A plan to measure EUV resist contamination in the presence of hydrogen

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Outline

Contamination of EUV optics

NIST facility for measuring contamination caused by resists

Contamination in the presence of hydrogen

Changes proposed to allow measurements with hydrogen

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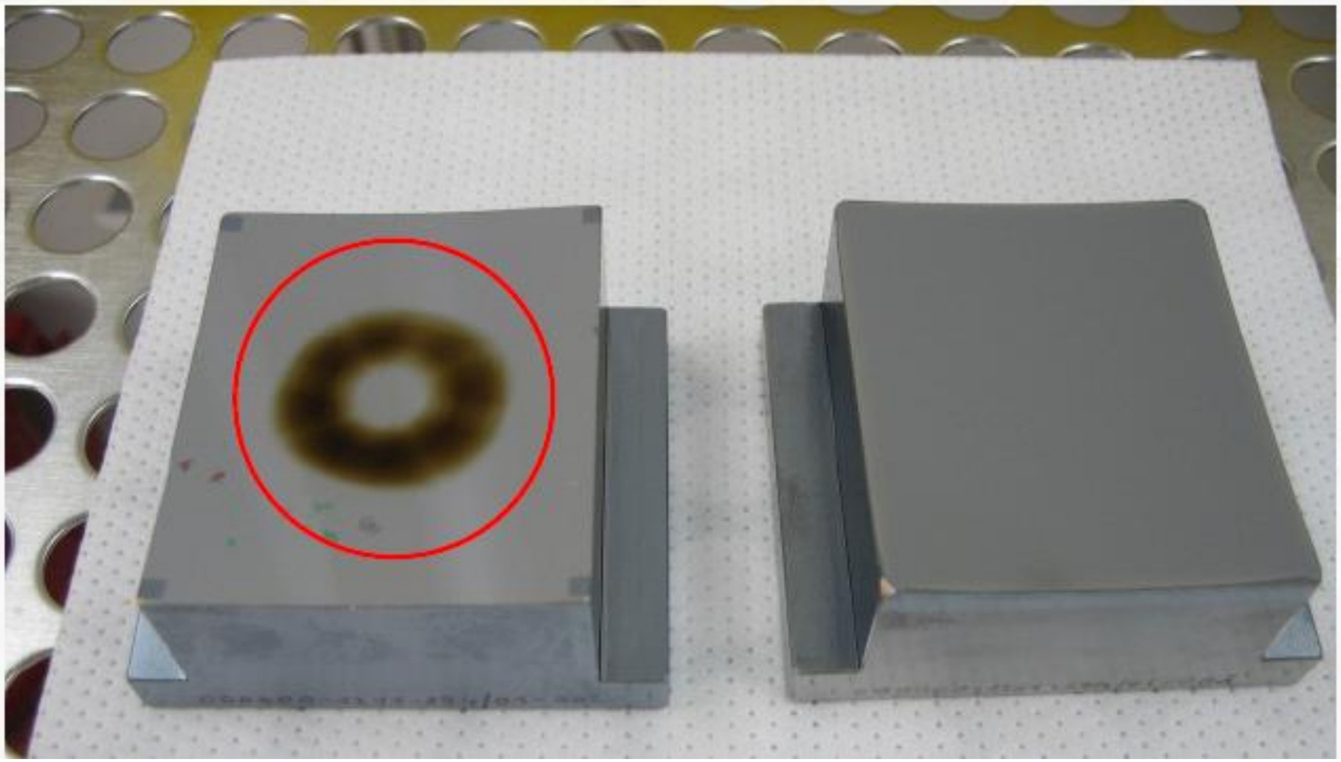
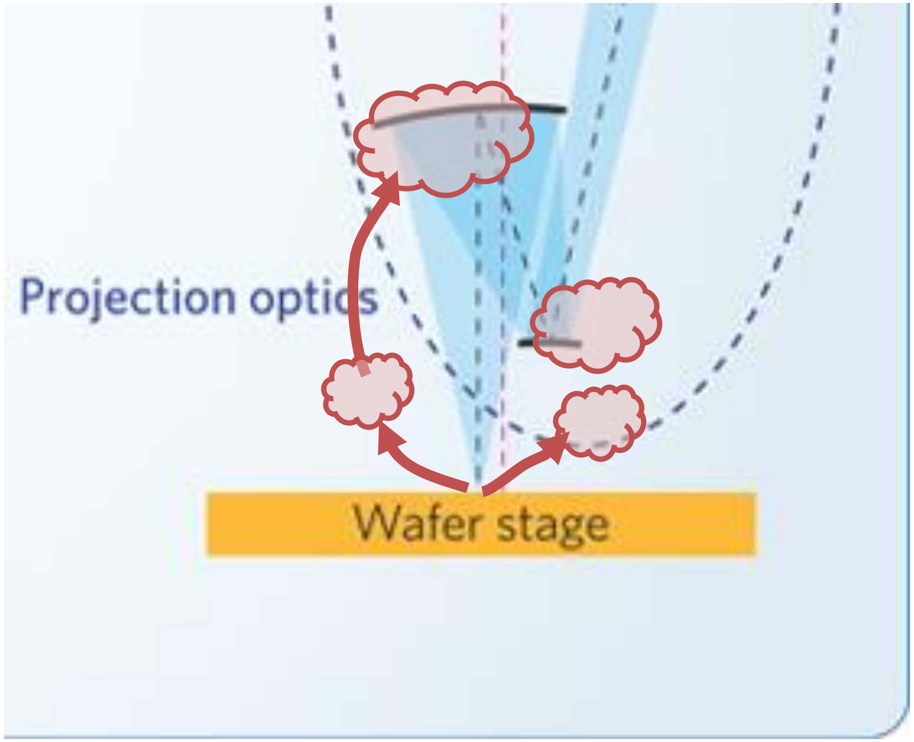
Contamination = decreased reflectivity

Contamination on illumination optics mirror N1
(old vs. new)



Intel

Outgassing + EUV = contamination



Seven steps to contamination

1. EUV causes photochemistry in resist.
2. Resist outgases organic vapors.
3. Organics travels to mirror.
4. Organics adsorb onto mirror.
5. EUV cracks adsorbed organics.
6. Cracked organics stick to mirror.
7. Mirror loses reflectivity.

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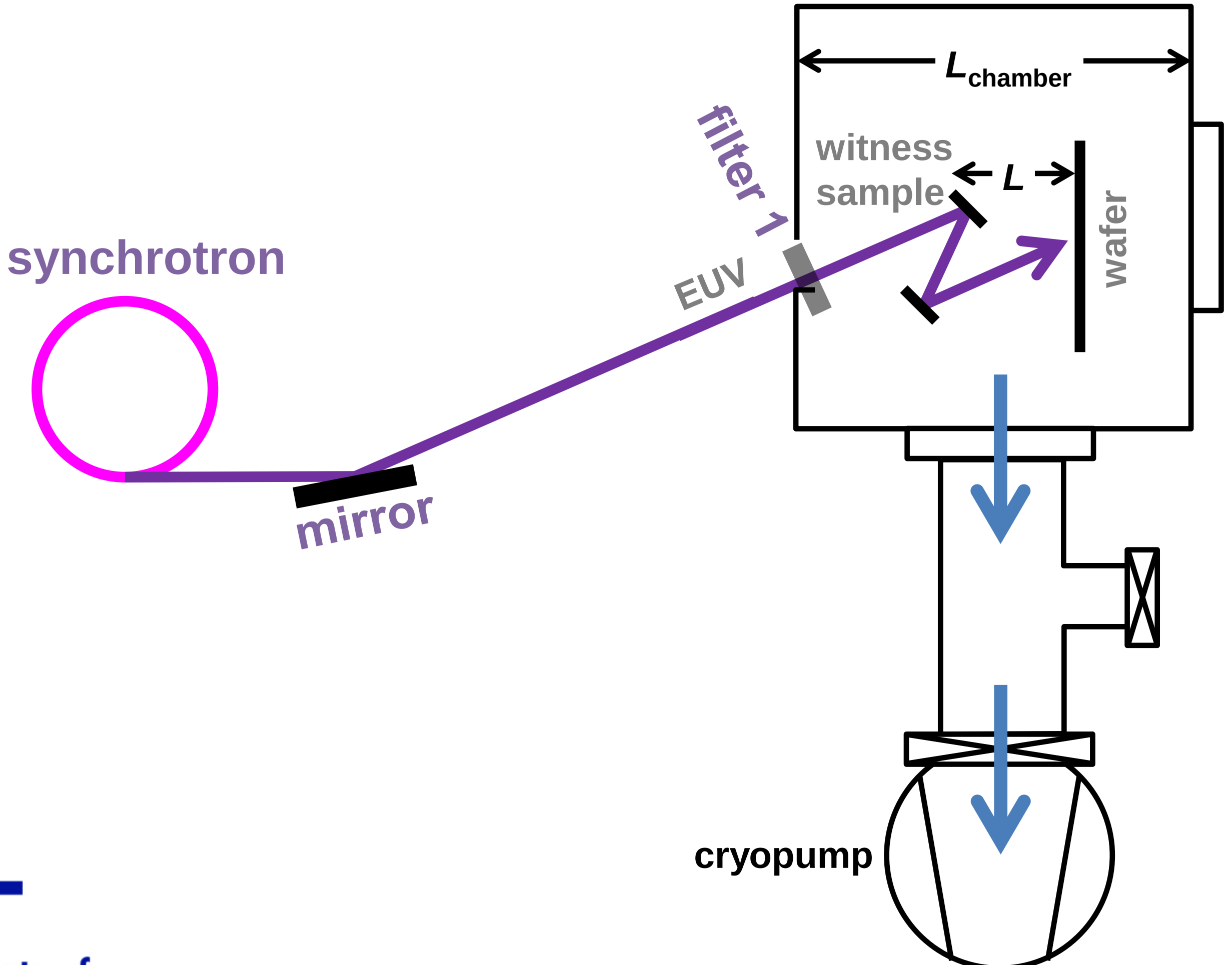
The present: Testing in vacuum

Organics leave wafer,
travel to chamber surfaces
and then to witness sample.



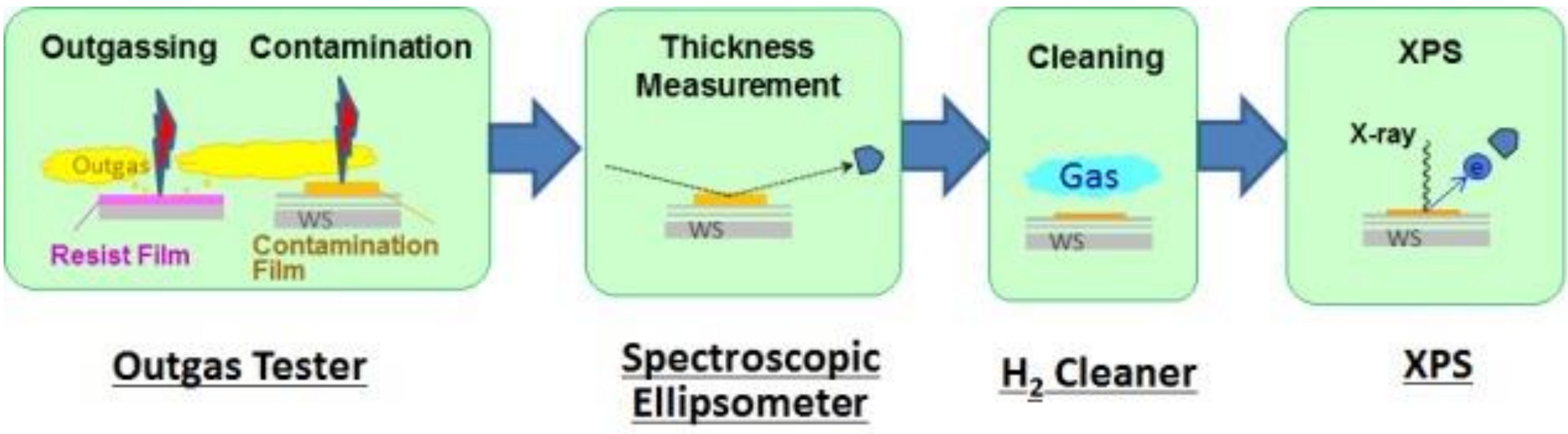
Protocol for contamination testing (in vacuum)

Expose wafer and witness sample.

Measure carbon thickness.

Remove carbon.

Measure "uncleanables".



graphic from E. Shiobara & I. Soichi (EIDEC)

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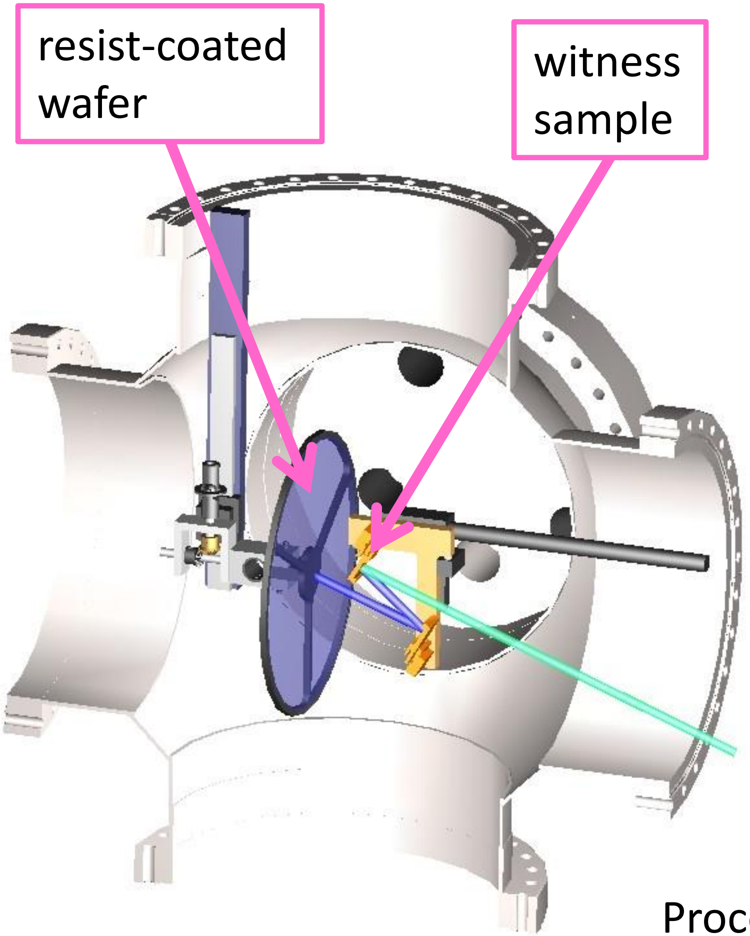
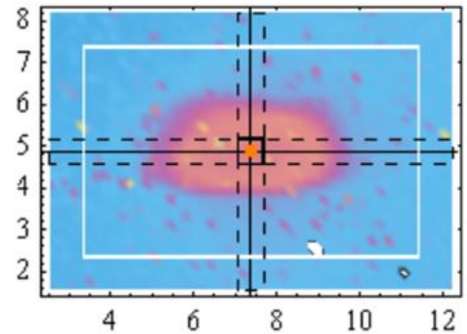
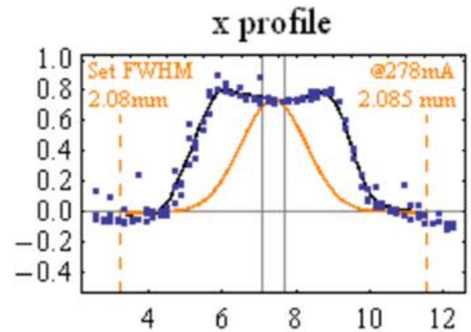
The witness-sample test at NIST



Ingredients
- synchrotron
- beamline vacuum chamber
- atomic hydrogen cleaner
- spectroscopic ellipsometer
- x-ray photoelectron spectrometer (XPS)





Report
- thickness of carbon spot
- reflectivity loss

Procedure
1) Coat wafer with resist.
2) Measure resist dose-to-clear E_0
3) Expose wafer to E_0 for 1 hour.
4) Use spectroscopic ellipsometer to measure carbon growth.
5) Use atomic hydrogen cleaner to remove carbon growth.
6) Use XPS to measure residual “non-cleanable” elements.

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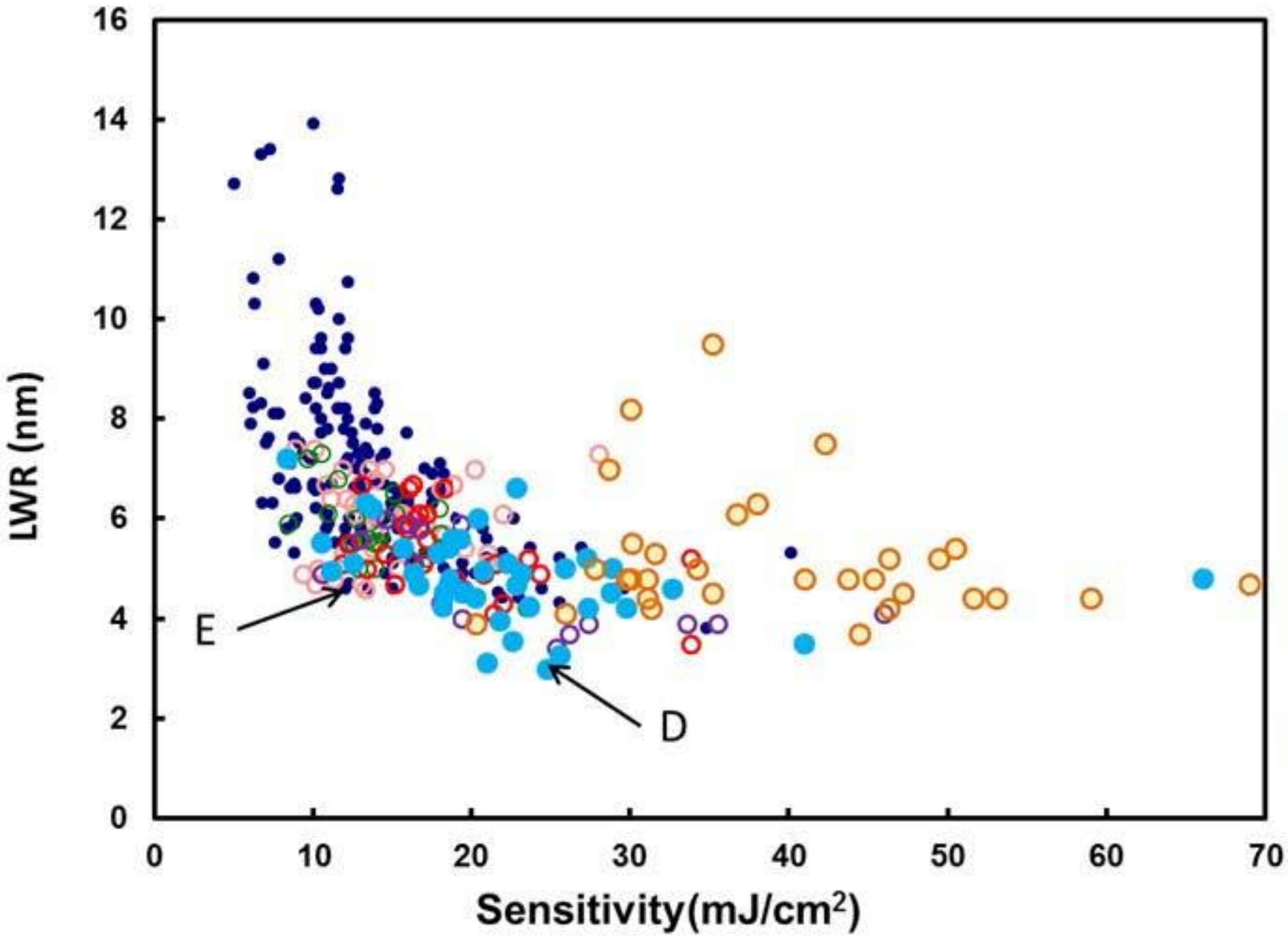
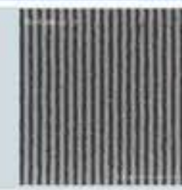
Trade-off between resist sensitivity and line-width roughness

Neisser et al., SPIE Extreme Ultraviolet (EUV) Lithography (2015)



	E	D
Image		
Size	24nm HP	17nm HP
LWR	4.7nm	2.9nm
Speed	10.1mJ/cm²	26.5mJc/m²

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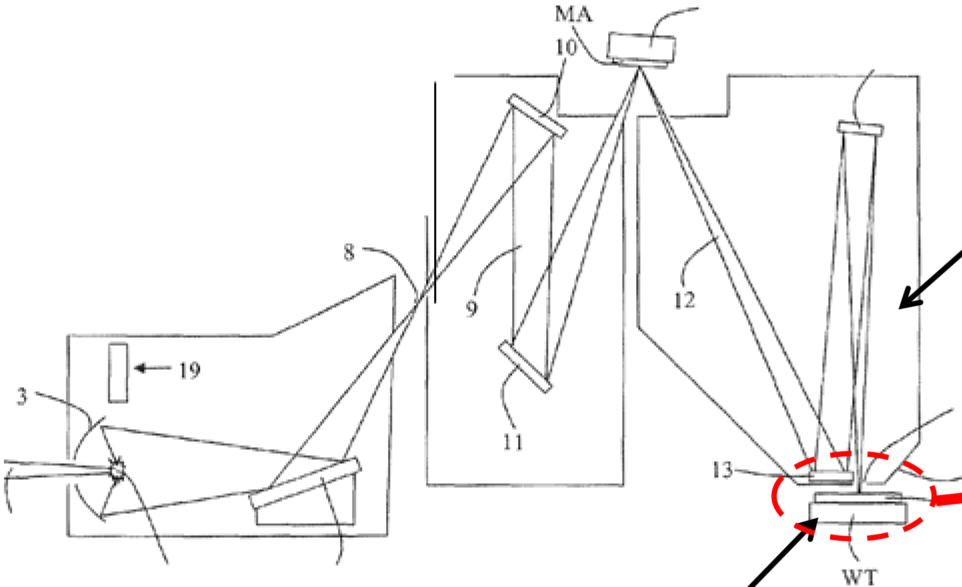
☹☹☹ **No big improvement** ☹☹☹

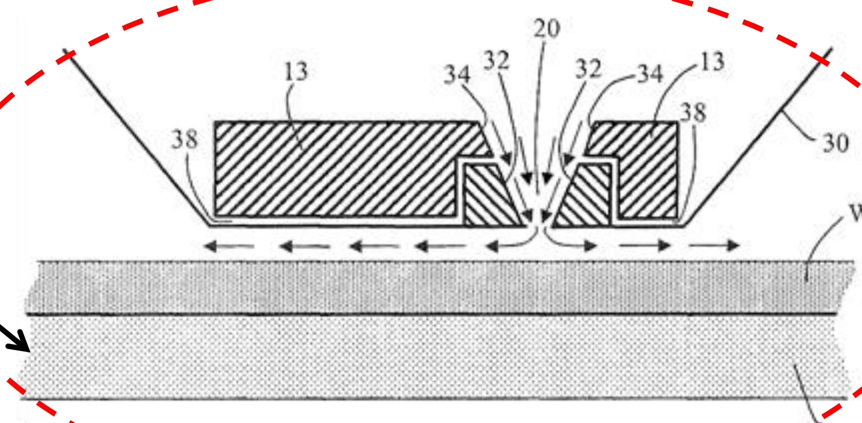
Gas flow keeps contamination away from the scanner optics



projection system

2014 [Nienhuys et al.] “Lithographic apparatus configured to suppress contamination from passing into the projection system and method”

wafer table



The case for tests in the presence of hydrogen

Facts:

- Recent progress with “traditional” chemically amplified resists has been slow.
- Non-traditional resists containing unusual elements, such as Hf, show promise.
- The interaction between unusual elements, EUV, and hydrogen is not well understood.

Hence...

It is necessary to measure EUV-induced resist contamination in the presence of hydrogen.

How much hydrogen?

pressure	typical in a scanner (1 mbar)
flow rate	enough to suppress outgassing of H_2O and O_2

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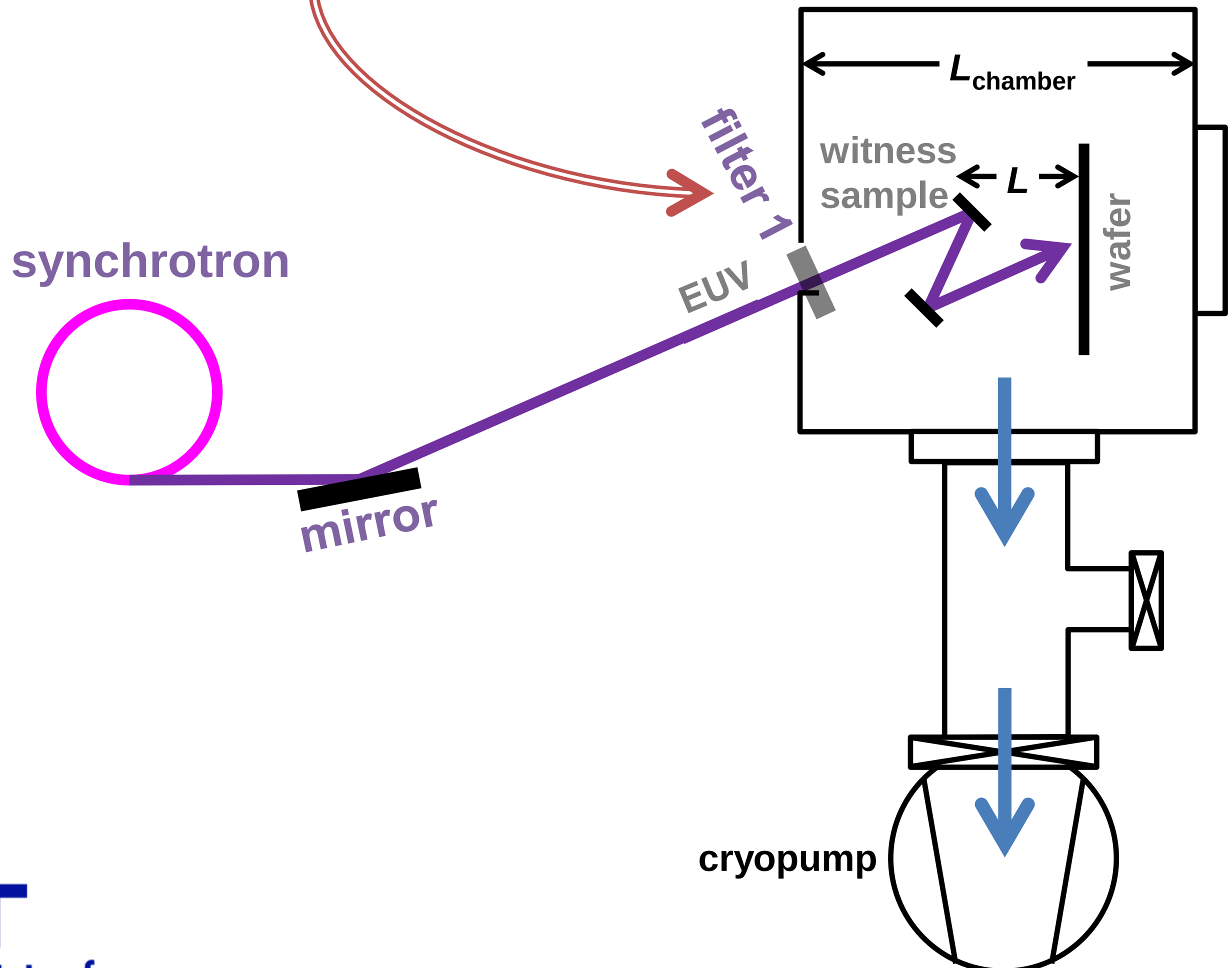
The present: Testing in vacuum

Filter keeps organics out of mirror and synchrotron.

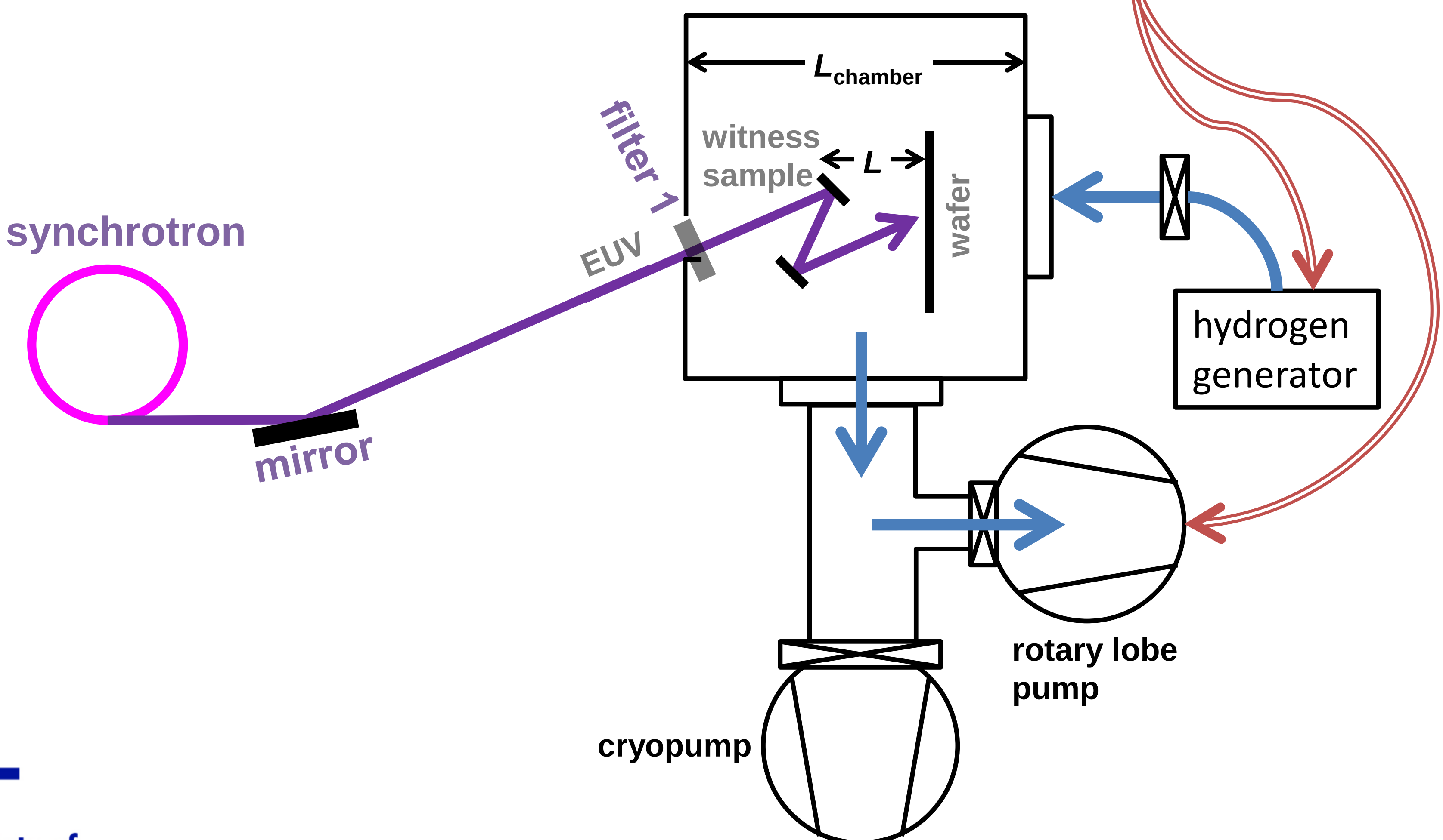
Organics leave wafer, travel to chamber surfaces and then to witness sample.



The plan: Test in the presence hydrogen

Contaminating vapors diffuse through hydrogen from wafer to witness sample.

Hydrogen flows through the chamber.



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Hydrogen pressure and flow rate

How much hydrogen?

pressure 1 mbar

flow rate enough to suppress outgassing of H_2O and O_2

Minimum pumping speed to suppress H_2O

$$\dot{V}_{\mathrm{pumpMin}} = \frac{Q_{\mathrm{water}}}{P_{\mathrm{H2O}}} = \frac{\left(6\times10^{-7}\ \mathrm{mbar\ L\ s^{-1}}\right)}{\left(1.0\times10^{-7}\ \mathrm{mbar}\right)} = 6\ \mathrm{L\ s^{-1}}$$

Corresponding flow rate

$$Q_{\mathrm{H2min}} = P\dot{V}_{\mathrm{pumpMin}} = 6\ \mathrm{mbar\ L\ s^{-1}} = 360\ \mathrm{sccm}$$

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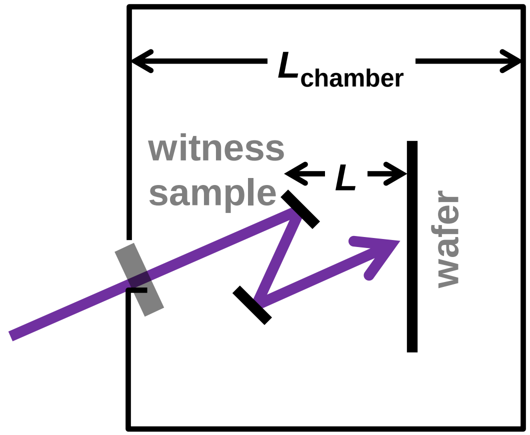
Convection vs diffusion

Q: How much time is needed for outgas species to diffuse to the witness sample?
A: 0.03 s



$$t_D \equiv \frac{L^2}{D} = 0.03\ \mathrm{s}$$

Q: How much time is needed for the H_2 flow to sweep out the volume L^3 ?
A: 0.8 s

$$t_{\mathrm{flow}} \simeq \left(\frac{L}{L_{\mathrm{chamber}}}\right)\frac{V_{\mathrm{chamber}}}{\dot{V}_{\mathrm{pump}}} \simeq \left(\frac{0.042\ \mathrm{m}}{0.5\ \mathrm{m}}\right)\frac{(56\ \mathrm{L})}{\left(6\ \mathrm{L\ s}^{-1}\right)} = 0.8\ \mathrm{s} \gg t_D$$

Convection is not a problem because $t_D \ll t_{flow}$

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Protecting the NIST synchrotron (SURF III) from hydrogen

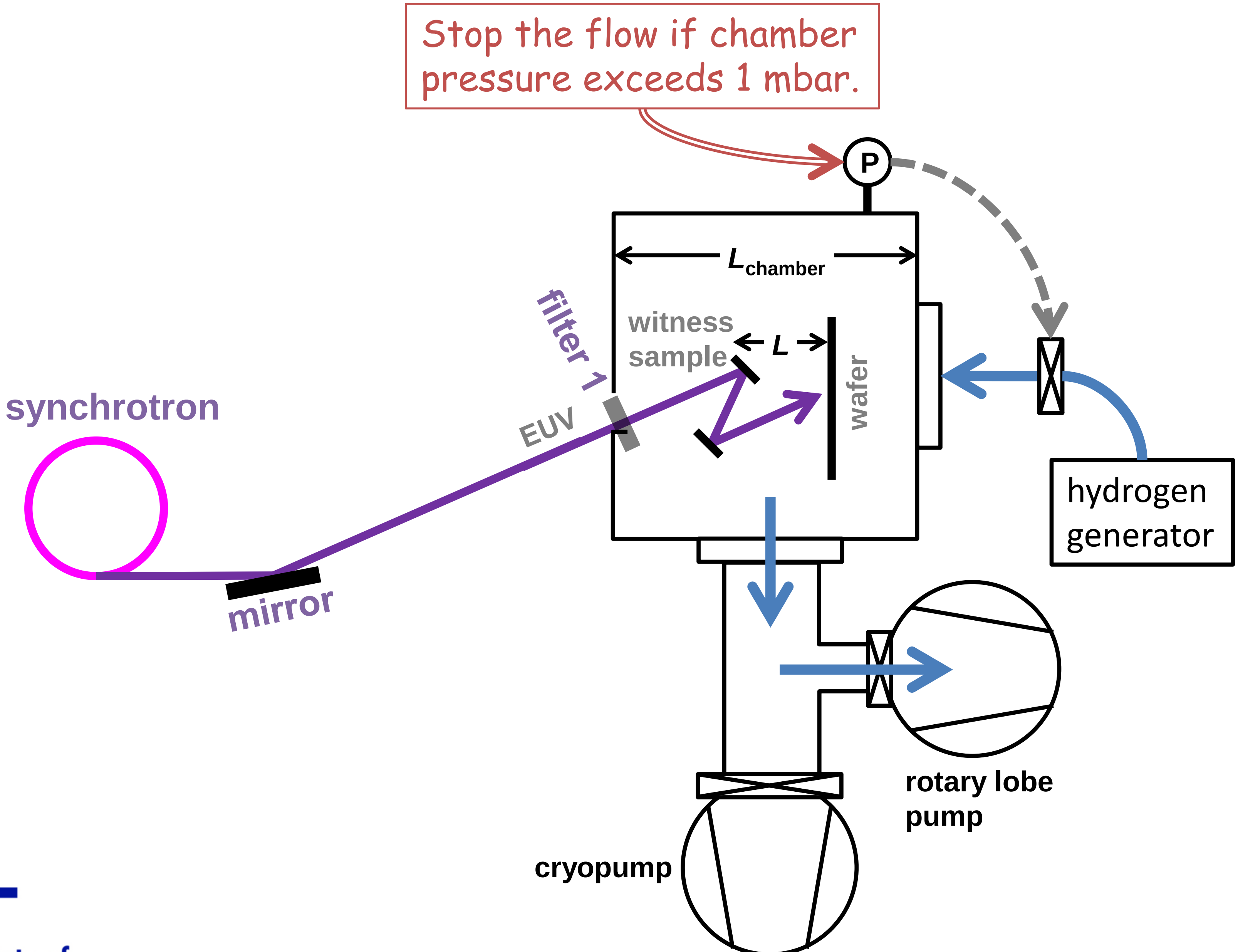
Facts:

- Exposing the SURF's ion pumps to a large hydrogen pressure will cause them to sporadically "burp" hydrogen afterwards, making SURF unusable.
- The ion pumps are integrated into the storage ring, so repairing them would require disassembling SURF.
- Disassembly and reassembly could take one year.

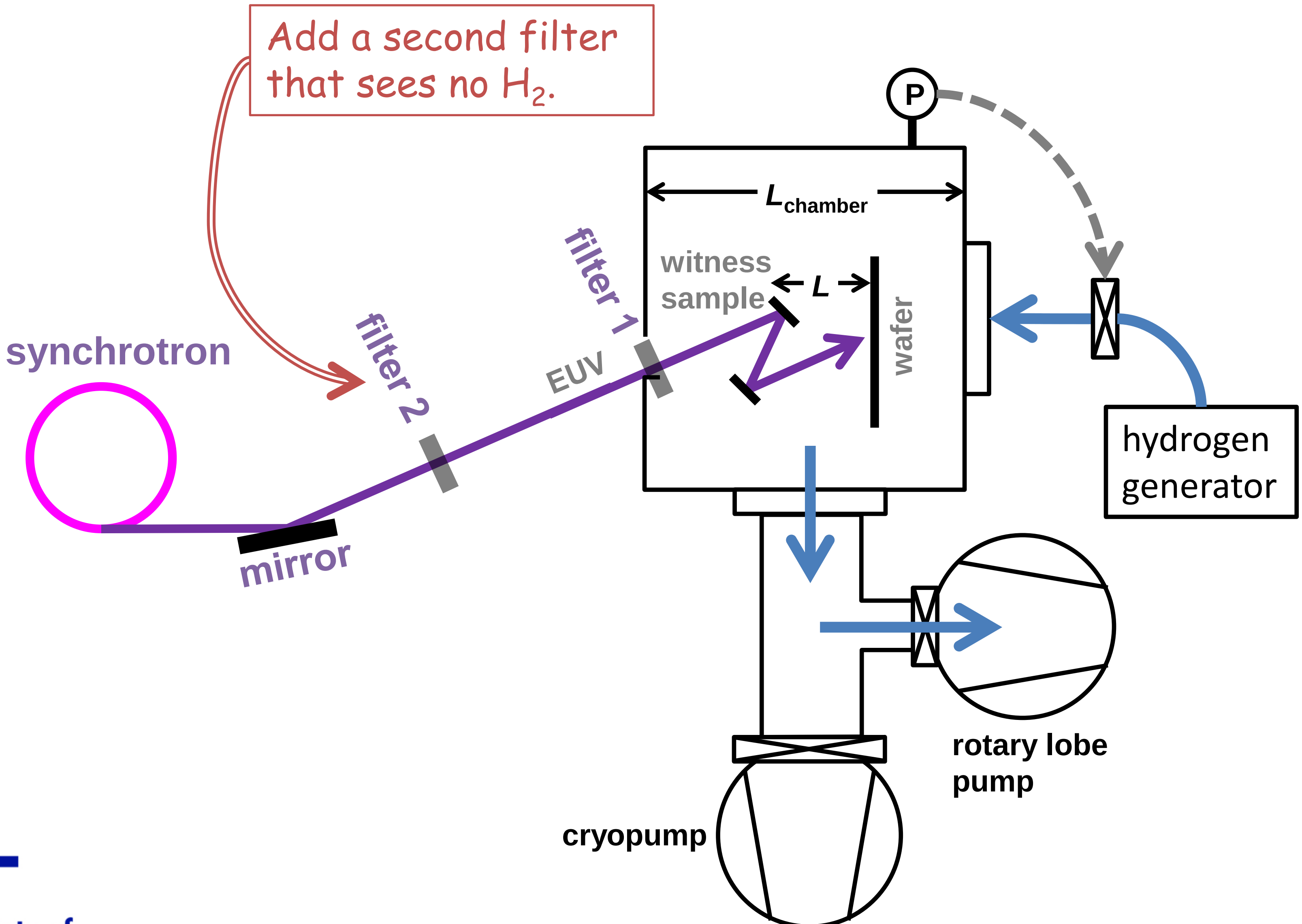
Hence...

SURF must be protected against a burst of hydrogen.

Protect the synchrotron



Protect the synchrotron



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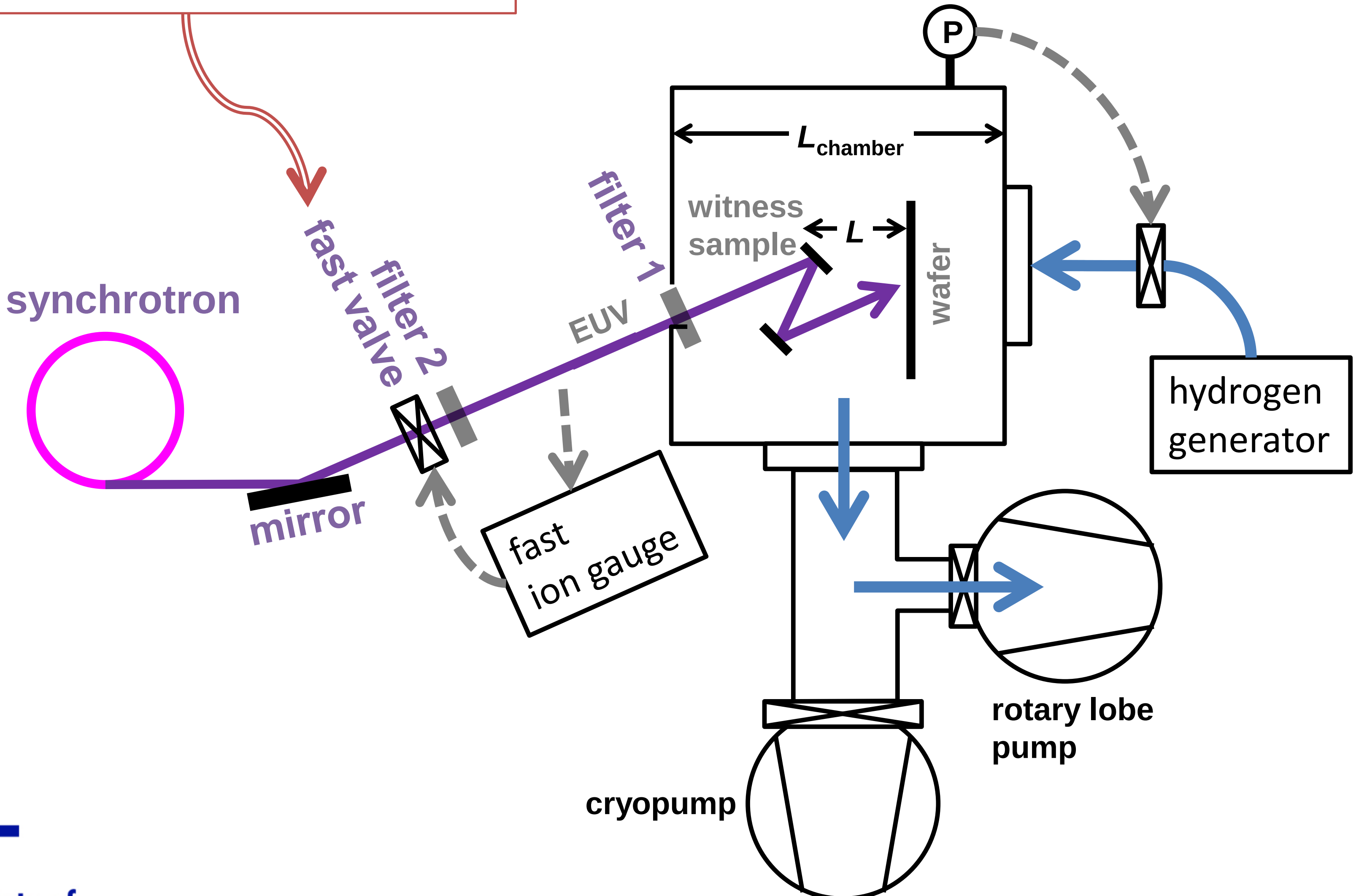
Protect the synchrotron

Shut the fast valve
if pressure in the beamline rises.



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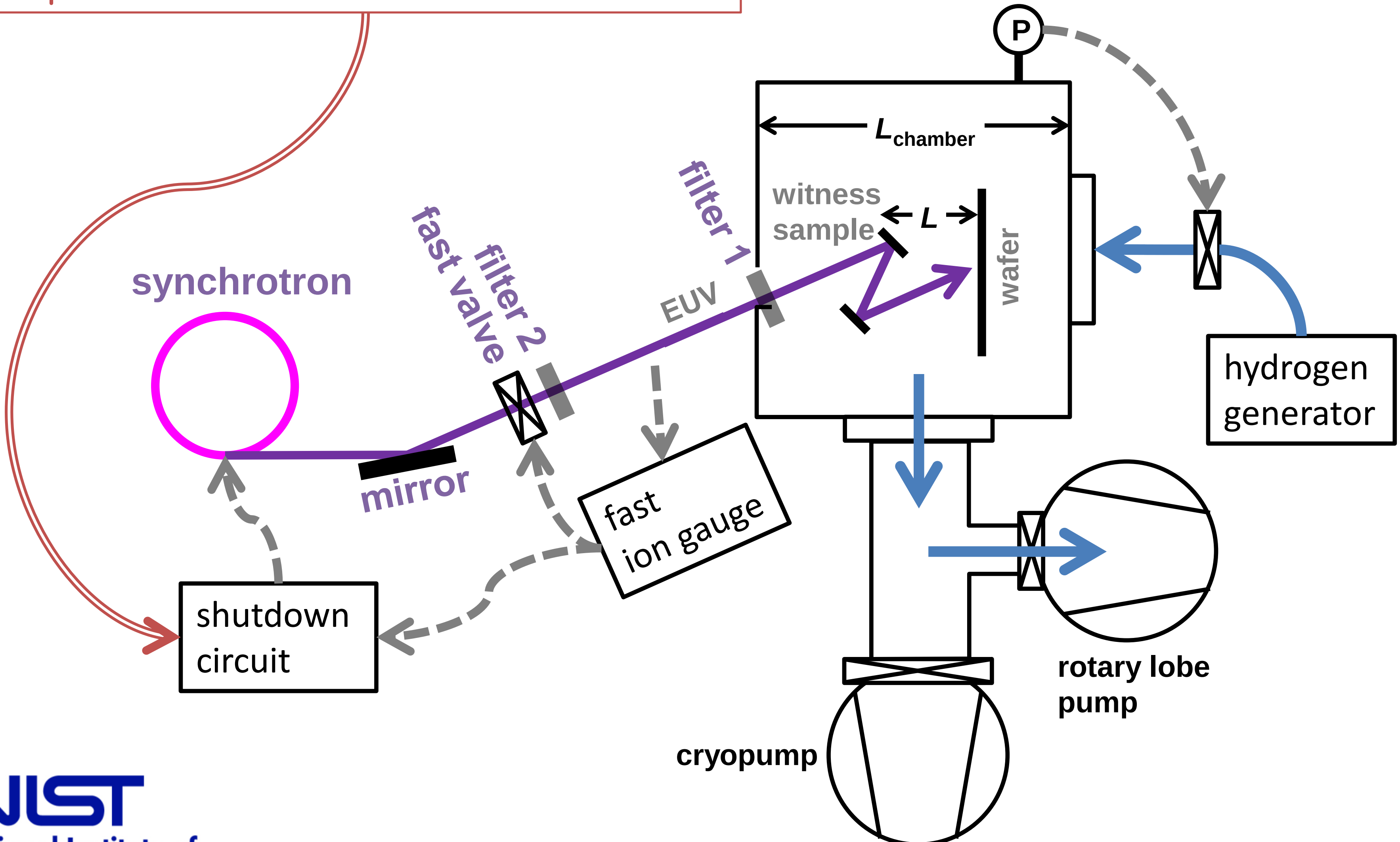
Protect the synchrotron

Stop the synchrotron's ion pumps
if pressure in the beamline rises.



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Summary

The contamination caused by EUV + resists + hydrogen is not well understood.

The concern is only with “non-traditional” resists that have unusual elements.

NIST is investigating the feasibility of contamination tests with hydrogen.

Hydrogen in the NIST synchrotron is a risk that must be addressed.

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