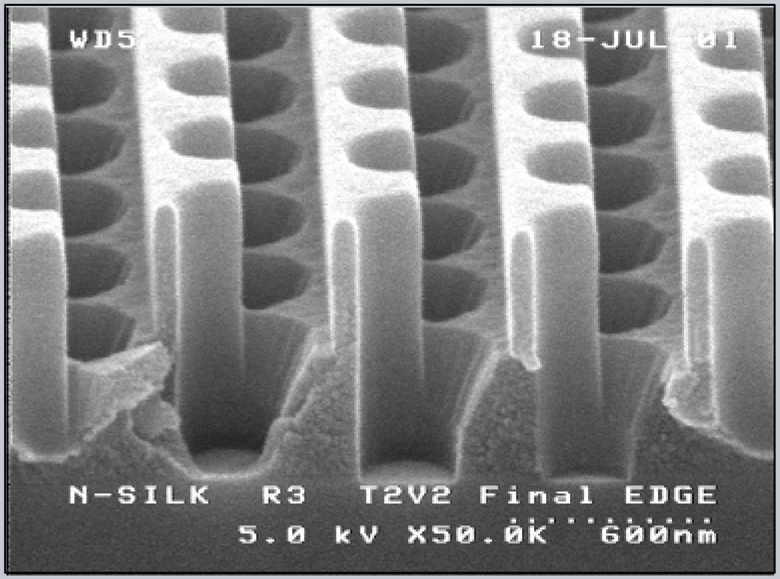
Etch rate Comparison

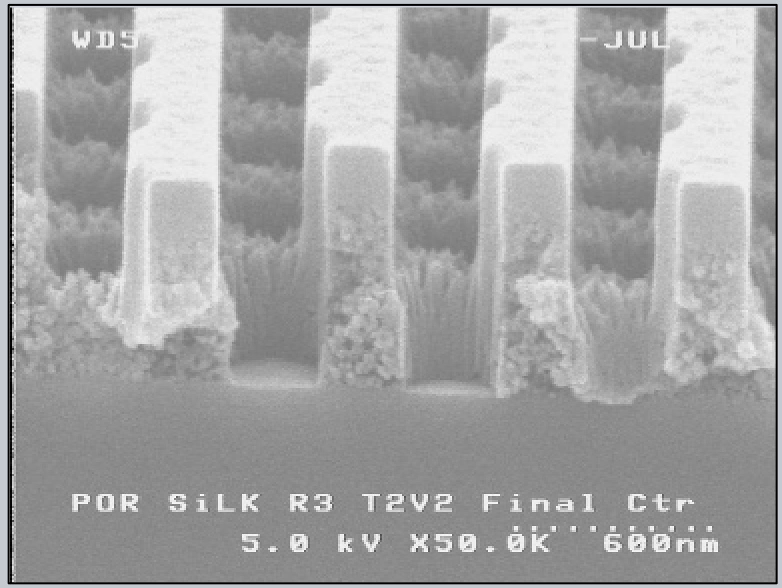
	SiLK ER (A/min)	OSG ER (A/min)
Non-Porous	**2250**	**2437**
Porous	**2970**	**3286**
ER Ratio	**1.32**	**1.35**

- Porous low-k etch rates are typically 20-30% higher than the non-porous film

Dense and Porous DD SiLK Etch - Comparison

SiLK	Porous SiLK





- **Dense and Porous SiLK: similar etch behavior: Etch Process recipe can be easily transferred from dense SiLK**
- **Higher Etch Rates for porous material**
- **Similar Integration**
- **For porous SiLK, rough etch front might require stop layer**

Dense and Porous SiLK Etch - Summary

- **Optimized SiLK etch process for Single and Dual Damascene applications have been developed on Lam Research dielectric etch systems, down to 130 nm feature CD.**
- **Different chemistries (reducing or oxidizing) can be used to etch SiLK.**
- **SiLK profile and microtrenching can be improved by gas additives and/or optimizing pressure, ESC temperature, and RF power.**
- **Responses such as HM facet, bowing and CD can be finely controlled using gas flows, 27 MHz power, 2 MHz power and pressure as factors. Process factors with the greatest effect on process performance vary with feature dimension.**
- **Dense and Porous SiLK etching display similar process trends, making processes transferable from dense to porous SiLK with ease. An porous SiLK DD integrated scheme has been demonstrated**

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