High Efficiency Xenon Recycling for EUV Sources

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1 Introduction

Xenon is one of the candidate source materials for EUV light production at 13.5 nm, offering the advantage of being potentially the cleanest of the source mediums being developed. A consistent supply of ultra high purity xenon is required for efficient light production in both laser produced (LPP) and gas discharge produced (GDPP) plasmas.

The cost of xenon has an important cost of ownership impact to the overall operating cost of the EUV tool. Xenon recycling will be critical to enabling cost effective xenon based EUV sources. BOC Edwards have developed a series of xenon recycling systems for both LPP and GDPP sources. The latest modular design includes gas separation technologies which enable recovery of xenon from systems which are using more than one inert gas for example, from systems using inert gas curtains for debris mitigation. The key to maximizing cost savings is to achieve high xenon recovery efficiency; the point-of-use design with patented features enables us to achieve > 98% recovery under normal operation.

2 Technical Challenges

Thermal Management

- Xenon has a low thermal conductivity (0.00415 W/mK) and high molecular weight m = 132; these properties can present significant thermal issues for pump mechanisms
- BOC Edwards has performed extensive characterization & optimization of both high vacuum and dry backing pumps for xenon applications
- Our latest iGX dry pump provides excellent xenon pumping and thermal stability without the need to run any purge gas. This is a key advantage within the xenon recycling system, avoiding any unnecessary dilution of the valuable xenon we are aiming to reclaim

Achieving High Xenon Recovery Efficiency

- Closed loop point-of-use design enables high recovery efficiency ≥ 98% under normal operation
- Using patented[1] feedback of the helium purge gas from the membrane back to the GC column to avoid xenon losses

3 Gas Separation

Selecting the optimal gas separation technology to recover xenon is a trade off between performance specifications such as purity & recovery efficiency and factors such as capital and operating costs.

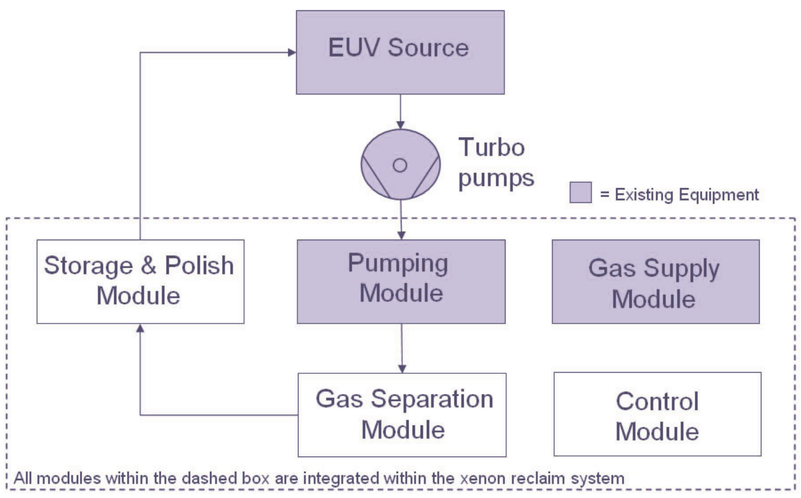
BOC has experience with a wide range of gas purification and separation technologies such as cryogenics, pressure swing adsorption and membrane technology. In the case where only one noble gas is being used or noble gas separation is not required, then titanium getter technology[2] can be used to purify xenon. However, in the lithography application the key aim is to achieve xenon separation from other noble gases such as helium and argon. This can be achieved using cryogenic technology however this is an expensive solution, therefore **our aim here is to achieve xenon separation from other noble gases using a non-cryogenic technique.**

For this application we have selected to combine two technologies:
Gas-Solid Chromatography (GC) is used to isolate xenon from all other gases[3]. The xenon atom has a long elution time through the column compared with other air components and other noble gas species thus providing very effective separation and isolation of xenon. The column uses a proprietary packing medium and uses helium as a carrier gas, in the next stage, this helium is removed to leave enriched xenon.

Membrane technology is then used to separate the xenon/helium mixture and enrich to > 99.5% xenon. The helium passing through the membrane will contain small quantities of xenon; another key feature of our design is the feedback of this helium back to the GC column enabling us to eliminate any xenon losses.

The advantages of this method are that the purity and recovery efficiency are largely independent of feed gas composition and they offer reliable, robust operation at comparatively lower capital & running costs compared with other gas separation techniques.

4 Xenon Recycling System Schematic Overview



5 System Features

Pumping Module
- Contains an iGX Dry Pump to back the turbo pumps
- Provides excellent xenon pumping & thermal stability
- Runs without nitrogen purge to avoid unnecessary dilution of the valuable xenon

Gas Separation Module
- Uses patented two stage separation to recover xenon gas:
  - Gas-Solid Chromatography (GC) - Xenon is isolated from all other gases
  - Membrane Separation - Xe/He Mix is enriched to > 99.5% Xenon

Storage & Polishing Module
- Receives enriched xenon gas from Separation Module
- Provides UHP storage and final polish before delivery back to the source

Gas Supply Module
- Contains xenon cylinders for initial charging of the system
- Provides system back-up in the event of system supply being out of specification

Controls Module
- Provides fully automated system control and interface with the source/tool

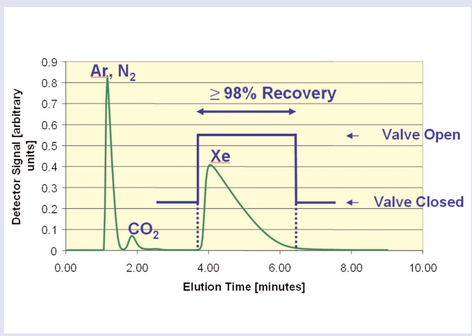
6 Performance

The point-of-use xenon recycling system has the following target specifications

• Recovery efficiency	≥ 98%
• Impurities:	
Non-noble gas	≤ 10ppm (5N)
Helium	≤ 0.5%
• Xenon purity	99.5%
• Xenon Max Gas flow	2 slm
• Total Max Gas Flow	10 slm

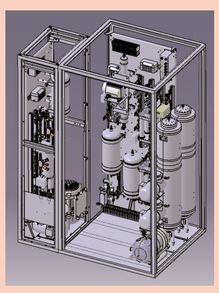
7 GC Trace of Xenon Elution from the GC Column

- Excellent baseline separation is achieved enabling high purity recovery of xenon i.e. 5N quality with non-noble gas impurities ≤ 10ppm
- Recovery efficiency is dictated by the gating of the xenon peak elution from the GC column. In this case we have selected to recover 98% of the peak, this decision is a trade-off versus a longer cycle time and is the only point in the system where a small percentage of xenon is lost.



8 Conclusions & Future Work

BOC Edwards has designed a xenon recycling system which will provide continuous delivery of high purity xenon for EUV source production. The high recovery efficiency ≤ 98% ensures cost savings are maximized. The integrated point-of-use design, minimizes footprint, such that the additional space requirements in the sub fab are small compared with those of the existing source support equipment. The modular design allows flexibility to meet the needs of specific applications and is readily adaptable to production needs.



References & Patents
1. US10/669,775 - Feedback of helium purge gas from the membrane back to the GC column
2. GB0418125 – Use of Ti getter material to remove halogen/PFC compounds
3. US11/019,843 – Use of chromatography technique to isolate xenon for recycling

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