DE LA RECHERCHE À L'INDUSTRIE

Overview of the sol-gel antireflective coatings performances and production rate for CEA high power laser facilities

SYMPOSIUM ON OCLA 2017| Eric Lavastre

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www.cea.fr

CONTEXT

HIGH POWER LASER FACILITIES AT CEA-CESTA

CEA-CESTA : LOCATION AND ACTIVITIES

- Activities
  - Management of physics experiments in large facilities such as facilities of thermomechanical tests, anechoic chambers, X-ray generators…
  - Operating of high power lasers facilities (LMJ and PETAL)
- Hubs of competitiveness
  - Route des Lasers (lasers and photonics)
  - Aerospace Valley

LABORATORY OF OPTICAL TECHNOLOGIES (LTO)

Missions

- **Specification** of optical components ⇨ to divide in elementary fabrication stages
- **Fabrication follow-up** of optical components
- **Optical logistics** : transit, import/export, storage management (location, quantity, performances preservation during the storage…)
- To Lead the **R&D** of optical processes

On behalf of

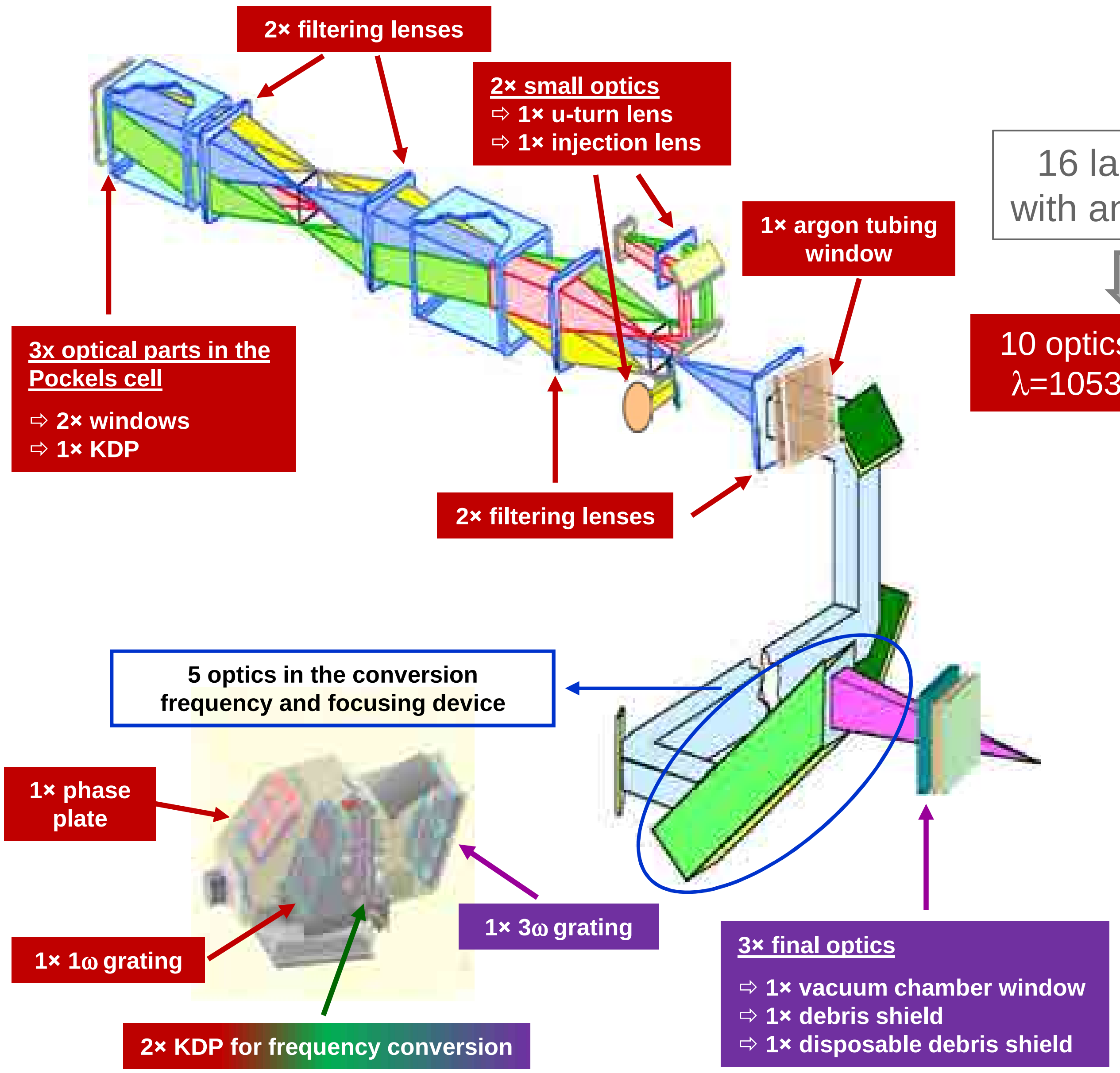
- High power lasers facilities at CEA: (LIL), LMJ, PETAL
- Other CEA labs
- Technical and Scientific studies or valorization

LTO team

- 14 permanent people and ~10 students
- People are skilled according to elementary optical fabrication stages

SOL-GEL COATINGS

ANTIREFLECTIVE COATINGS FOR THE LMJ FACILITY



2× filtering lenses

2× small optics
- ⇨ 1× u-turn lens
- ⇨ 1× injection lens

1× argon tubing window

3x optical parts in the Pockels cell
- ⇨ 2× windows
- ⇨ 1× KDP

2× filtering lenses

5 optics in the conversion frequency and focusing device

1× phase plate

1× 3ω grating

1× 1ω grating

2× KDP for frequency conversion

3× final optics
- ⇨ 1× vacuum chamber window
- ⇨ 1× debris shield
- ⇨ 1× disposable debris shield

1 laser beam

16 large optics (40cmx40cm) coated with antireflective sol-gel single layers

10 optics used at λ=1053nm (1ω)

4 optics used at λ=351nm (3ω)

2 optics used at 1053/526/351nm

LMJ = 176 laser beams
➲ at least 3000 parts

2 types of substrates

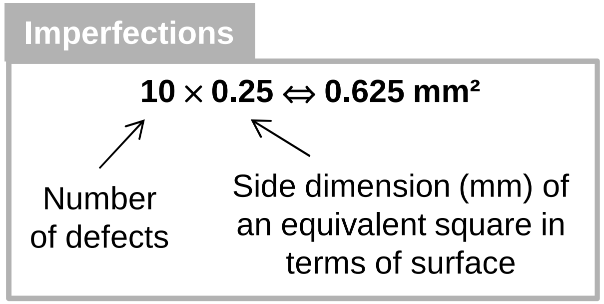
Fused silica

KDP crystals

MAIN ANTIREFLECTIVE COATINGS SPECIFICATIONS

Optical parts used at λ=1053nm (1ω)

- **Transmittance per side** > 99.8%
- **Imperfections** *(ISO10110-7)* < 20×0.3 / 25×0.275 / 30×0.25 according to the parts
- **Laser damage densities at 3ns** < 0.01cm^{-2}@18 J/cm^2 and < 0.4cm^{-2}@25 J/cm^2



Imperfections

$10 \times 0.25 \Leftrightarrow 0.625\ mm^2$

Optical parts used at λ=351nm (3ω)

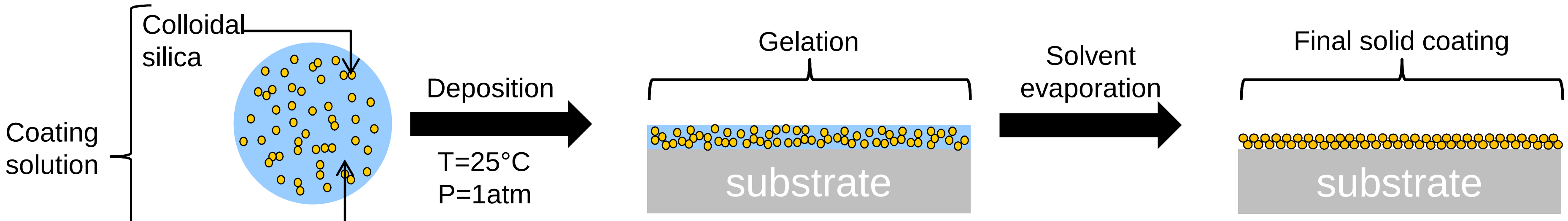
- **Transmittance per side** > 99.8%
- **Imperfections** < 10×0.25
- **Laser damage density at 3ns** < 0.01cm^{-2}@14 J/cm^2

Specific parts with differents coatings on each side

- **Phase plate** ⇨ imprinted side : T>99.8% at λ=1053nm and λ=351nm
  ⇨ « alignment » side : 99.2% < T1ω < 99.6% and R3ω > 3%
- **SHG** ⇨ input side : R<0.5% at λ=1053nm
  ⇨ output side : R<2.3% at λ=1053nm and R<0.6% at λ=526nm
- **THG** ⇨ intput side : R<0.5% at λ=526nm
  ⇨ output side : R<0.7% at λ=351nm

TWO TYPES OF COATINGS FROM A LIQUID PROCESS

Sol-gel coatings made from a colloidal silica solution



Coating solution

Colloidal silica

Ethylic alcohol

Deposition

T=25°C
P=1atm

Gelation

substrate

Solvent evaporation

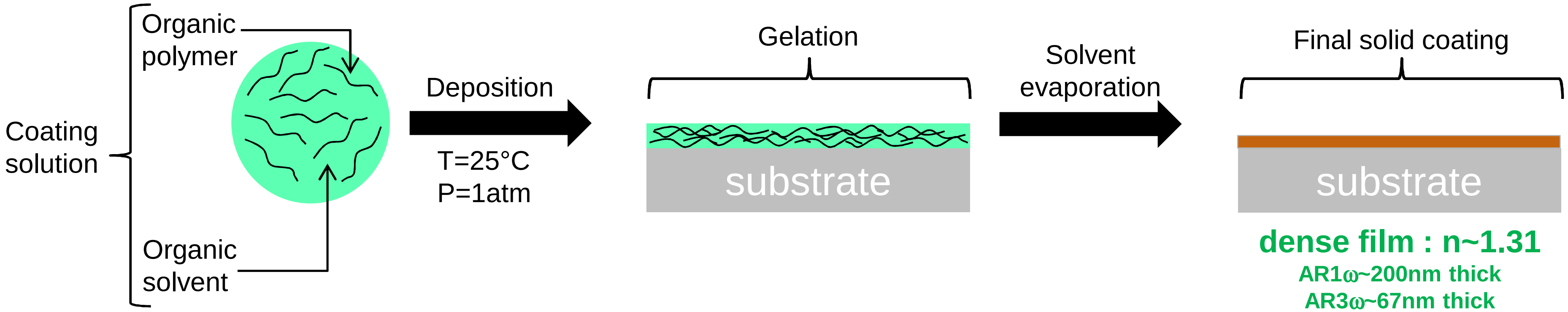
Final solid coating

substrate

porous film

n(1ω)~1.22 ⇨AR1ω~215nm thick
n(3ω)~1,24 ⇨AR3ω~71nm thick

Sol-gel coatings made from organic polymer solution



Coating solution

Organic polymer

Organic solvent

Deposition

T=25°C
P=1atm

Gelation

substrate

Solvent evaporation

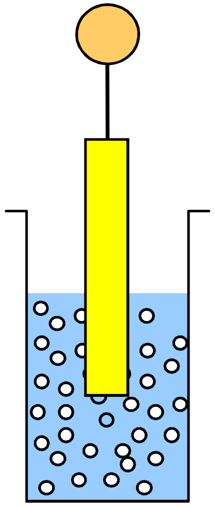
Final solid coating

substrate

dense film : n~1.31

AR1ω~200nm thick
AR3ω~67nm thick

TWO SOL-GEL COATINGS METHODS



Dip-coating

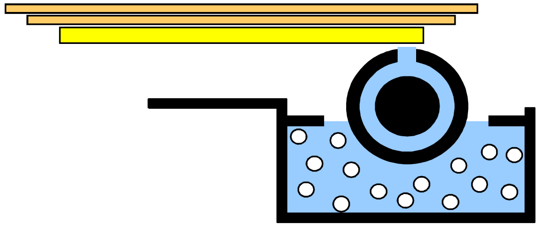
- ☺ **Two coated large sides simultaneously**
- ☺ **Parts shapes :** flat, convex, concave…
- ☺ **Easy parts loading**
- 😐 Not appropriate for one coated side or differents coatings on each side
- 😐 A large quantity of coating solution is required

The sol-gel technology has been developped by CEA and then transferred to a company .

A specific production facility and coating equipments have been designed by CEA.

$\text{thickness} = C\times(\text{speed})^n \quad n \sim 2/3$

- ☺ **Appropriate for one coated large side or differents coatings on each large side**
- ☺ **A small volume of solution is required**
- 😐 Parts shape : flat only
- 😐 The parts loading required specific adjustements



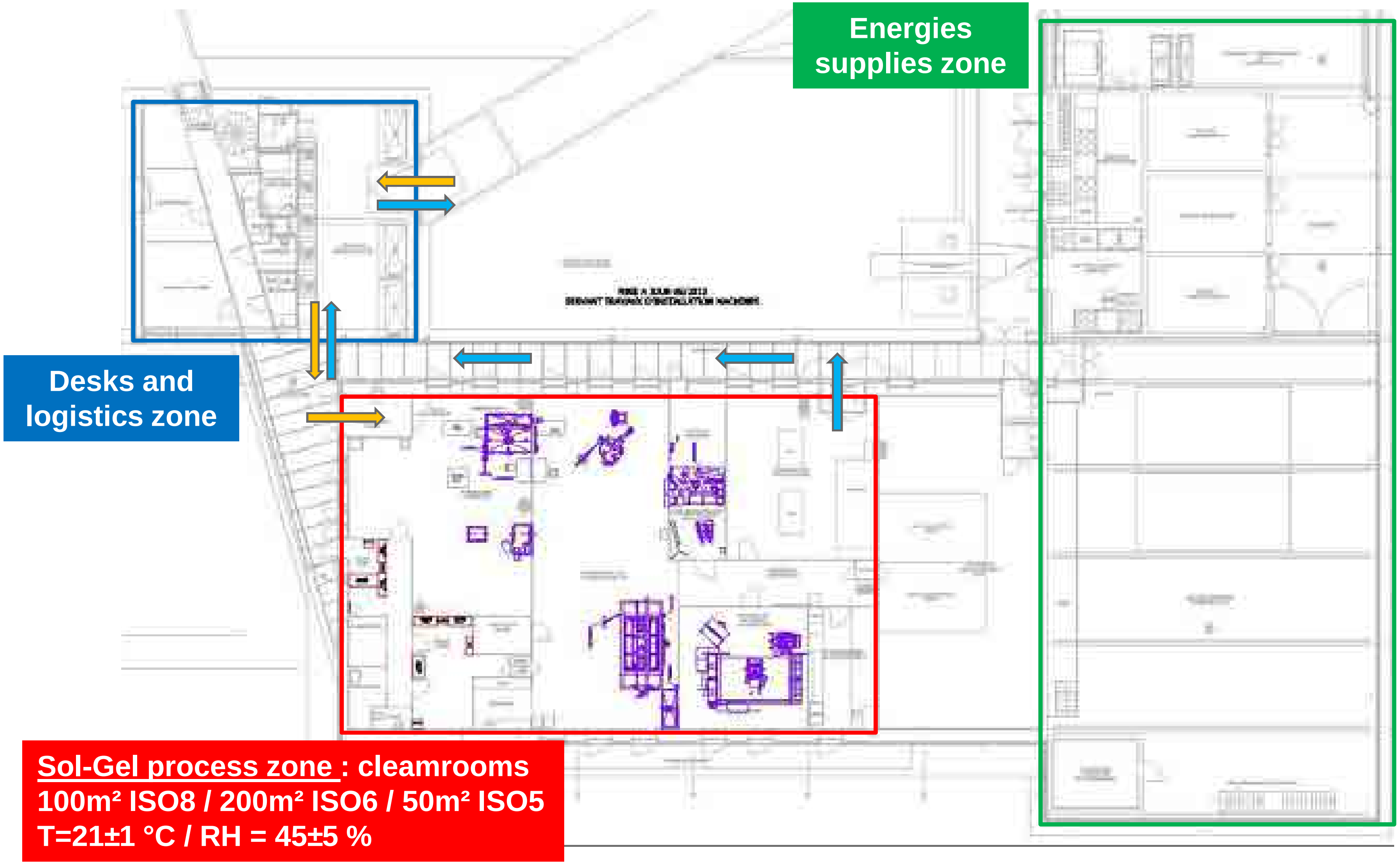
Meniscus-coating

PRODUCTION FLOW

AND

PERFORMANCES

SOL-GEL PRODUCTION FACILITY

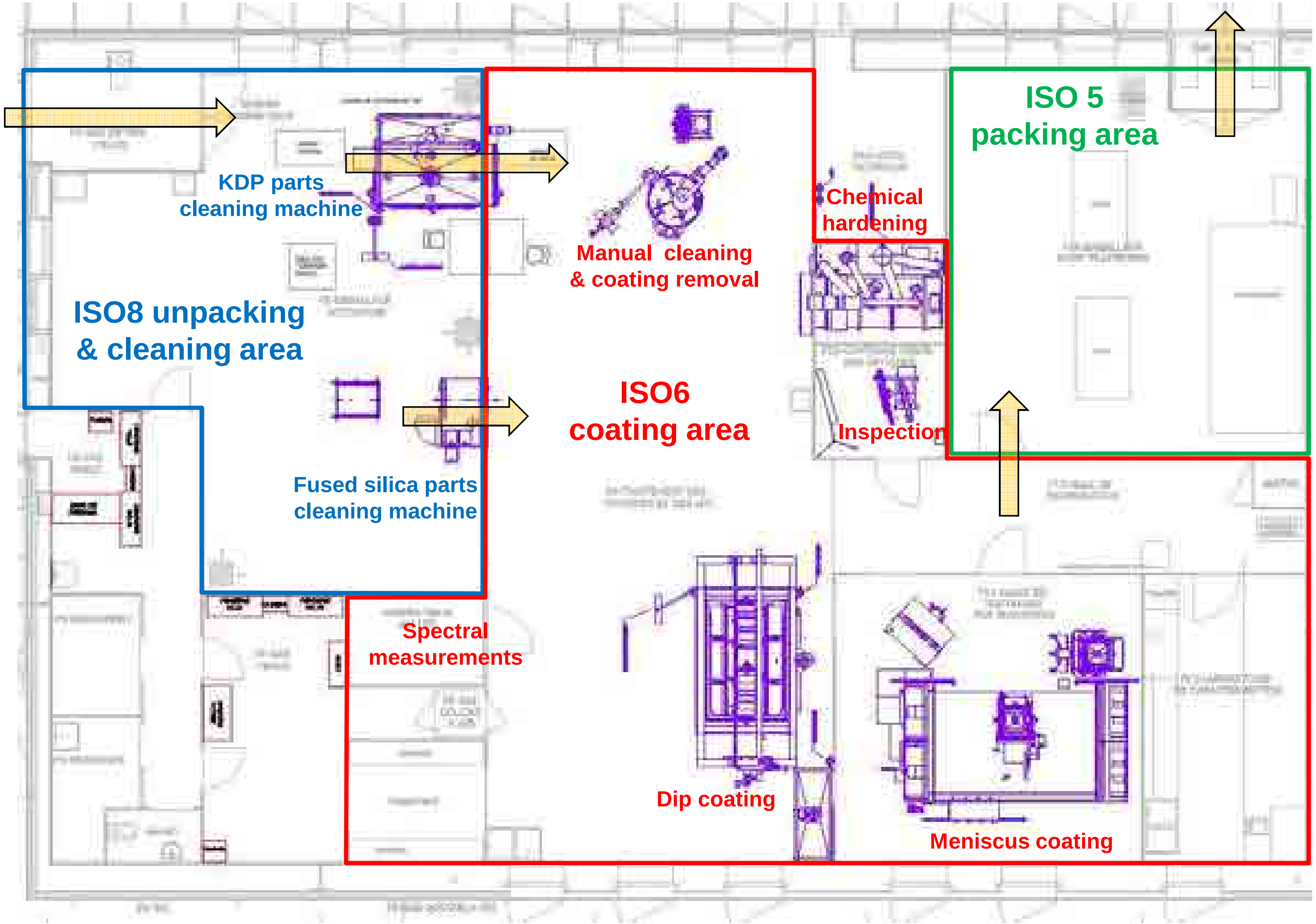


Energies supplies zone

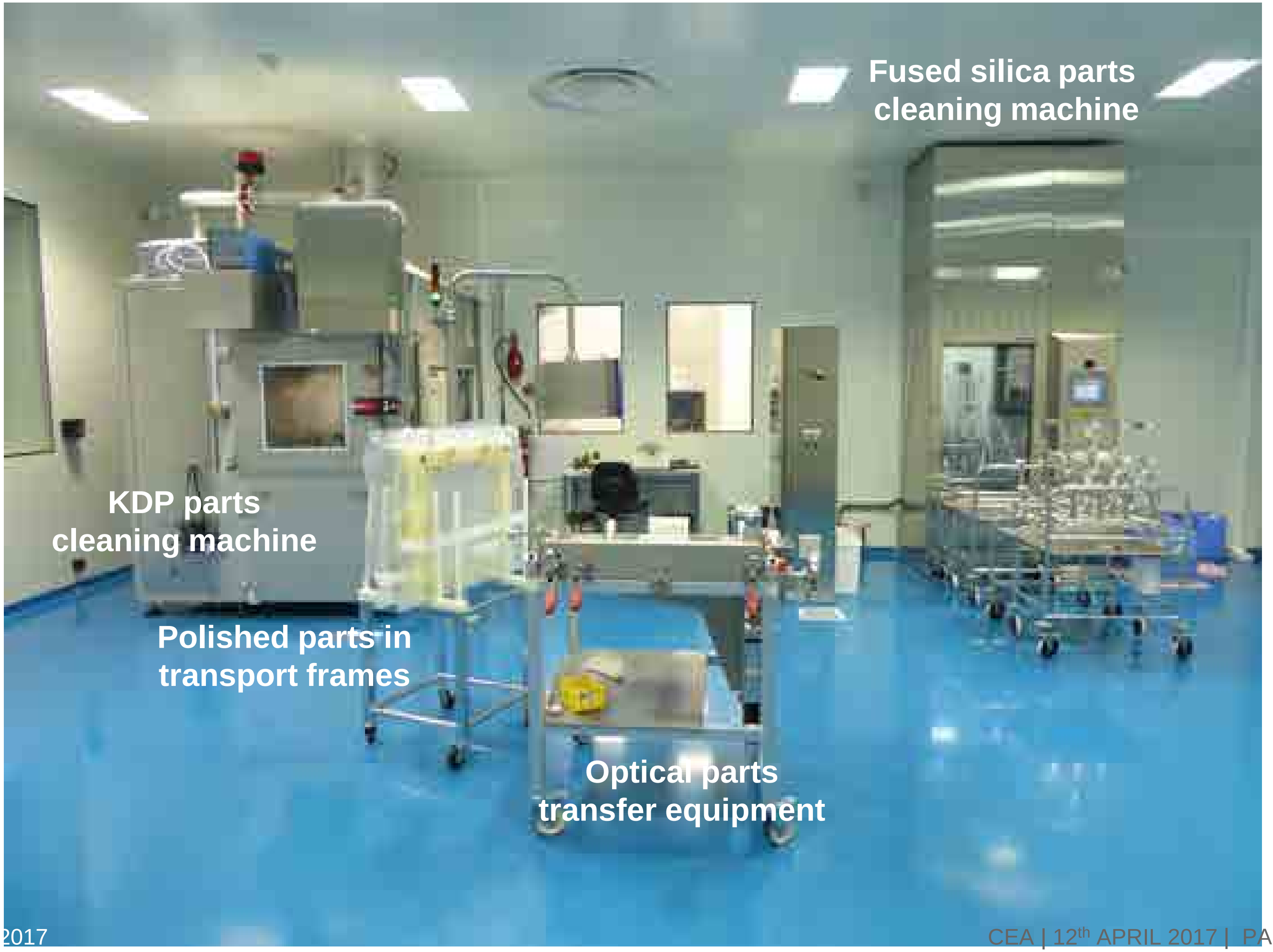
Desks and logistics zone

Sol-Gel process zone : cleamrooms
100m² ISO8 / 200m² ISO6 / 50m² ISO5
T=21±1 °C / RH = 45±5 %

PRODUCTION FLOW AND PERFORMANCES



ISO8 UNPACKING / CLEANING AREA



ISO8 UNPACKING / CLEANING AREA

ISO8 UNPACKING / CLEANING AREA

3rd tank equipped With C_2Cl_4 spray system

Moving stainless Steel frame

1rst tank filled of kerosene

2nd tank filled of toluene

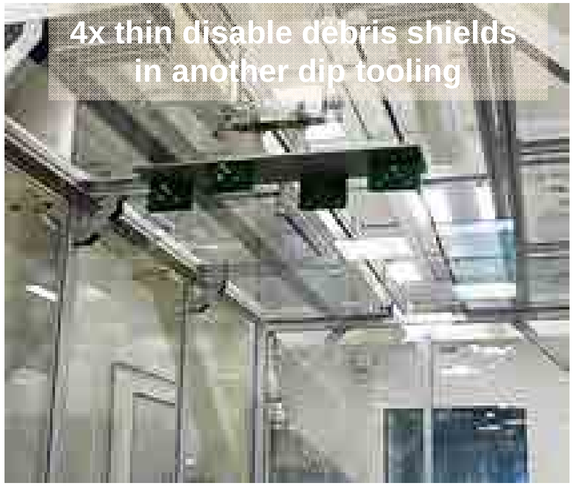
ISO8 UNPACKING / CLEANING AREA

ISO 6 COATING AREA

DIP COATING MACHINE

Dip coating machine

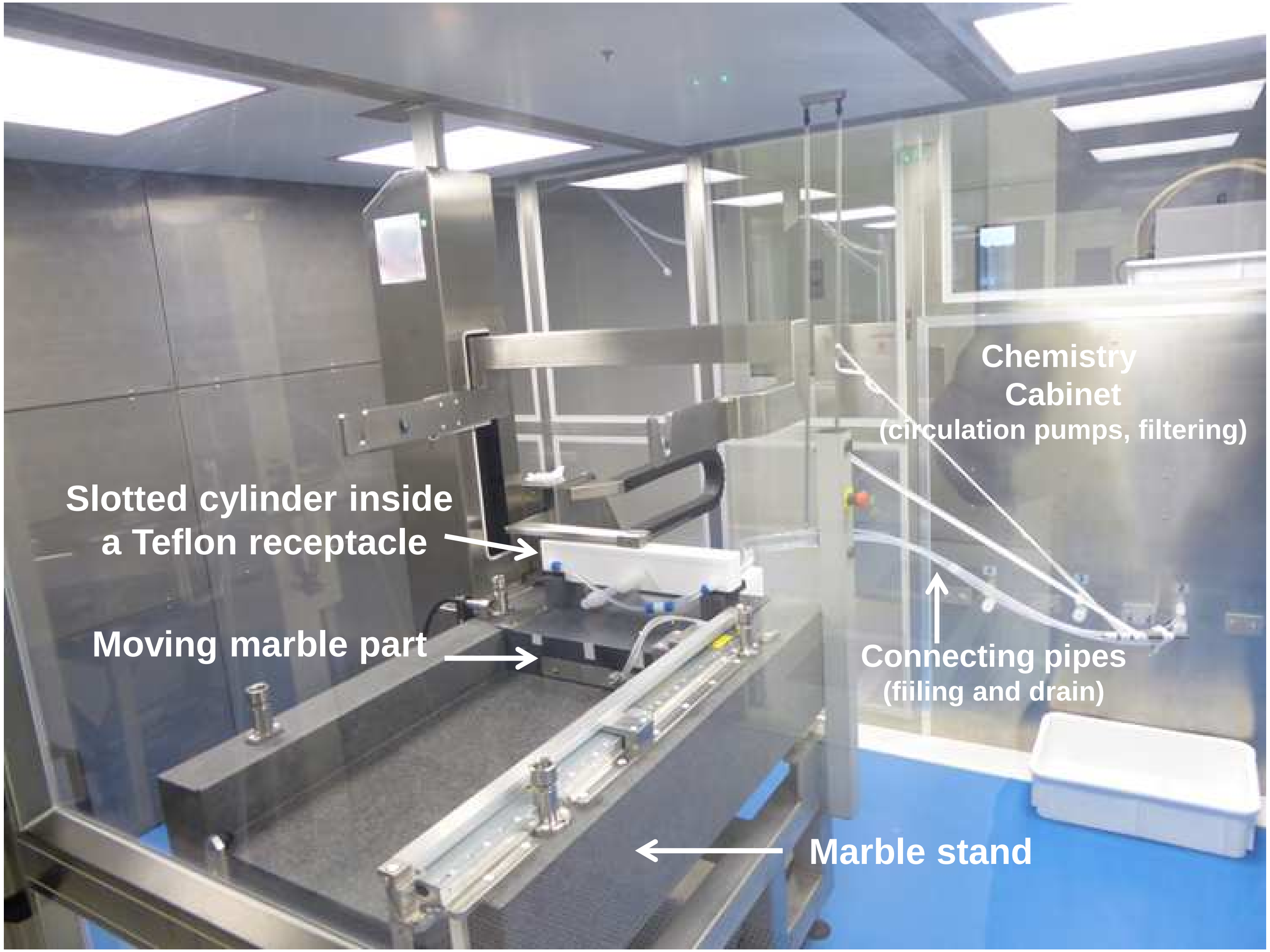
Thick optics in a dip tooling



4x thin disable debris shields in another dip tooling

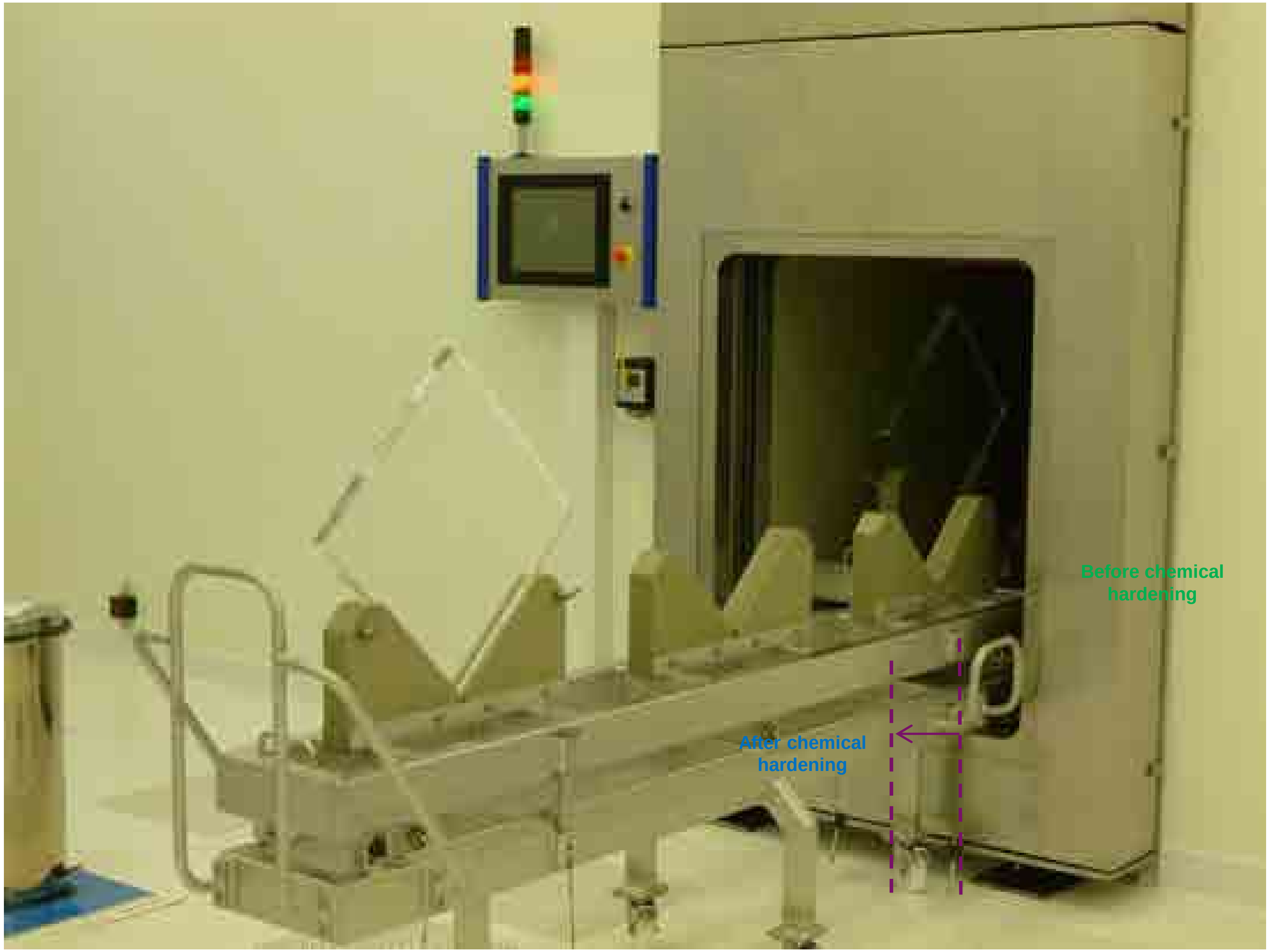
DIP COATING MACHINE

MENISCUS COATING MACHINE

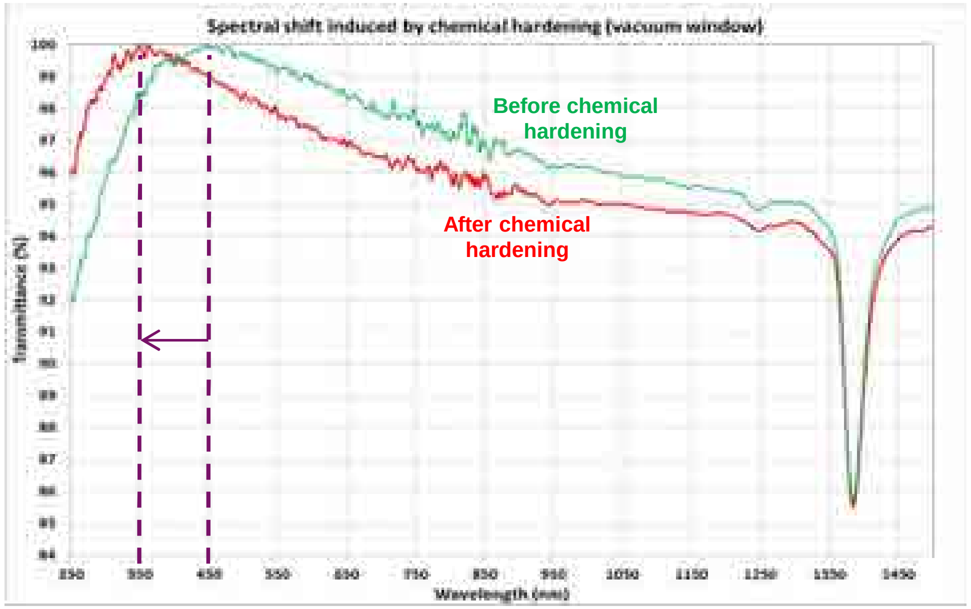


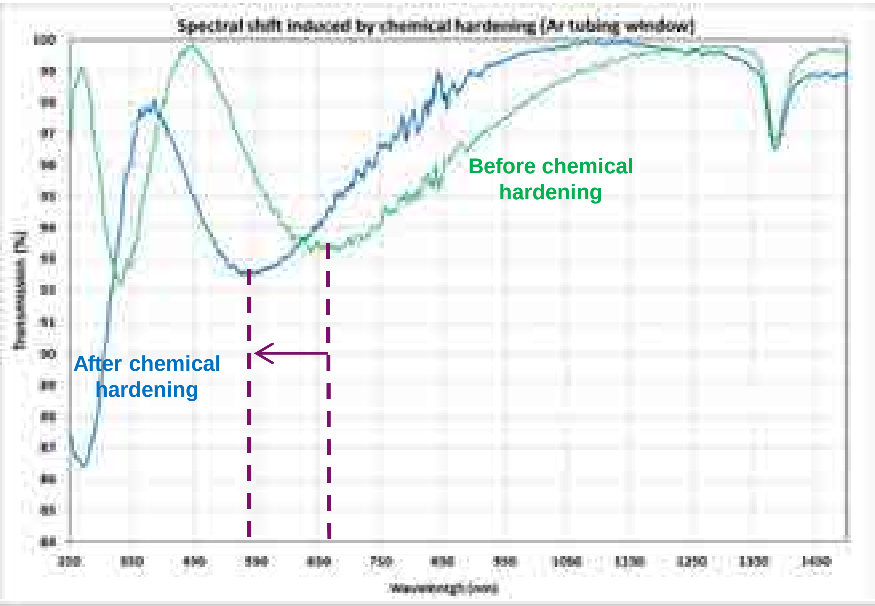
MENISCUS COATING MACHINE

CHEMICAL HARDENING



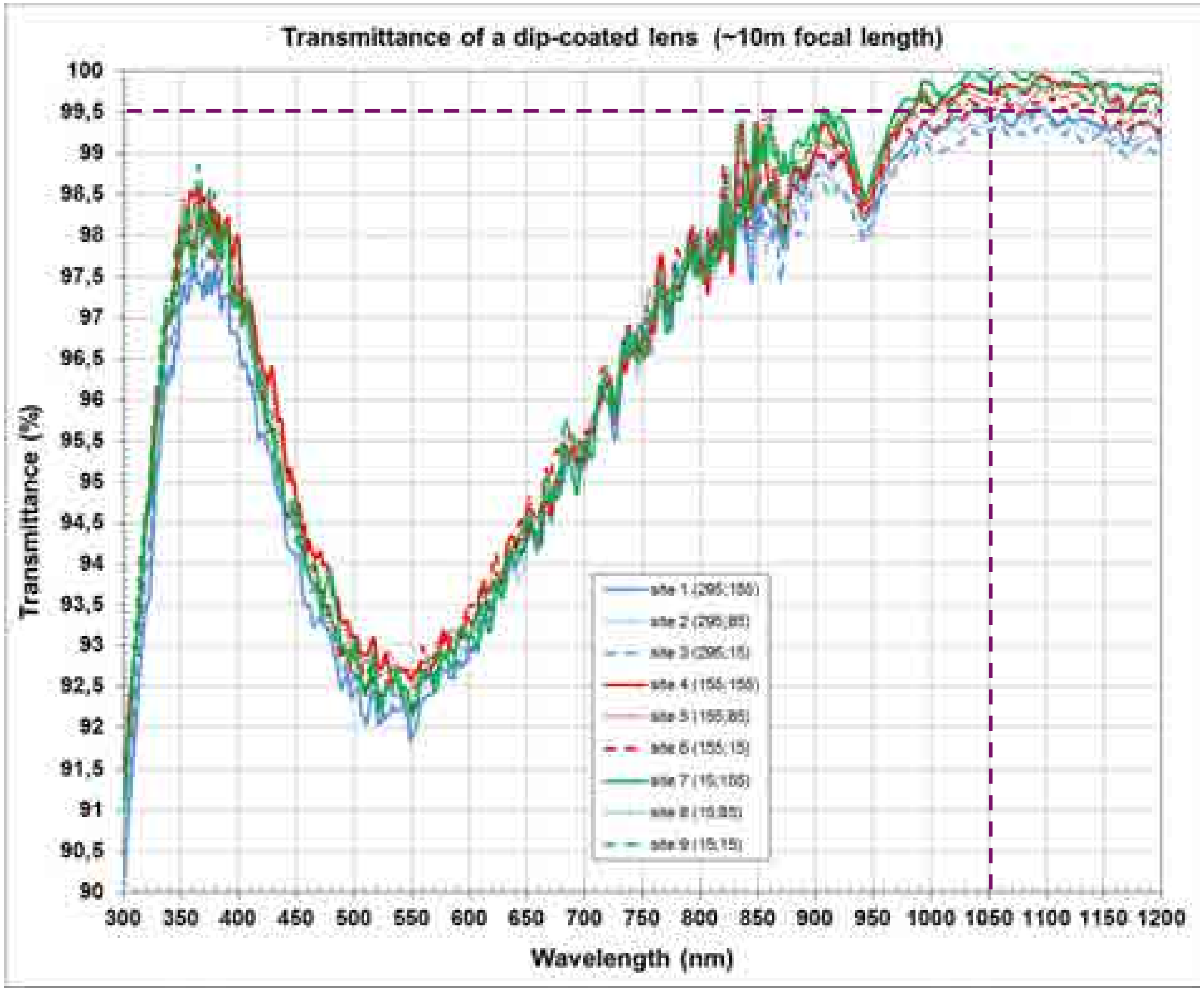
CHEMICAL HARDENING



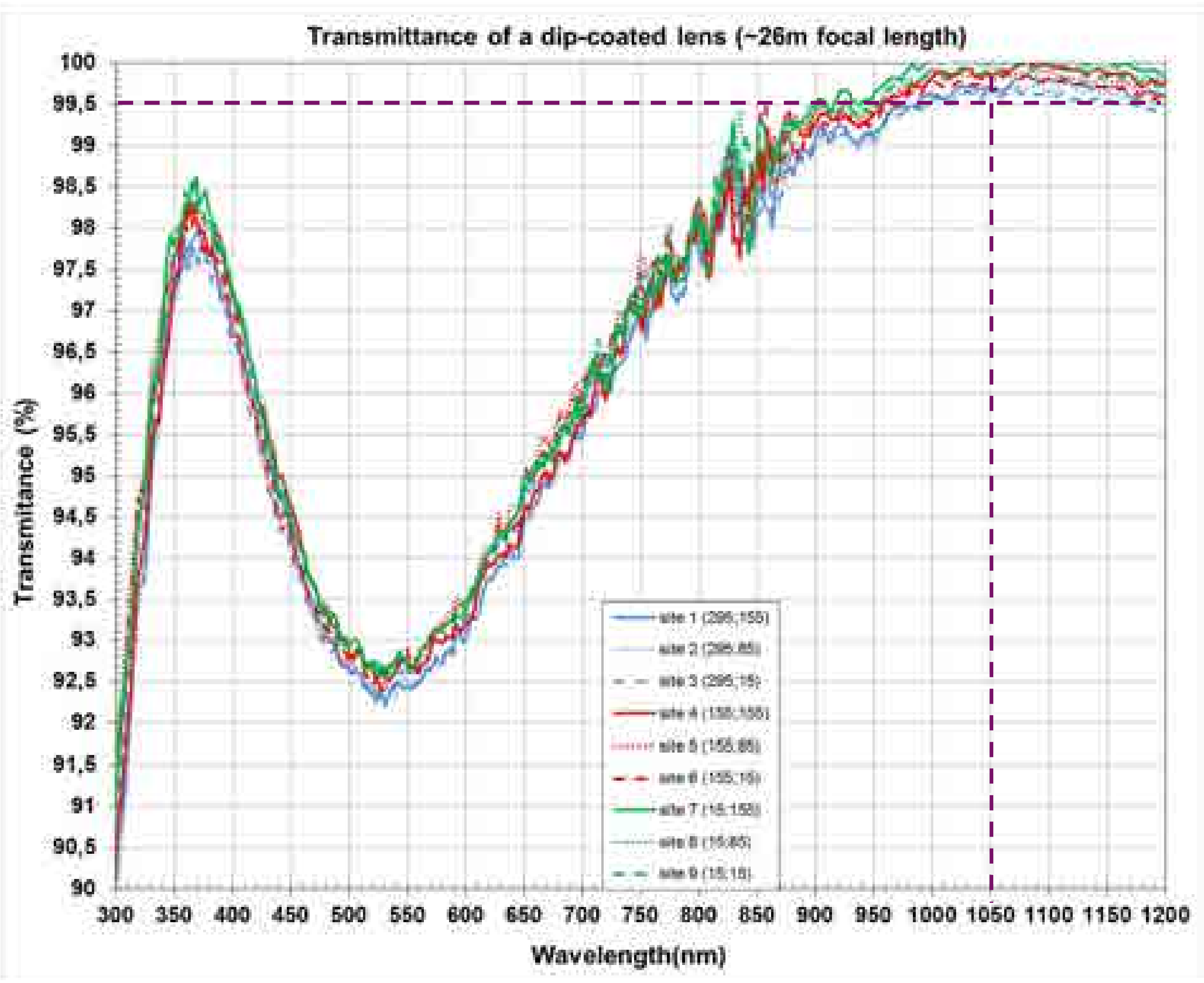


SPECTRAL MEASUREMENTS

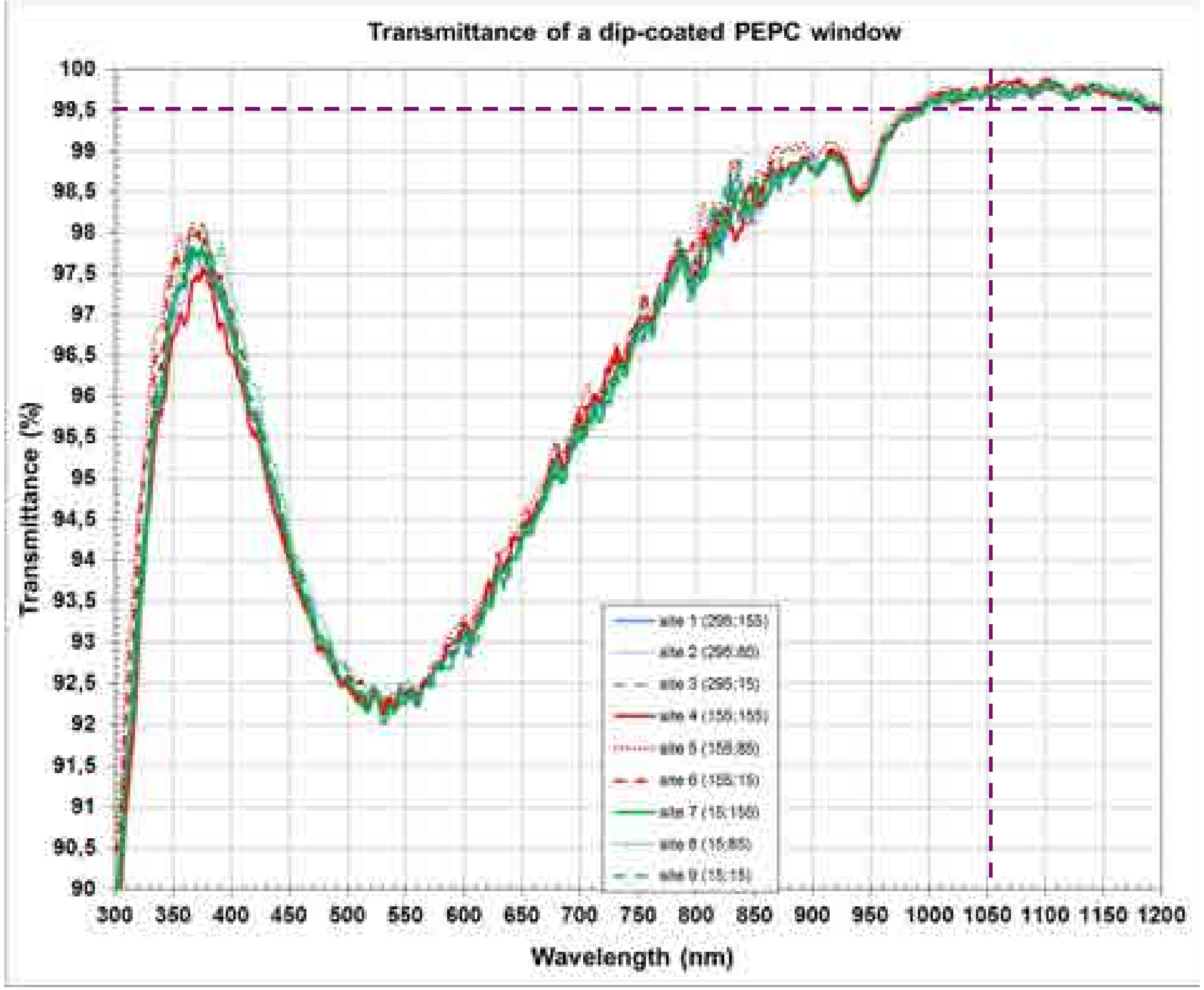
TRANSMITTANCE PERFORMANCES



TRANSMITTANCE PERFORMANCES



TRANSMITTANCE PERFORMANCES



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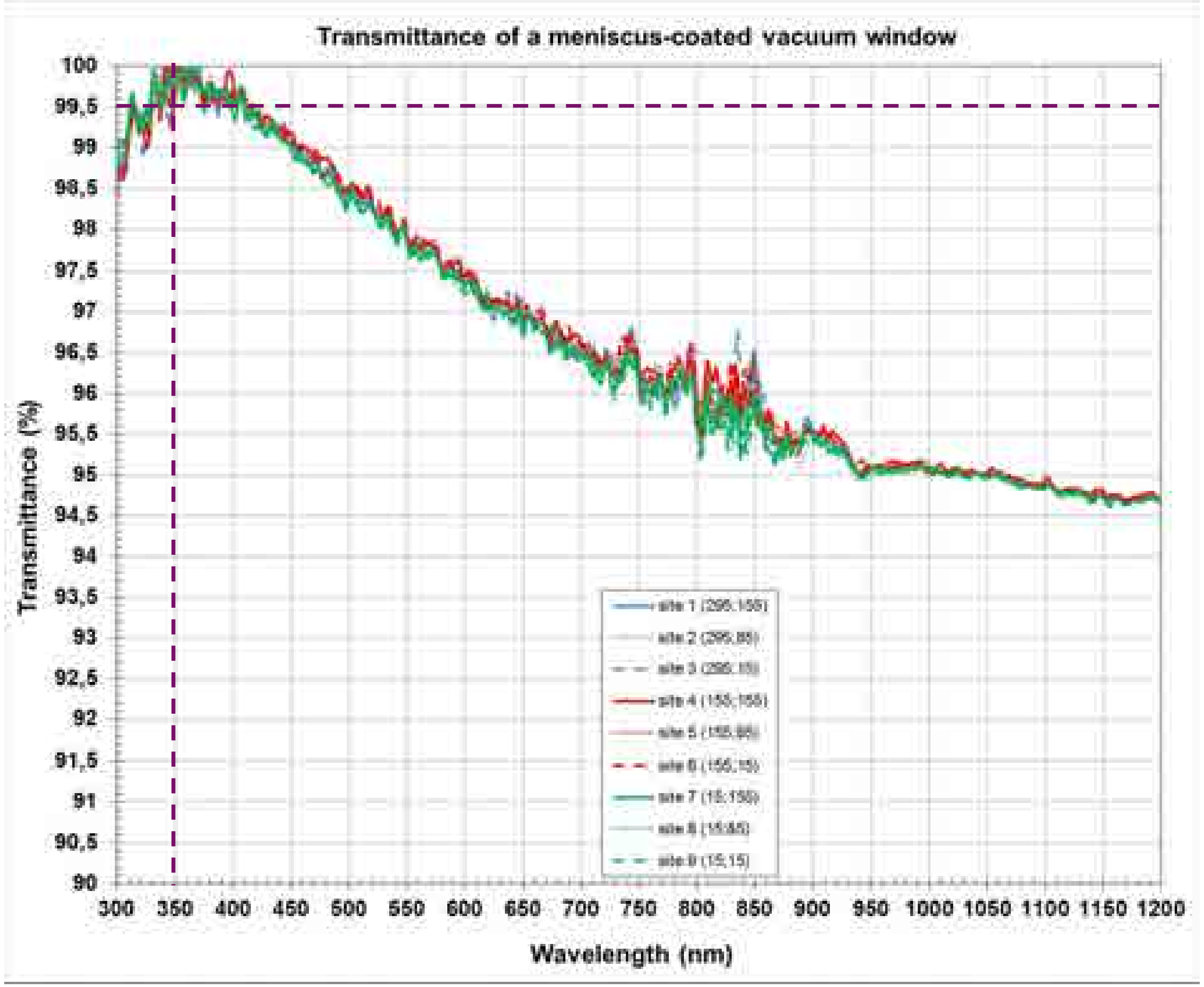

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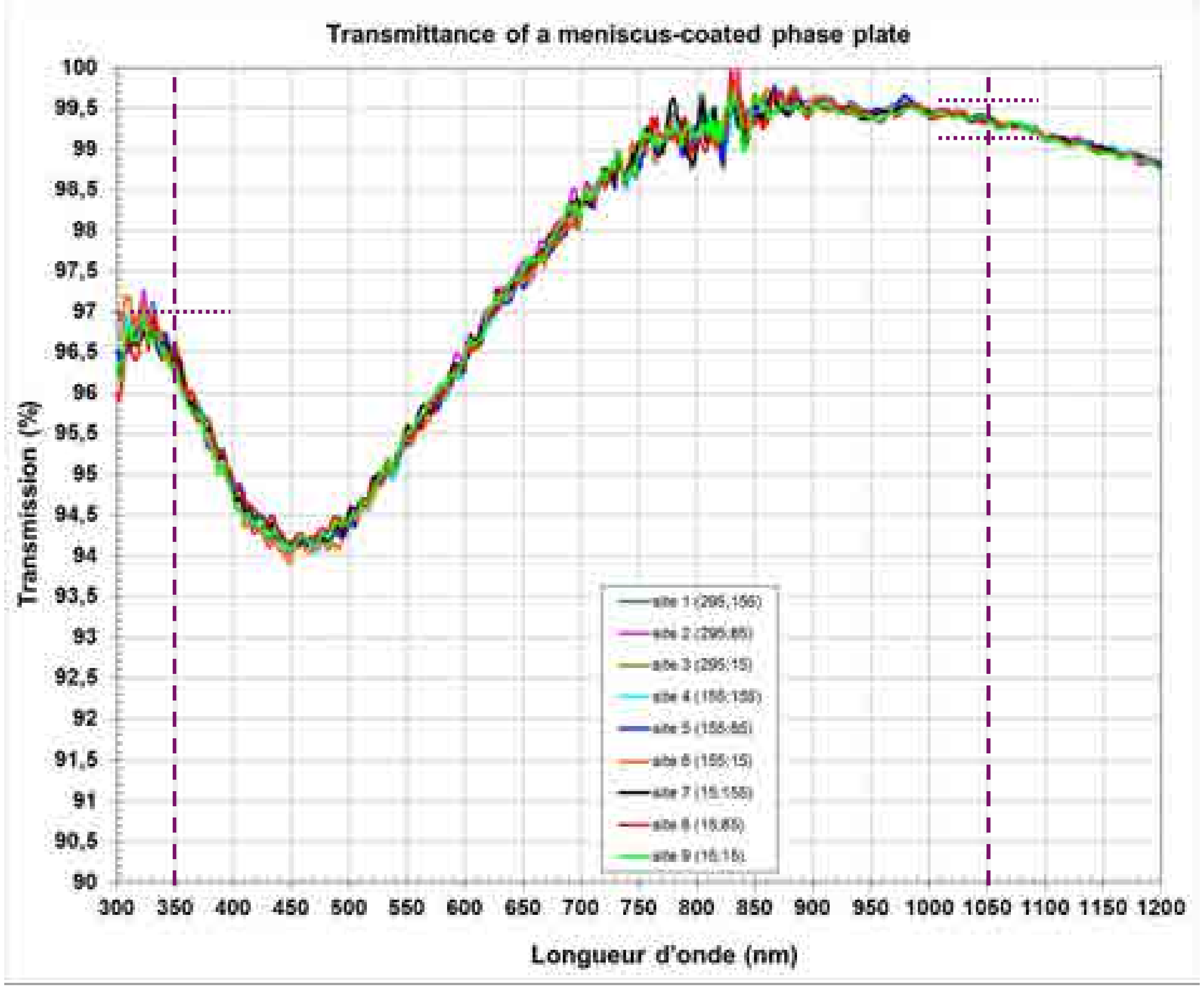
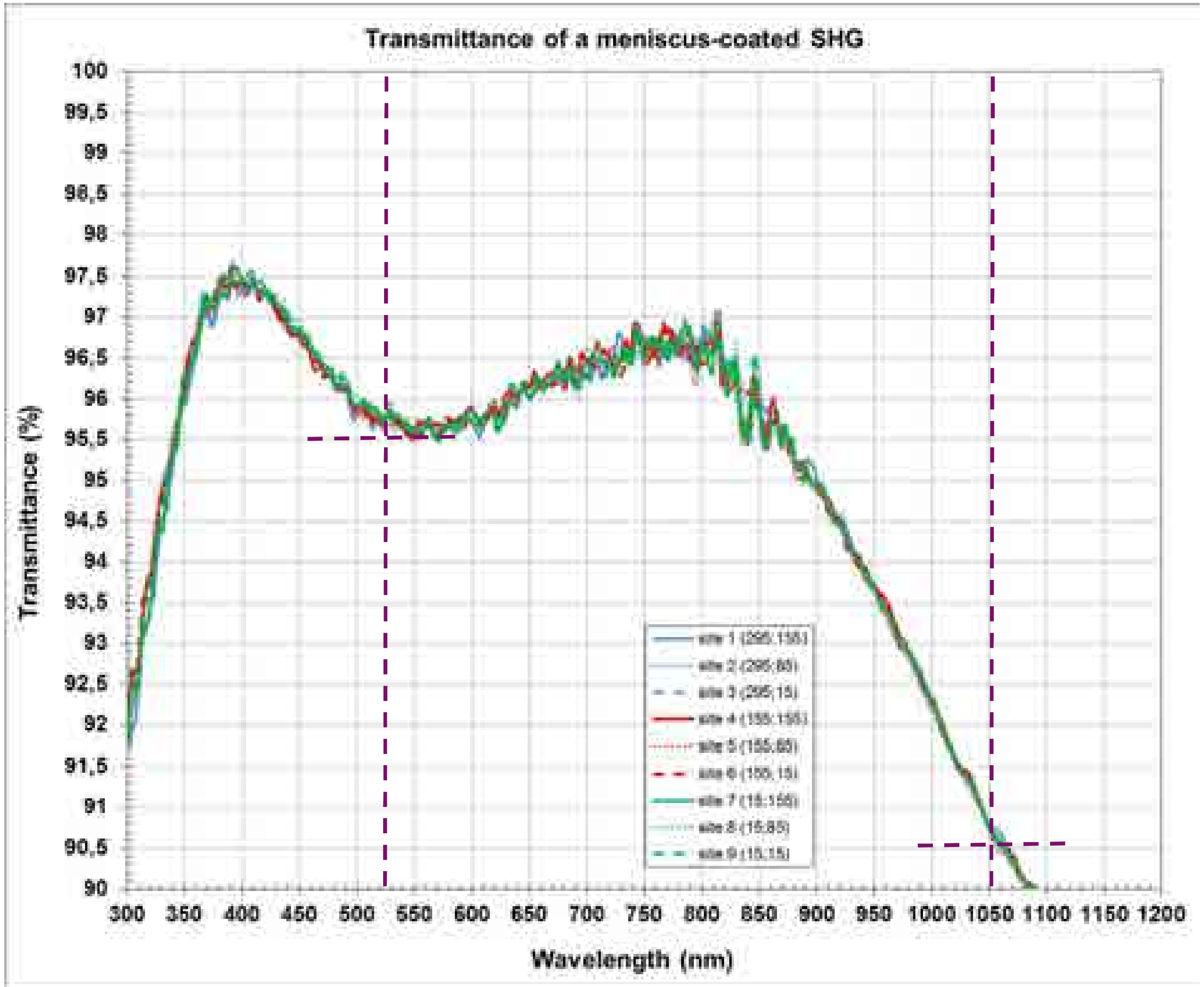


TRANSMITTANCE PERFORMANCES



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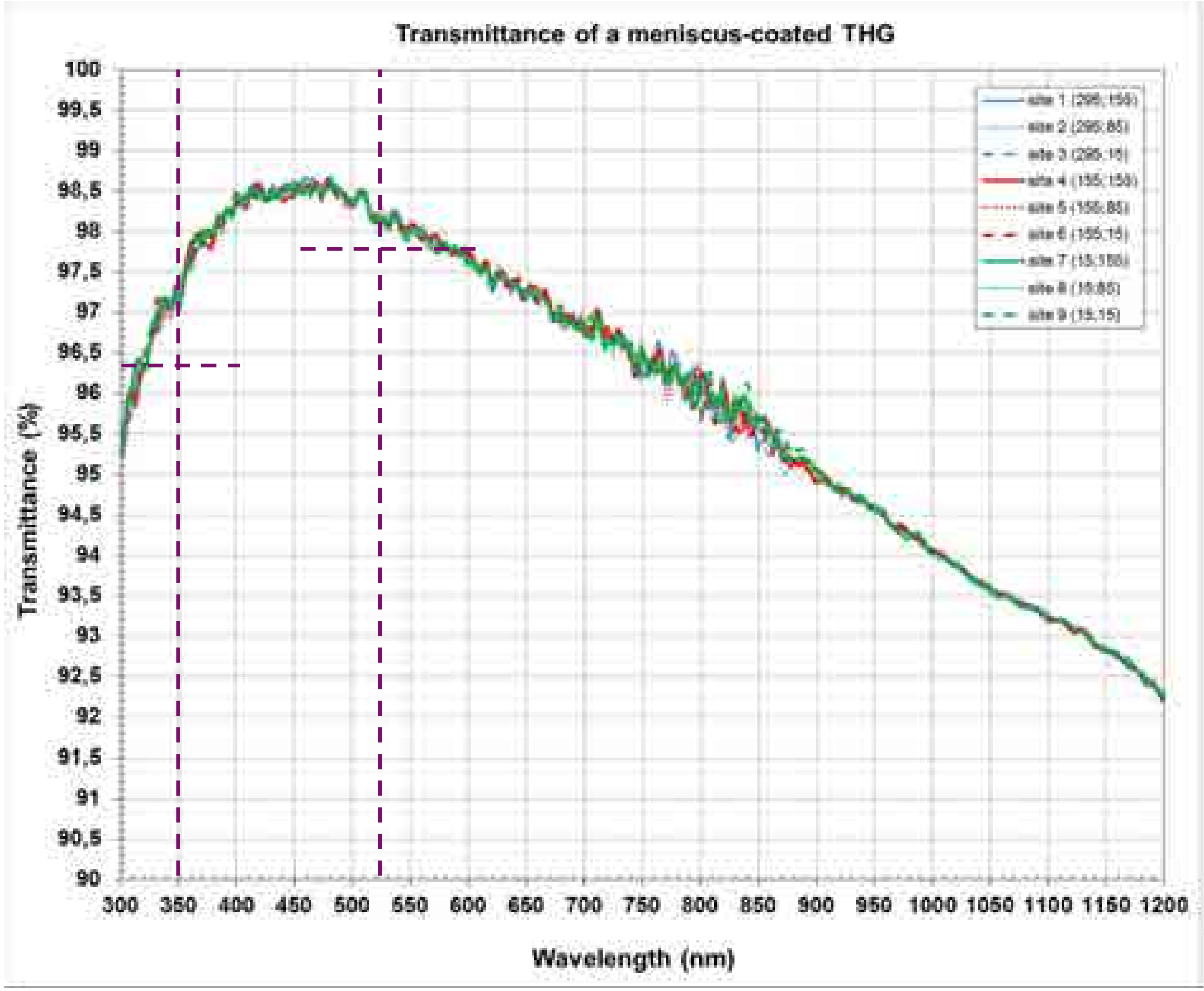
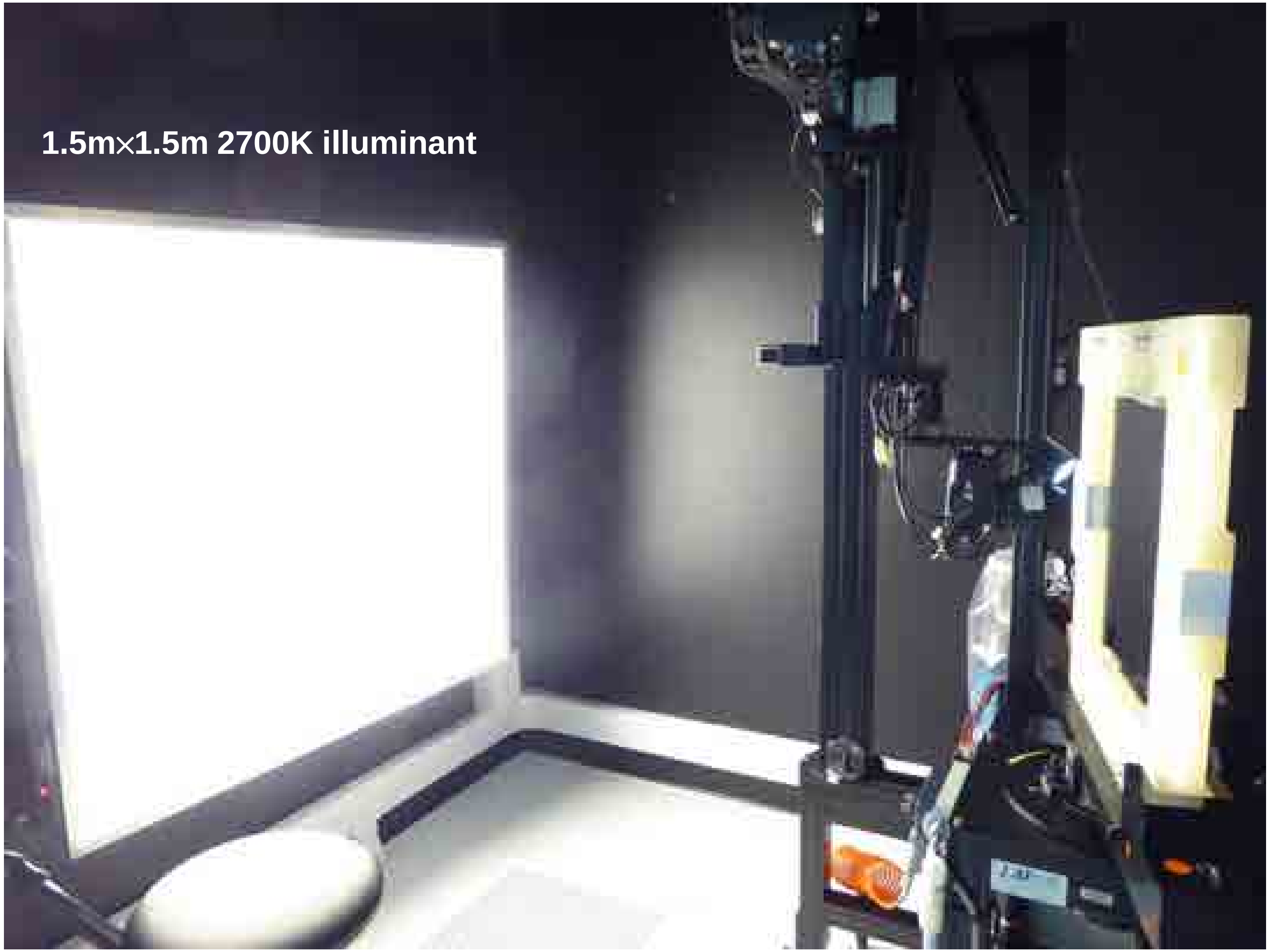


FINAL INSPECTION



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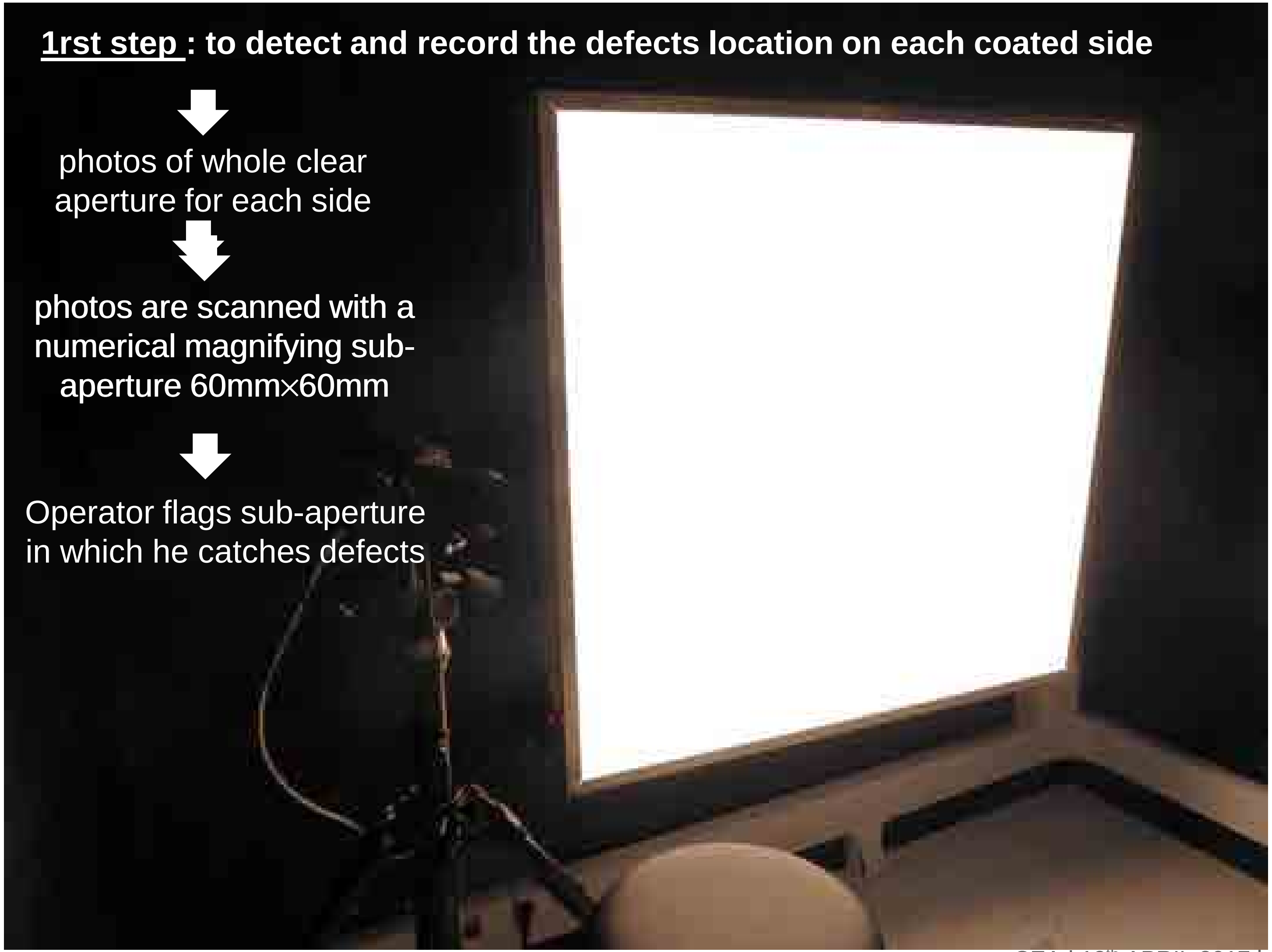


<u>**1rst step**</u> **: to detect and record the defects location on each coated side**

↓

photos of whole clear aperture for each side

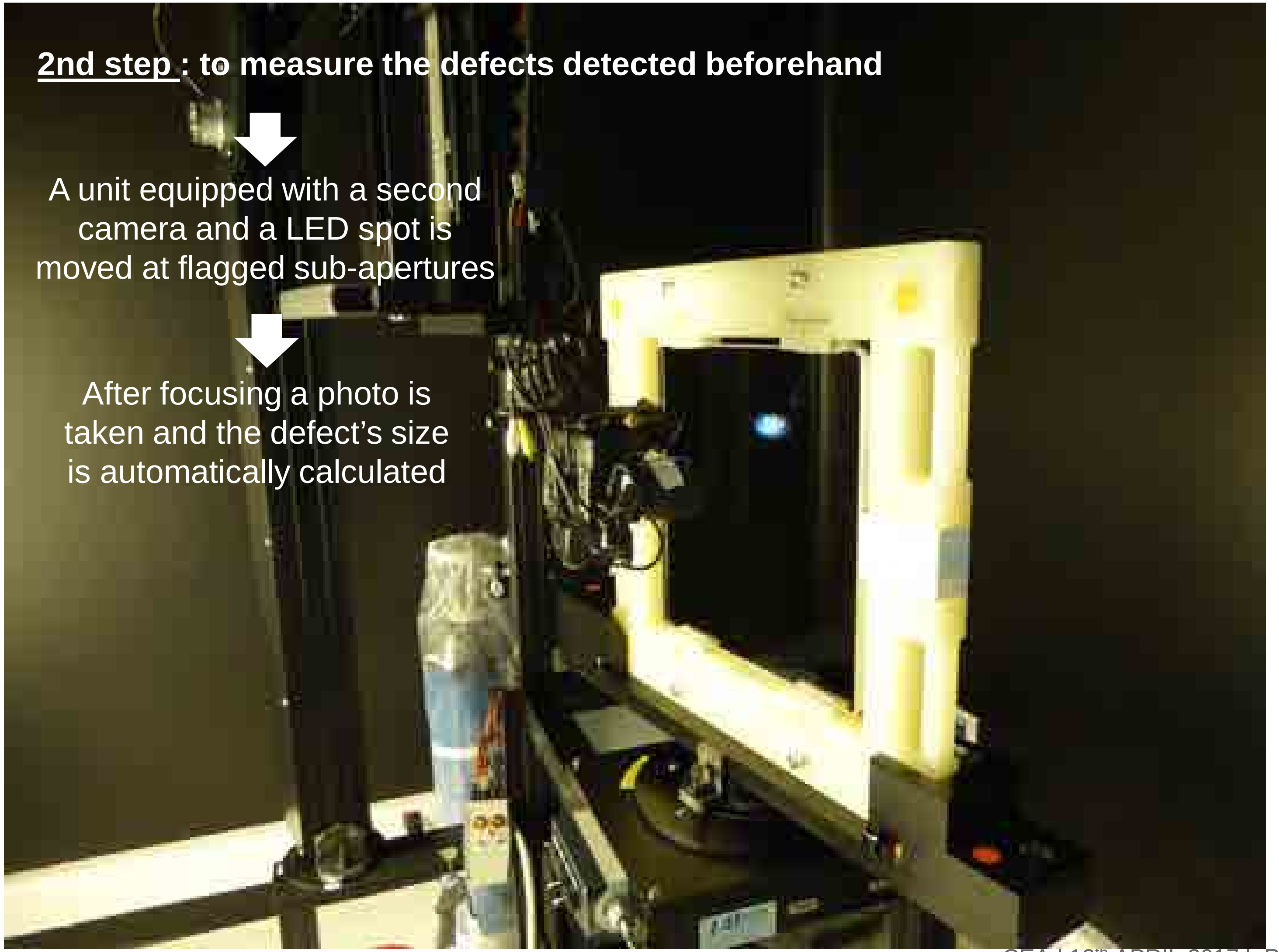
↓

photos are scanned with a numerical magnifying sub-aperture 60mm×60mm

↓

Operator flags sub-aperture in which he catches defects

FINAL INSPECTION



2nd step : **to measure the defects detected beforehand**

↓

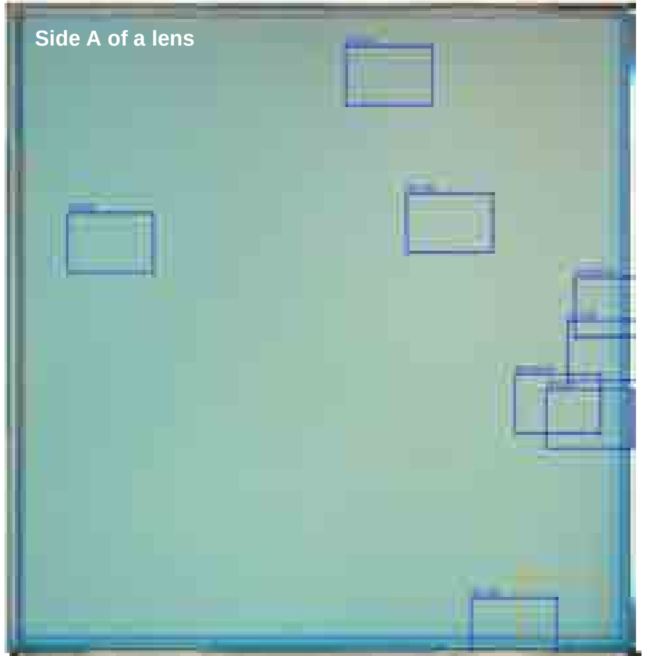
A unit equipped with a second camera and a LED spot is moved at flagged sub-apertures

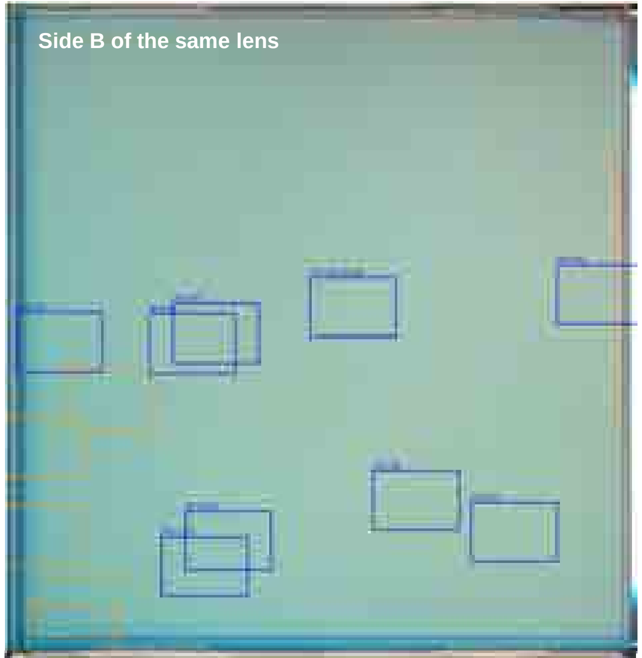
↓

After focusing a photo is taken and the defect's size is automatically calculated

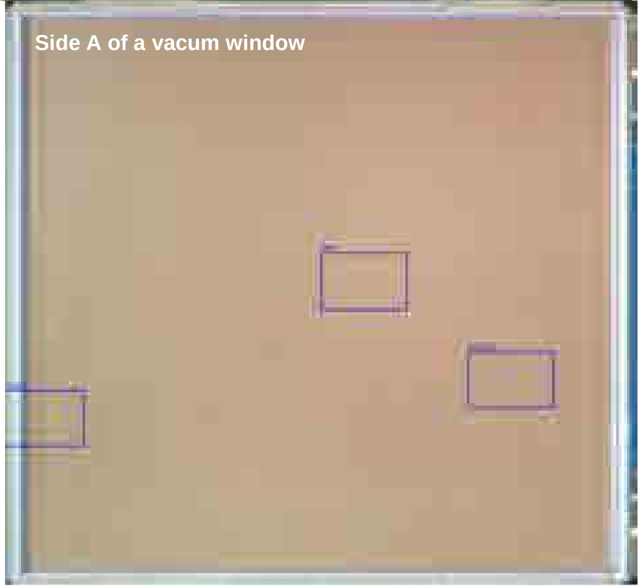
FINAL INSPECTION

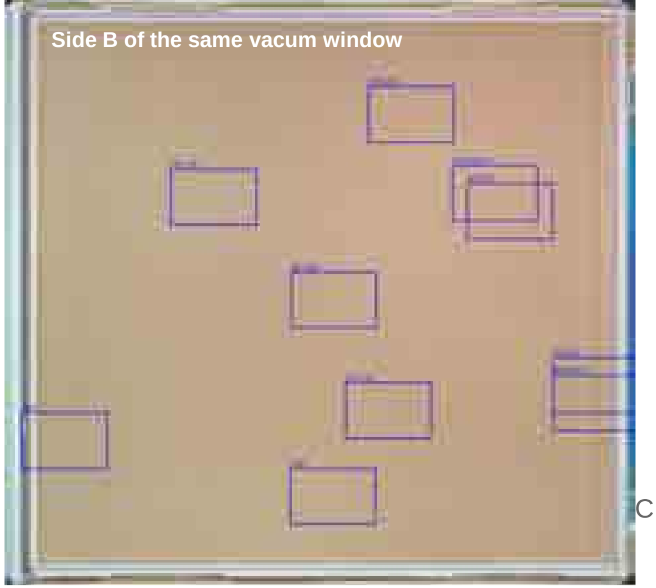
AR1ω dip coating


Side A of a lens

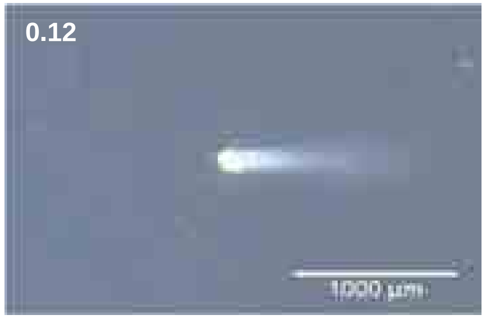

Side B of the same lens

AR3w meniscus coating


Side A of a vacum window


Side B of the same vacum window

Typical defects



COATING REMOVAL

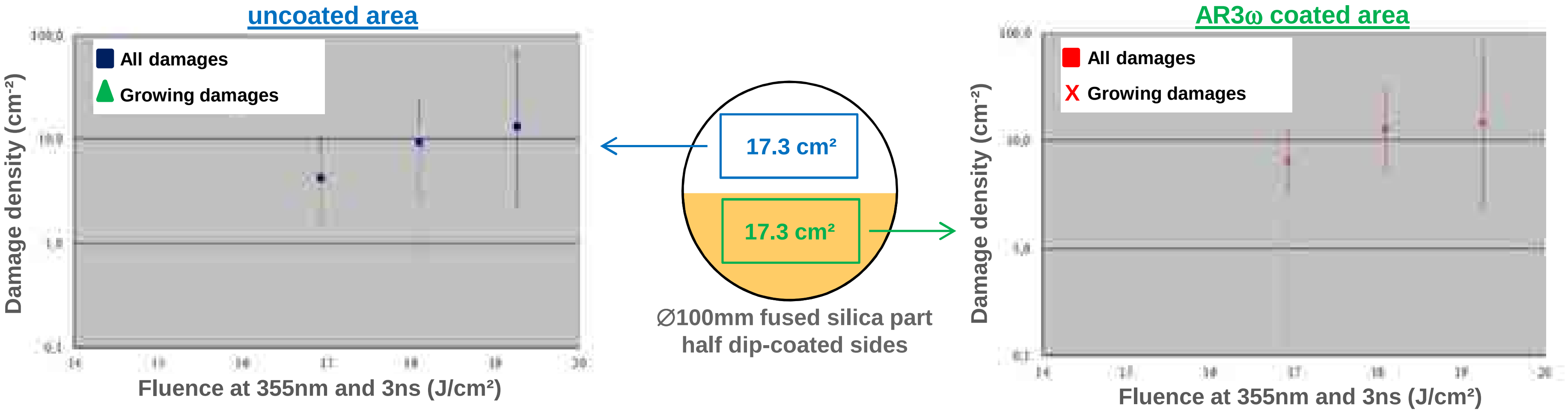
Before chemical hardening

After chemical hardening

LASER INDUCED DAMAGE THRESHOLD

LIDT checked by sampling on representative small parts

- AR3ω : Raster scan method on large surface (CEA bench) ➲ damage density



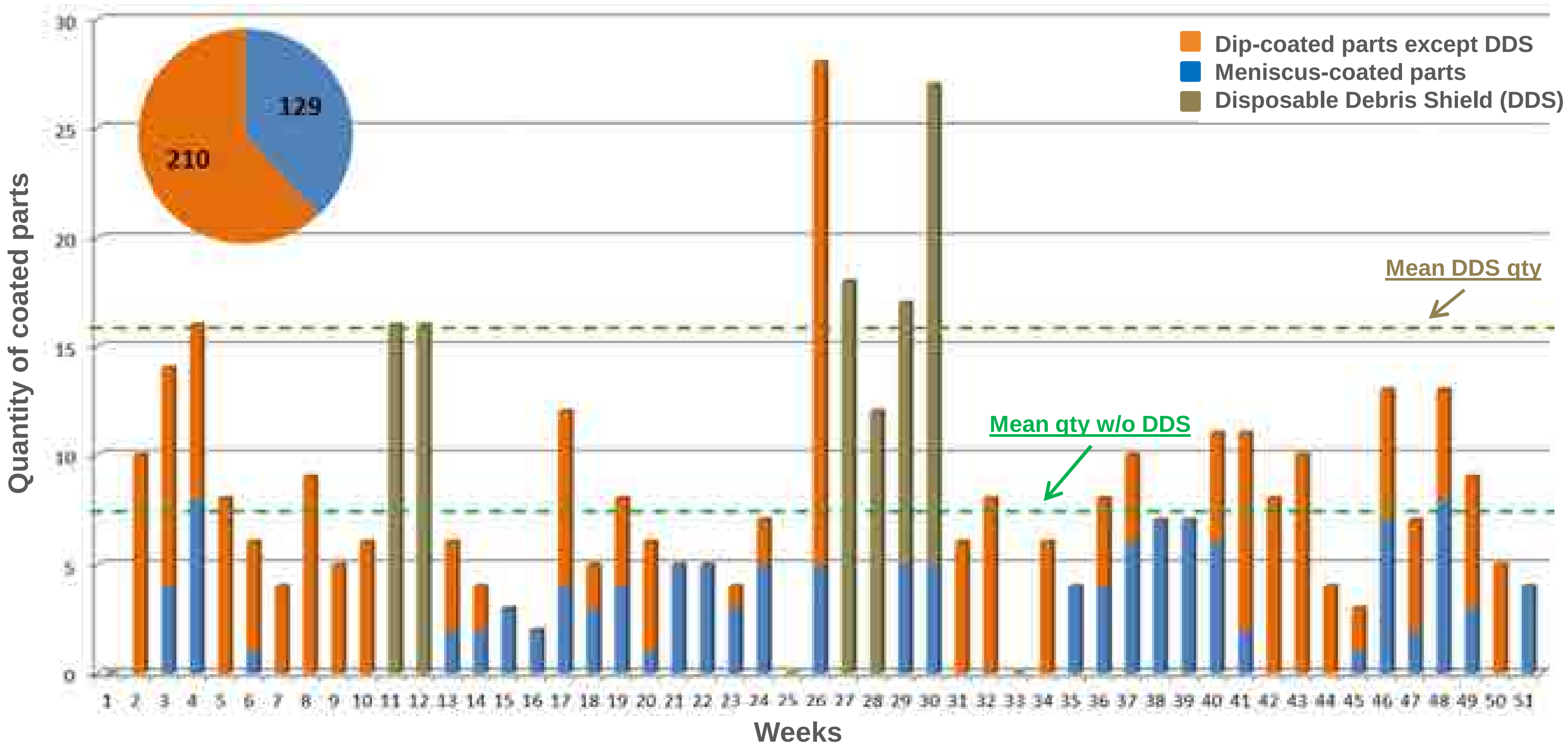
∅100mm fused silica part
half dip-coated sides

- AR1ω : Raster scan method on 1cm² surface ➲ damage threshold

Coating types	AR1ω dip coating + hardening	AR1ω dip coating w/o hardening	AR1ω meniscus coating + hardening
Damage thresholds (J/cm²)	50	50	40

PRODUCTION RATE

PRODUCTION RATE (2016)



- Quantity of coated parts except DDS : 339 ➲ mean ~8 parts/week and max ~16 parts/week
- Quantity of coated DDS : 96 ➲ ~16 DDS/week
- Total quantity : 435 in 2016
- Total expected quantity in 2017 : ~575 including 172 DDS

YIELD – 2016 (EXCEPT DDS)

- **345 polished parts have started the coating process**
  - **6 parts have been stopped before the coating stage because of different problems**
    - **cleaning dysfunctions, handling issues …**
  - **339 parts have been coated**
    - **only 2 unusable parts after coating**

- **The yield of compliant parts beginning the coating process is better than 97%**
  - **the coating process is efficient for such large optical parts**

- **The yield of compliant parts after coating is better than 99% (only 2/339 have been rejected)**
  - **the coating stage is high-yield because it is well controlled**

Such yields are essential because the coating stage is less than 10% of the total cost of a finished part.

CONCLUSIONS

AND

PROSPECTS

CONCLUSIONS AND PROSPECTS

- **The sol-gel technology has been transferred successfully from CEA to industry**

- **Today the production facility, the equipments and the know-how allow to reach a high-yield production in compliance with LMJ requirements**

- **The production rate could be increased by adding other equipments (dip-coater, cleaning machine…)**

Thank you

for your attention

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