ULTRA-CLEAN VACUUM, THE RIGHT LEVEL AT THE RIGHT LOCATION

TNO innovation for life

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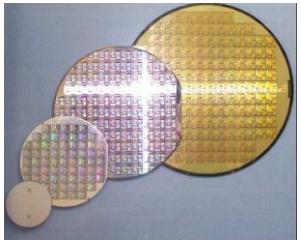
ULTRA-CLEAN VACUUM, THE RIGHT LEVEL AT THE RIGHT LOCATION

- Why is this required?
  - examples of molecular contamination
    - EUV
      - Contamination process
    - TEM
- Method of preventing this contamination?
  - Example EBL2
  - VCCN Guideline 12; Product cleanliness with respect to particles and chemicals
- Conclusion

EUV LITHOGRAPHY



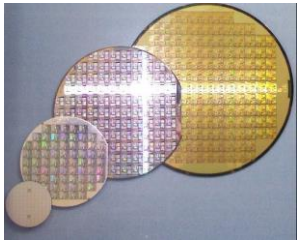
- Strong decrease in critical dimension on chips, with new lithography method

source: ASML

- EUV lithography
- wavelenght:13,5 nm
- Ultra-clean vacuum
- Move from lenses to mirrors

source: Carl Zeiss SMT

EUV LITHOGRAPHY



- Strong decrease in critical dimension on chips, with new lithography method

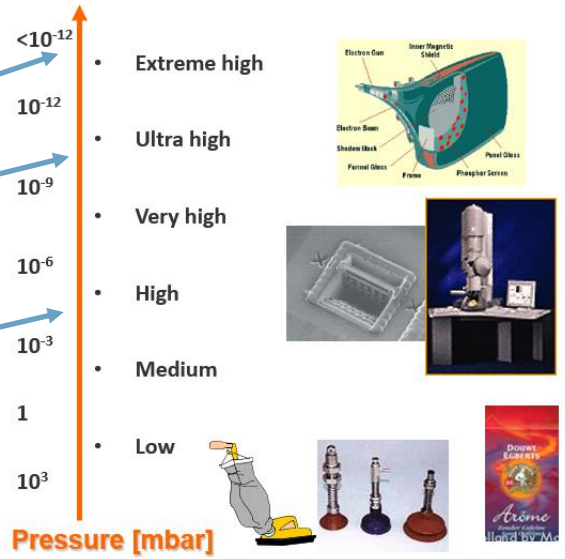
source: ASML

- EUV lithography
- wavelenght:13,5 nm
- **Ultra-clean vacuum**
- Move from lenses to mirrors

source: Carl Zeiss SMT

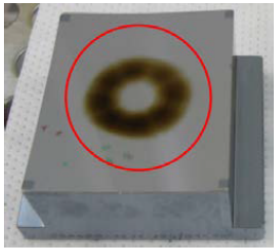
VACUUM

- Vacuum is a space devoid of matter and at zero pressure [Wikipedia]
  - In practice a space at zero pressure and matter is not achievable
  - 10^{-12} mbar still contains 10^{5} molecules per cm^{3}
  - 10^{-6} mbar will result in 1 mono layer growth per second
- Vacuum has many applications
- In “big science” starting at high vacuum
  - CERN and on the moon
  - SEM
  - Fluorescent light

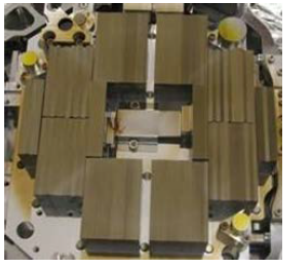


Carbon contamination

- ‘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?



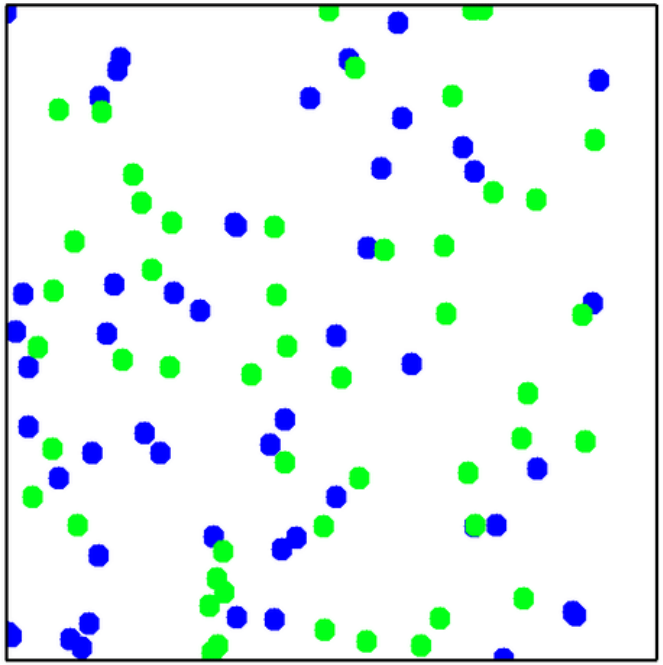
SEMATECH MET, 2007



ADT mirror, 2007

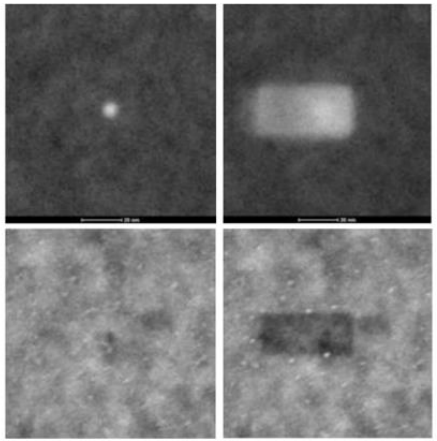
EUV optics lifetime, Radiation damage, contamination, and oxidation; M van Kampen (ASML); PXRNM workshop 2016

CONTAMINATION GROWTH



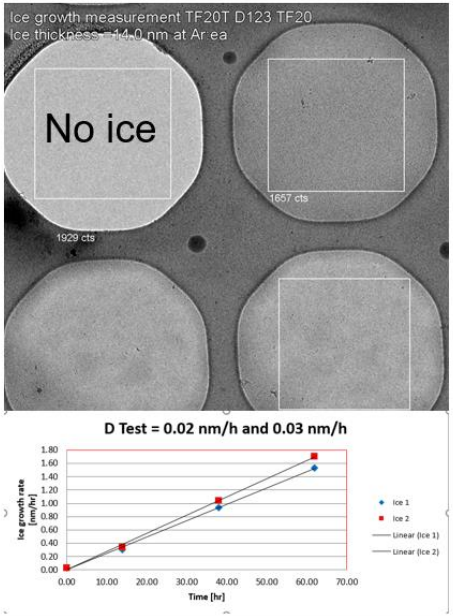
Contamination measurement on TEM

Example:
C_xH_y contamination level via Carbon
Grown in STEM mode on sample

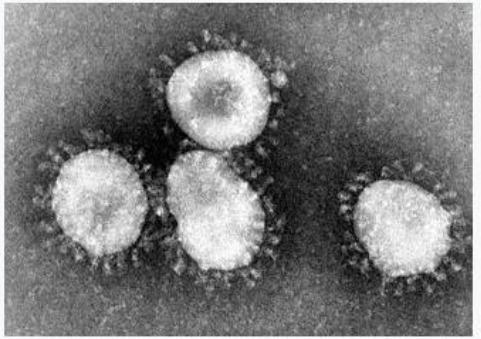


Measurement examples, contrast difference on SiN window of measuring sample @950 kx.
Upper contaminated, lower clean (sample etching)
Left reference image, right image after focus window.

Example:
H_20 contamination via
Ice Grow on TEM Cryo sample,
Transmission loss in time



Orthocoronavirinae



Transmission electron micrograph of a coronavirus

(Wikipedia)

ThermoFisher SCIENTIFIC

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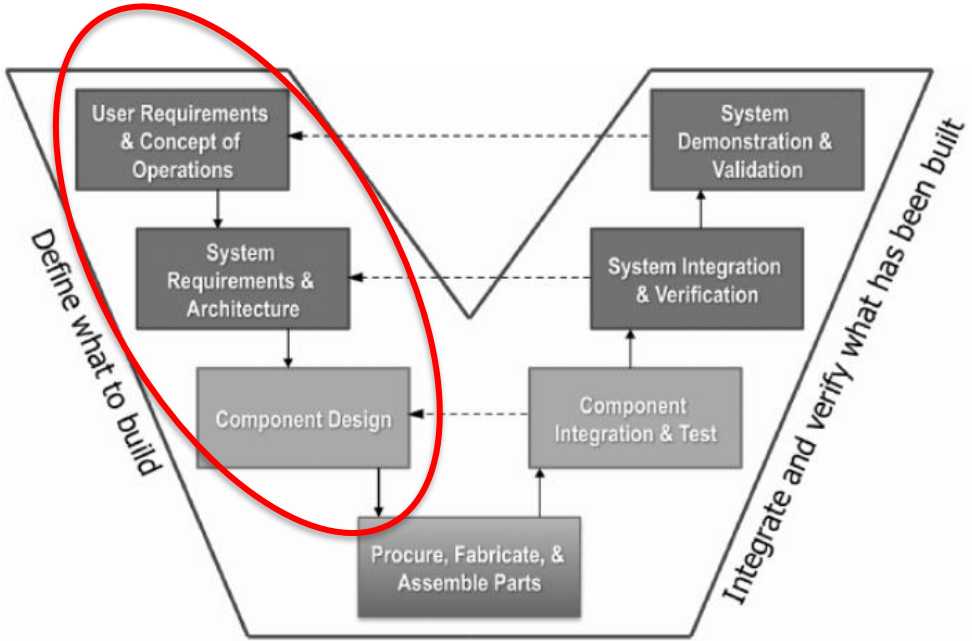
EXAMPLE : EBL2

- EBL2 is a research facility at TNO to facilitate EUV related contamination research by exposing samples and reticles to EUV radiation
- For this an ultra clean vacuum system and particle “free” system is mandatory

CONTAMINATION BUDGET

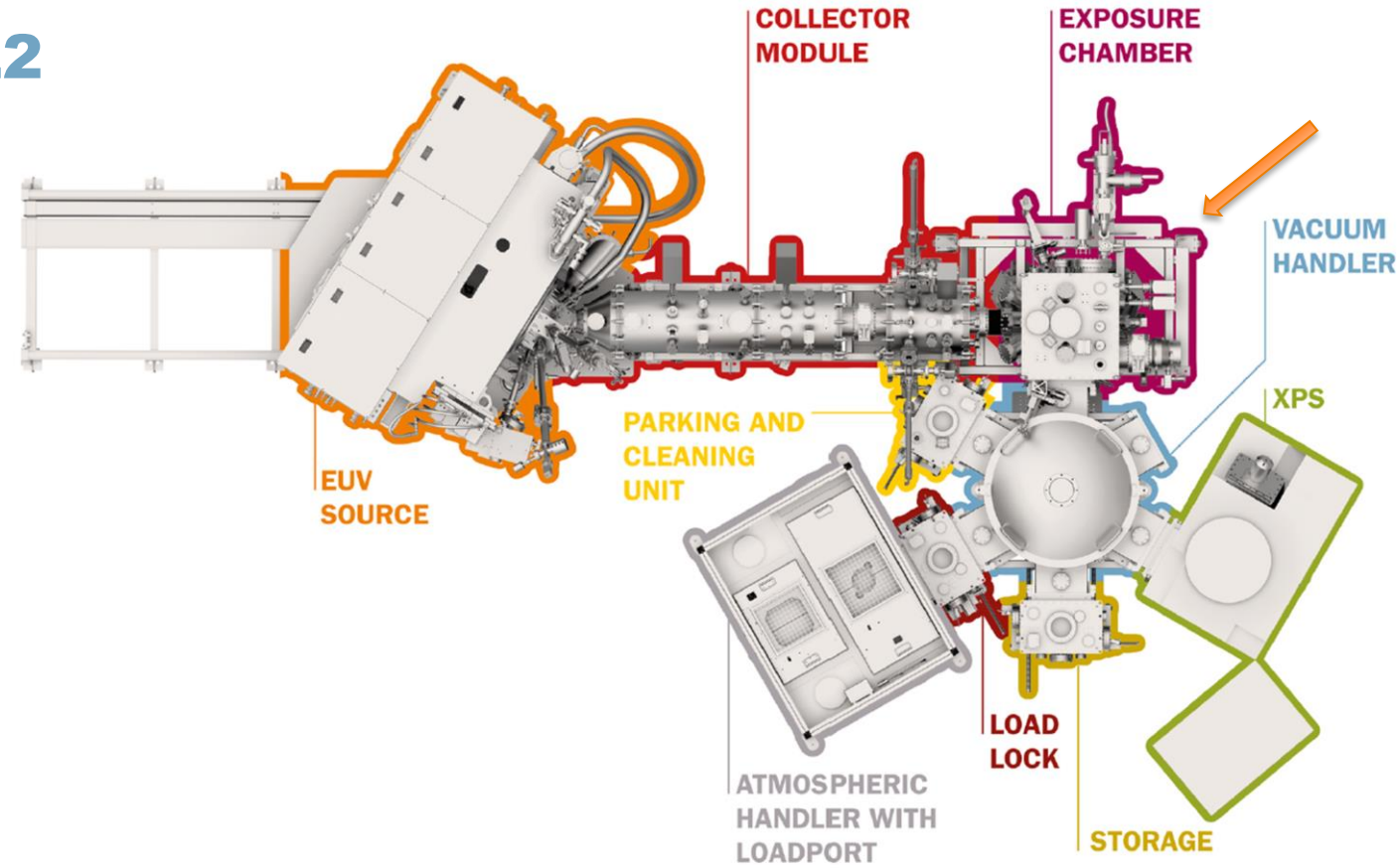
- Systems approach
  - Contamination budget
    - The right level at the right location

- Sample route through EBL2

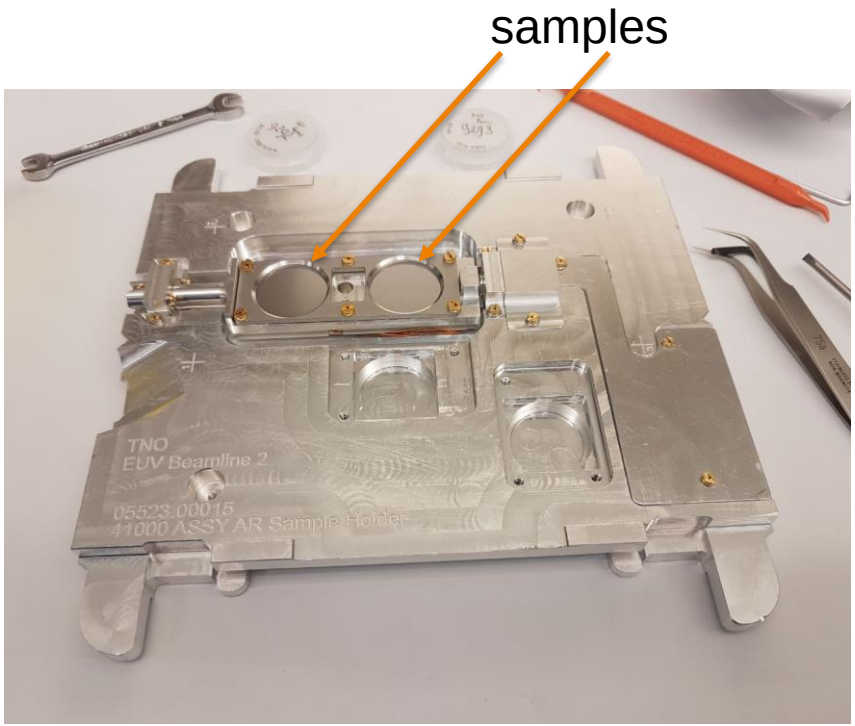


Sauser, Brian & Gove, Ryan & Forbes, Eric & Ramirez-Marquez, Jose. (2010). Integration maturity metrics: Development of an integration readiness level. Information Knowledge Systems Management. 9. 17-46.

EBL2


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

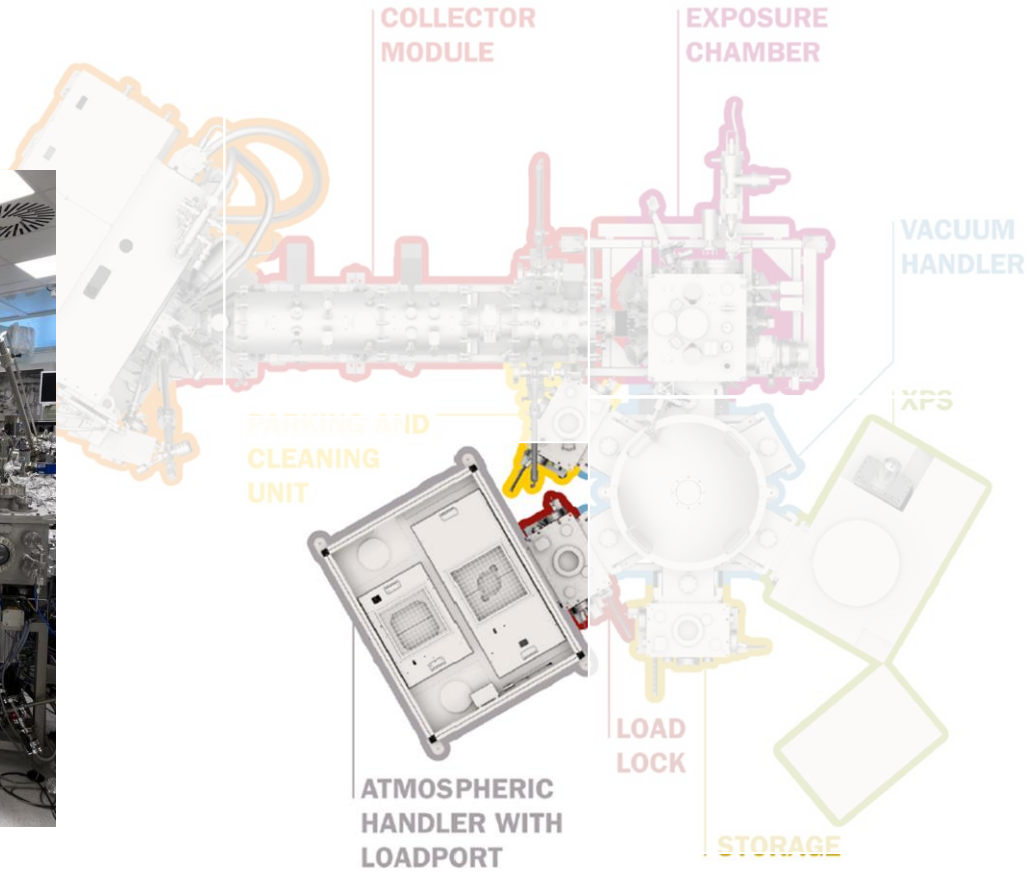
EBL2


samples
TNO
EUV Beamline 2
05523.00015
41000 ASSY AR Sample Holder


G1: Pod present 1 OK
G2: Pod present 2 OK
R1: Pod Opener is busy
R2: Automatic Mode
G1 I G2 I R1 I R2
CAUTION
LASER RADIATION INSIDE

EBL2


TNO
ISO 4
ISO 1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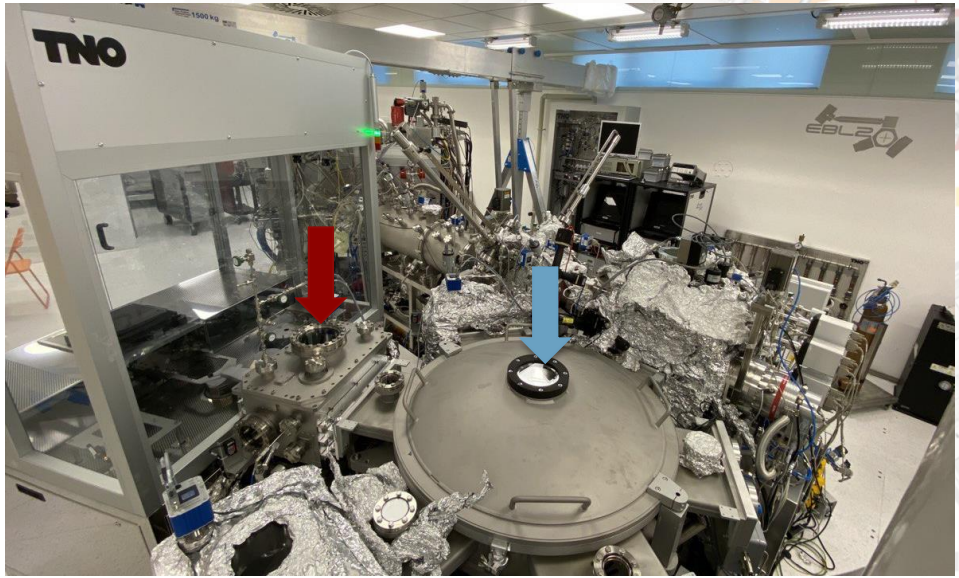
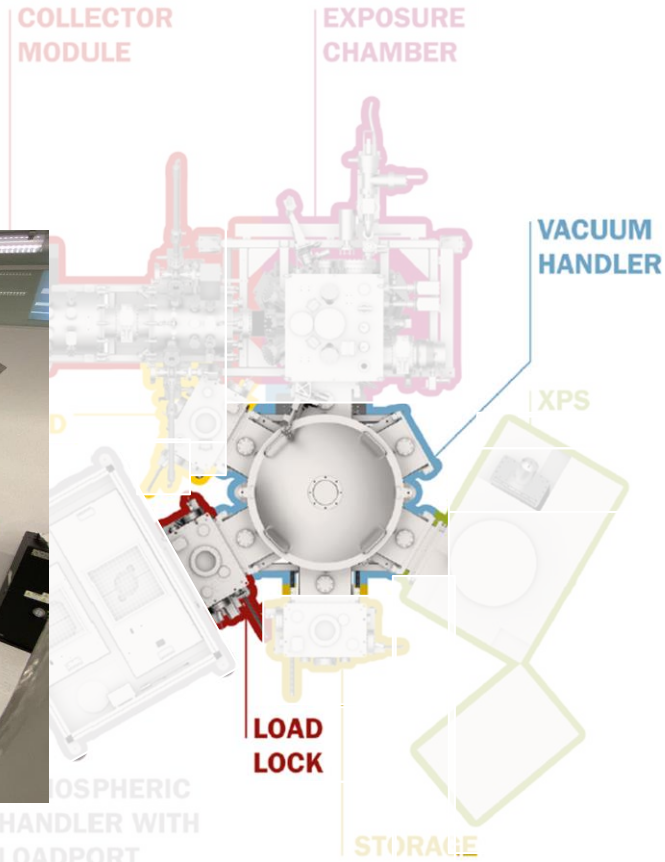

TNO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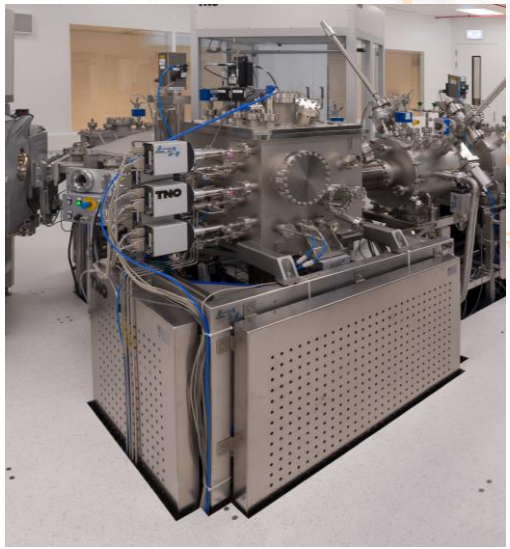
EBL2



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EBL2 VACUUM

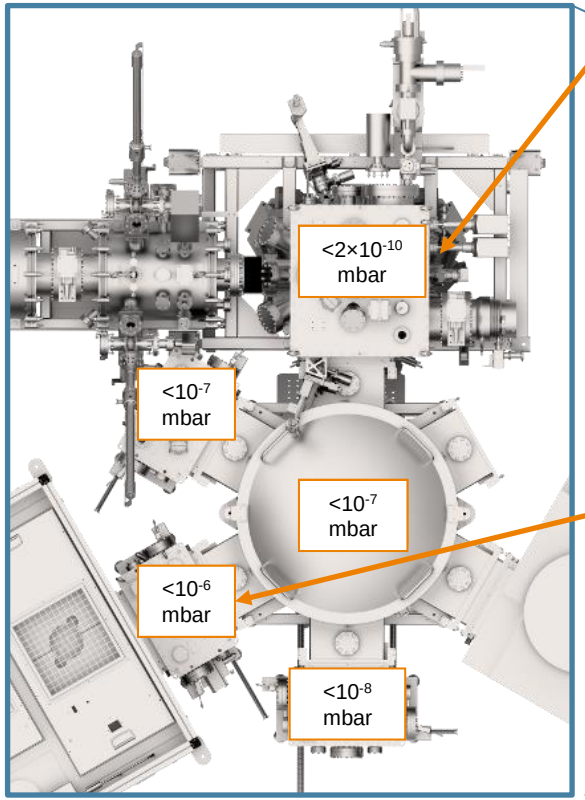
Table 4-9 Exposure Chamber qualification requirements

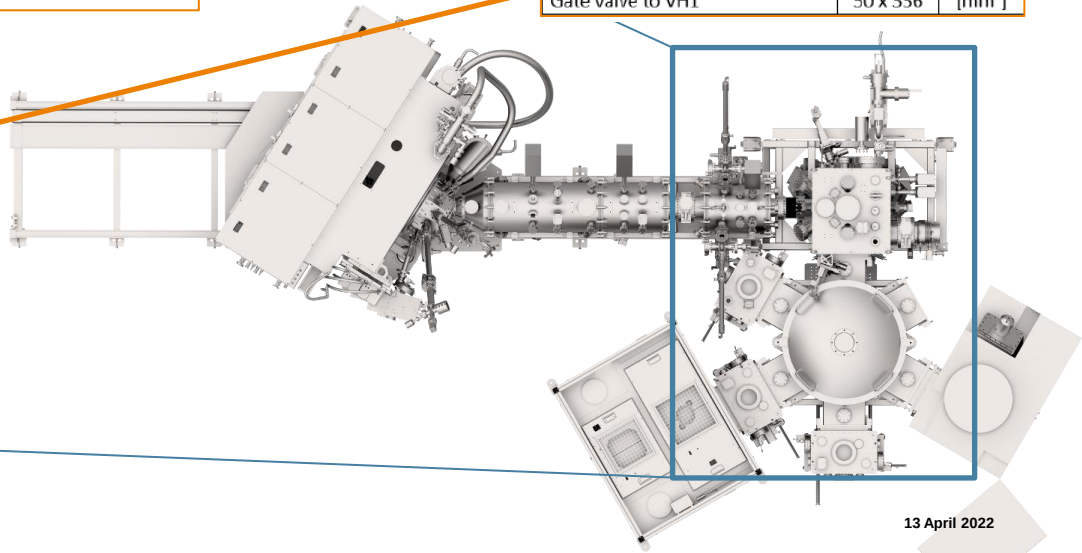
Requirement	Value	Unit
Total end pressure	$<1 - 2 \cdot 10^{-10}$	[mbar]
Partial pressure H_2	$<10^{-10}$	[mbar]
Partial pressure H_2O	$<10^{-10}$	[mbar]
Partial pressure N_2	$<10^{-12}$ (integrated)	[mbar]
Partial pressure O_2		
Partial pressure C_xH_y 45-100		
Partial pressure – C_xH_y 101-200		
He leak rate	$<1*10^{-10}$	[mbar.l/s]

Table 4-2 Load Lock process requirements

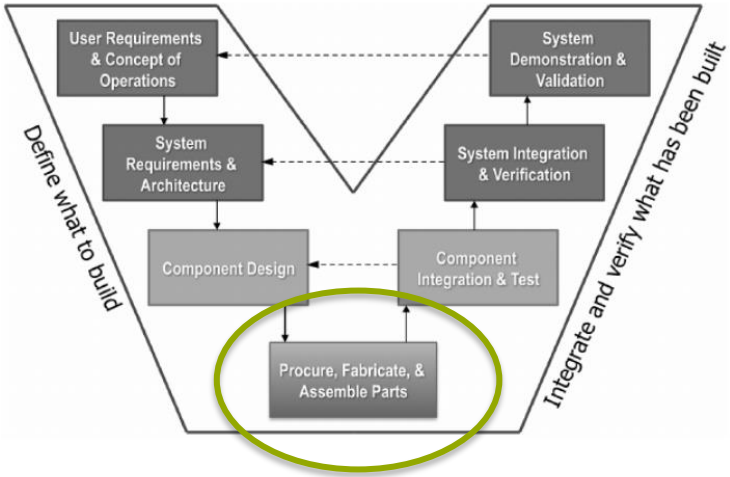
Requirement	Value	Unit
Total pressure	$<10^{-6}$	[mbar]
Partial pressure H_2	NA	
Partial pressure H_2O	NA	
Partial pressure N_2	$<10^{-7}$	[mbar]
Partial pressure O_2	$<10^{-8}$	[mbar]
Partial pressure C_xH_y 45-100	$<10^{-9}$	[mbar]
Partial pressure – C_xH_y 101-200	$<10^{-10}$	[mbar]
Partial pressure Ar	NA	
Partial pressure Xe	NA	
Evacuation (pump down) time	15-20	[min]
Gate valve to VH1	50 x 336	[mm²]

Grade 1 cleaning,(additional requirements on used materials)





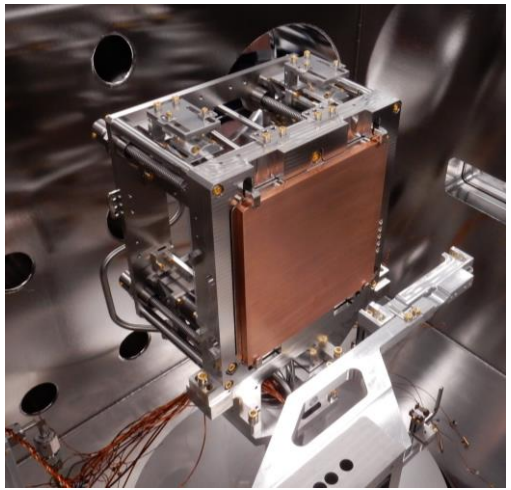
MANUFACTURING

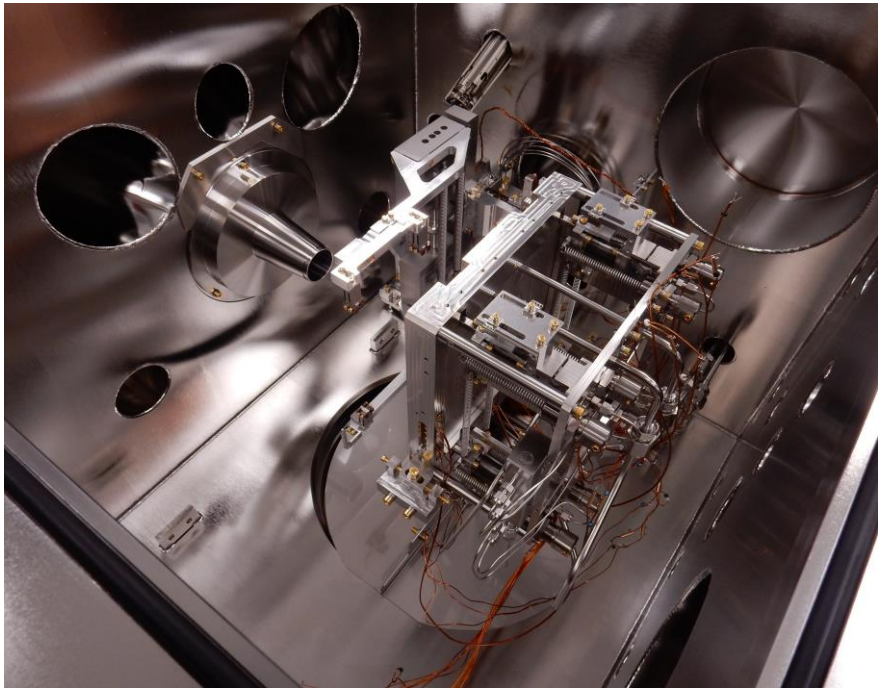


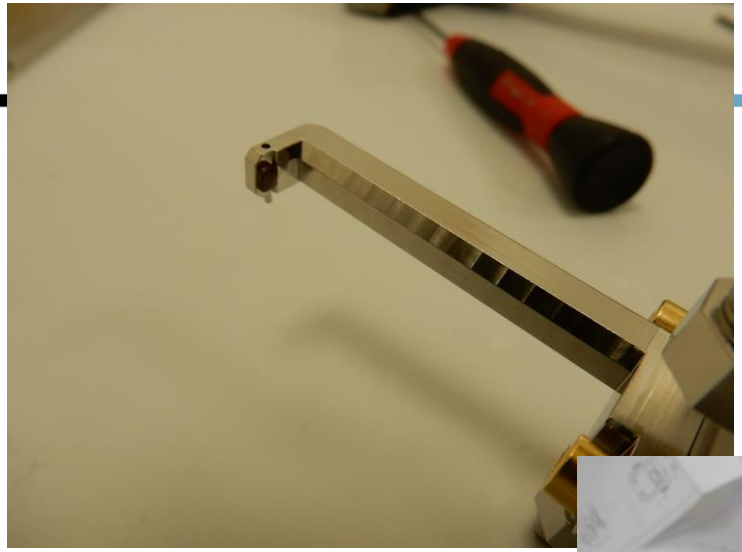
- Used materials and design must allow cleaning
  - Resistant for wet chemical cleaning
  - Resistant for required temperatures
  - Surfaces must be reachable
- Machining equipment must be clean
  - Use of correct lubrication and cooling fluids
  - Dedicated tools for clean products, no cross use of tools allowed
- During assembly prevent contamination of product
  - clear instruction of staff

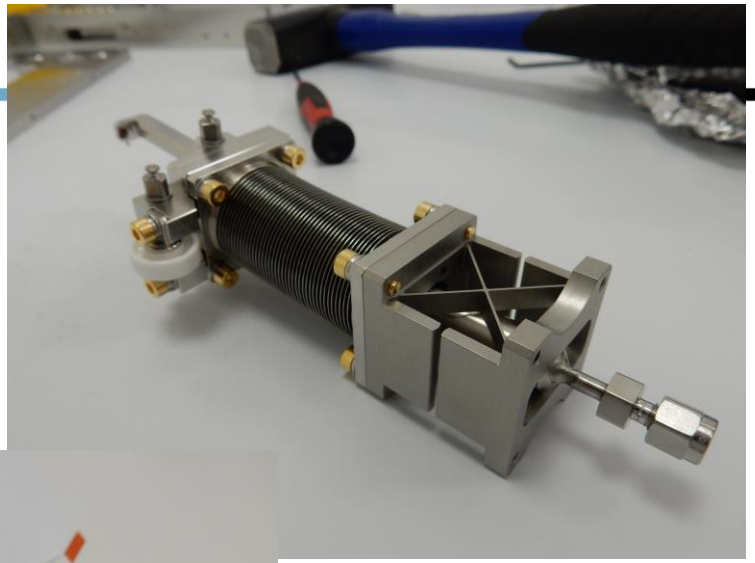
PRODUCTION / DESIGN EXAMPLES

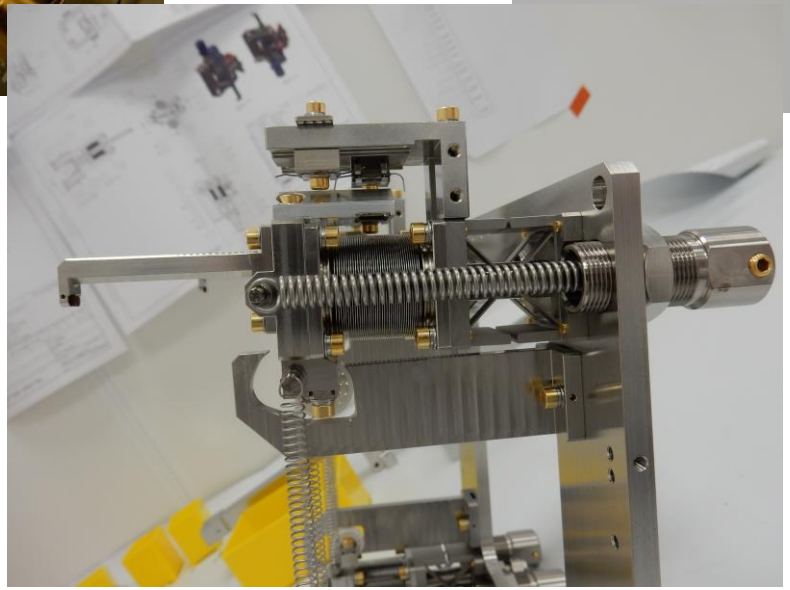
- Sample handling in exposure chamber EBL2
- Strong limitation on allowed materials
- Parts must be able to be cleaned





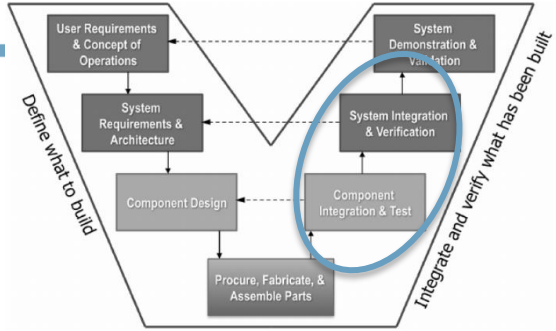


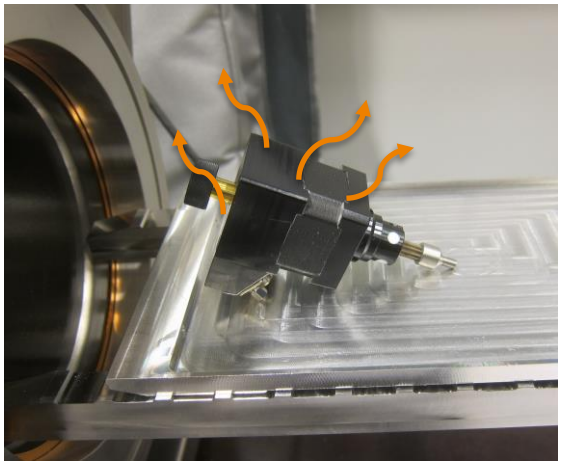




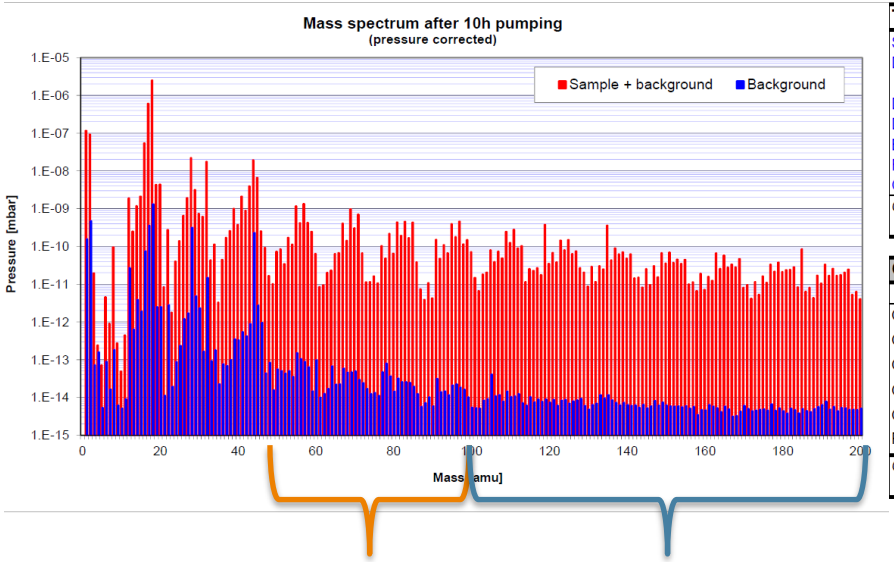

BINDER

VALIDATION CLEANLINESS; OUTGAS MEASUREMENT;





VALIDATE OUTGASSING



Test details

Sample Id:	[redacted]	Pump speed [l.s^{-1}]:	25
Description:		System:	ATOM
Date:	20-Nov-15	Ratio: IG/RGA	0.6
Data filename:	[redacted]	RGA Id:	QMA 422: SN 44248116
Background file:		Ion gauge Id:	IG (YEA07221)
Filename:			
Operator:	[redacted]		Sample Outgassing 200amu v7
Comments:	Black coated stepper motor with sub-D connector, no vents to prevent for virtual leakage, no appearant (visible) lubricationon outside		

Outgassing rate at 1h:

	Sample (background subtracted)	(background)
Q_{total} [mbar.l.s^{-1}]	NA	7.50E-07
Q_{H2O} [mbar.l.s^{-1}]	NA	4.69E-07
$Q_{CxHy<101amu}$ [mbar.l.s^{-1}]	NA	6.41E-10
$Q_{CxHy>100amu}$ [mbar.l.s^{-1}]	NA	2.75E-11
Q_{CxHy} [mbar.l.s^{-1}]	NA	6.68E-10
$P_{ion\ gauge}$ [mbar]	NA	3.00E-08

Outgassing rate at 10h:

	Sample (background subtracted)	(background)
Q_{total} [mbar.l.s^{-1}]	8.79E-05	7.50E-08
Q_{H2O} [mbar.l.s^{-1}]	6.33E-05	3.30E-08
$Q_{CxHy<101amu}$ [mbar.l.s^{-1}]	4.51E-07	1.40E-10
$Q_{CxHy>100amu}$ [mbar.l.s^{-1}]	1.15E-07	1.72E-11
Q_{CxHy} [mbar.l.s^{-1}]	5.66E-07	1.57E-10
$P_{ion\ gauge}$ [mbar]	3.52E-06	3.00E-09

Comments: High outgassing of H2O and CxHy, traces of CxFy/fluorocarbons (119, 135, 185 amu), high O2 traces probably be due to virtual leakage

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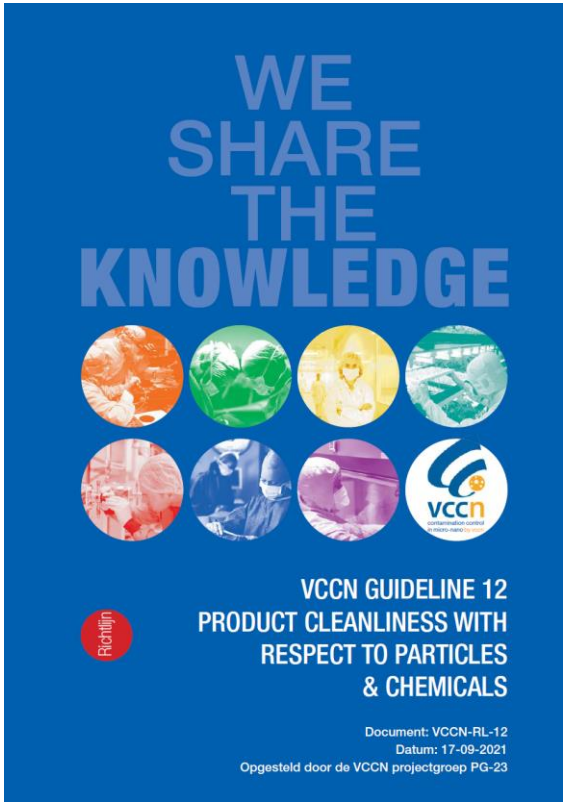
GUIDELINE 12

PRODUCT CLEANLINESS WITH RESPECT TO PARTICLES AND CHEMICALS

- Released by the VCCN on October 14th 2021
- Joined effort by OEM and suppliers
- Using ISO standards and not internal/ companies standards



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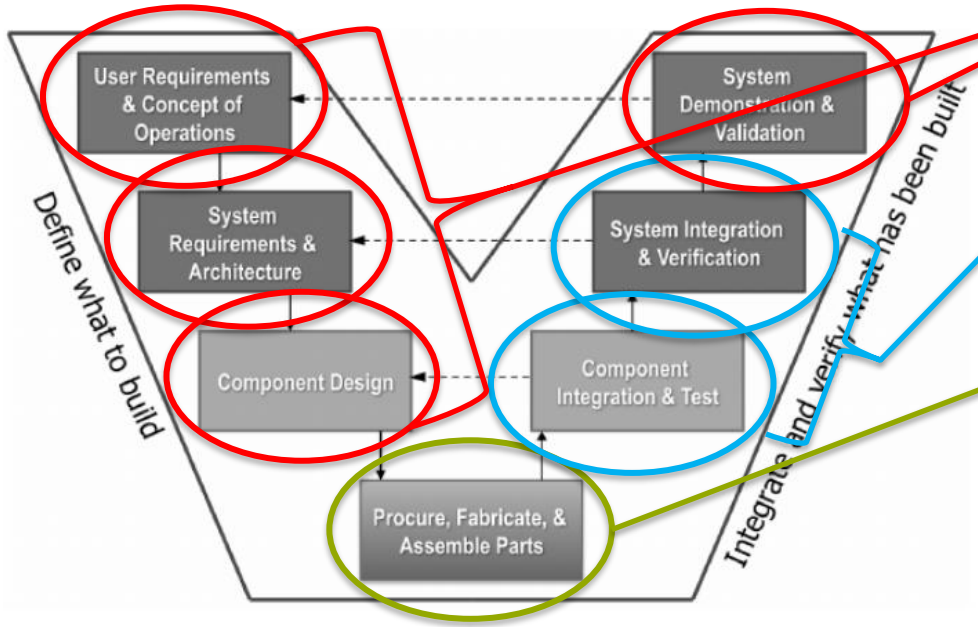

CONCLUSION

- The need for cleaner and cleaner products will increase in the future
- To control cost, understanding the impact of a cleanliness requirement is needed from both the end user and the supplier
- This understanding should result in “the right level at the right location”


THANK YOU FOR YOUR TIME
TNO
innovation
for life