An Advanced Cleaning Technique that is Environmentally Benign

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  - Drive toward advanced cleans
  - Emerging all dry clean processing
  - Next generation clean challenges
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  - Process
  - Example of results
- Conclusions

Drive Toward New Generation Cleans

- Cost Reduction
  - Reduction or elimination of solvents
  - Reduction in excessive use of water
  - Integrated clean processing
- Technology
  - Compatibility with new IC materials
  - Limitations of water-related wetting
    - surface tension
    - corrosion promotion
- Environmental
  - Use environmentally benign chemicals
  - Recycle chemical reagents

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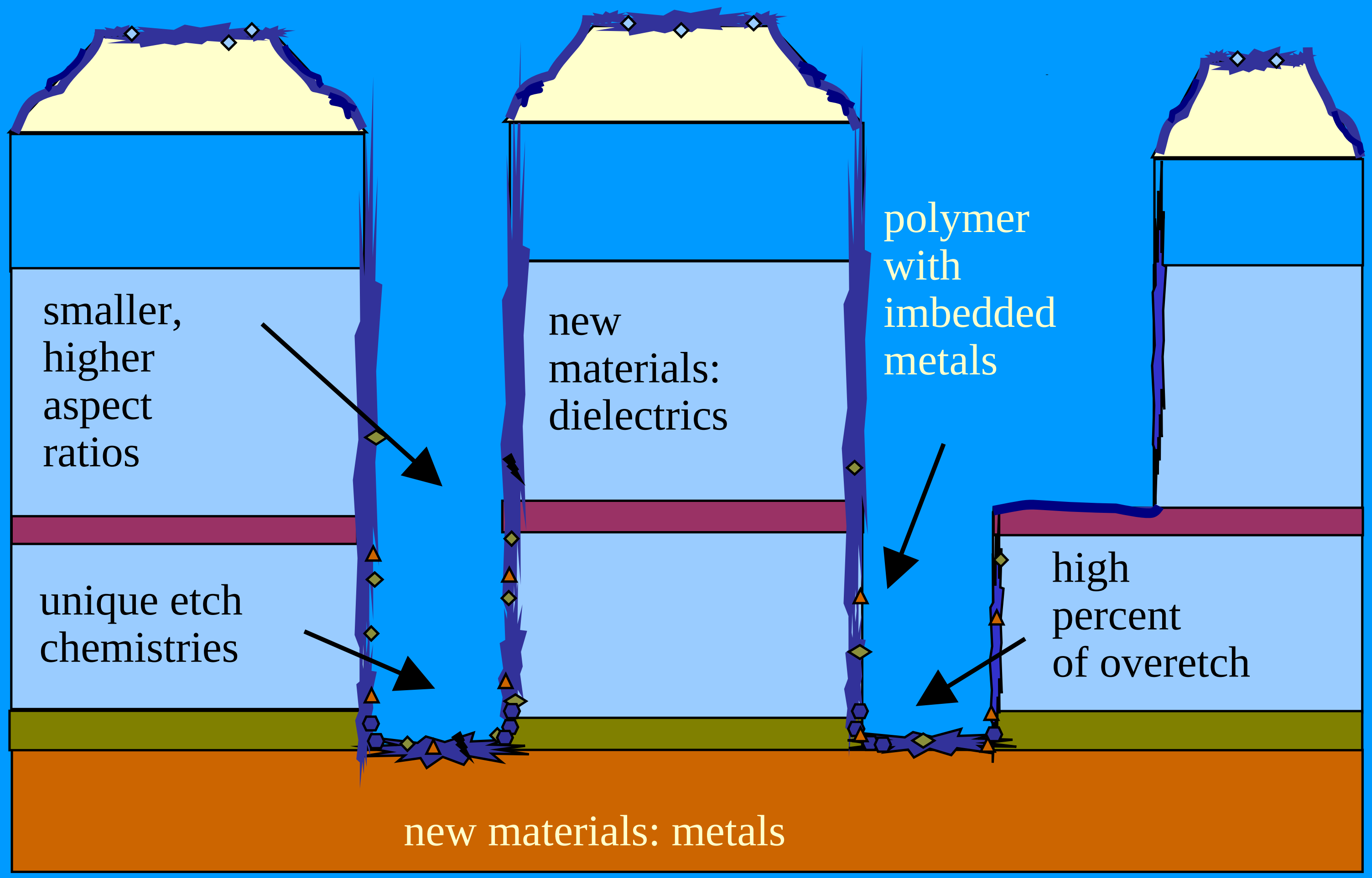
Next Generation Clean Requirements



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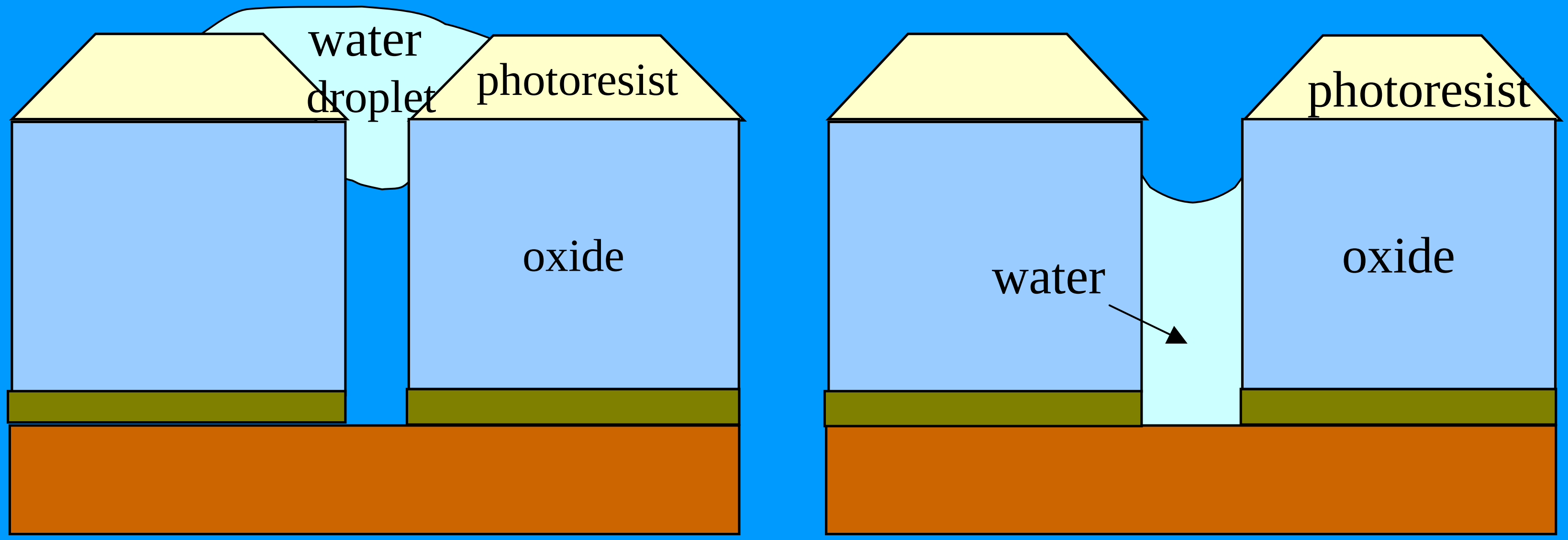
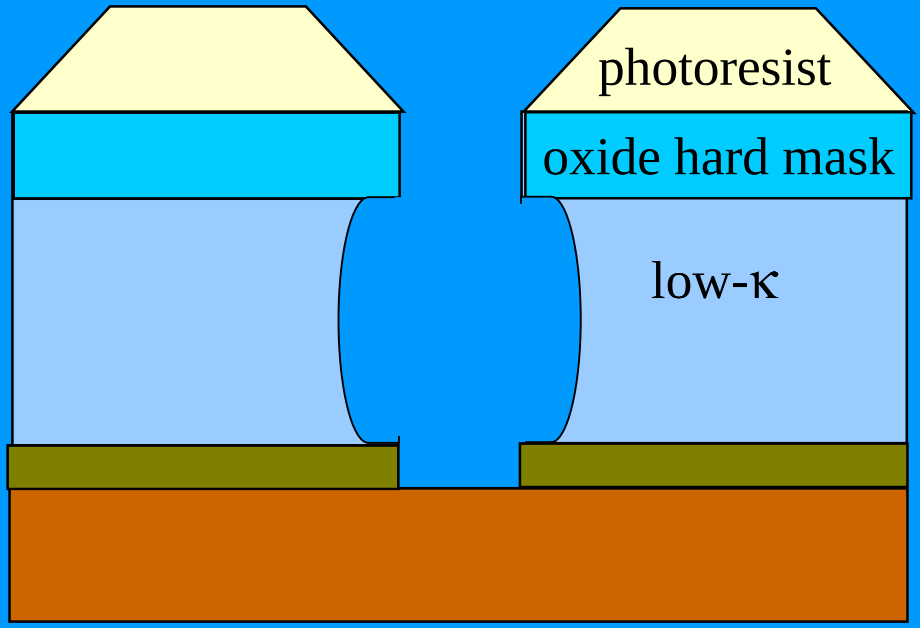
Clean Challenges

- Water surface tension and viscosity
  - High surface tension and high viscosity of water
    - Prevents drying of high aspect ratio vias
    - Prevents wetting if extremely small vias



Clean Challenges

- Compatibility with new IC materials
  - High organic percent low-κ materials will be a challenge to clean
    - Augmentation of the dielectric constant
    - Undercutting of the hard mask



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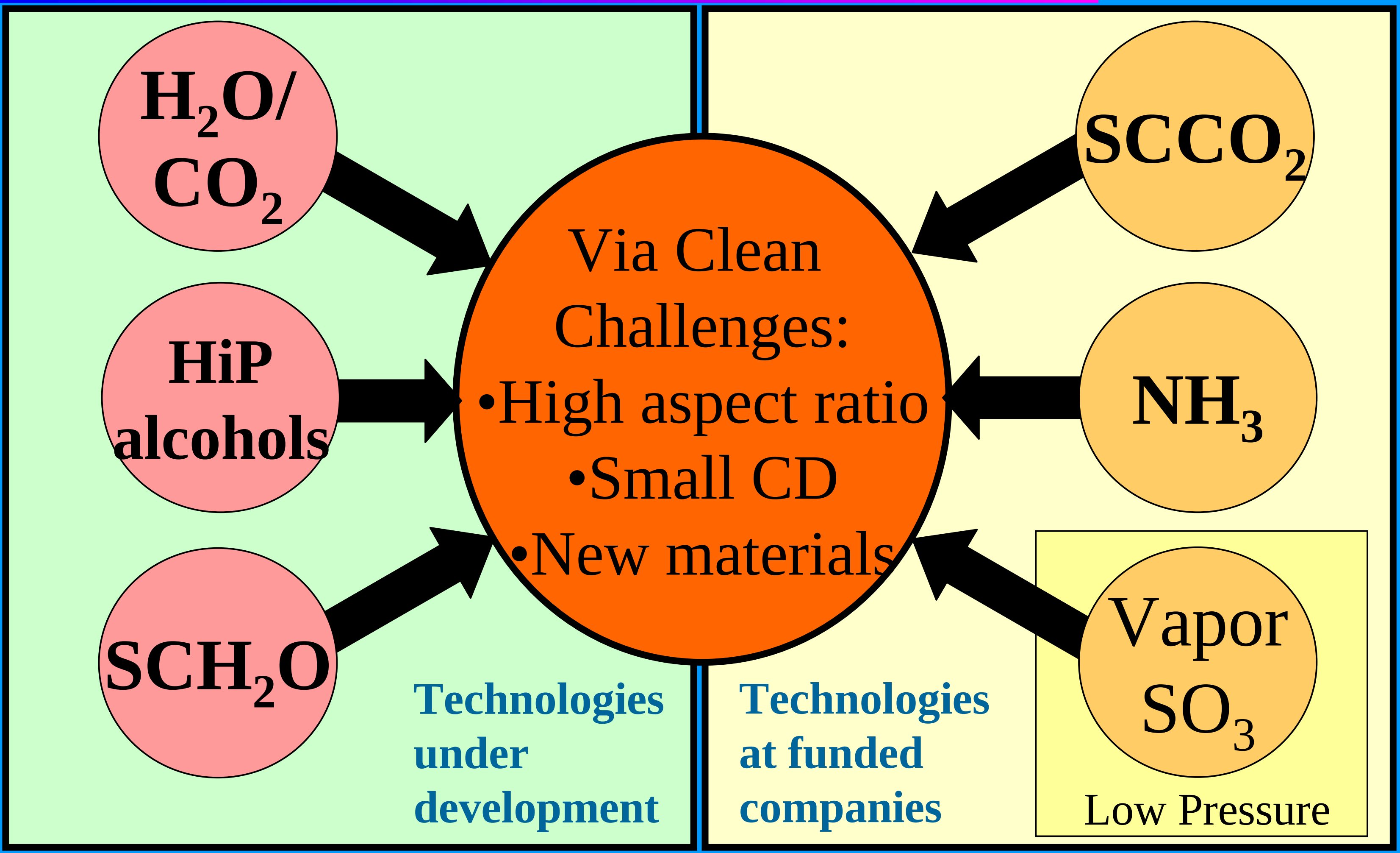
Emerging Dry Clean Technologies

- Particle Removal
  - Laser cleaning
  - Cryogenic snowballs- CO_2 or Ar/N_2
  - Charged liquid clusters
- Post-Etch Residue Removal
  - Supercritical Fluids- CO_2 based
  - Low Pressure Gas- SO_3 based
  - High Pressure Fluid- NH_3 based
    - Densified Fluid Cleaning (DFC)

Emerging High Pressure Clean Technologies



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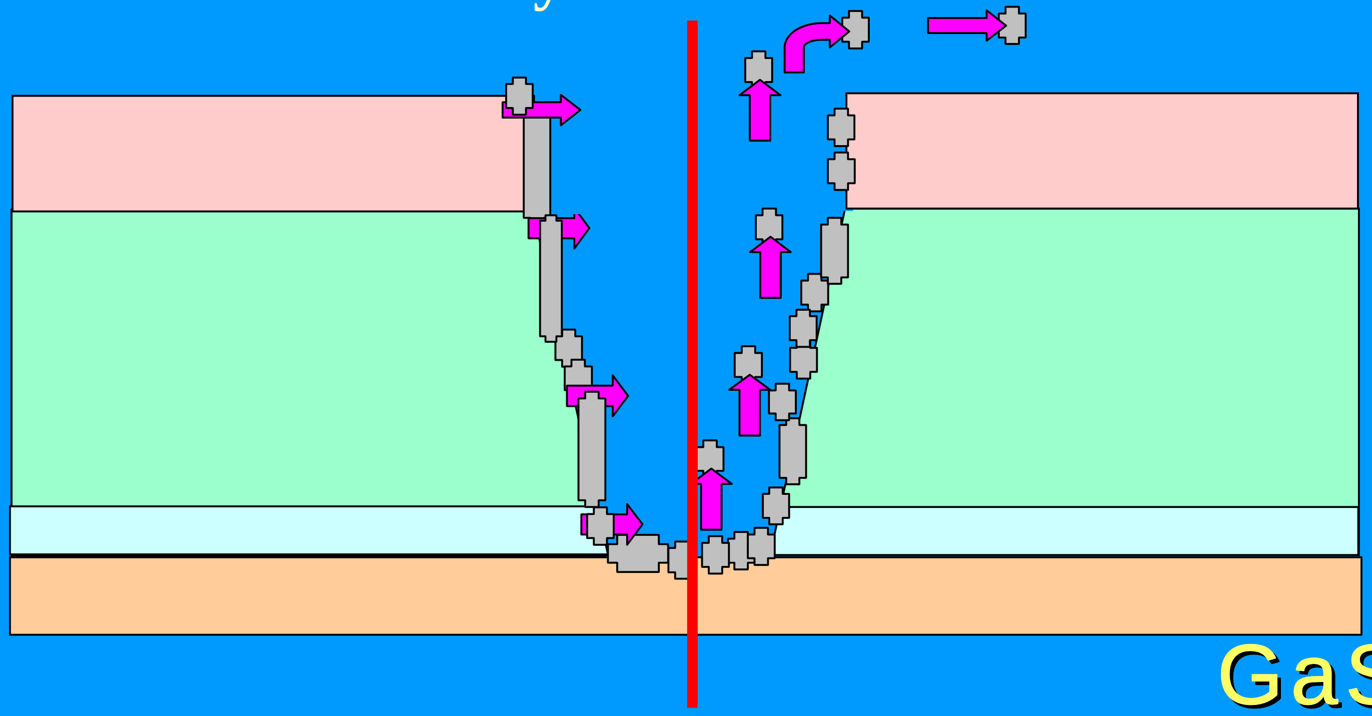
Advantages of High Pressure Technology

- Able to penetrate high aspect ratios
- Able to remove residue from small vias
  - Low surface tension
  - Low viscosity



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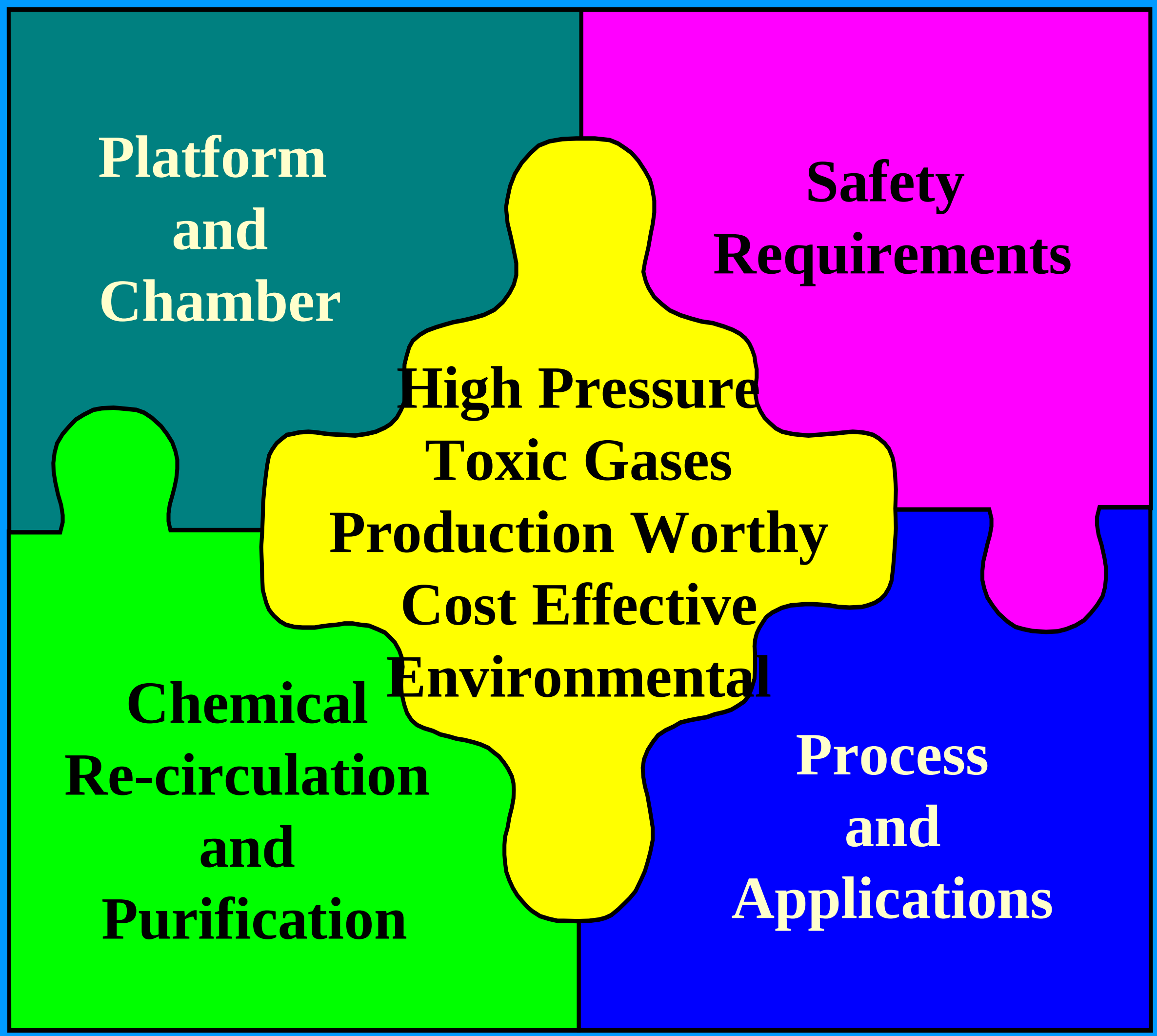
High Pressure Cleaning



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Densified Fluid Cleaning- DFC

- Densified Fluid Cleaning
  - A non-aqueous cleaning technology
  - Using anhydrous liquid ammonia
  - At elevated pressure and low temperature
- DFC is applied to post-etch residue removal
  - Applications
    - via/trench
    - metal cleans
    - deep trenches
    - low- κ materials

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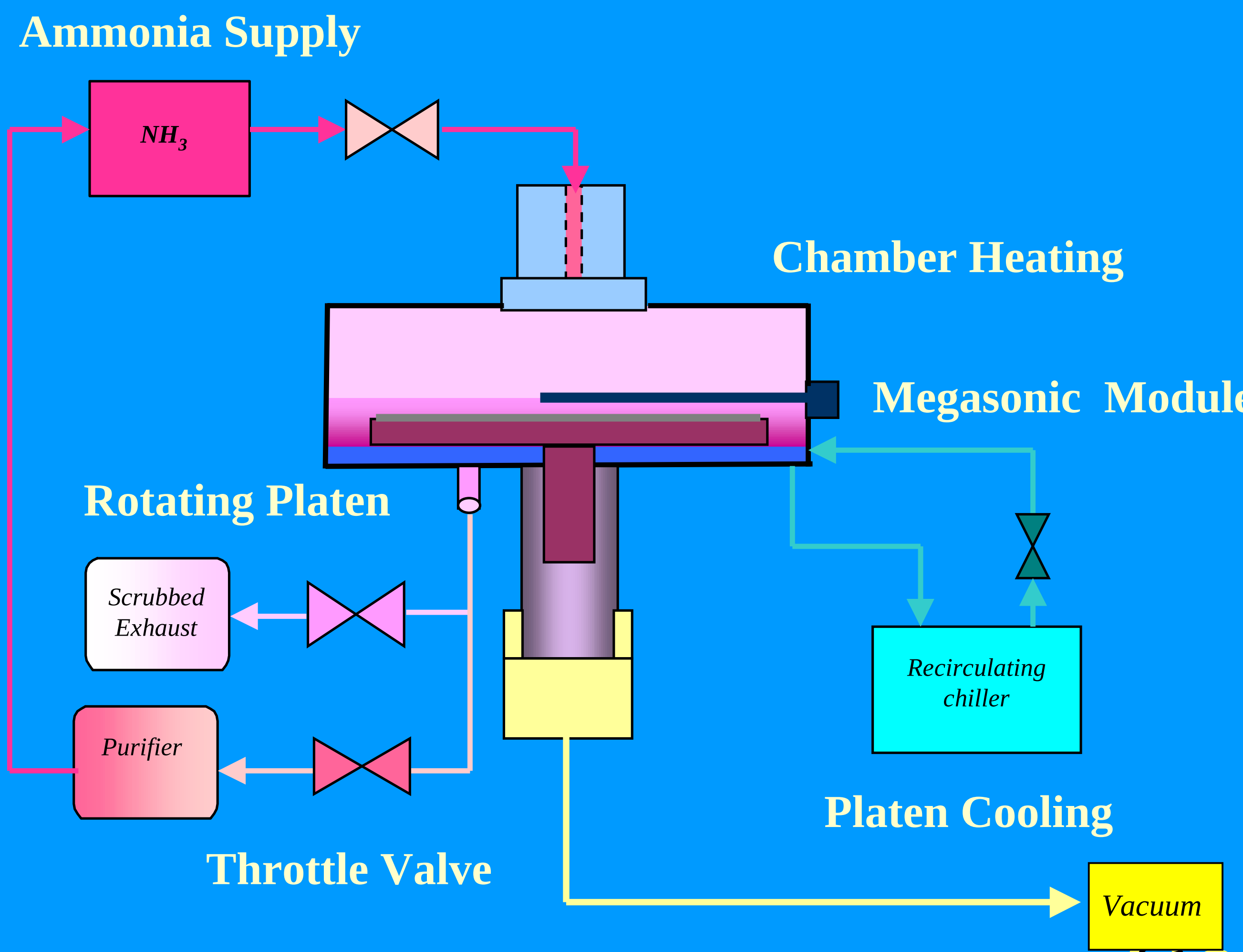
DFC Process Module



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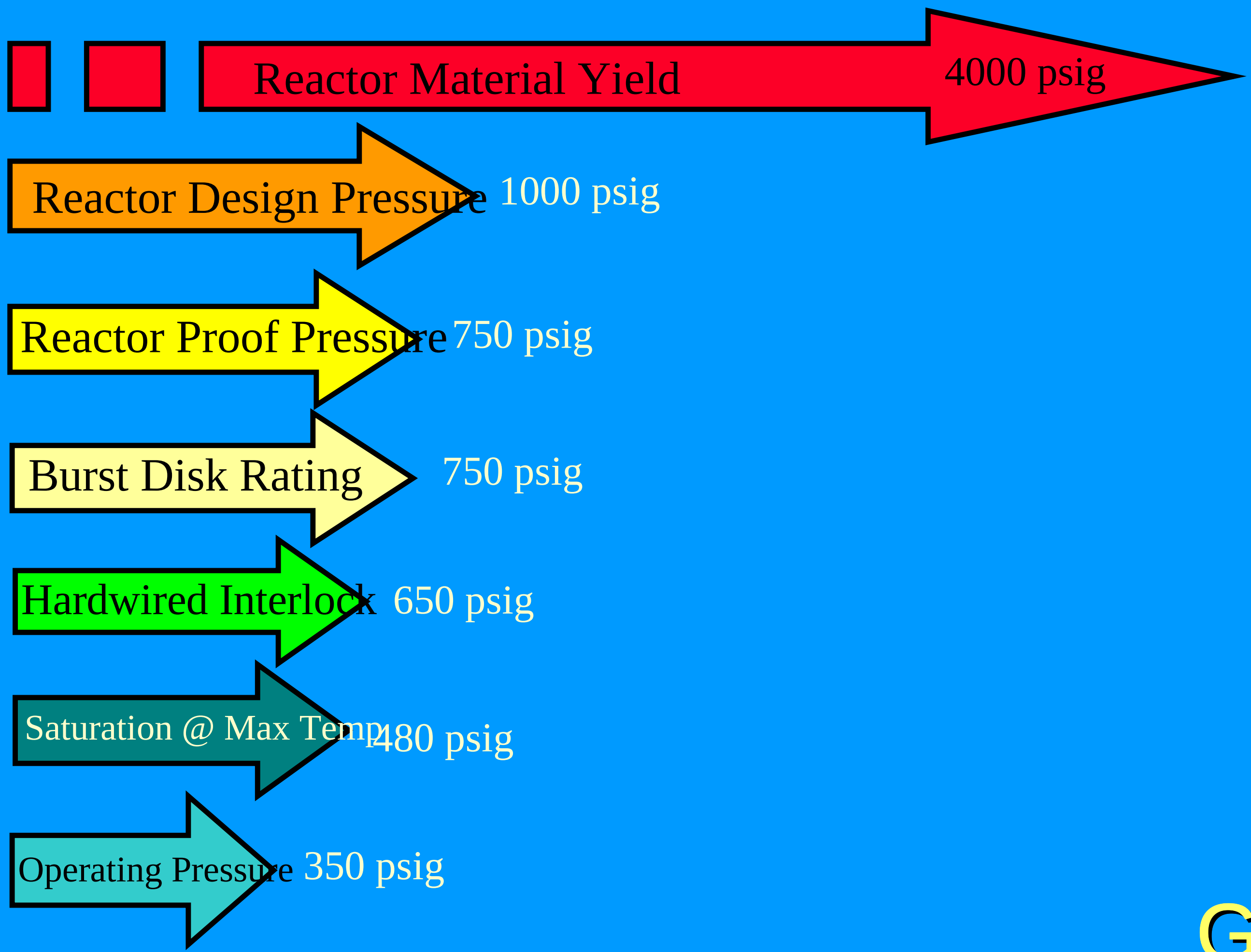
Reactor Safety - Design Considerations



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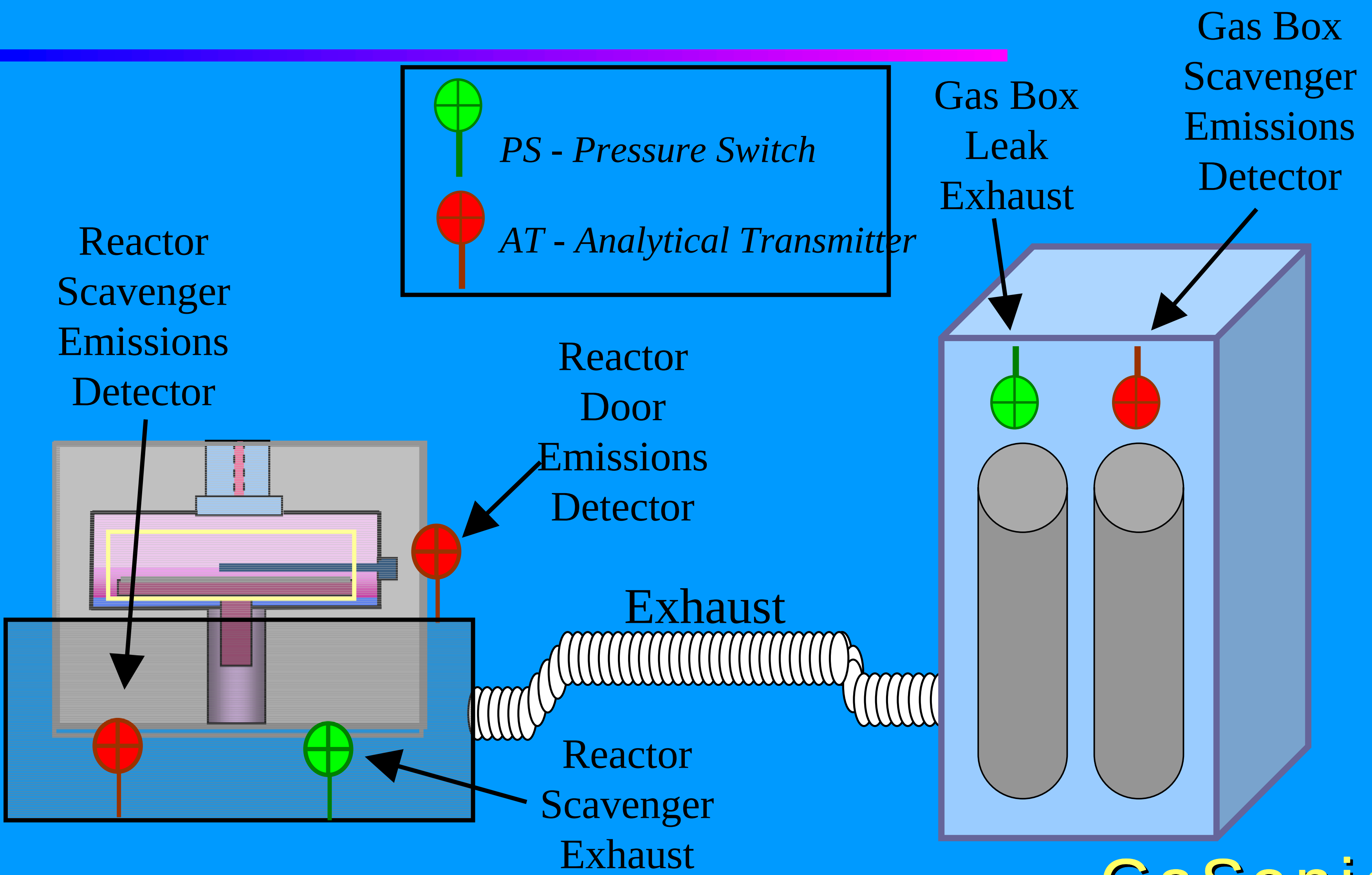
Fugitive Emissions Control



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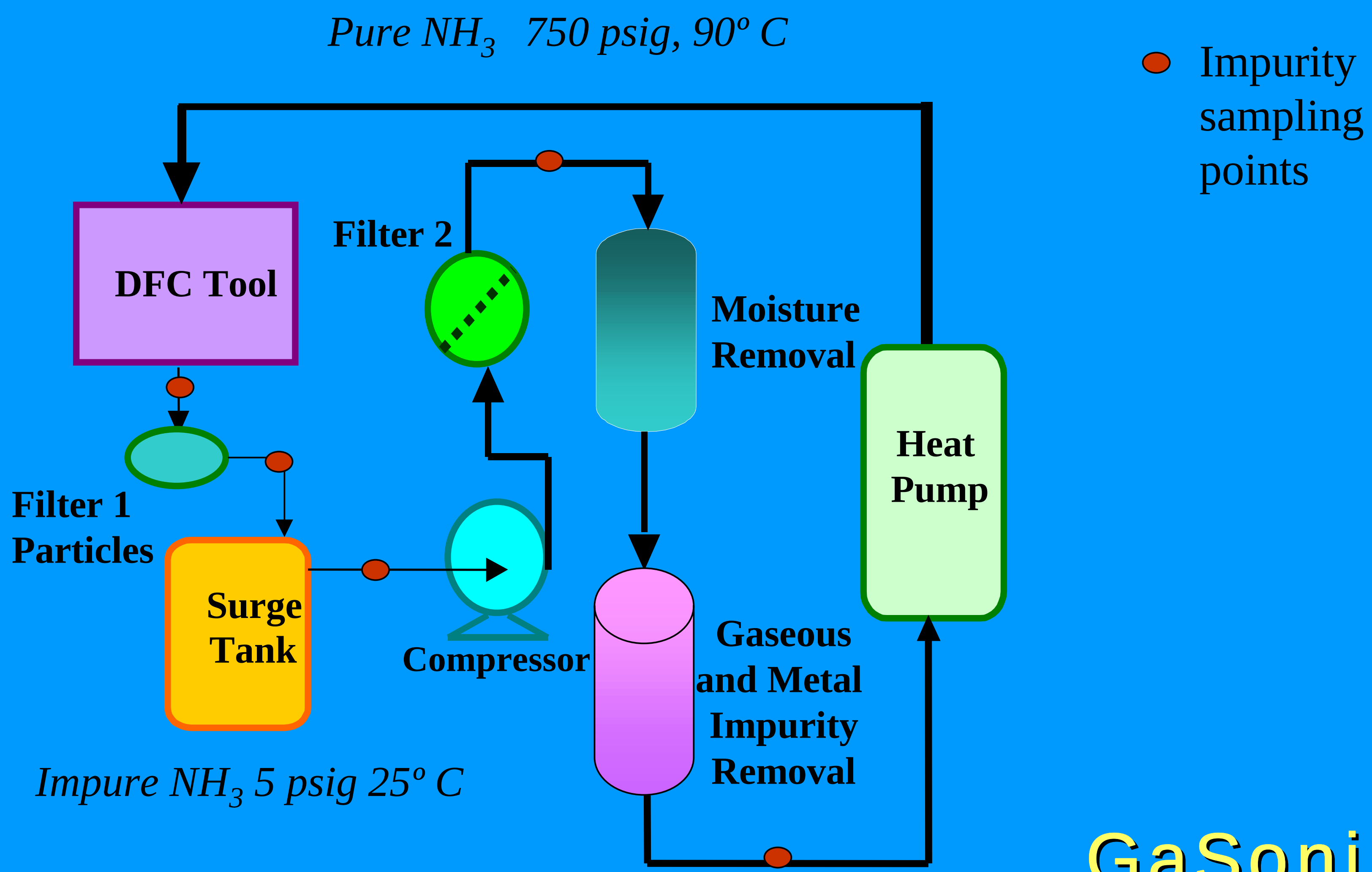
Purification Process Flow



Prototype Purifier at GaSonics

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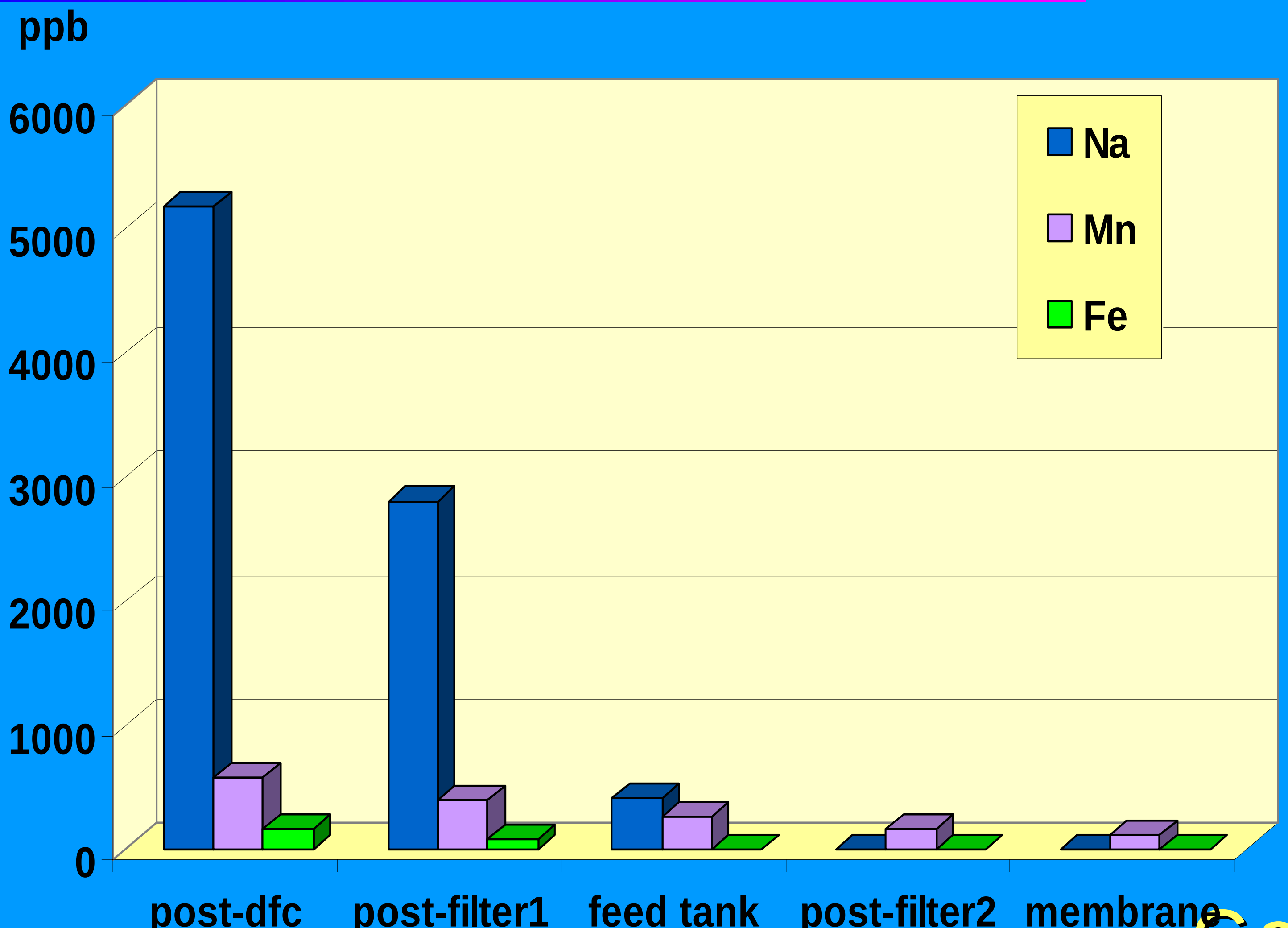
Purifier Results for Metal Contamination



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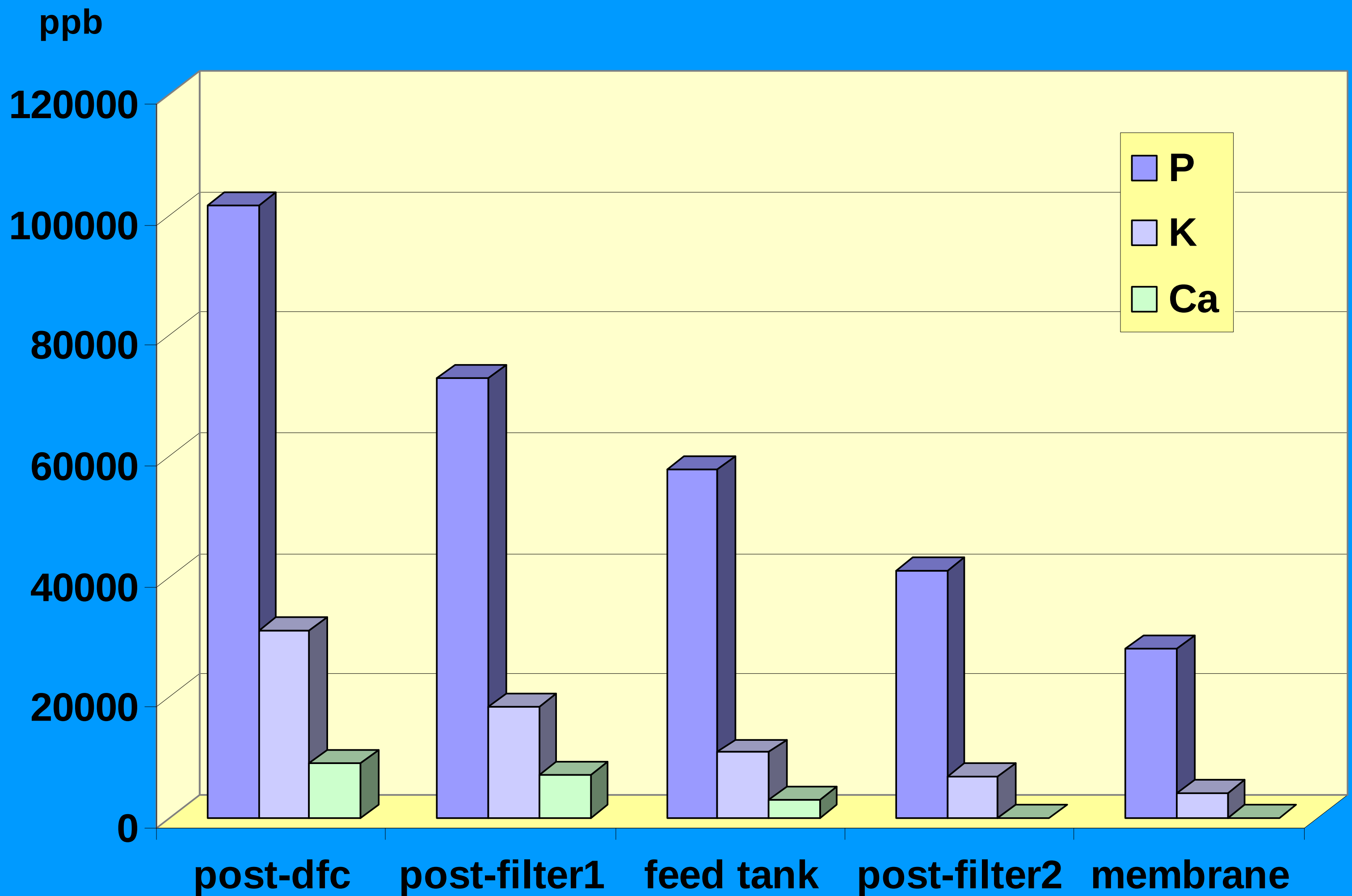
Purifier Results for Metal Contamination



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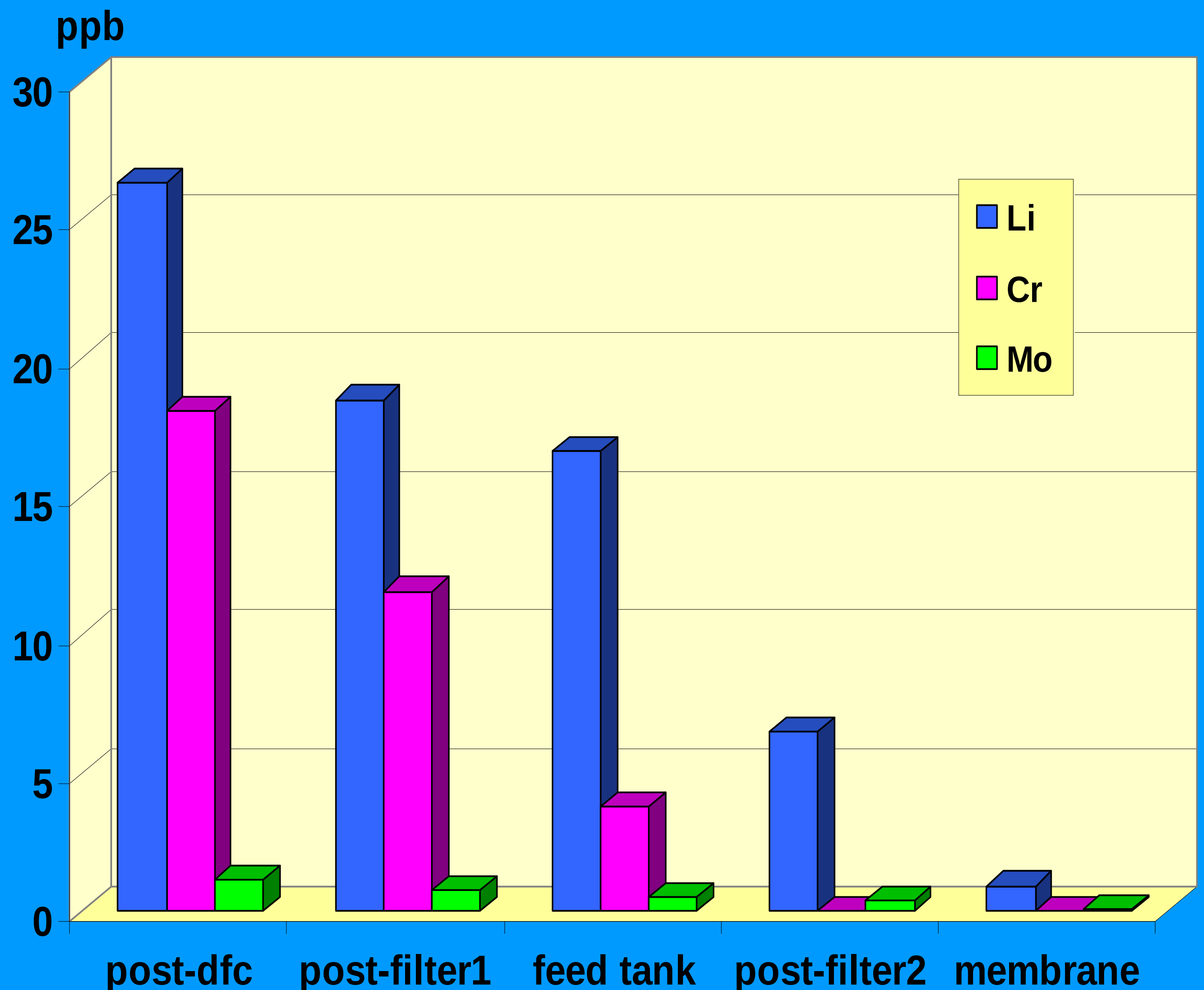
Purifier Results for Metal Contamination



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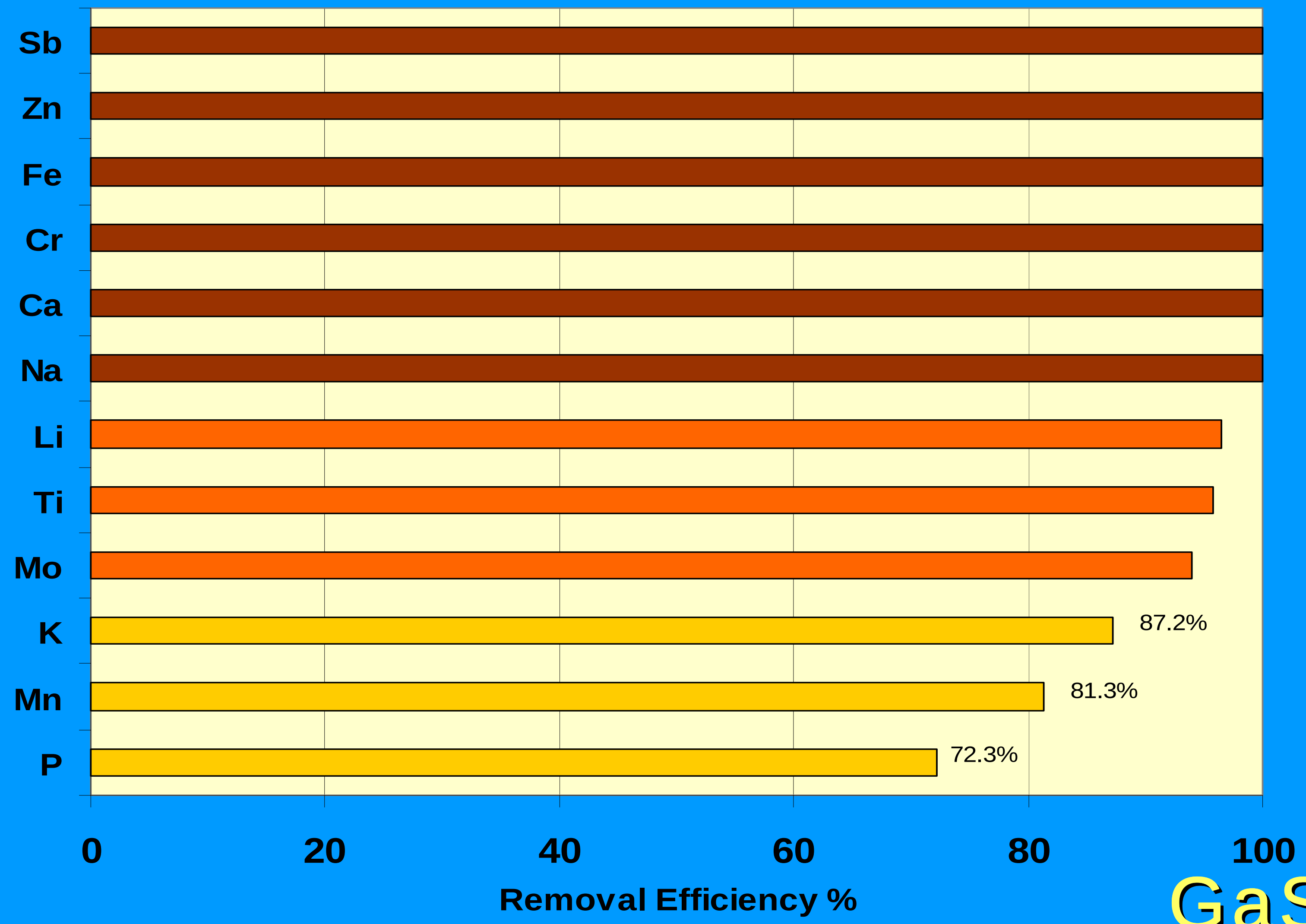
Metal Contamination Removal Efficiency



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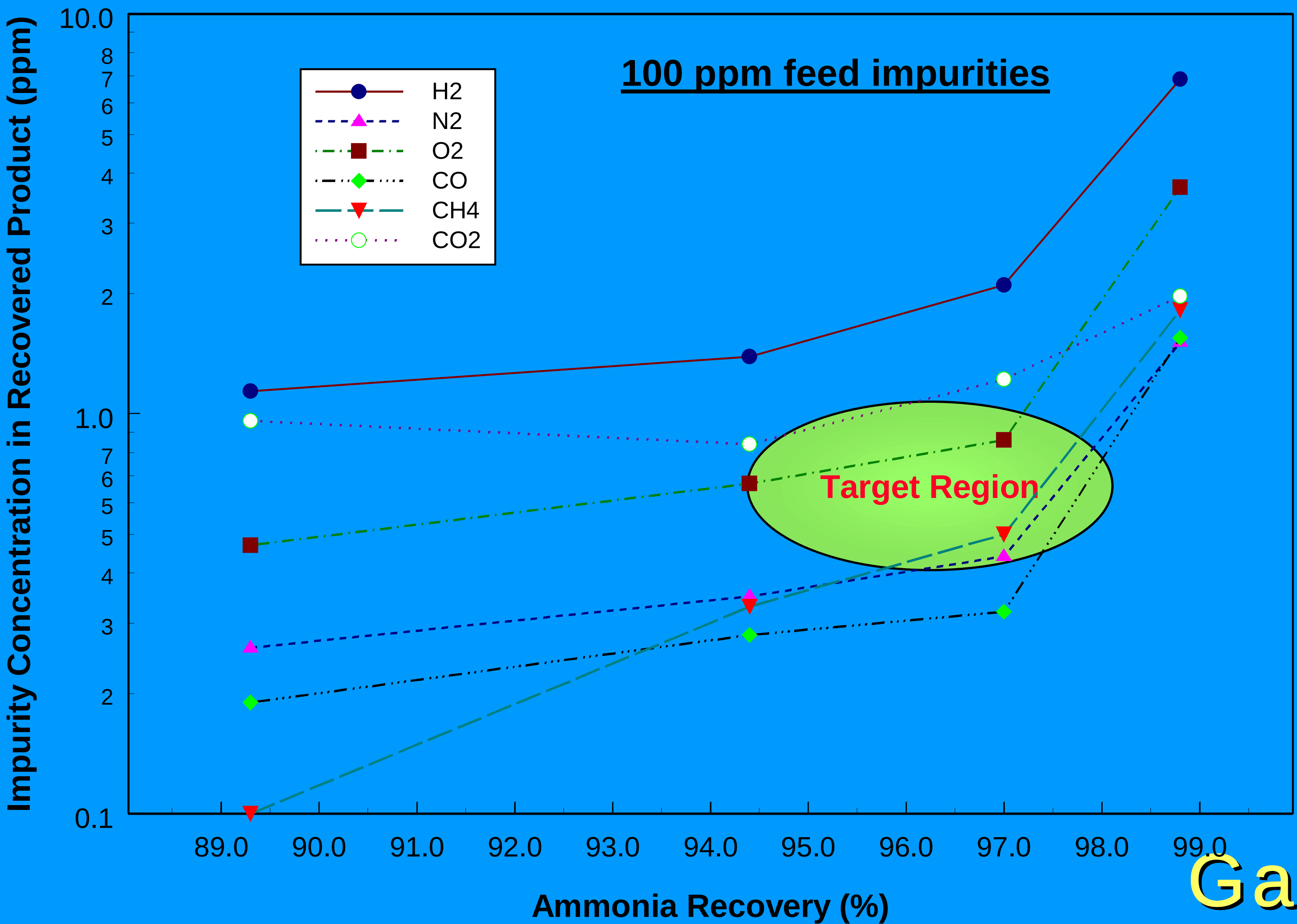
Ammonia Recovery vs. Product Purity



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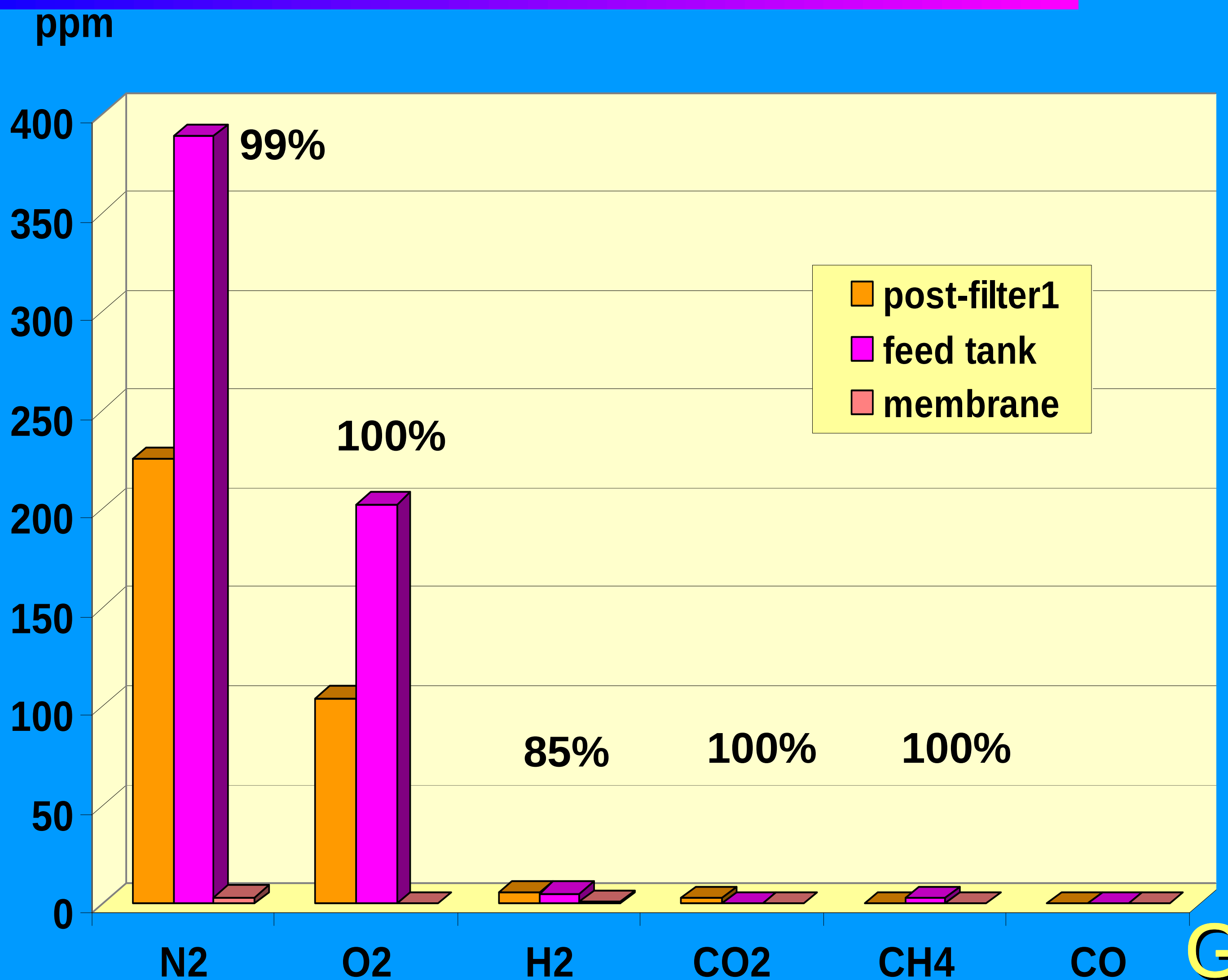
Purifier Results for Gaseous Contamination



Ammonia Recovered at 97%

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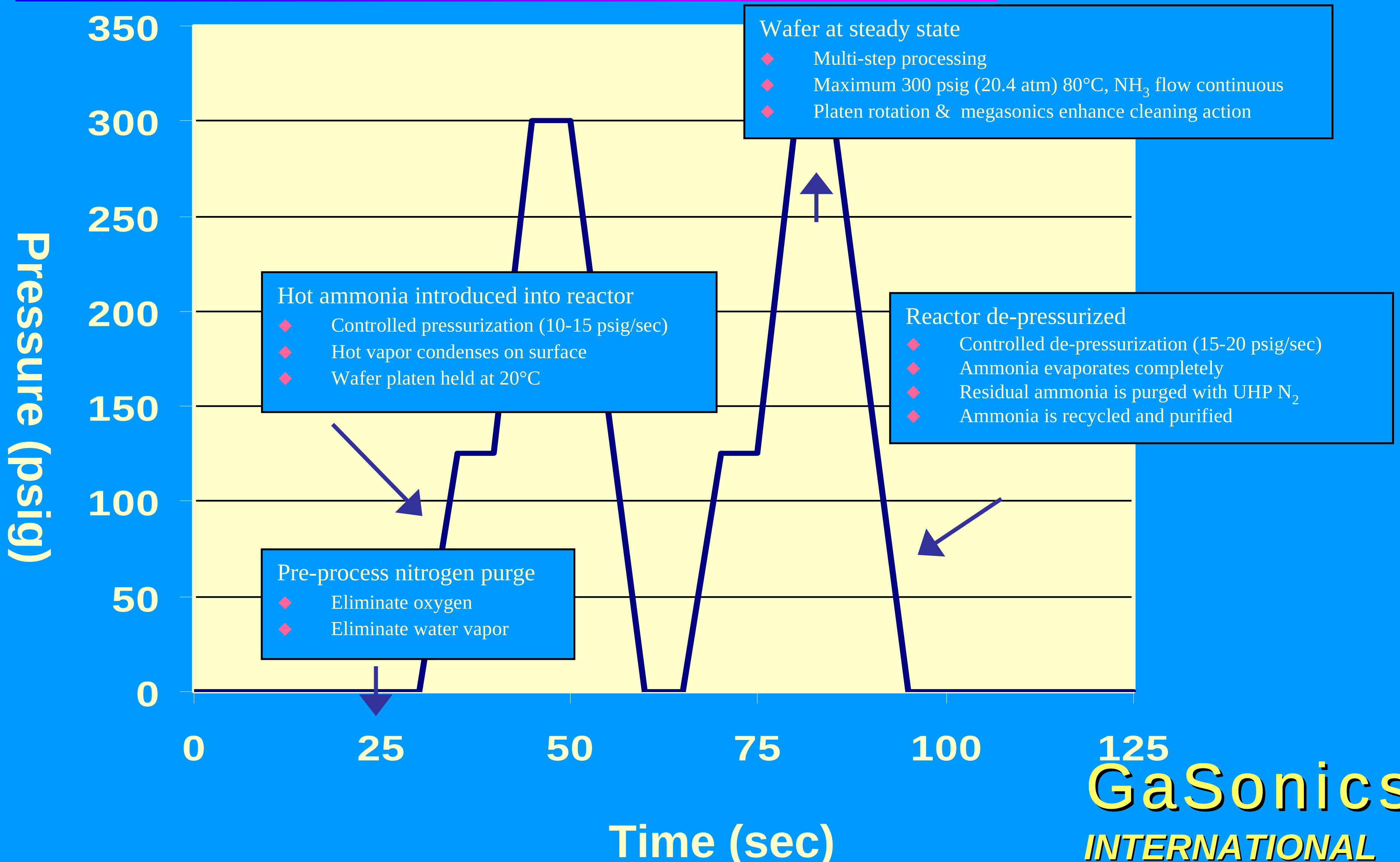
DFC Process Sequence



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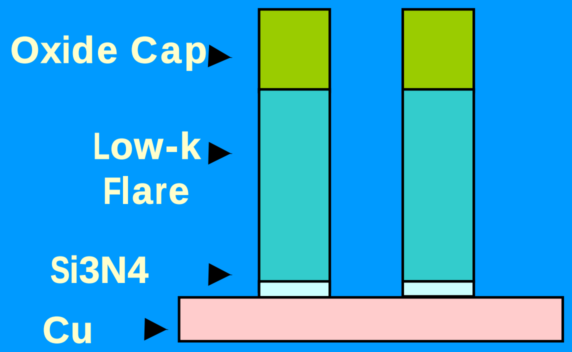
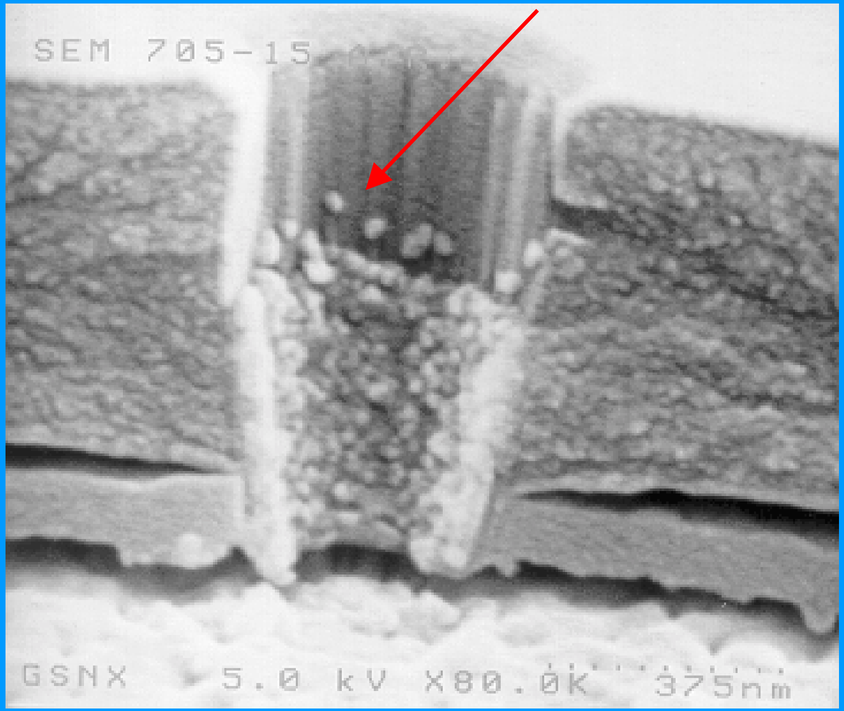
Via to Low-κ/Copper: Post-Etch

Presented at ECS Fall 1999 Clean Symposium

Structure:



Sidewall Polymer
and Metal Residue



Acknowledgements go to Sematech for providing samples

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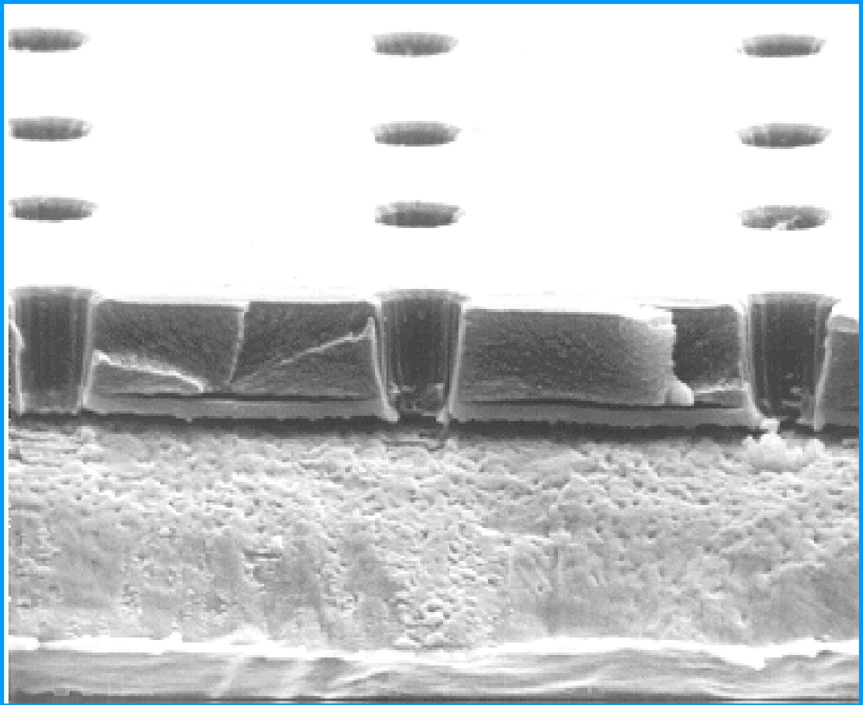
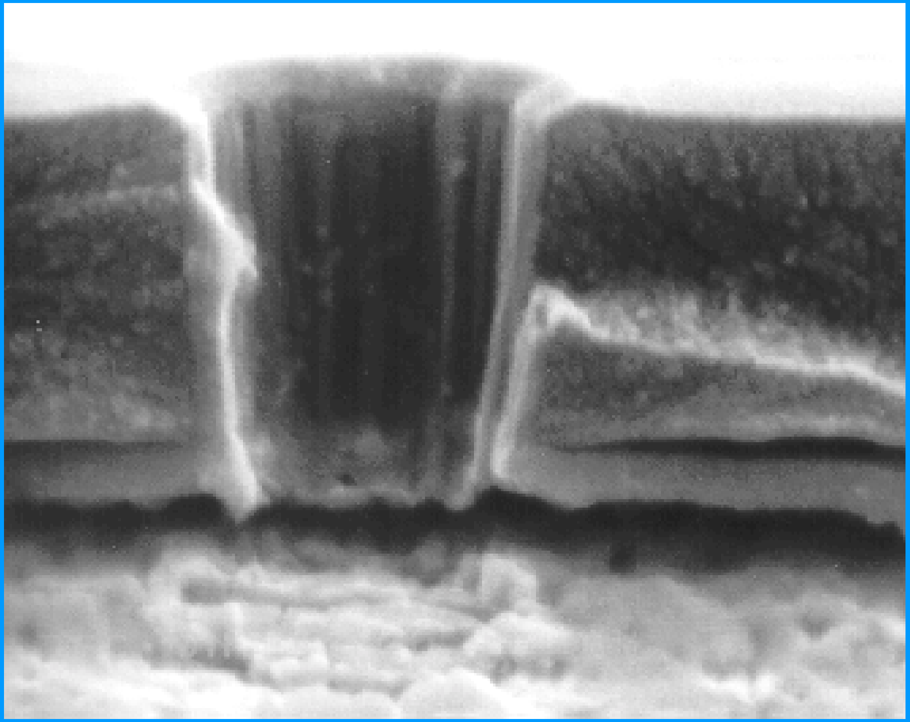
Via to Low-κ/Copper: Post-DFC

Presented at ECS Fall 1999 Clean Symposium

After DFC process only: Residue-free





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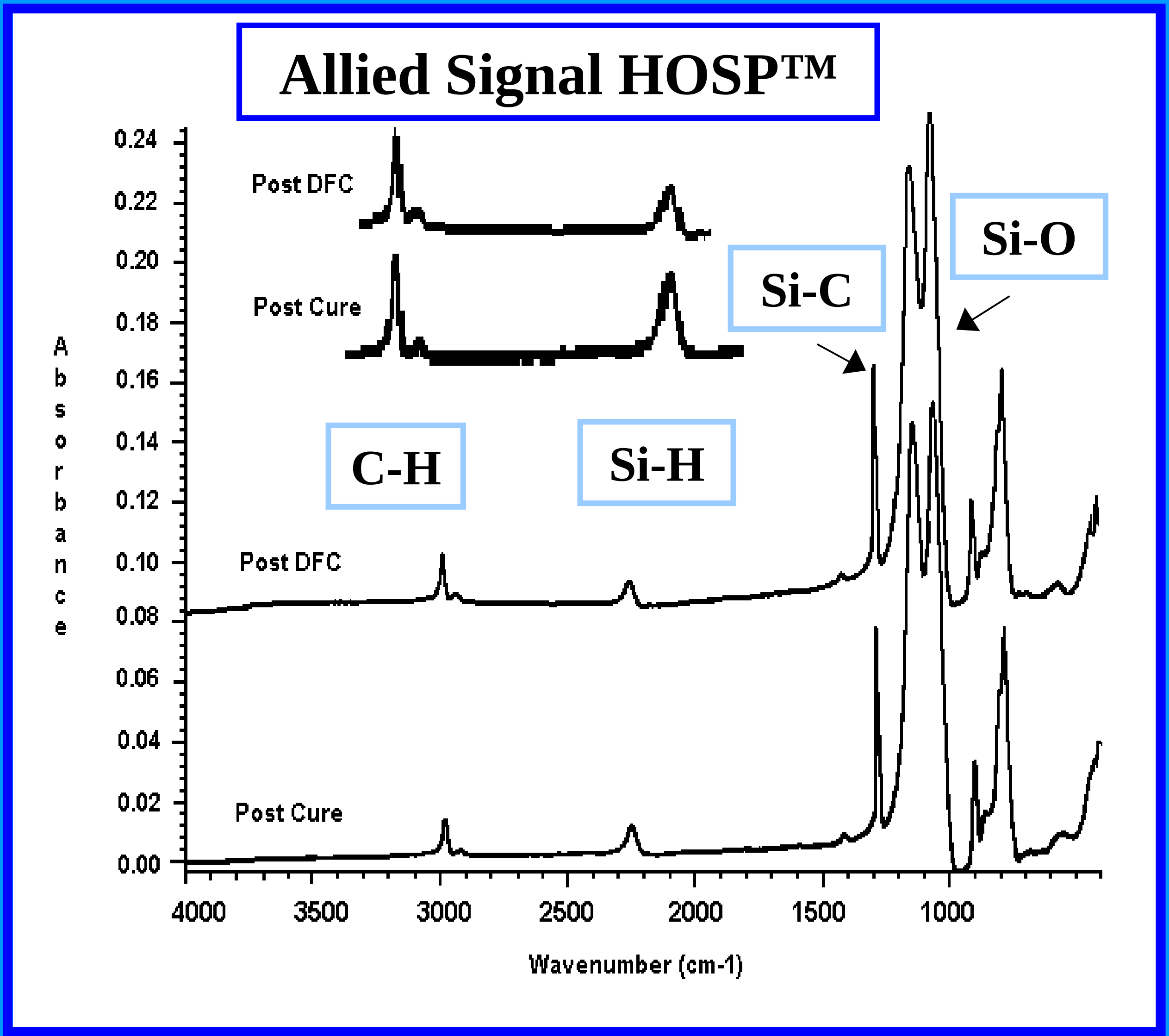
Effects on Thin Films: Low-κ FTIR



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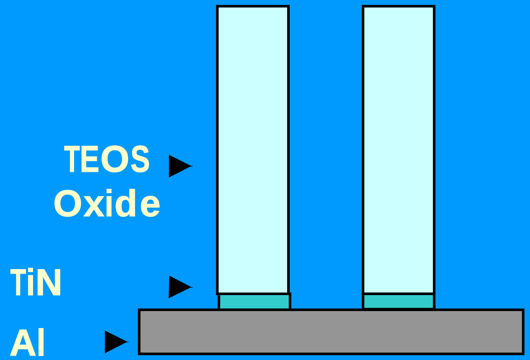
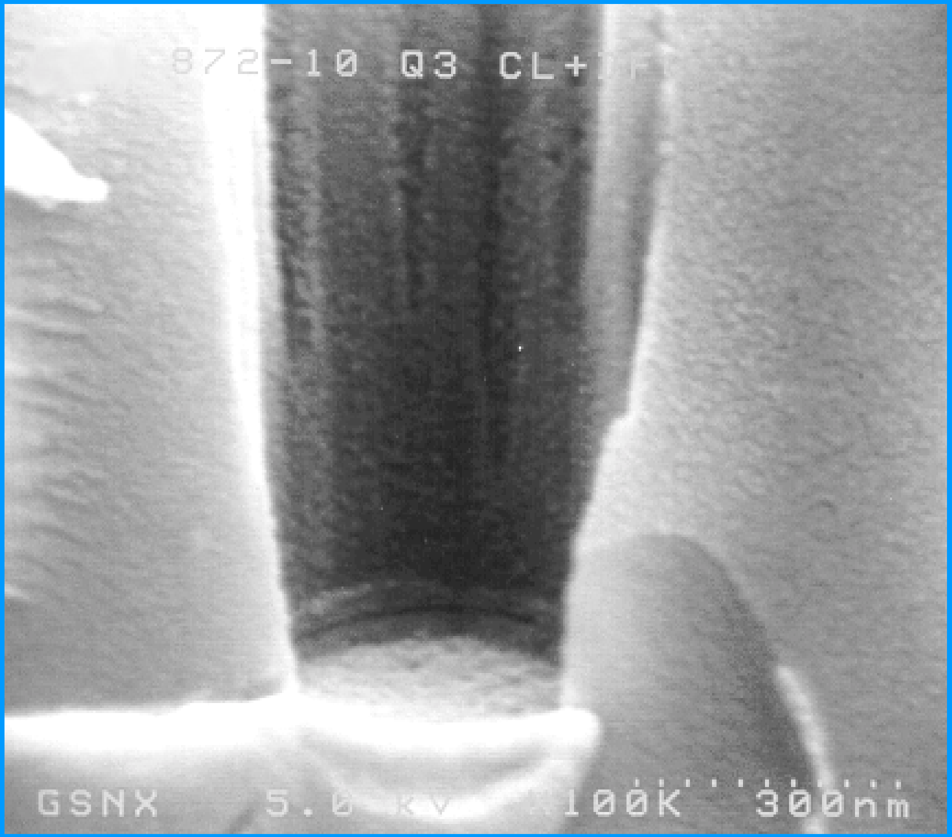
Via to TEOS/Al: Post-Plasma and DFC

After Microwave Plasma + DFC: Residue-free

Structure:





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Effect on Thin Films Exposed to DFC

Film	Thickness Change	Index of Refraction
After 5 minute exposure to DFC		
SiO_2	0.01 %	0.02 %
TEOS	0.05 %	0.03 %
SOG	< 0.7 %	0.1 to 0.2 %
Flare™	< 0.01 %	< 0.01 %
HOSP™	0.03%	< 0.01 %
Poly-Si	None	None

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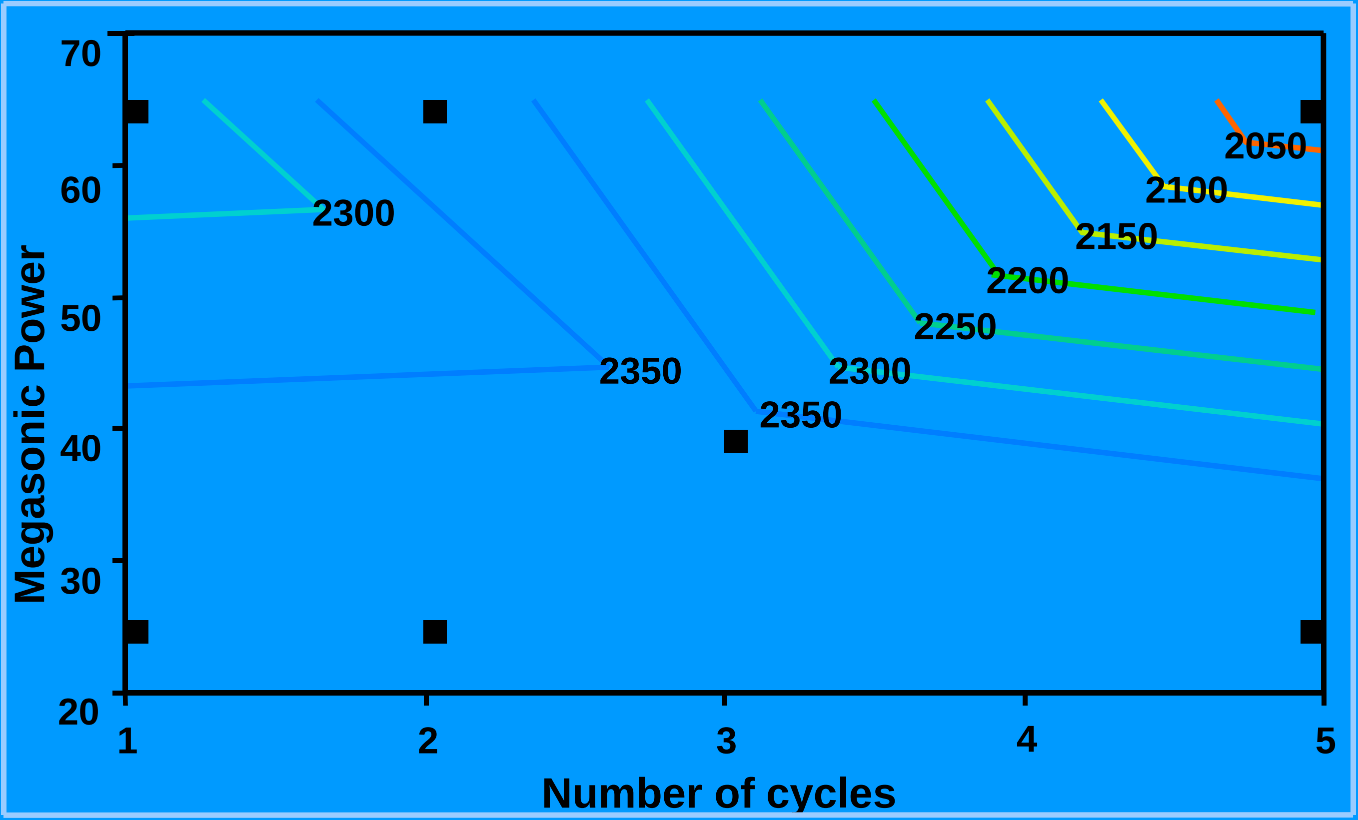
Process Development: Characterization

Design of Experiment 1



- Varied
  - Meg Power
  - Pressure
  - Cycles
  - Rotation
- Recipe Optimized

Response:

PR removed (Å)

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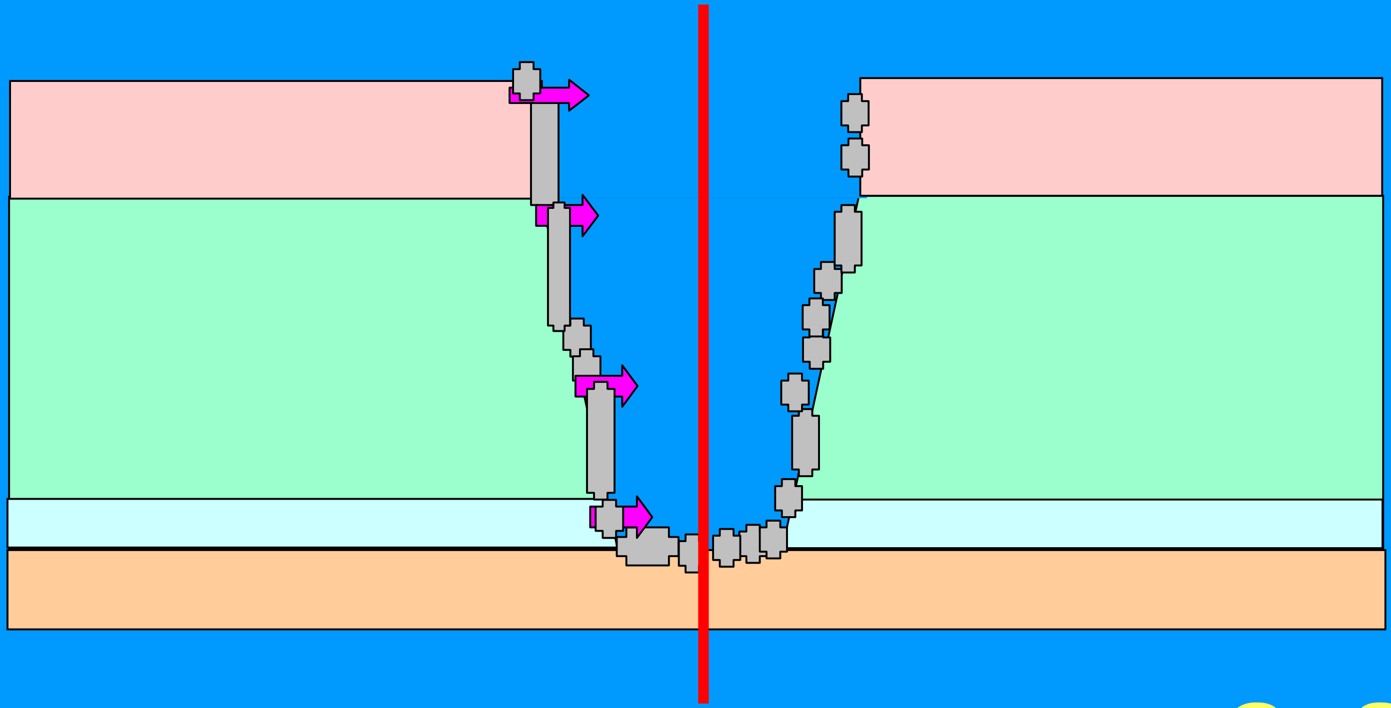
Clean Mechanisms

- Removal of Residue and Particles
  - Physical
    - Breaking apart matrix- liquid gas phase changes
    - Washing away particles- fluid shearing flow
    - Megasonic action- cavitation or pressure pulses
    - Thermophoresis- temperature gradient
  - Chemical
    - Swelling residue and photoresist
    - Dissolving residue
    - Solvating metals

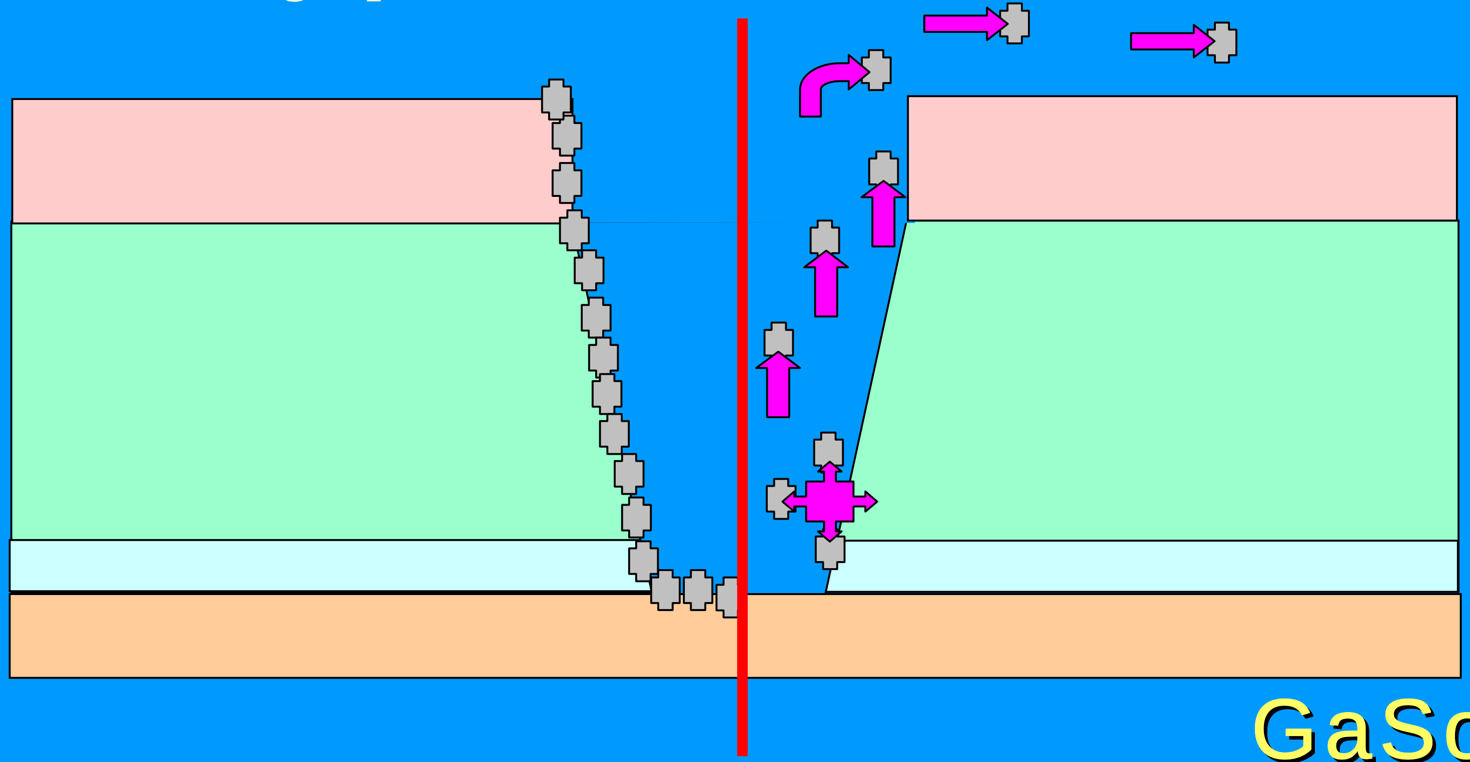
Clean Mechanism

- Residue removal physically
  - Gas rapidly evolving from liquid
  - Breaks apart residue matrix to particles



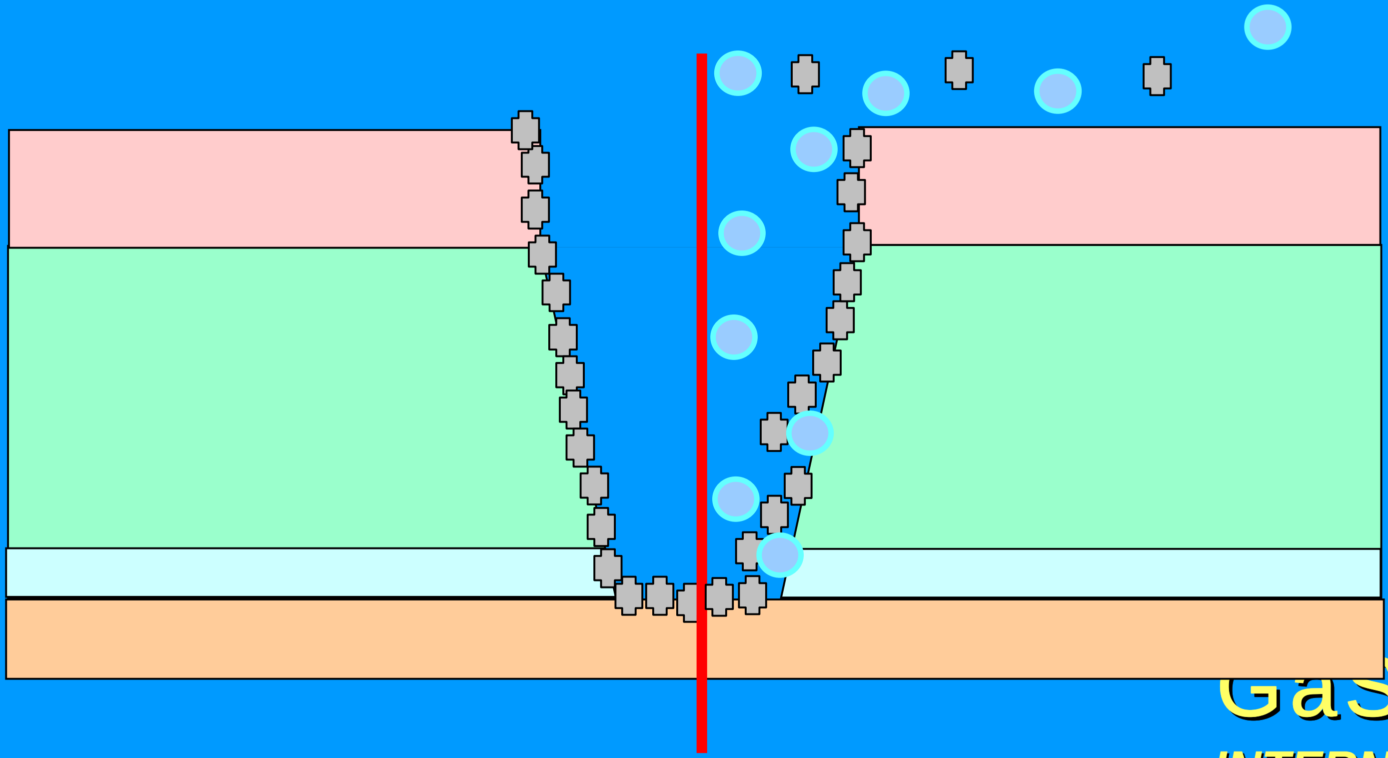
Clean Mechanism

- Residue removal mechanism similar to thermophoresis observed with snow and aerosols
  - heat transfer by shearing gas flow as $NH_{3\ (\ell)}$ evaporates
  - dislodges particles and is removed in downstream flow



Clean Mechanism

- Residue removal by megasonics
  - Cavitation or pressure pulses from acoustical streaming
  - Dislodges particles by high pressure imploding bubbles or pressure gradient



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Conclusions

- DFC is a non-aqueous, non-damaging, low temperature wafer cleaning technology
- A two step all dry process is used to remove post-etch residues
  - Microwave plasma + DFC
- DFC does not affect materials used in integrated circuit device manufacturing
  - Oxides
  - Low-κ

Acknowledgments

- GaSonics
  - Duong Nguyen
  - Bob Shepherd
- BOC
  - Piotr Sadkowski