Recent Advances in Photoresist Processing Using Supercritical CO_2

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Uniqueness of Our Research

- Our Research Interests:
  - Completely solventless processing with $SFCO_2$
  - All dry, resistless, solventless lithography for low-κ dielectric patterning

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Topics of Presentation

- General Overview of Lithographic Process
- Recent Achievements:
  - Fluorinated Resists
  - Patternable Low-κ Dielectrics

    (Gina L. Weibel (Cornell), Hilton Pryce Lewis (MIT))
- Dissolution Rate Measurements in $SFCO_2$
  - Equipment design
  - Issues anticipated
  - Early results
- Summary

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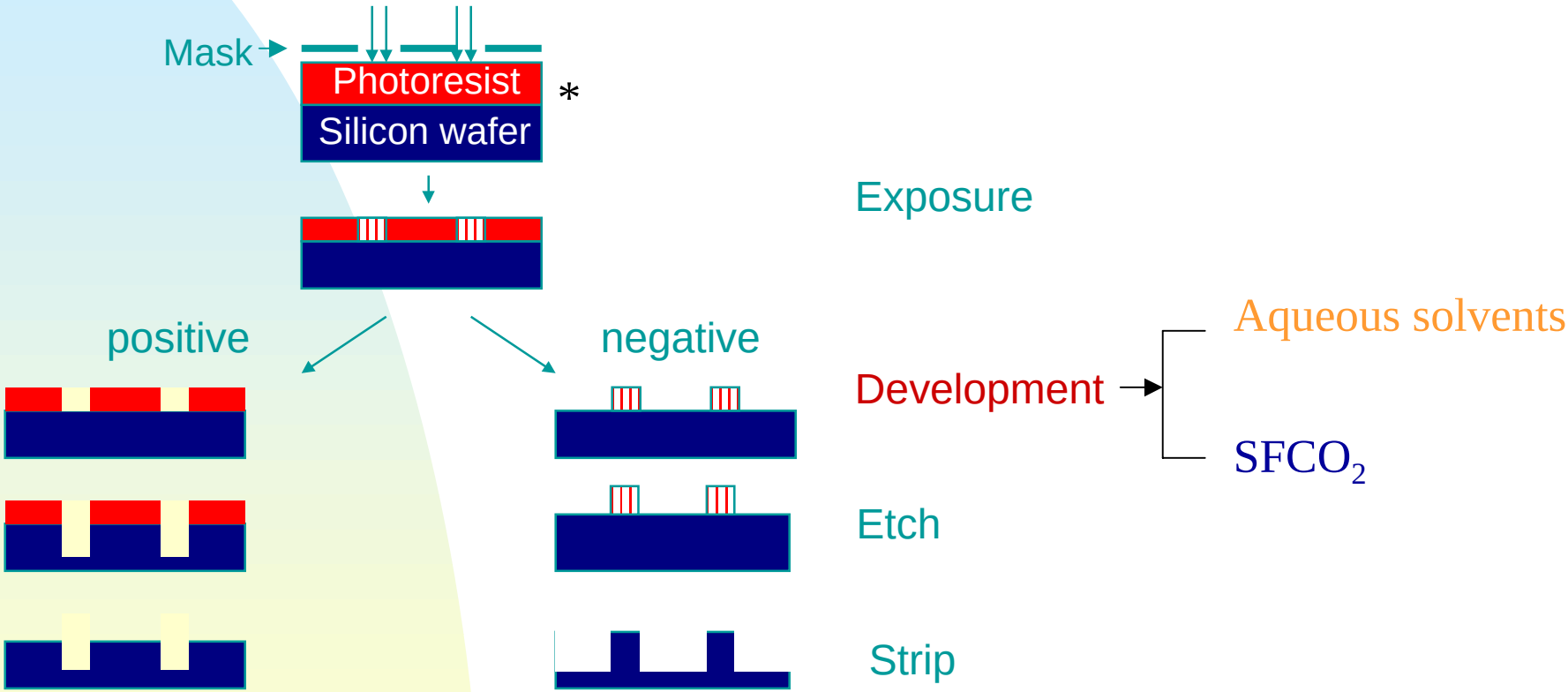
General Overview of the Lithographic Process



*__Chemically amplified resists__ contain Photoacid Generators, Dissolution Inhibitors, Base Additives, Surfactants … to aid sensitivity and performance

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Advantages of $SFCO_2$ Processing

Desirable Properties of Fluorinated Resists

- ✔ E-beam Patternable (NGL)
- ✔Transparent at 157nm
- ✔Chemically Amplified
- ✔CO_2 Developable

Benefits of Fluorinated Resist Processing with $SFCO_2$

- ✔ No Solvents
  - ✤ Environmental considerations
  - ✤ Worker health and safety
- ✔ Greater Feature Properties
  - ✤Tunable solvating power
    - ➢ Facile processing optimization
  - ✤ Low surface tension of CO_2
    - ➢ Avoid feature collapse
    - ➢ High aspect ratio
- ✔ Save Money
  - ✤ CO_2 is abundant
  - ✤ CO_2 can be recycled
  - ✤ No hazardous waste storage, disposal

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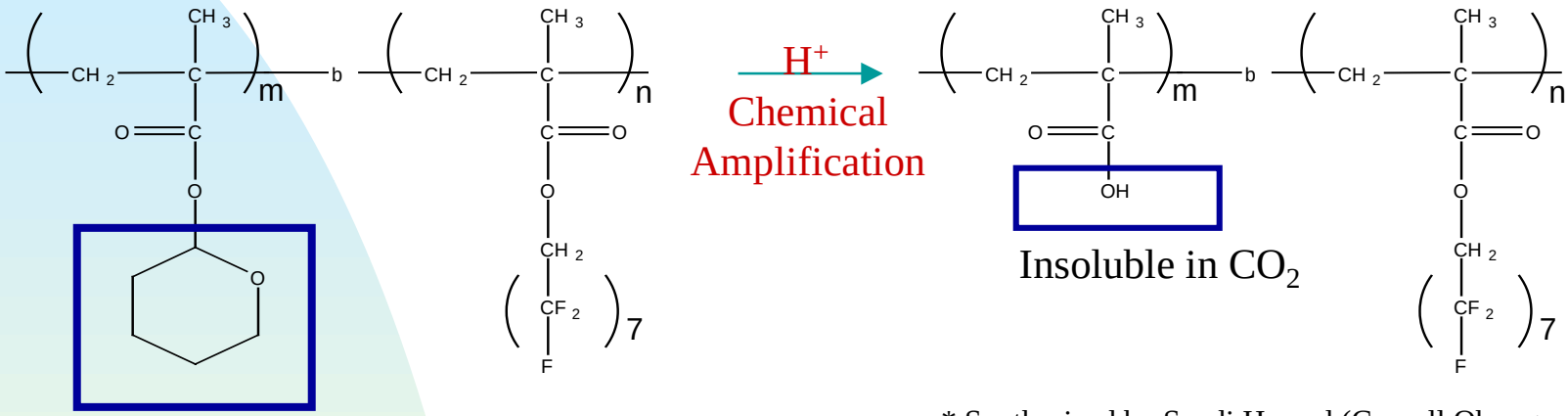
Chemically Amplified, E-beam Patternable, CO_2 Developable, Negative Tone Resist

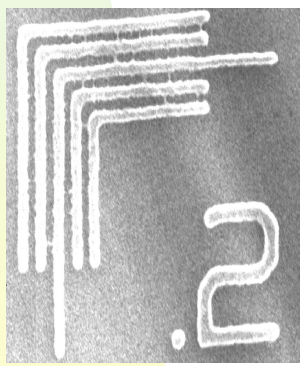


Soluble in CO_2

Insoluble in CO_2

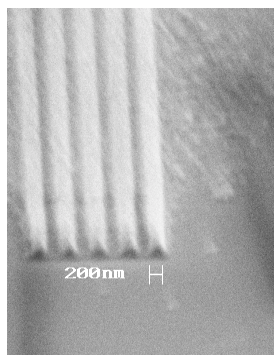
* Synthesized by Sandi Hamad (Cornell Ober group)

193nm exposure

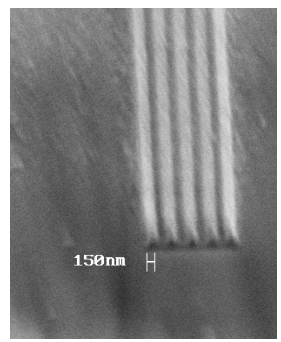


Sundararajan, Ph.D.

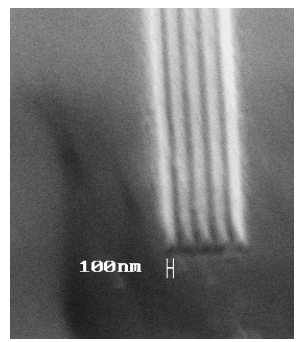
E-beam exposures



.2μ line/space



.15μ line/space



.1μ line/space !!!

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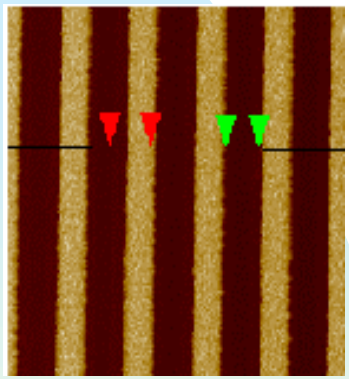
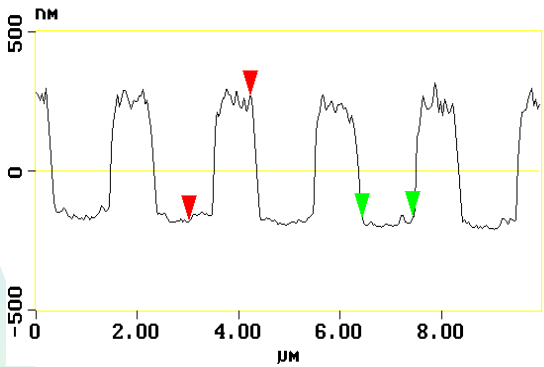
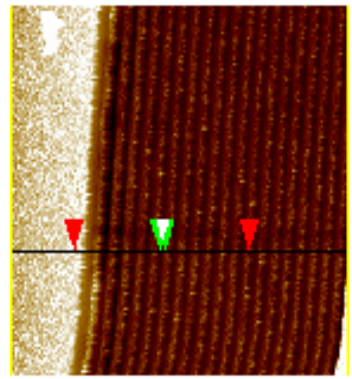
CO_2 Processing of CVD Deposited, E-beam Exposed, Low-κ Dielectric for Interconnects



1.0 μ Lines/ spaces



Cross section



0.25 μ Lines/ spaces

–Demonstrated patternable hot-filament CVD fluorocarbon films (HFPO)

- Film composition can be tailored
- E-beam used to effect solubility change

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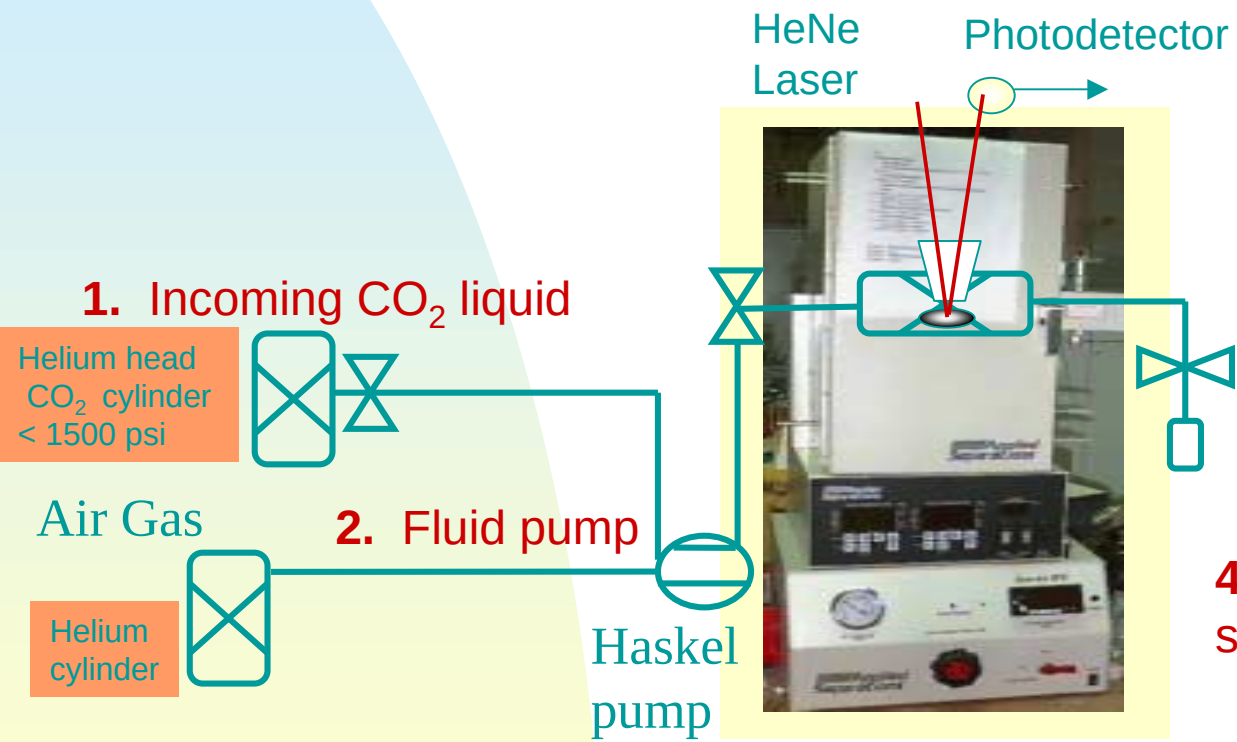
CO_2 Processing - Experimental Equipment



- Photoresist Development
- Dissolution Rate Monitoring
- MEM Device Drying

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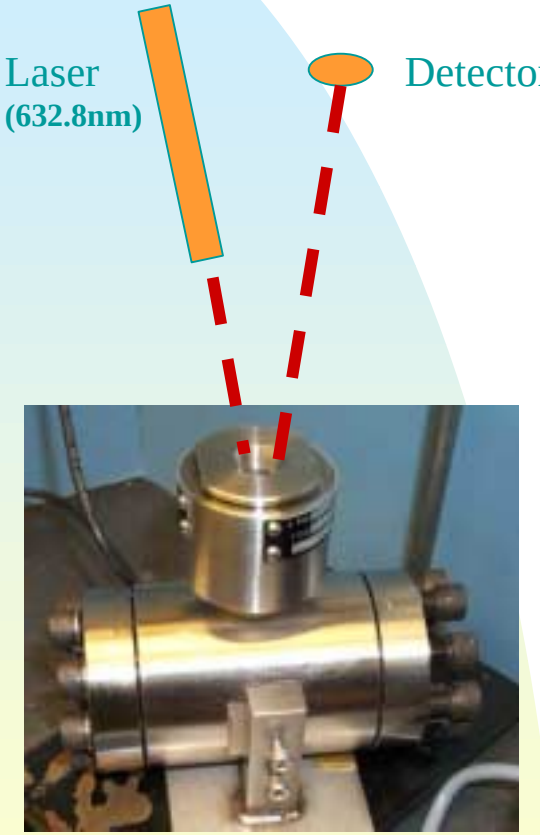
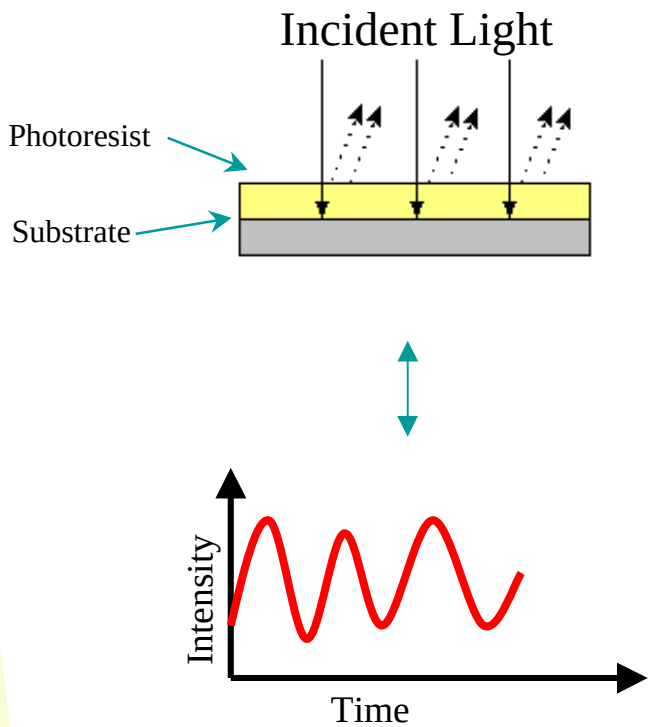
Dissolution Rate Monitor (DRM)





Interferometer

Laser reflects off
- photoresist surface
- silicon surface

Interference gives sinusoidal pattern

Period of oscillation provide details on rate of thickness change

* Dissolution rate measurement techniques in supercritical fluids not yet firmly established

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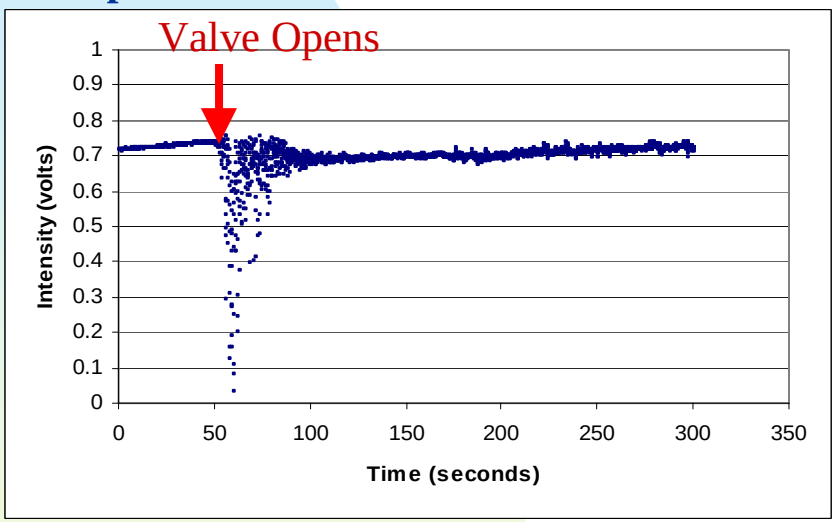
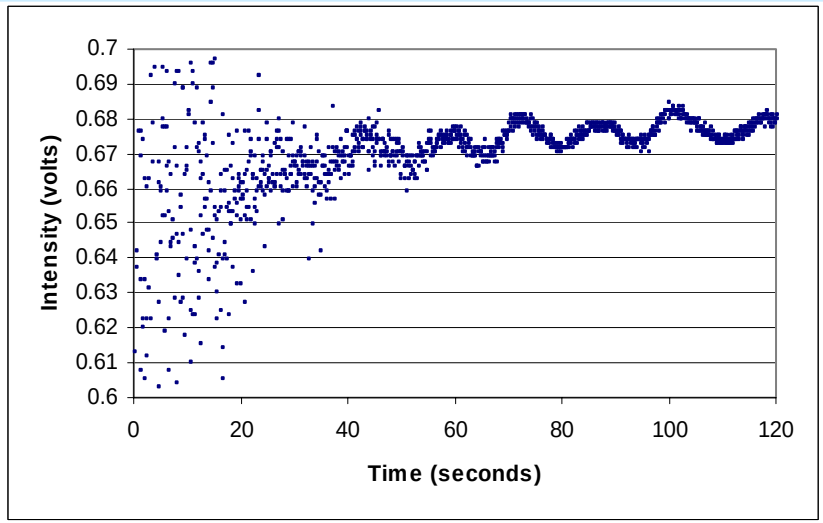
Early Results from Dissolution Rate Monitor

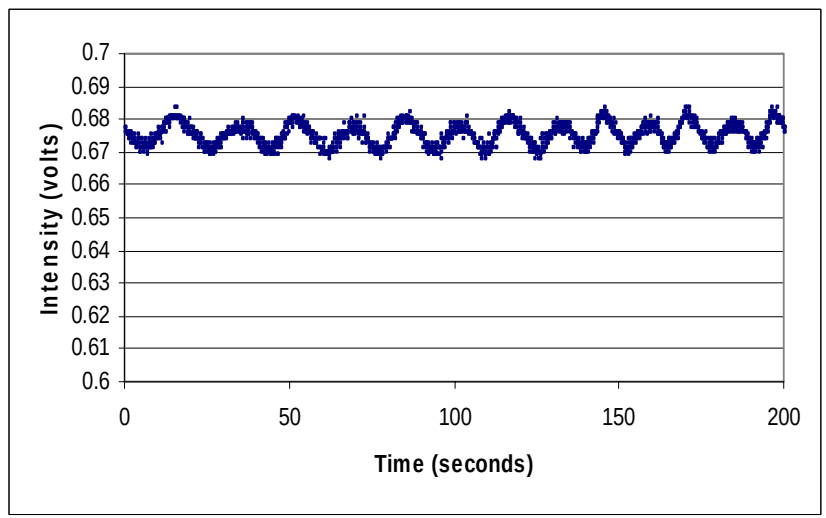
Pressure ~ 1100 psi (too low ?)
Temperature ~ 55 ºC



Blank silicon wafer.



Silicon wafer coated with THPMA-F_7MA



Entering CO_2 scatters light
Equilibration time ~ 50 sec
Is film shrinking or swelling?

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Issues to Be Addressed

- Achieving High Pressures in Short Times
  - Currently only ~ 1100 psi under 60 seconds
  - Need a better pump system (?)
- Rapid CO_2 Equilibration
  - Pre-chamber equilibration
  - More efficient heat transfer in inlet tubes
- Impurities in CO_2 Affecting Dissolution Behavior
  - Helium head cylinder
- Understanding Physical Properties of $SFCO_2$ (e.g., RI as a function of pressure/temperature)

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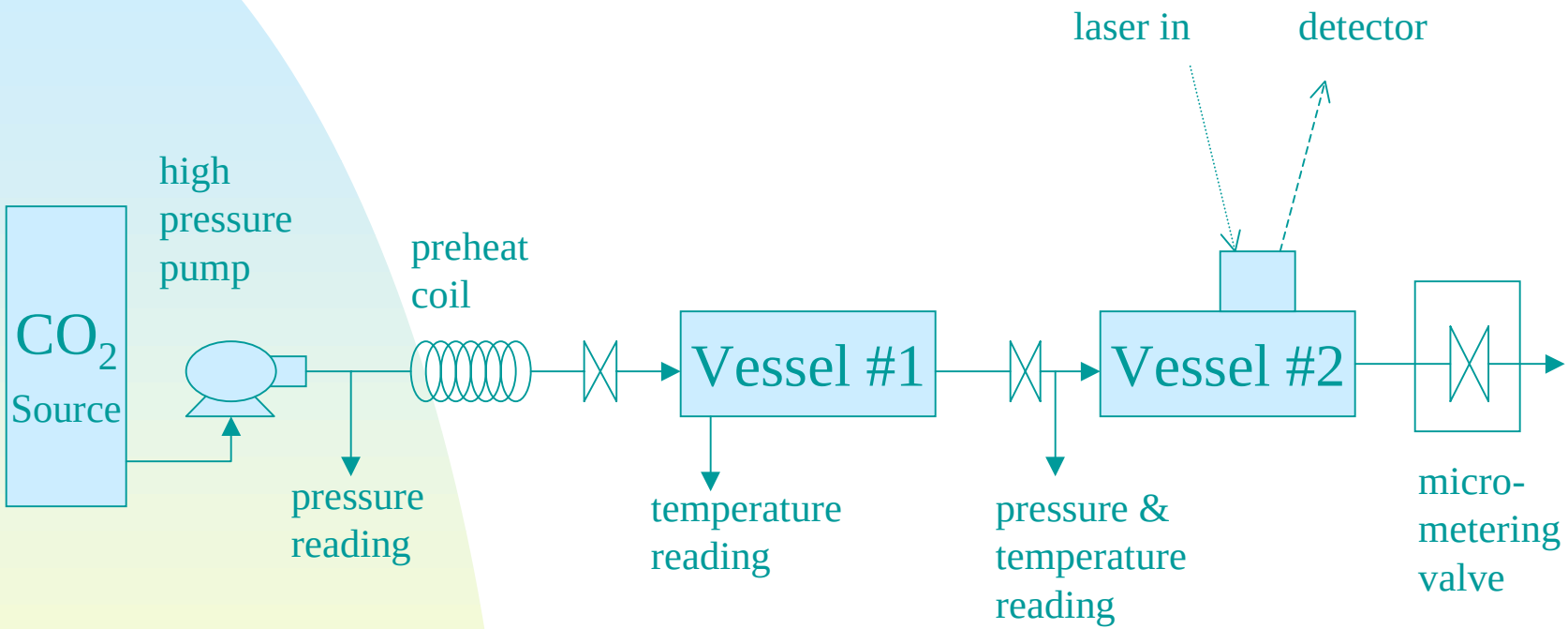
Equipment Design



- No need for Helium
- Equilibration to supercritical conditions before entering processing vessel
- Eliminate scattering by solid or liquid CO_2

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Summary

- Continue to Achieve Higher Resolution Limits for Fluorinated Resist with $SFCO_2$
  - **E-beam exposed features of ~ 100nm**
- Demonstrated Patternable Hot-filament CVD Fluorocarbon Films
  - **Film composition can be tailored**
  - **E-beam used to effect solubility change**
- Successfully Developed CVD Polymer with $SFCO_2$
  - **Density/solvating power of CO_2 can be controlled**
  - **Promise of EHS benefits for semiconductor processing**
- Dissolution Rate Monitor to Provide Insights to Development Process
  - **Early results indicate potential usefulness**
    - **Phase behavior/properties of CO_2 in supercritical phase**
    - **Rate of dissolution to optimize processing conditions**
- Challenges and Issues
  - **Decouple factors that affect film thickness changes**

Acknowledgement

- Semiconductor Research Corporation
- NSF/SRC Engineering Research Center for Environmentally Benign Semiconductor Manufacturing
- Cornell Nanofabrication Facility (CNF)
- MIT Lincoln Labs
- MIT MRSEC Facilities
- Gleason Research Group (MIT)
- Ober Research Group
- Praxair

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