EUV SYSTEM WASTE HYDROGEN RECYCLING AND NOBLE GAS RECOVERY

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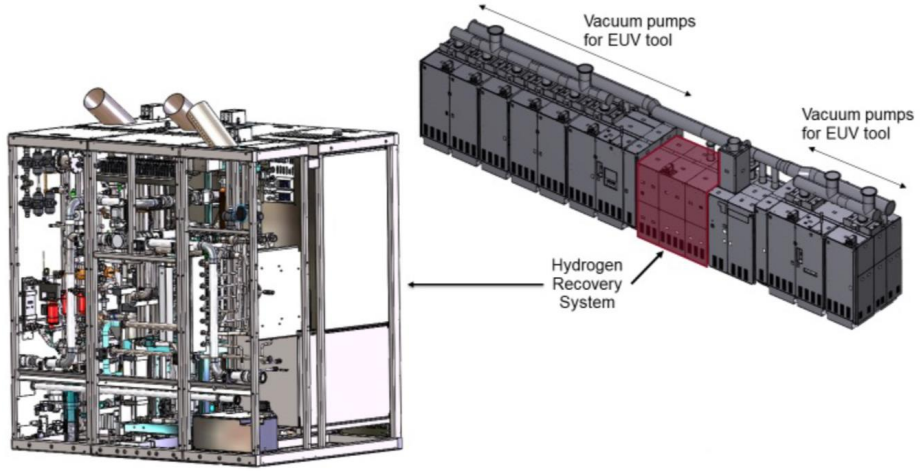
IWAPS
International Workshop on Advanced Patterning Solutions

Outline

- H_2 recovery system (HRS) integrated into EUV Vacuum pump
- Xenon gas recovery system (XRS) integration
  - Xe gas usage in EUV source and Dry ETCH process
  - approach of recycle methods
  - ROI challenge
- Krypton gas recovery for Dry Etch process
- Summary

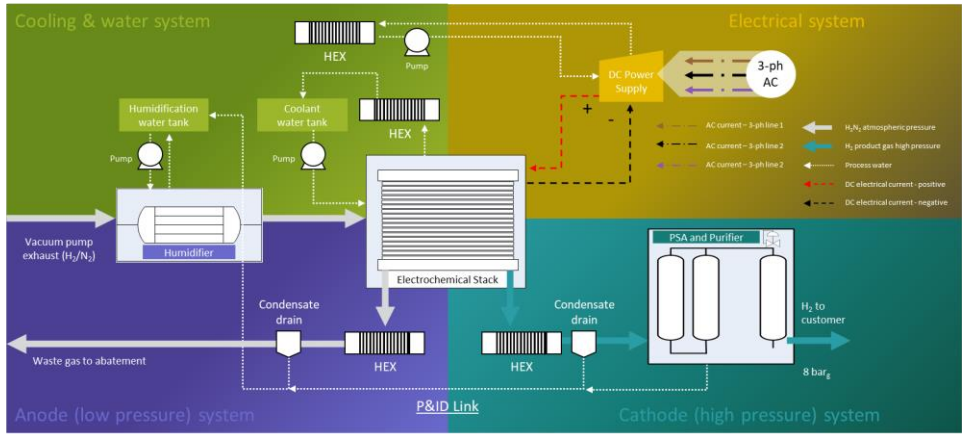
Hydrogen recovery and recycling from EUV Lithography tool

- Hydrogen is used in large quantities in EUV Lithography – flow rates and installed base are increasing
- Recycling
  - *Reduces risks from Supply continuity and transportation*
  - *Reduces the total energy and carbon footprint of the EUV Lithography process*
- Edwards has developed a recycling system to integrate with the Edwards EUV vacuum and abatement system
- Collects hydrogen from Source and delivers hydrogen to exceed the requirements of the leading EUV OEM
  - *Used in Source and Scanner*

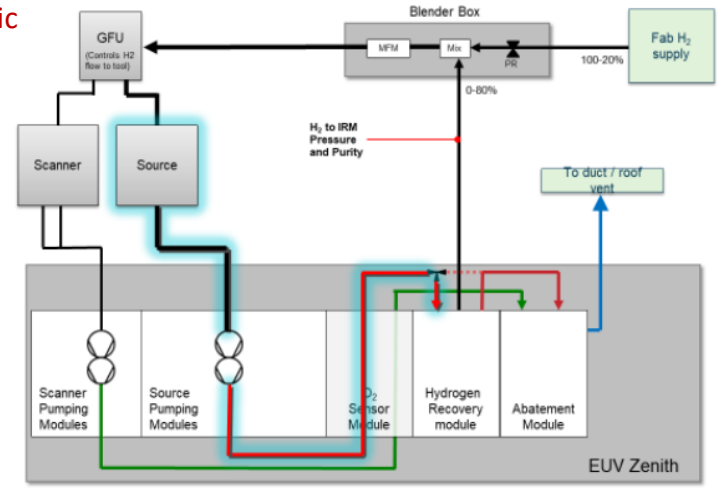


- Trial at IMEC under the *Sustainable Semiconductor Technologies and Systems* (SSTS) program
- The system has been upgraded during the trial.

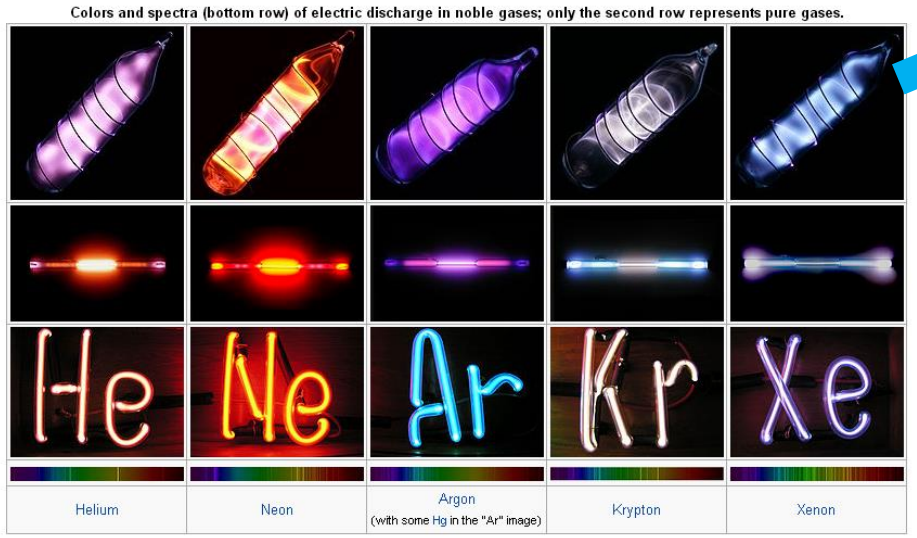
HRS Flow schematic



System Schematic

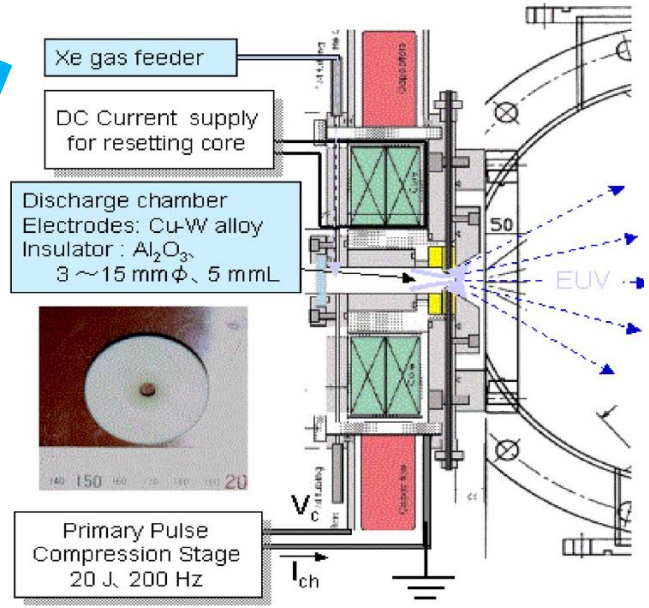


Xenon Gas use in compact EUV source

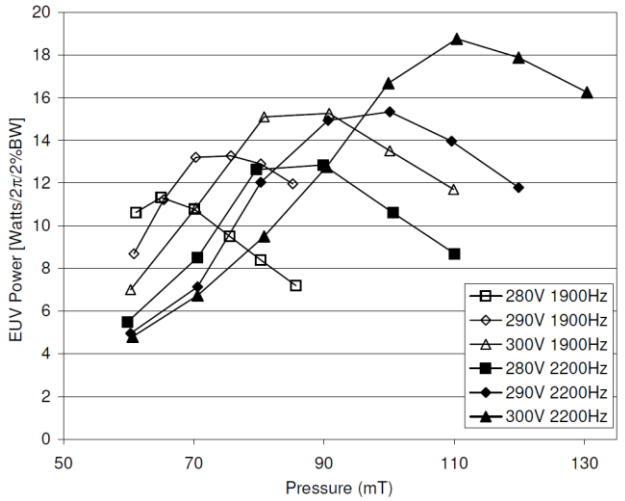


- Flow rate of Xe (sccm: Standard cubic litre per minute)
  - 6 sccm @ interval of 90ns (11K Hz)
  - 50 sccm @ interval of 110ns (9K Hz)
- Xenon cost
  - *5 USD/litre in gas bottle*
  - *15 USD/hour or 28USD/ million shots*
  - *0.11 MUSD/year (24 hours*300 days)*
- 95% recycle of Xe will save 0.1 MUSD/year material cost.

Gas Discharge Plasma (GDP)

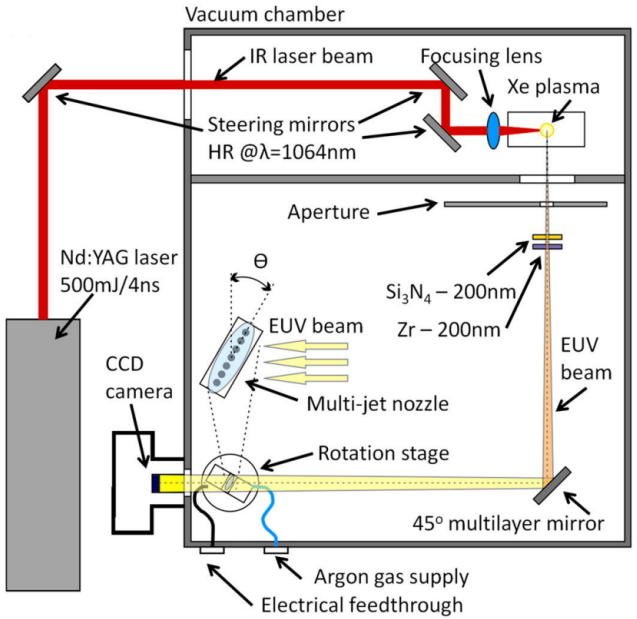


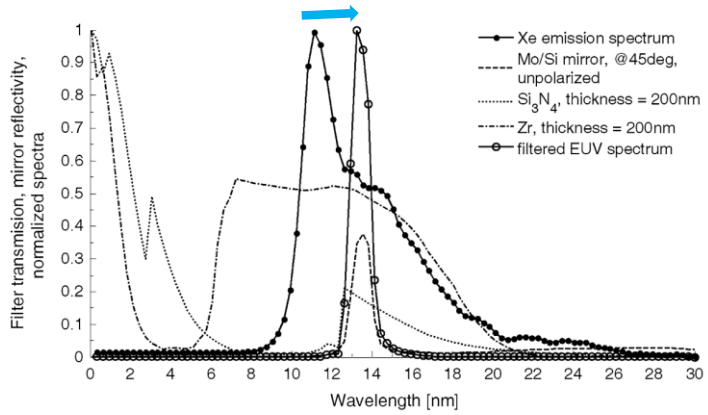
IAS Annual Meeting 2005



Conference on Emerging Lithographic Technologies.2008

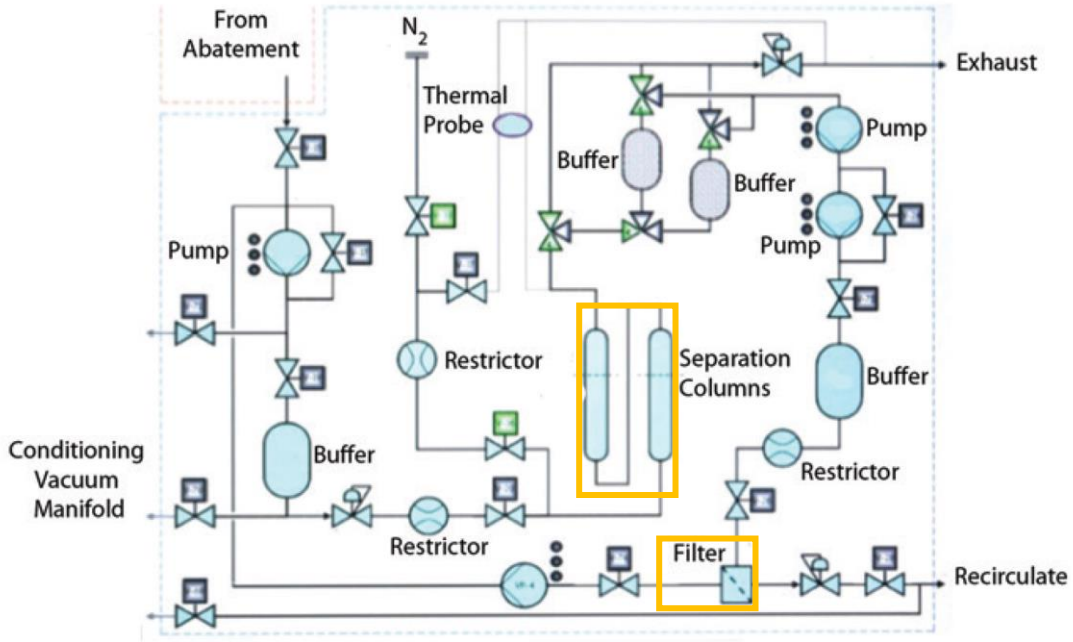
Laser Produced Plasma (LPP)



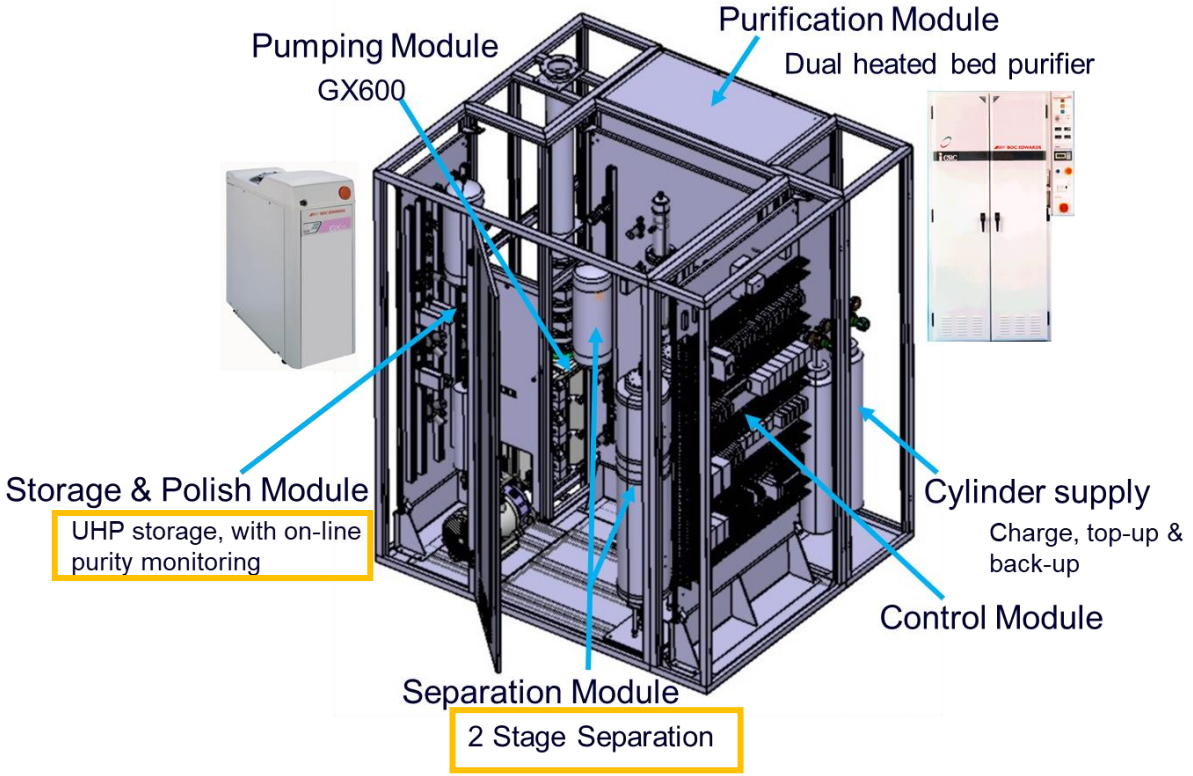


Applied Physics B 117.1(2014)

Xe recycle “option one”-2 stage separator



Solid state technology, 2018, 61(9)



- 2 stage filter core module separate Xe from N_2 and He
  - 1st stage: Gas Chromatography by adding He as carrier gas
  - 2nd stage: Membrane separate Xe and He with 99% efficiency
- Both stage needs vacuum regeneration
  - Can not continue recycle when cartridge is saturated
  - Need signal with tools to get regeneration timing

Operation cost concern:

- 5N He and N_2 is consumed to recover Xe
- Gas is compressed few times, thermal loss
- lifetime of columns is not long enough

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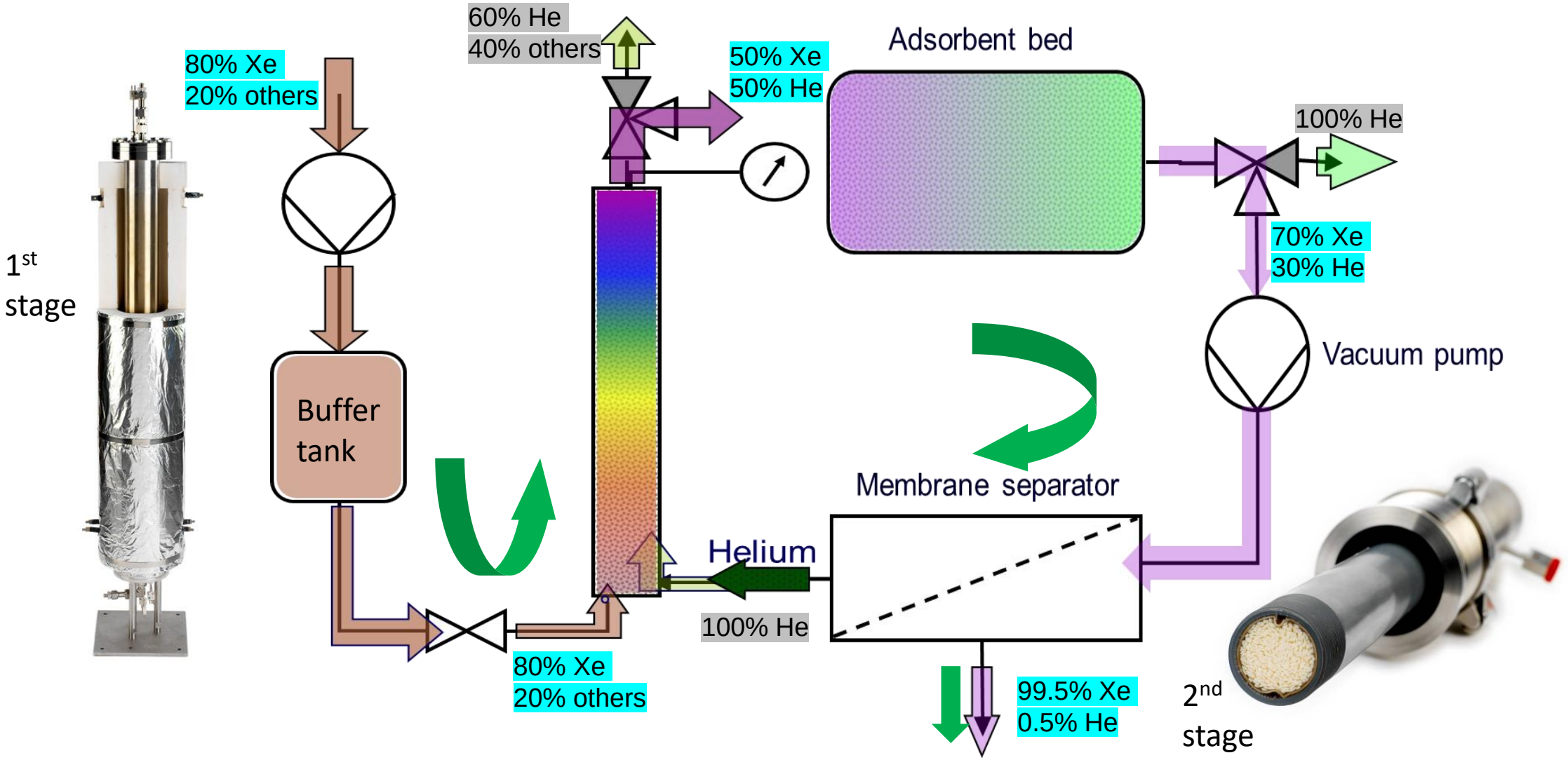
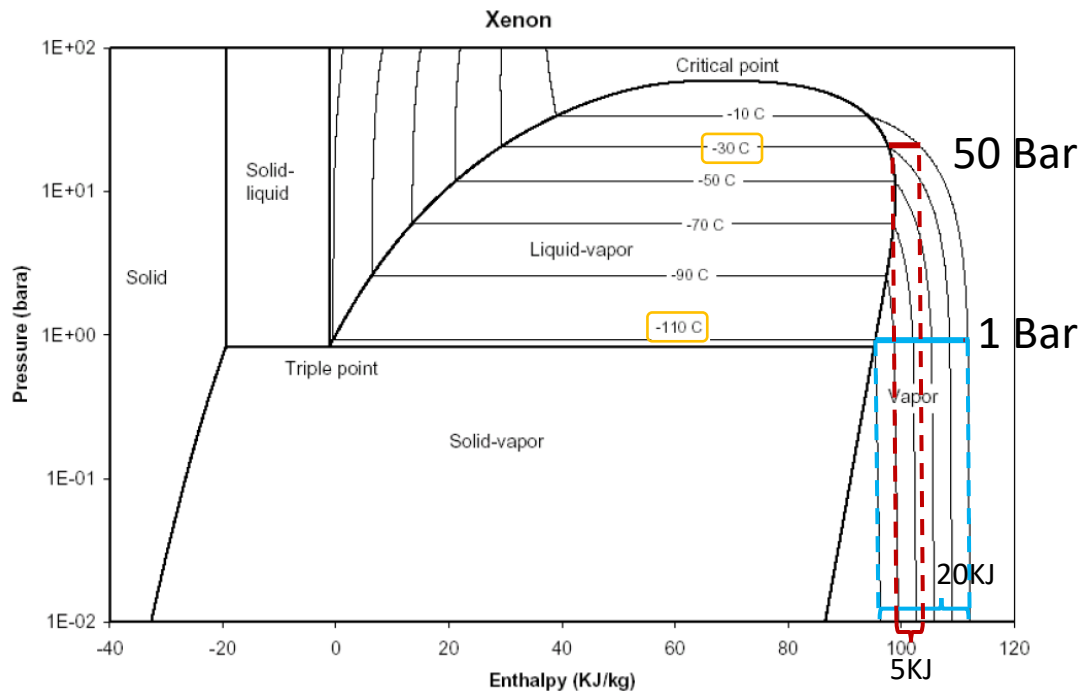
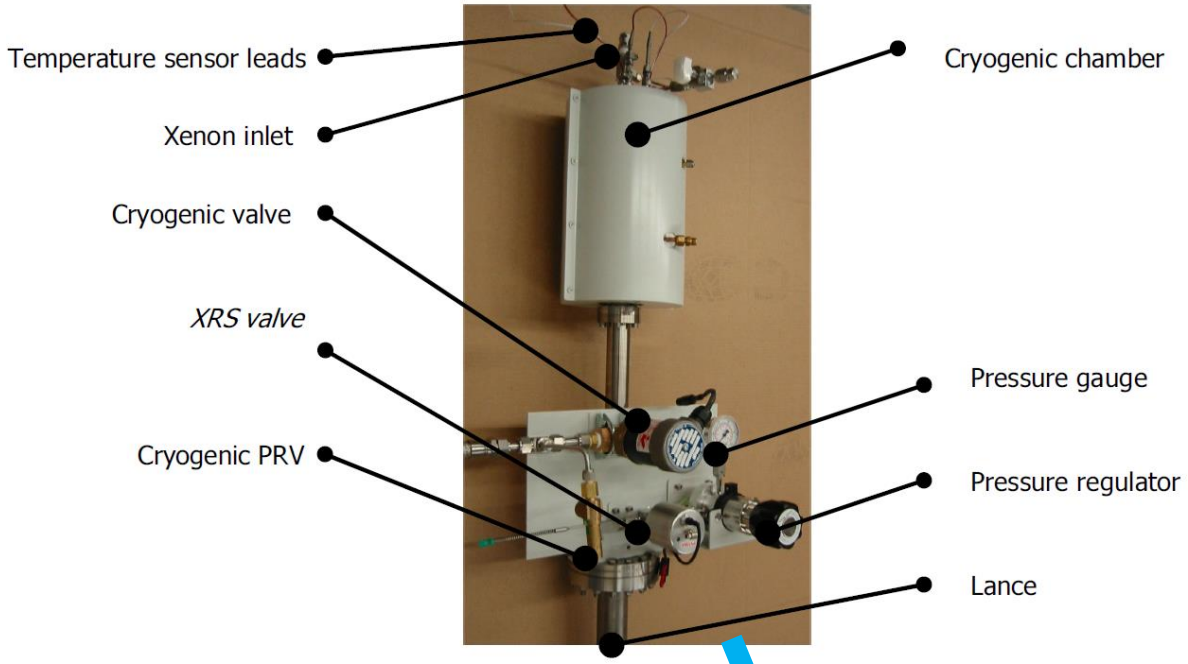
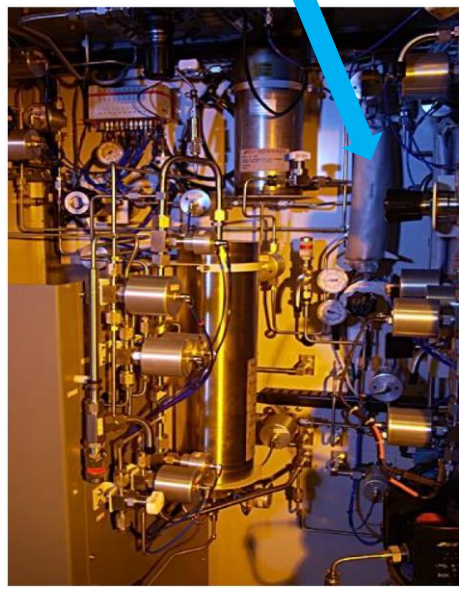
Gas Chromatography and Membrane



Xe recycle “option two”-cyogenic







- Xe gas liquefication at -110C under atmospheric pressure
  - Every kg of Xe need heat removal of 20KJ under -110C
  - Liquid N_2 required as coolant
- Pressure rise Xe up to 50 Bar, liquefication temperature improves to -30C
  - 5KJ/Kg heat removal under -30C
  - Cost of operation improved

Emerging Lithographic Technologies VIII pt.2, 2004

Proc. of SPIE Vol. 5374

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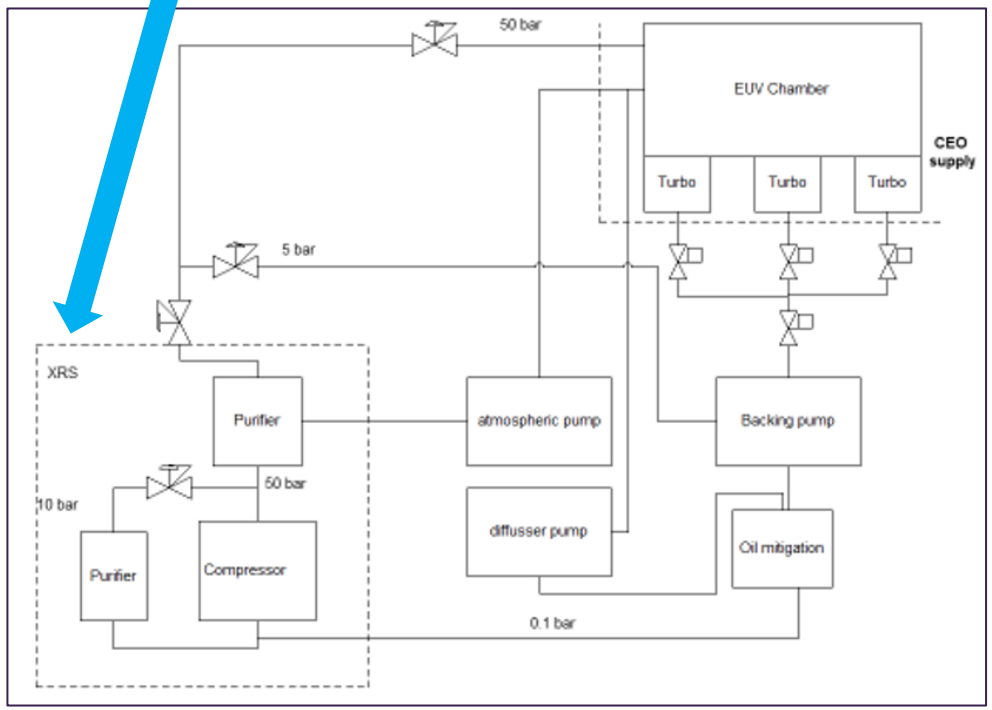
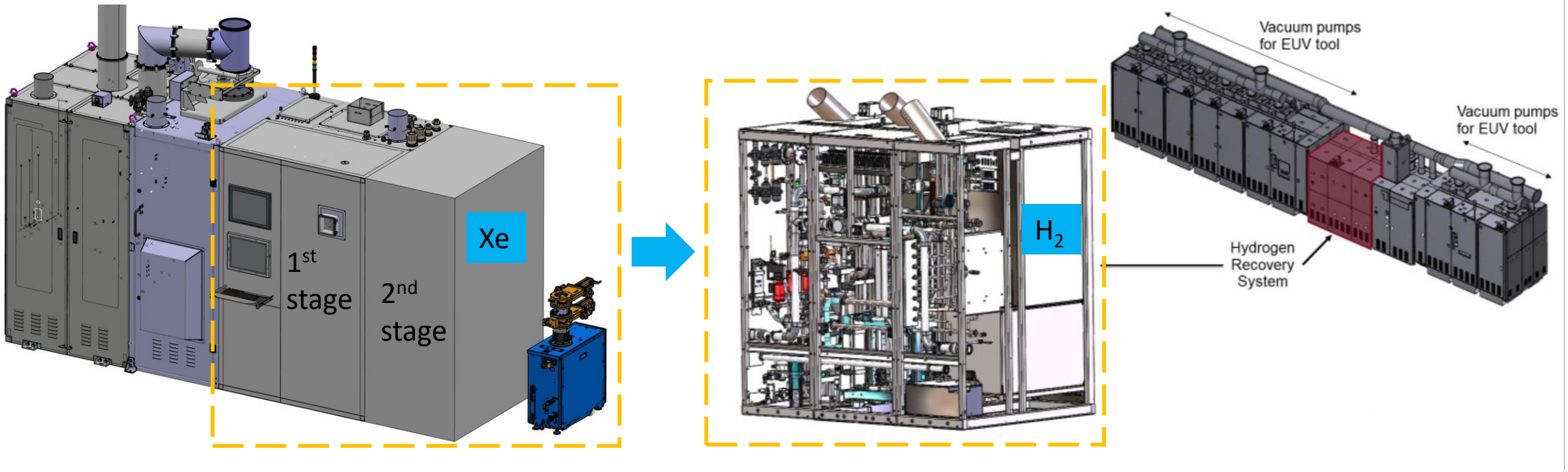
Xe recycler on site demonstration

- Xe gas recycler works with a legacy LPP source system
  - 50 Bar Xe gas has been supplied continuously
  - Regulated to 5 bar for dry vacuum pump purge
  - Oil remover and purifier as consumable parts
  - 98% recover rate @ 1ppb impurity (water or Oil)

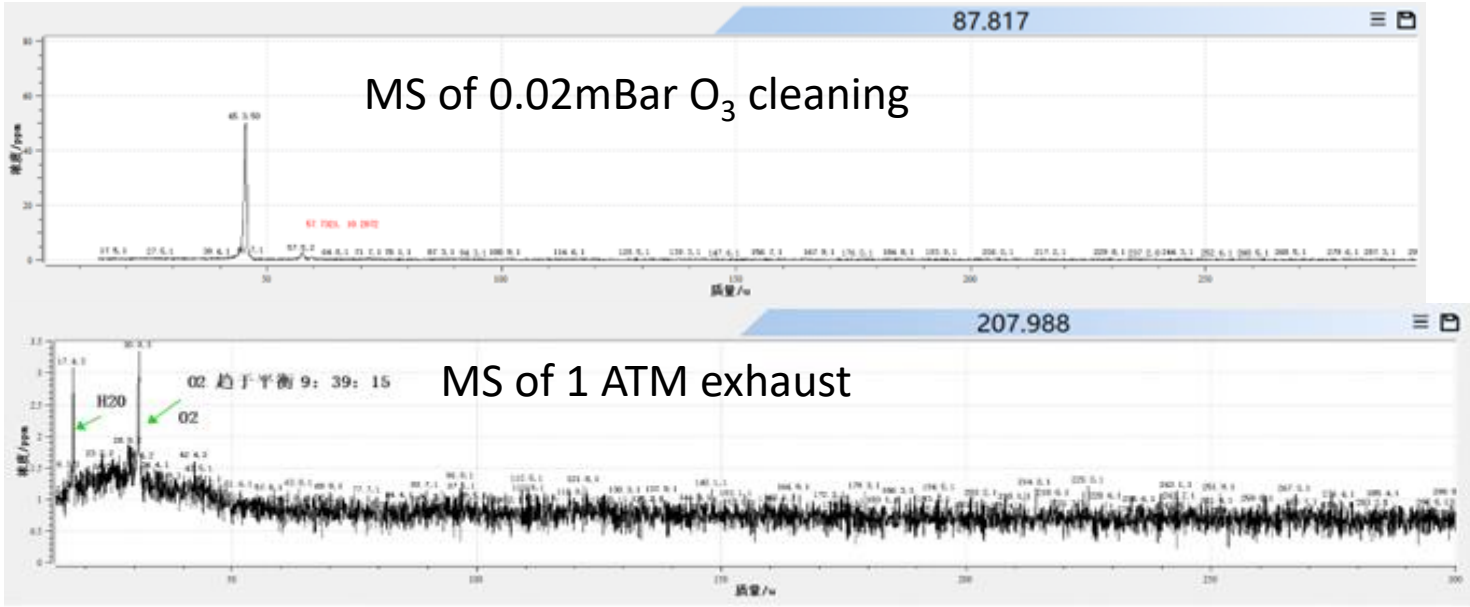


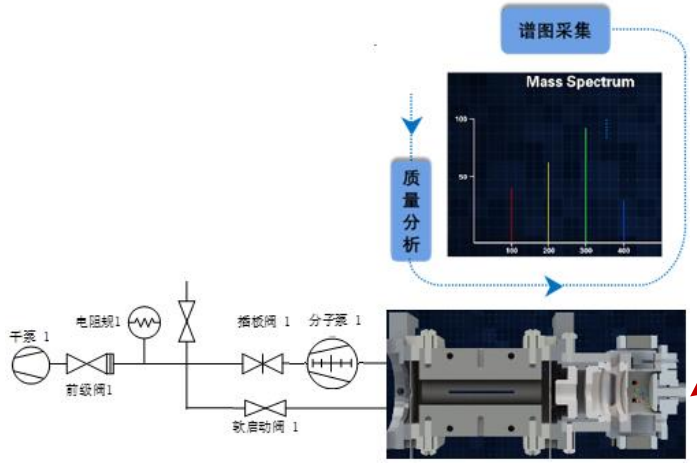
Xe recycler modularization

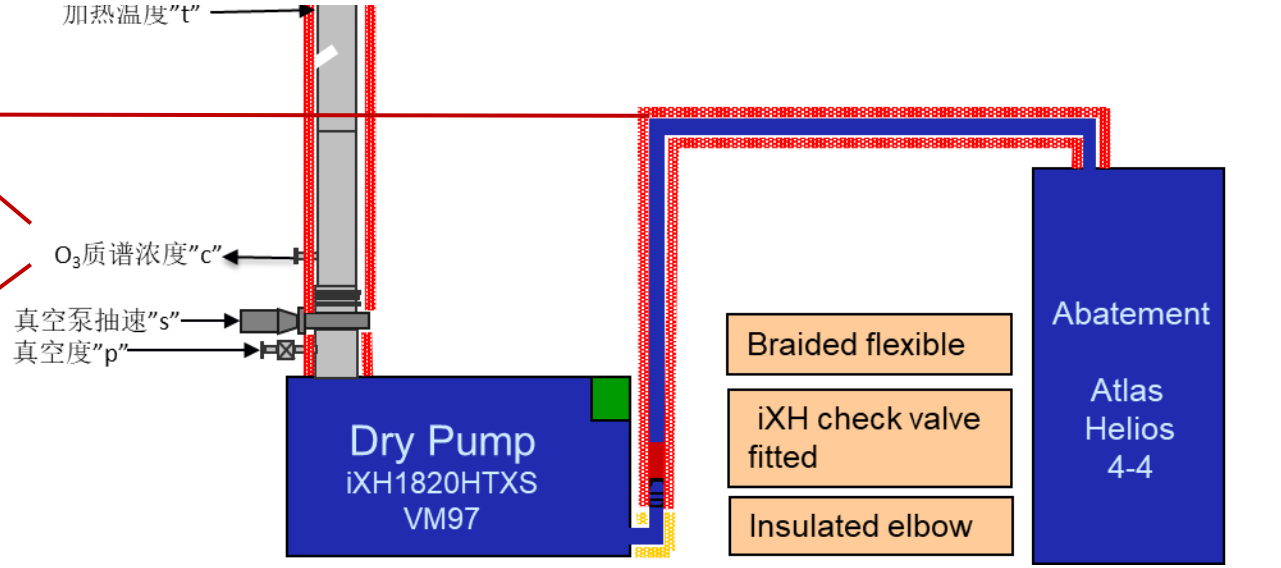
- Integrated into small footprint as H_2 recovery system (HRS)
- Swappable with HRS
- Xenon and Krypton gas shares same platform



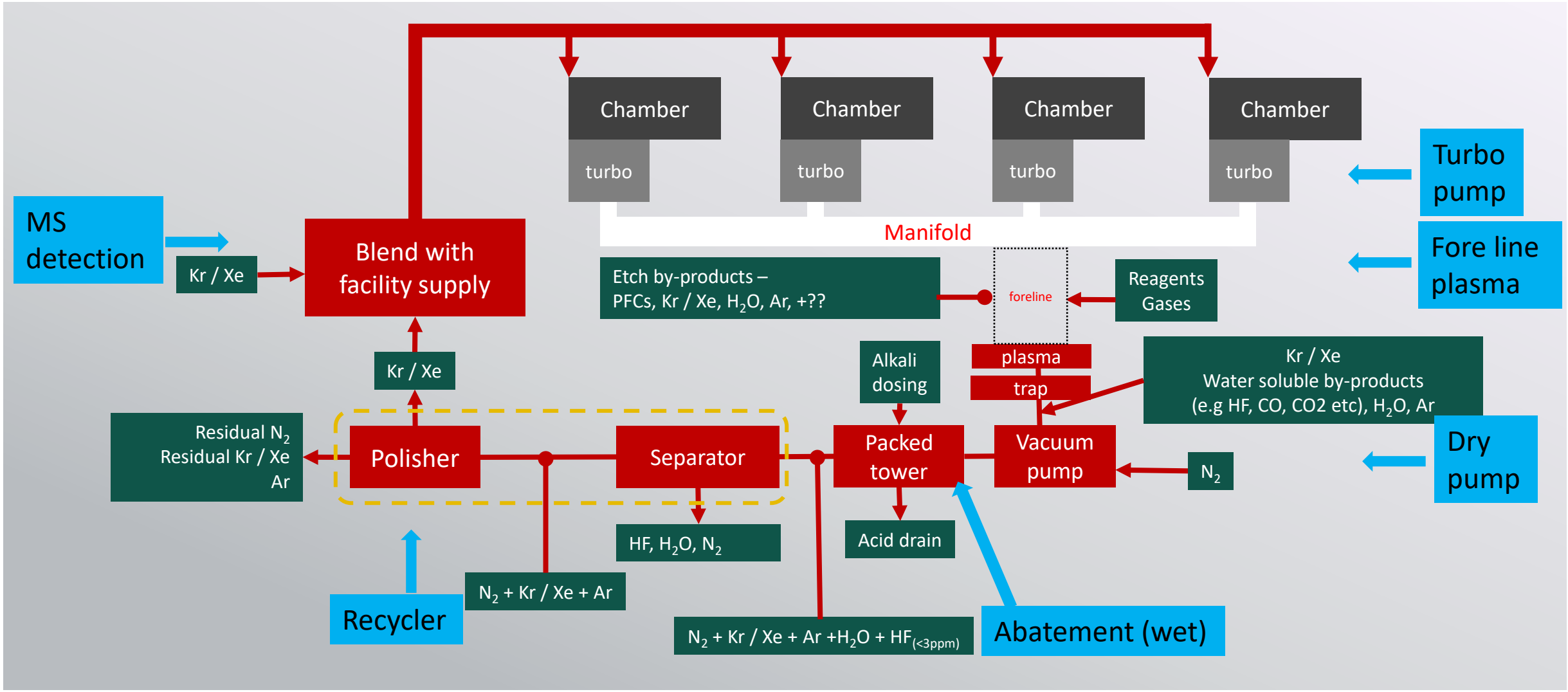
Contamination and O_2 Detection







Noble Gas Recovery turnkey solution (Dry ETCH process)



Recycler Return of Investment (ROI)

- Why?
  - Mitigates supply chain risks
  - Total energy (eCO_2) reduction
  - Emissions reduction
  - TCoO reduction
  - Social responsibility

- Why not?
  - Adds risks
    - Complexity
    - Downtime
    - Contamination
  - Adds cost
  - Increases space

Noble gas costing

Gas	Concentration in air	Embodied energy (MJ / std litre)
Argon	0.9%	0.7
Krypton	1 ppm	38
Xenon	0.09 ppm	500

Separation of Krypton or Xenon from etch process exhaust requires 270 kJ / standard liter.

Summary

- EUV source Xe gas can be recycled
- Operation cost needs improve
- Xe and Kr recovery compatible

Emissions

Green-
house gas reduction

Recycling Hydrogen

Recycling Xenon, Krypton, Helium, (Other)

Research
CO_2 *capture*

Research
NOx to NH_3 *reuse*

Recycling/reuse/removal technologies tied into wafer material roadmap technologies.

1. CDP- carbon data project declaration https://data.cdp.net/Emissions/2020-City-Wide-Emissions/p43t-fbkj/data

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