A systematic approach for contamination control

EVC 2024

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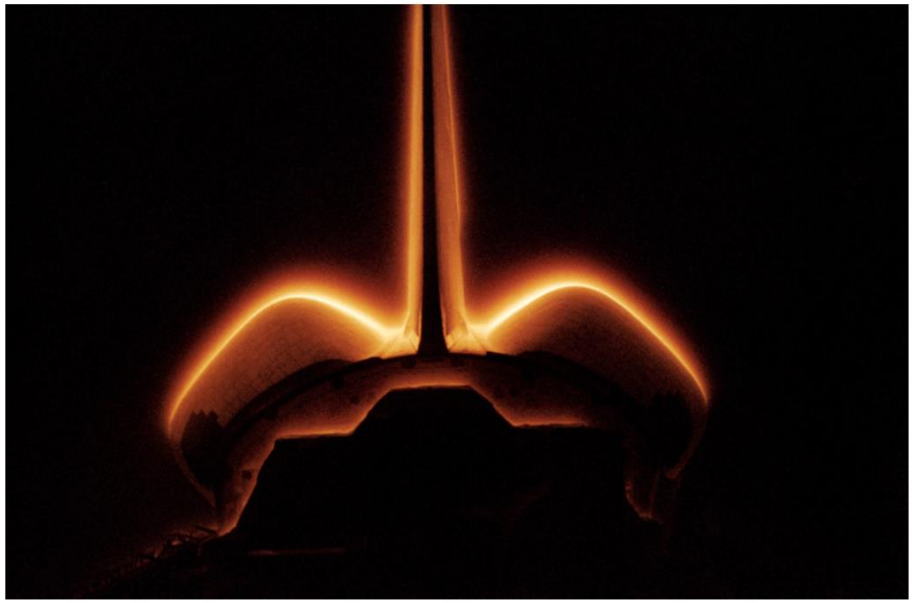
TNO innovation for life

Question



Shuttle glow When atomic oxygen from the high atmosphere combines with nitric oxide on the surface of the space shuttle, the resulting excited nitrogen dioxide returns to the ground state emitting an apparent glow.

https://www.collegesidekick.com/study-guides/introchem/glow-of-space-shuttles

William Andrew
Applied Science Publishers

Handbook of Environmental Degradation of Materials

2005, Pages 465-501

Chapter 23 - Degradation of spacecraft materials

Joyce Dever, Bruce Banks, Kim de Groh, Sharon Miller

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https://doi.org/10.1016/B978-081551500-5.50025-2

Publisher Summary

This chapter provides descriptions of specific s
spacecraft materials. It summarizes space expo
individual and combined space environmental
on effects of Earth orbit environments because
flown in Earth orbits, which have provided a si
effects. Issues associated with interpreting mat
and deficiencies of ground testing are identifie
reducing or preventing space environmental de
selection. The chapter concludes that spacecraf
environments have been found to undergo deg
threats including atomic oxygen, contaminatio
temperature cycling, and micrometeoroids and
space environment degrades or damages mate
of an individual spacecraft environment and th
altered by these environmental exposures.

Home > CEAS Space Journal > Article

Property changes in materials due to atomic oxygen in the low Earth orbit

Original Paper | Open access | Published: 28 June 2021
Volume 13, pages 415–432, (2021) Cite this article

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Aki Goto, Kaori Umeda, Kazuki Yukumatsu & Yugo Kimoto

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Abstract

We expect satellites at altitude below 300 km, very low Earth orbit (VLEO), making observations of the Earth at optical wavelength with increasingly higher resolution. The density of atomic oxygen (AO) at VLEO is significantly higher than that at LEO; severe degradation of spacecraft materials (polymers) due to the high-flux AO is a serious concern. To clarify VLEO environmental effects on spacecraft materials, we designed the Material Degradation Monitor (MDM) and MDM2 missions. The MDM is a material exposure experiment onboard the Super Low-Altitude Test Satellite (SLATS). It aims to understand reactions and degradation of polymeric materials depending on AO fluence in VLEO. In the MDM, samples of spacecraft material were exposed at altitude of 160–560 km; their degradation behaviors were observed optically by a CCD camera for 1.8 years. The MDM2 is a material exposure experiment onboard the International Space Station (ISS) and aims to correctly understand surface reactions and degradation of the same samples used in the MDM at a given AO fluence. In the MDM2, the samples were exposed at altitude of 400 km for 1 year and then returned to Earth for analysis. Based on the results from both missions, we will help in the molecular design of more-durable

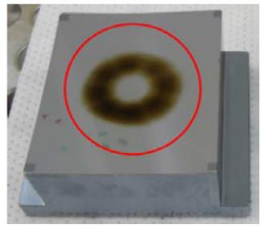
Other examples of contamination threats in vacuum system

Carbon contamination

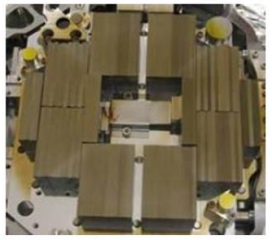
ASML

Public
Slide 11
<Date>

- 'Vacuum' contains residual (hydrocarbon) contaminants
- Hydrocarbons adsorb on (mirror) surfaces
- EUV photons and secondary electrons cause
  - Transformation of C_xH_y chains to aC:H
  - Reduction of H-content with irradiation dose
  - Radiation-induced outgassing of fragments
- EUV lifetime issue
  - How fast does carbon grow under actual tool conditions?



SEMATECH MET, 2007



ADT mirror, 2007

EUV optics lifetime, Radiation damage, contamination, and oxidation; M van Kampen (ASML); PXRNM workshop 2016

Mitigation of systematic approach is needed

- We cannot remove the atomic oxygen from Space…

☐ 4	Space Environment Effects on Advanced Ceramic Coating for Aerospace Thermal-Proof Re-entry Systems	Pastore, R., Delfini, A., Albano, M., (...), Piergentili, F., Marchetti, M.	2024	Engineering Materials Part F1842, pp. 385-405	
	View abstract ⌄ TNO LinkSolver View at Publisher Related documents				
☐ 5	The atomic oxygen resistant study of a transparent polyimide film containing phosphorus and fluorine *Open Access*	Shu, C., Wu, X., Zhong, M., Yan, D., Huang, W.	2023	Applied Surface Science 631,157562	
	View abstract ⌄ TNO LinkSolver View at Publisher Related documents				
☐ 8	Ground Testing of the 16th Materials International Space Station Experiment Materials	Plis, E.A., Bengtson, M.T., Engelhart, D.P., (...), Collman, S., Scott, T.R.	2023	Journal of Spacecraft and Rockets 60(2), pp. 385-390	2
	View abstract ⌄ TNO LinkSolver View at Publisher Related documents				

Reflectometer EBL2

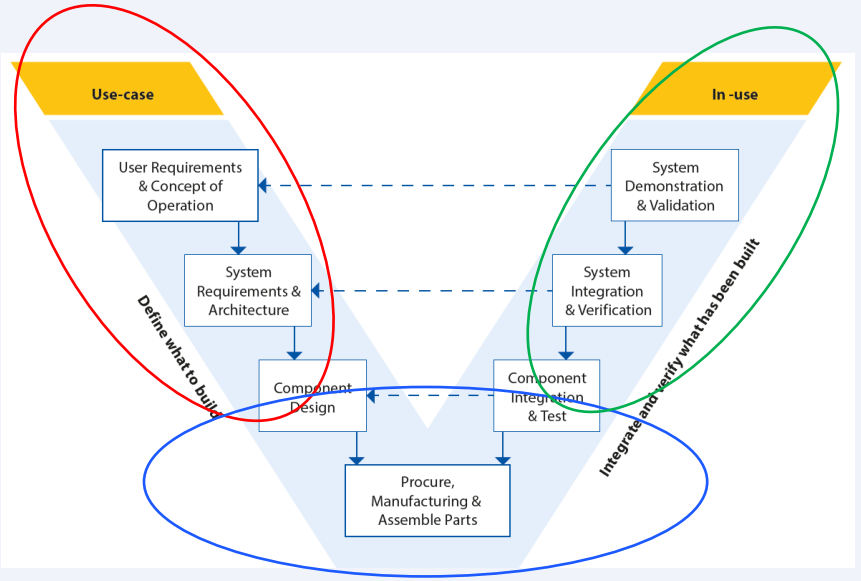
- Reflectometer will be used to measure in-situ changes on the surface of the EBL2 sample
- EBL2 is a research facility at TNO to facilitate EUV related contamination research by exposing samples to EUV radiation
- For this an ultra clean vacuum system and particle “free” system is mandatory
- www.tno.nl/ebl2

ECSEL Joint Undertaking

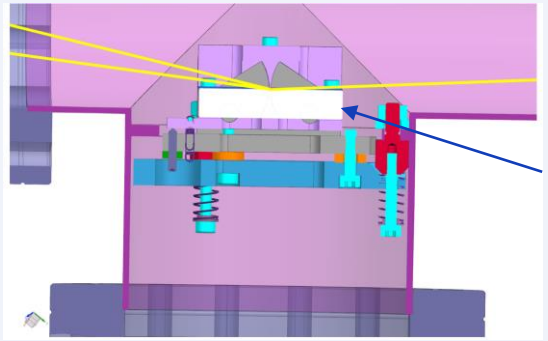
“This project has received funding from the ECSEL Joint Undertaking (JU) under grant agreement No 783247. The JU receives support from the European Union’s Horizon 2020 research and innovation programme and Netherlands, Belgium, Germany, France, Austria, United Kingdom, Israel, Switzerland.”

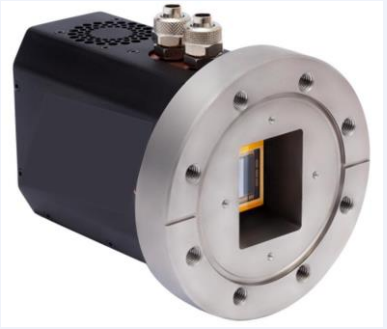
The right level at the right location

- Systems approach;
  - Define
  - Make
  - Validate

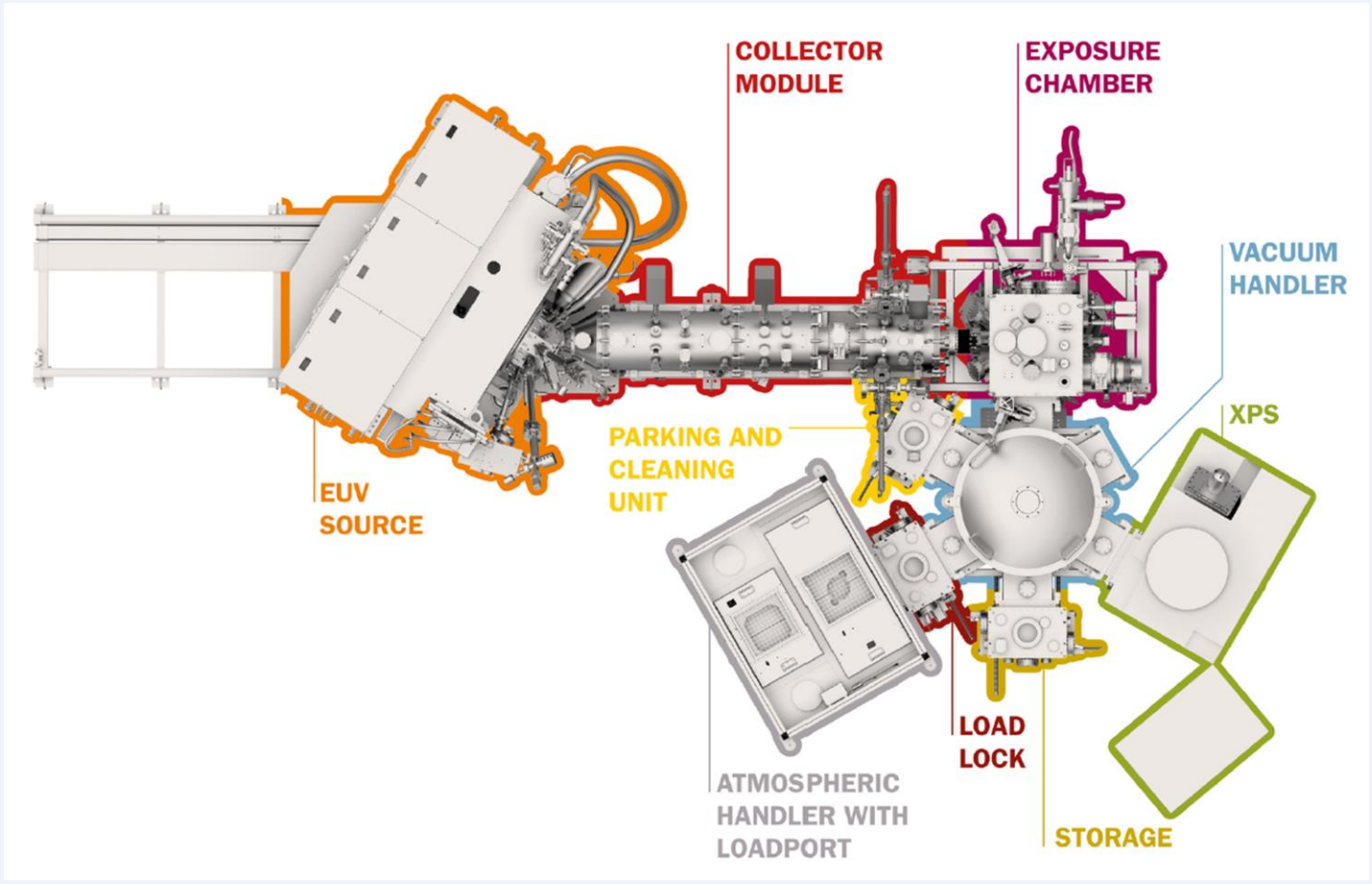


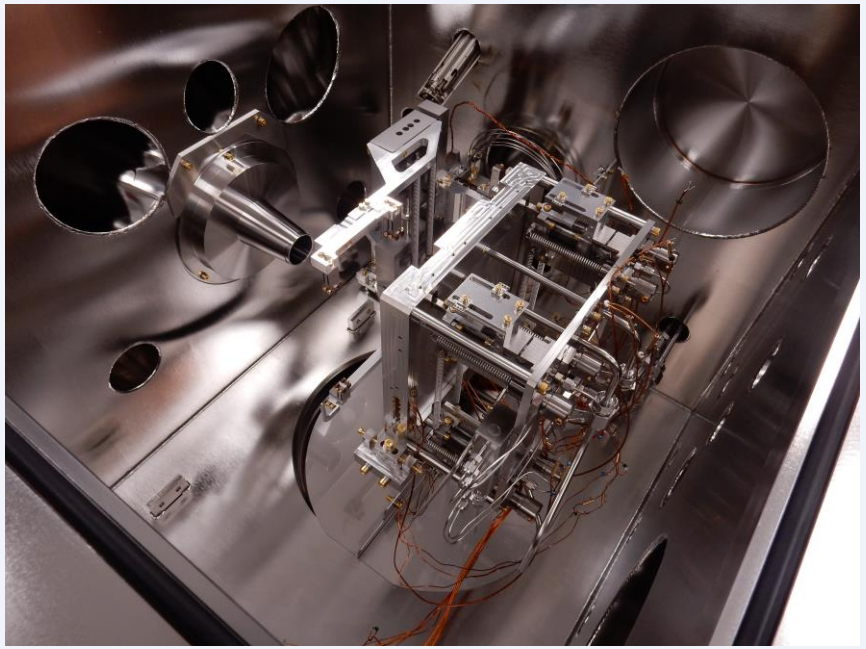
- The reflectometer will measure in-situ the reflection changes of EUV exposed samples
  - Optical sensor, with grating
  - EUV source of EBL2 is used as input light

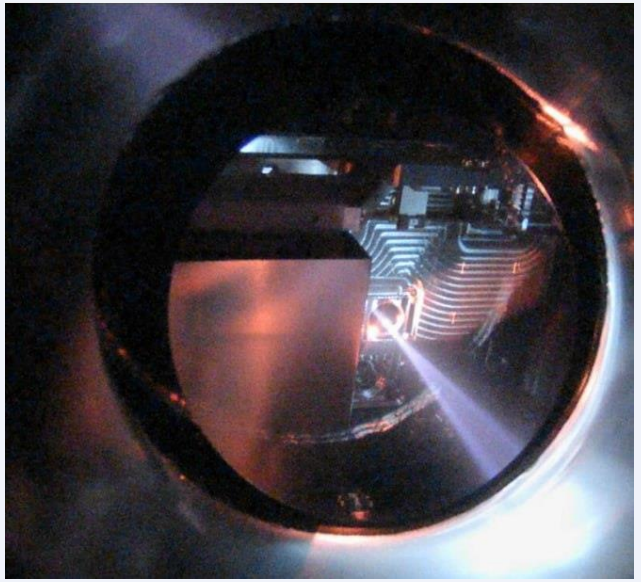




EBL2


COLLECTOR MODULE
EXPOSURE CHAMBER
VACUUM HANDLER
XPS
PARKING AND CLEANING UNIT
EUV SOURCE
LOAD LOCK
ATMOSPHERIC HANDLER WITH LOADPORT
STORAGE





Normal requirements for such system

Spot size

Optical design

Spot shape

cost

Measurement time

repeatability

accuracy

Photon budget

Requirements for same system with cleanliness requirements

Spot size

particles

Optical design

Bake-out temperature

materials

Spot shape

cost

outgassing

Measurement time

Wet chemical cleaning

Partial pressures

repeatability

vacuum

accuracy

Cross contamination

Plasma

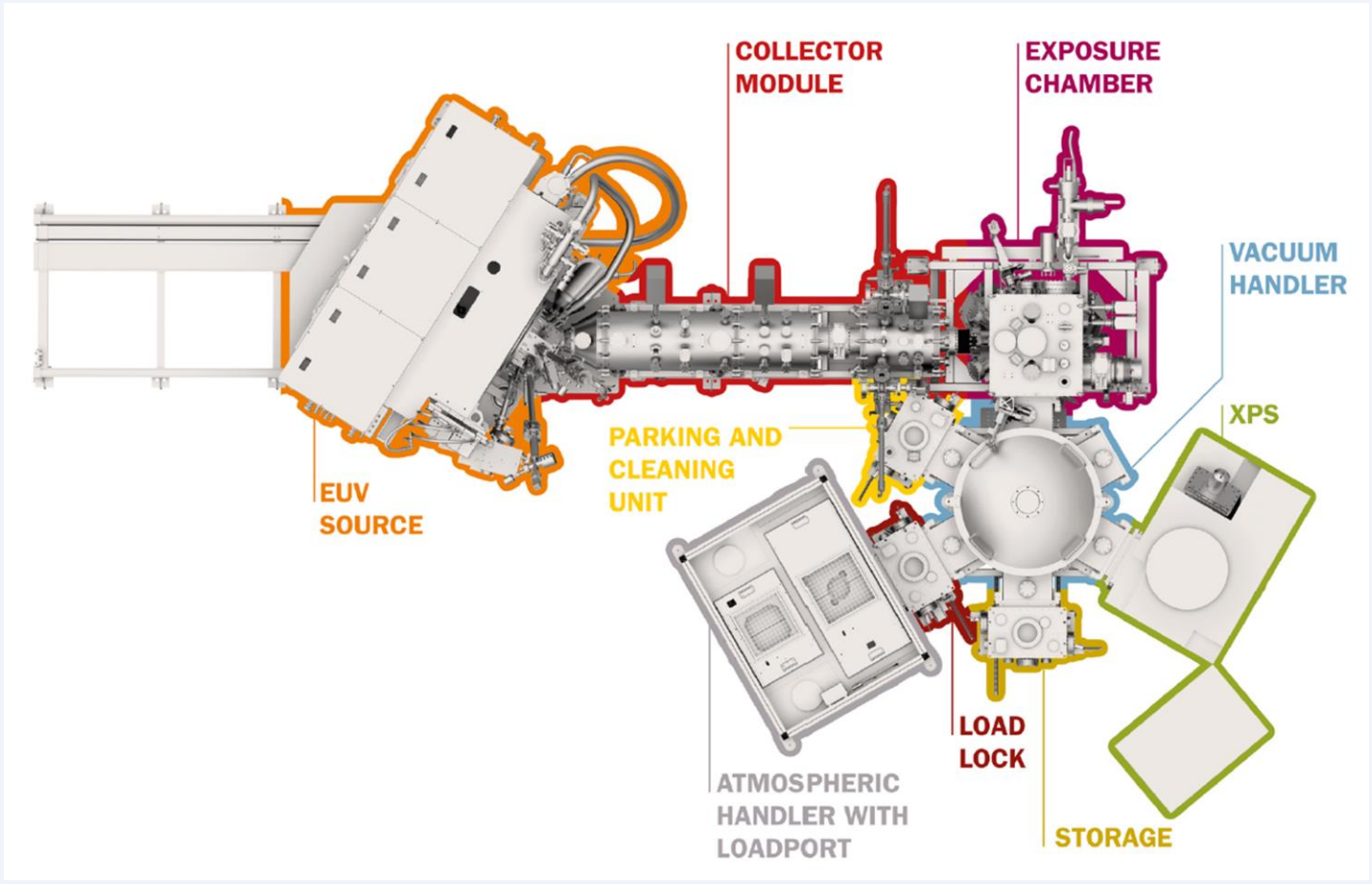
Photon budget

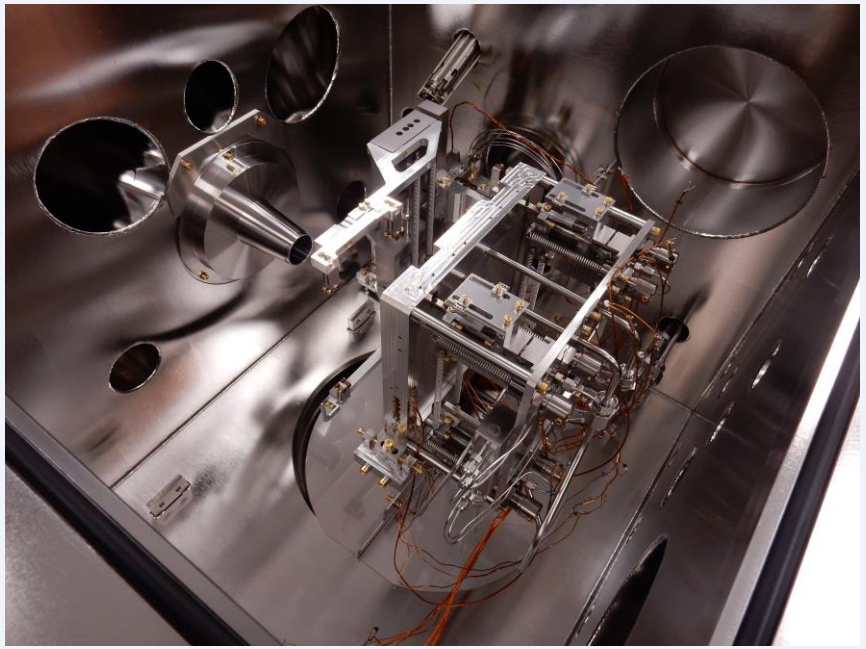
H2

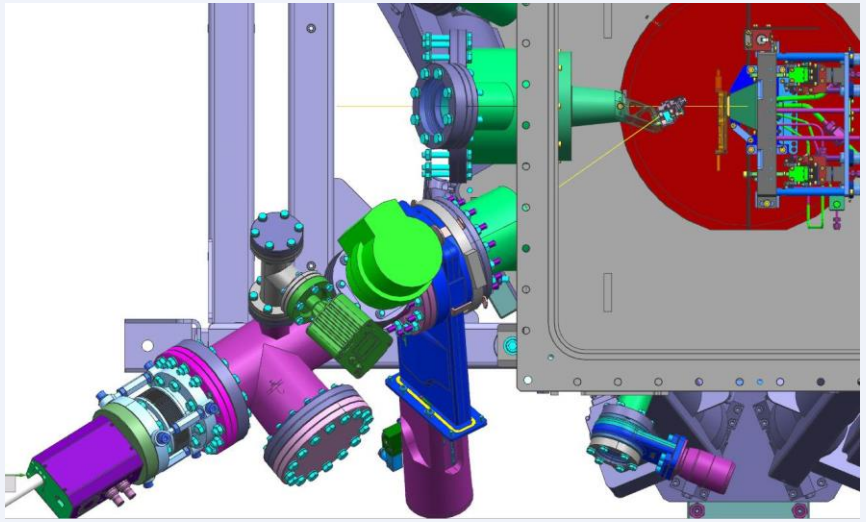
Reduction environment

packaging

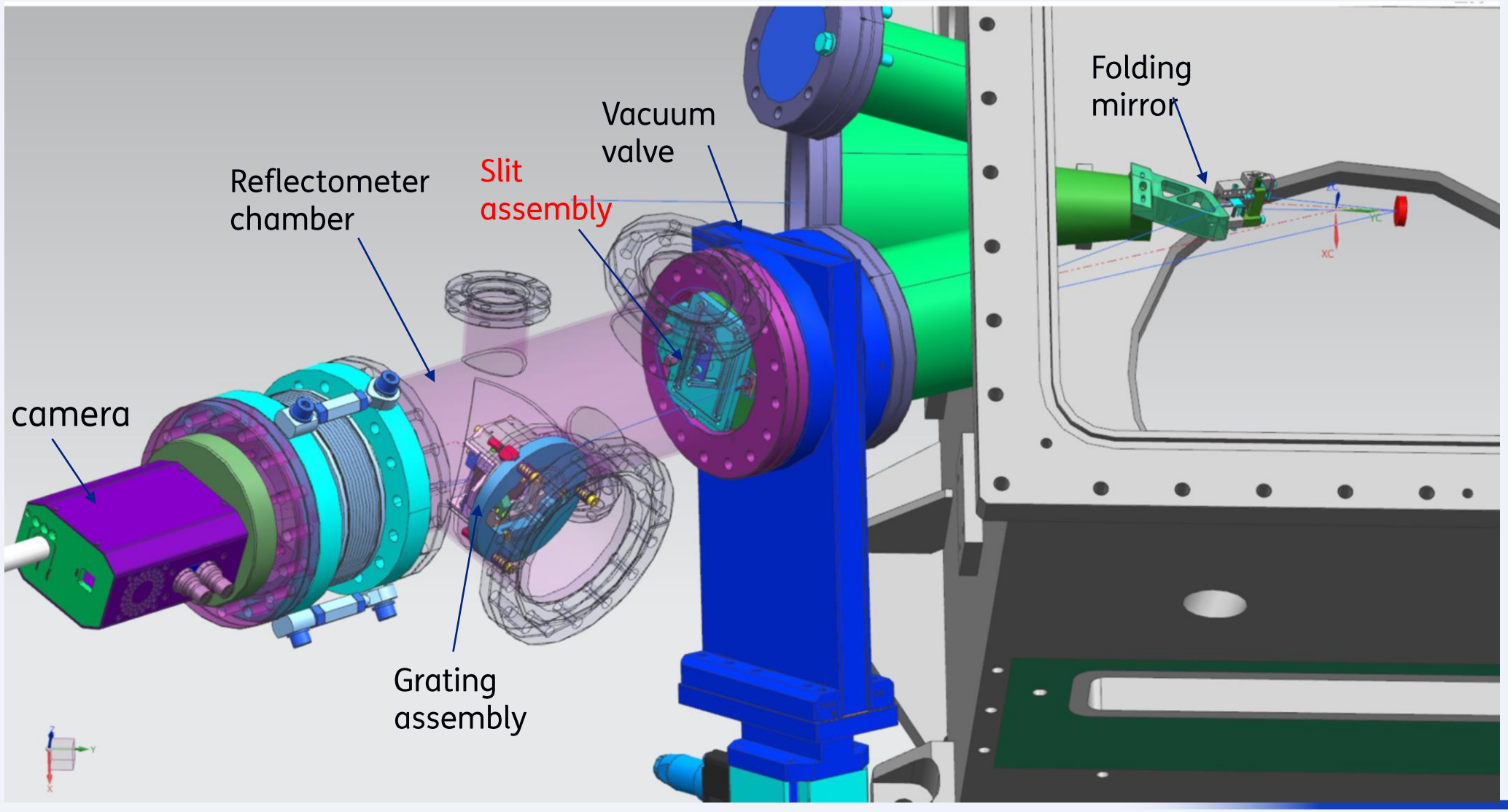
EBL2 → differential pumping system





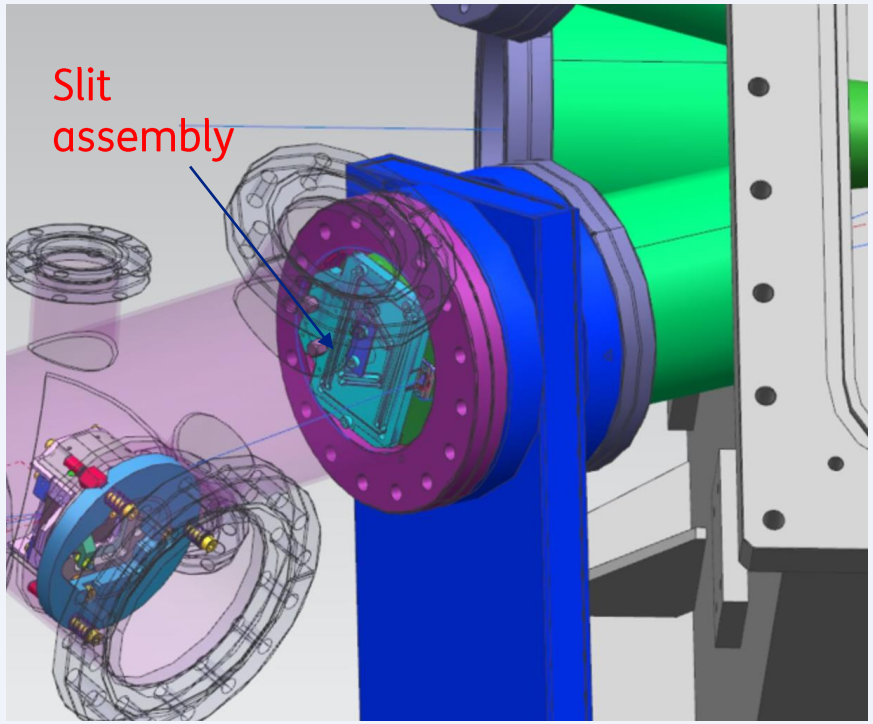


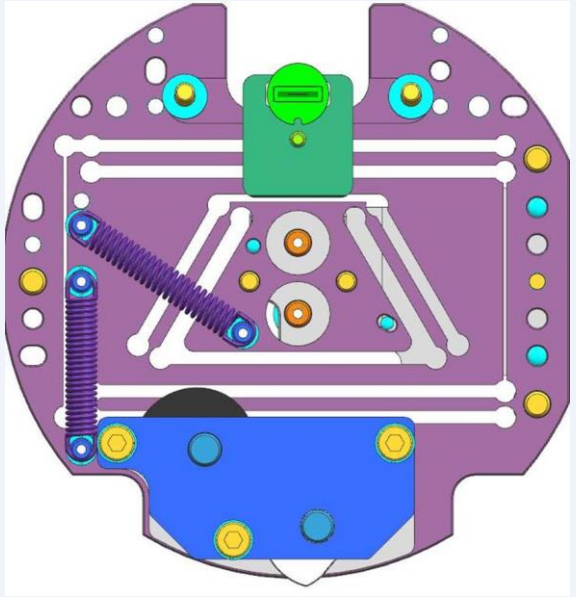
EBL2 reflectometer design

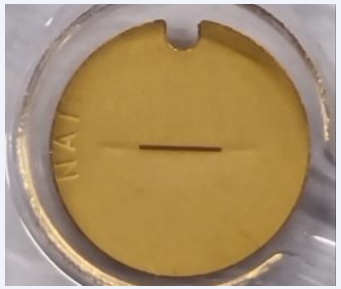


EBL2 reflectometer design

- Differential pumped system

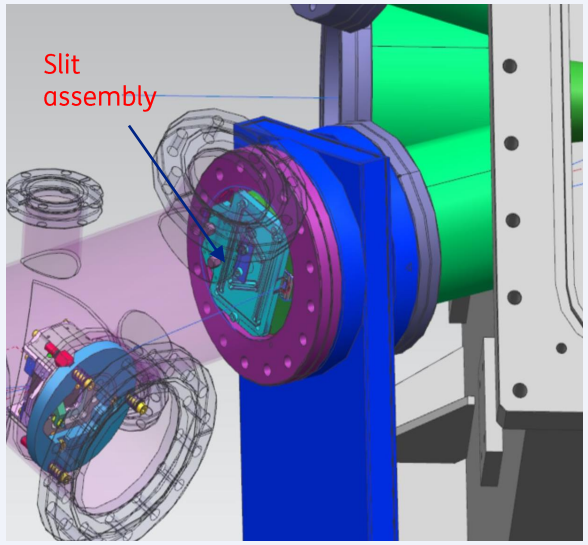


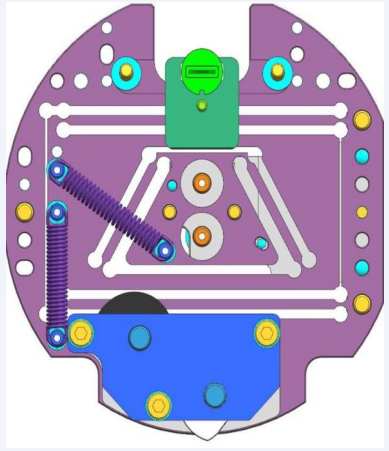


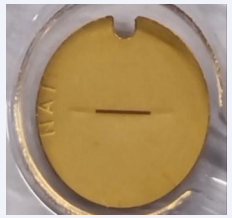


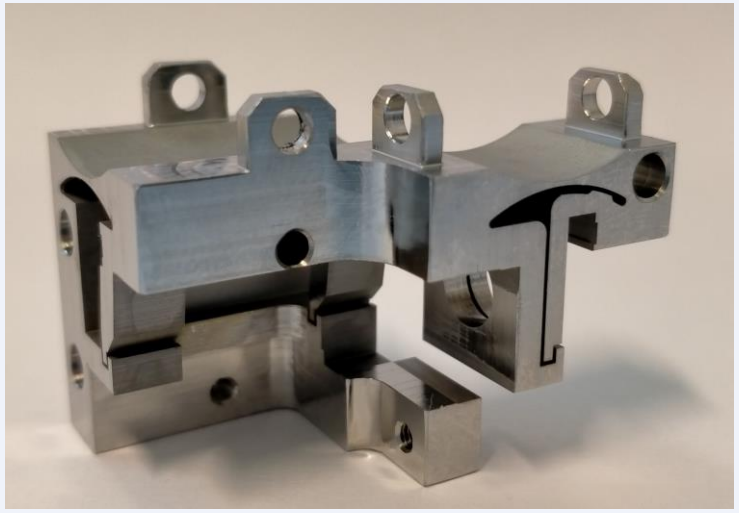
EBL2 reflectometer design

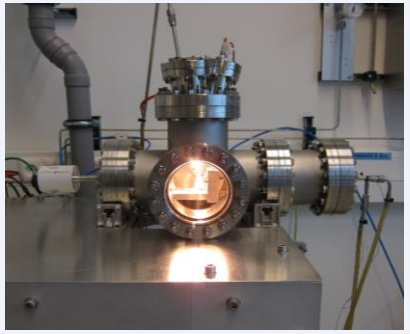
- Only one small assembly in ultra-clean



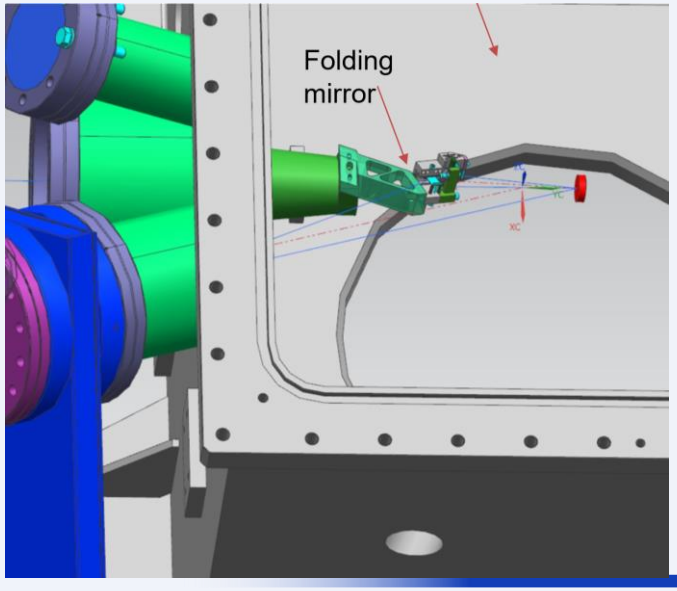






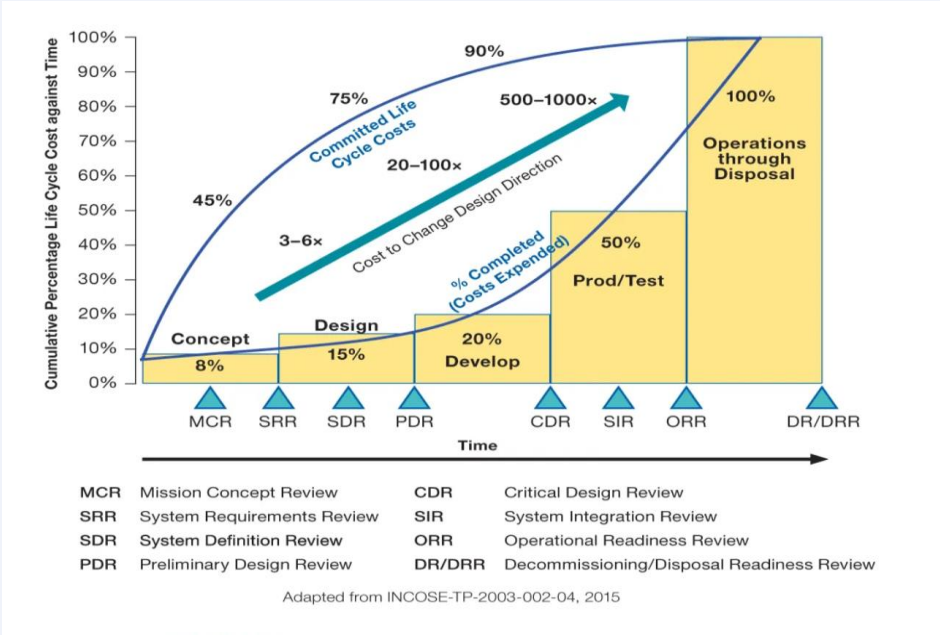


Cleanliness testing



Conclusion

- Vacuum, and especially ultra-clean vacuum requires a systematic approach, starting at the use-case
- Repair actions are very expensive
- Presented example is only one way of solving contamination challenges, this presented solution did enable the use of COTS items
- The future of vacuum technology will see more and more stringent requirements towards vacuum environment
- **The future is ultra-clean vacuum**



https://www.nasa.gov

IUVSTA workshop 102

IUVSTA WORKSHOP 102 ULTRA-CLEAN VACUUM

- Ultra-clean vacuum: why, how, and how to measure
- Organized by TNO the Dutch vacuum society (NEVAC)
- 3-6 februari 2025
- Delft, the Netherlands
- Key objective is knowledge sharing;
  - Science and industry
  - And between technology domains
    - Semicon, Space, Quantum, big science

- www.tno.to/ucv

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Theme name

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