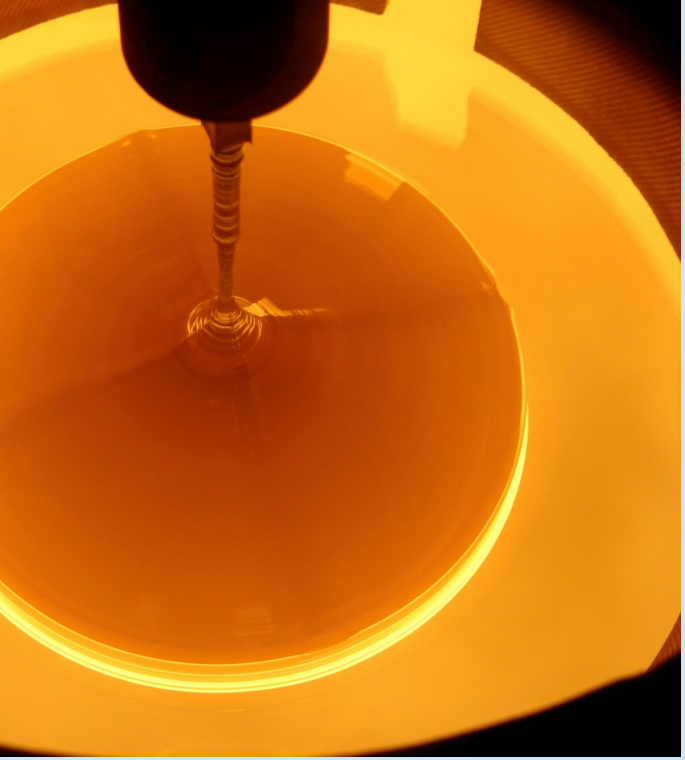
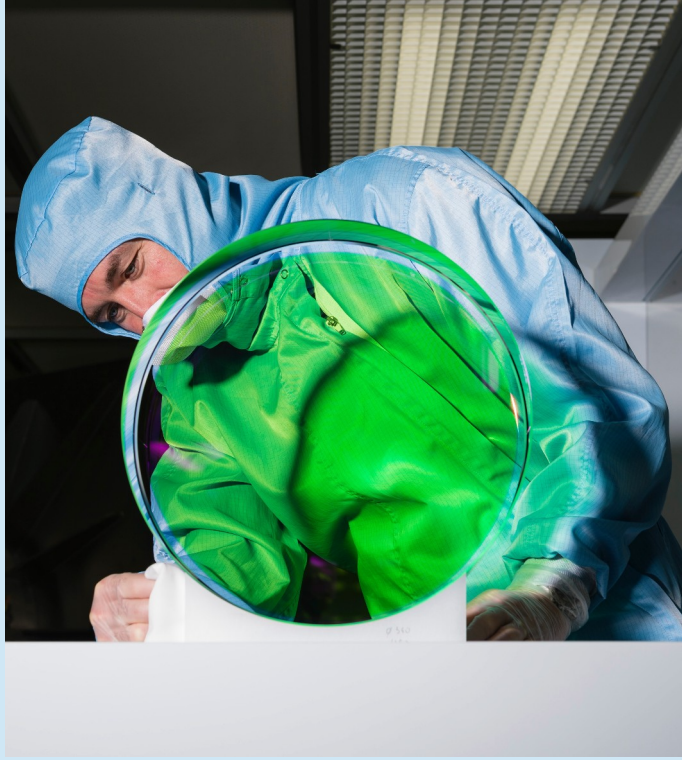




Development of sapphire mirrors @ Lyon

J. Degallaix for LMA – IP2I and iLM

ET-0XXXA-24

ET annual meeting - 11/2024

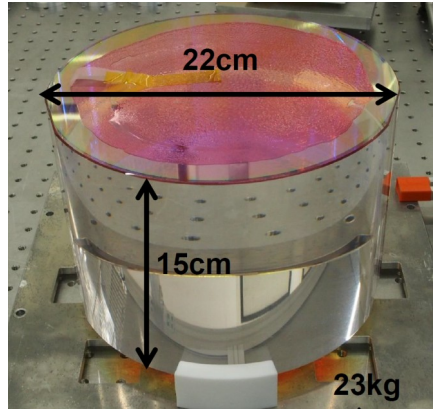
I
Introduction
- sapphire presentation

The cryogenic mirrors

- fused silica is no longer compatible

- substrate candidates
  - silicon (baseline for ET)
  - sapphire (KAGRA)

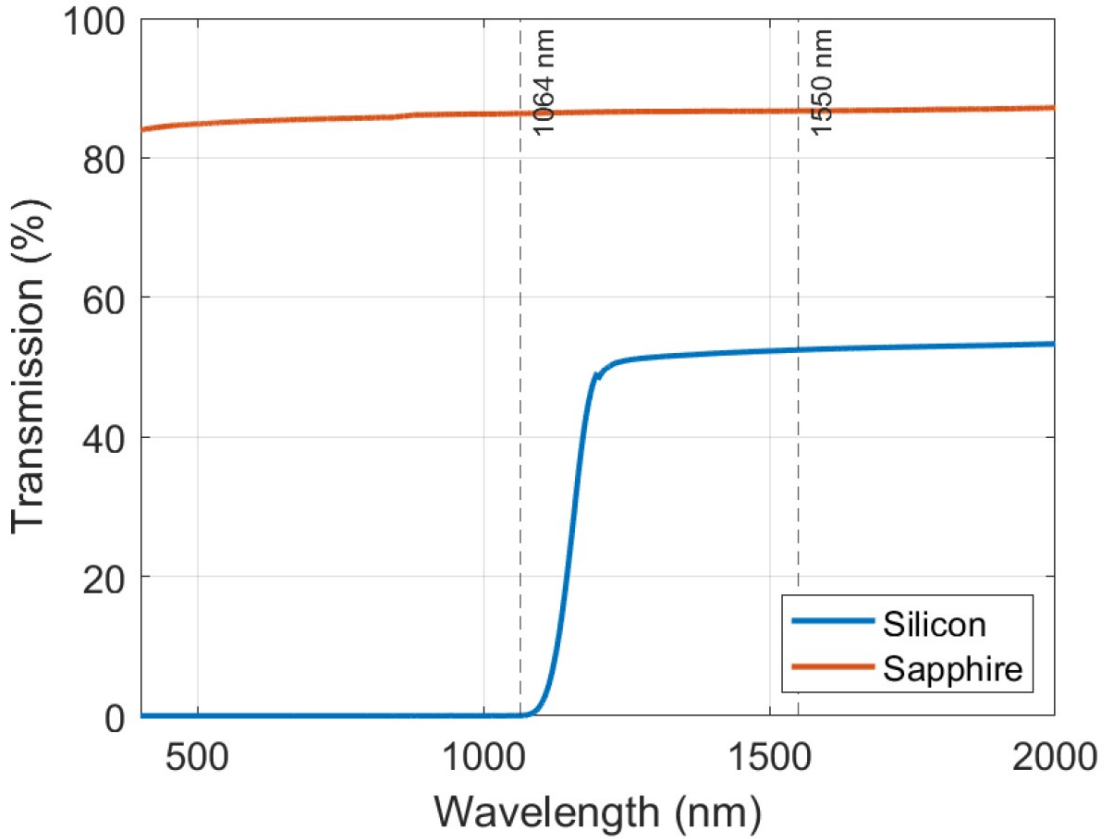
- must be available in Ø 450 mm, 200 kg
  - and with outstanding optical properties
  - with the matching low noise coating



Today, no solution for such substrates !

Advantages of sapphire

Transmission of a window : (without AR coating)



Sapphire transparent @ 532 nm et 1064 nm

Can use the same eco-system as current generation of instruments

Advantages of sapphire

	Sapphire		Silicon	
Parameter	10K	20K	10K	20k
Thermal Conductivity κ [W/(m.K)]	2900 (c-plane) [81]	4300 (c-plane) [82]	1000 (111) [83]	3000 (111) [83]
Thermal Expansion a [K^{-1}]	5.3×10^{-10} [84]	4.6×10^{-10} [84]	4.8×10^{-10} [85]	-2.9×10^{-9} [85]
Specific Heat C [J/(kg.K)]	0.085 [86]	0.72 [86]	0.276 [87]	3.41 [87]
Density ρ [kg/m^3]	3997		2331	
Young's modulus Y [GPa]	464		169 (110) [88]	
Poisson ratio σ	$0.27 - 0.30$		0.22	

Better thermal conduction → lower thermal gradient, better heat conduction through the suspension

Les avantages du saphir

	Sapphire		Silicon	
Parameter	10K	20K	10K	20k
Thermal Conductivity κ [W/(m.K)]	2900 (c-plane) [81]	4300 (c-plane) [82]	1000 (111) [83]	3000 (111) [83]
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Young's modulus Y [GPa]	464		169 (110) [88]	
Poisson ratio σ	$0.27 - 0.30$		0.22	

Higher density, mirror ×1.7 thinner

(lower impact of the absorption / birefringence, better aspect ratio)

Issues highlighted by KAGRA

(relative) high optical absorption - not uniform

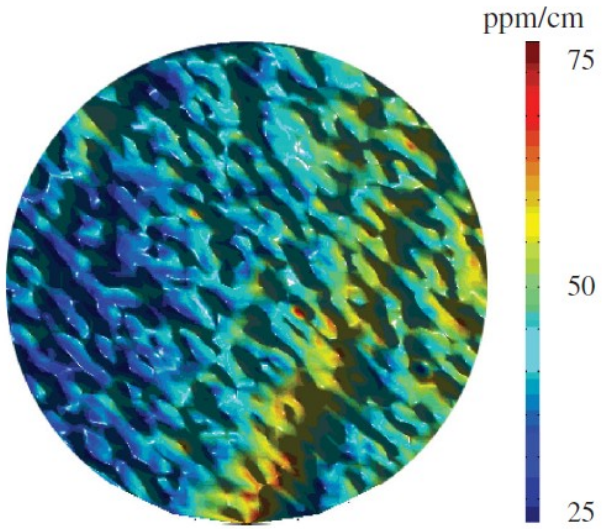

FIG. 7 (color). Absorption of 100 mm sapphire substrate in ppm/cm. The aperture size is 50 mm and the interaction point is 2 mm from the surface. There is a line where absorption is higher than the other regions.

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Presence of birefringence in transmission

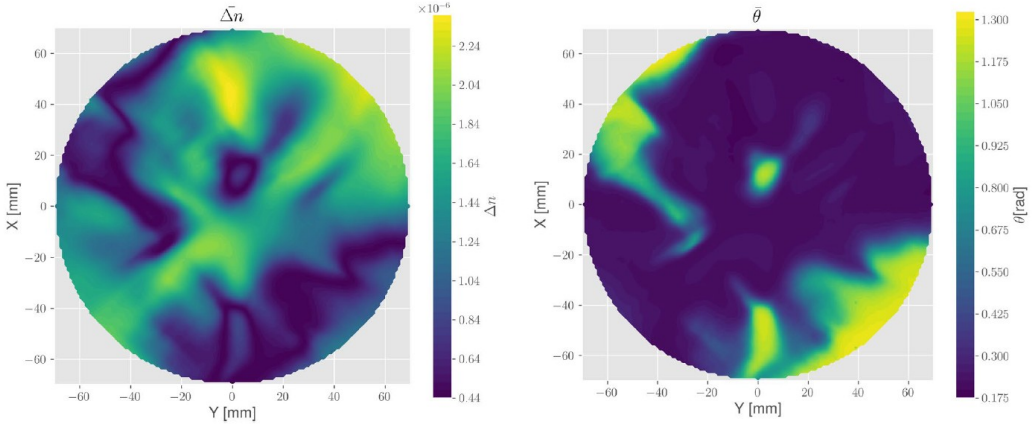


Figure 4. Mean distribution of both birefringence Δn and θ-angle, calculated from the six input-polarization combinations which led to no miscalculations.

doi

II
Strong support in Lyon for sapphire

Local and regional situation

- on the campus of Lyon I
  - specialist of sapphire at iLM
  - expert in growth
  - LMA characterization benches

Monocrystalline fibers and ribbons

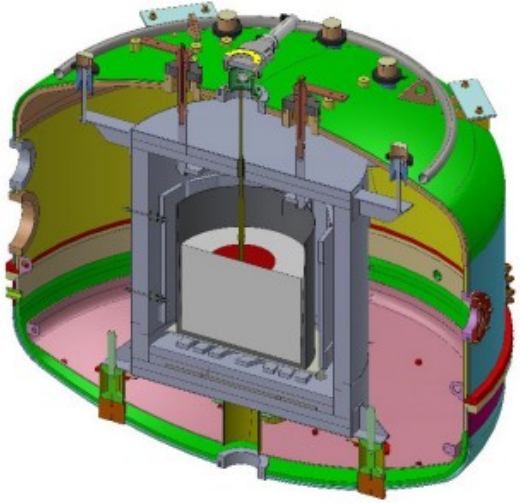
- a regional eco-system
  - RSA le rubis (~ Grenoble)
  - plateform Crystal Innov (~ Chambéry)
  - and equipment manufacturers

Several fundings obtained

Projet	Date	Financeur	Porteur *Partenaires*	Objectifs
OSAG	2019 - 2022	Idex	iLM (G. Cagnoli) *LMA*	Achat four de croissance et banc de caractérisation optique au LMA
UIA	2019 - 2022	Région	Polygon Physics *LMA*	Démonstration de polissage ionique sur saphir
DOSFaP	2020 - 2025	Région	LMA (J. Degallaix) *iLM*	Thèse iLM-LMA pour la réduction des pertes optiques dans le saphir
Veloce	2022	CPER	IP2I - LMA	Achat d'une machine de polissage compatible saphir
SEPO 450	2024 - 2027	Région	ECM Greentech *iLM, LMA*	Création de nouvelles offres (four, rodage, mesure de surface) par les équipementiers pour la production d'optiques en saphir

Results – a custom growth furnace

Scaled to grow sapphire of Ø 450 mm

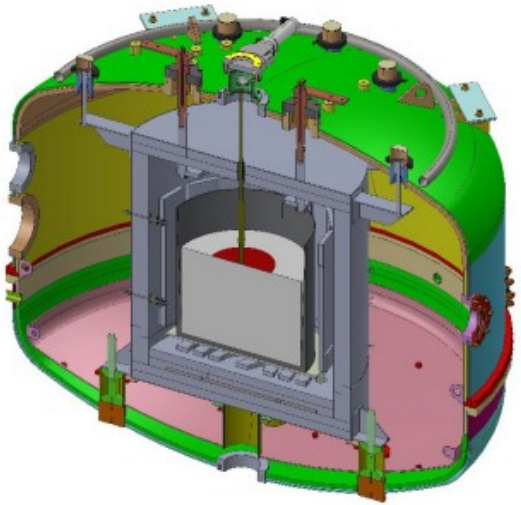


Inside and outside of the oven

- sapphire of Ø >300 mm already produced
- no obvious defect
- optical characterization once we managed to cut the boule

Results – a custom growth furnace

Scaled to grow sapphire of Ø 450 mm



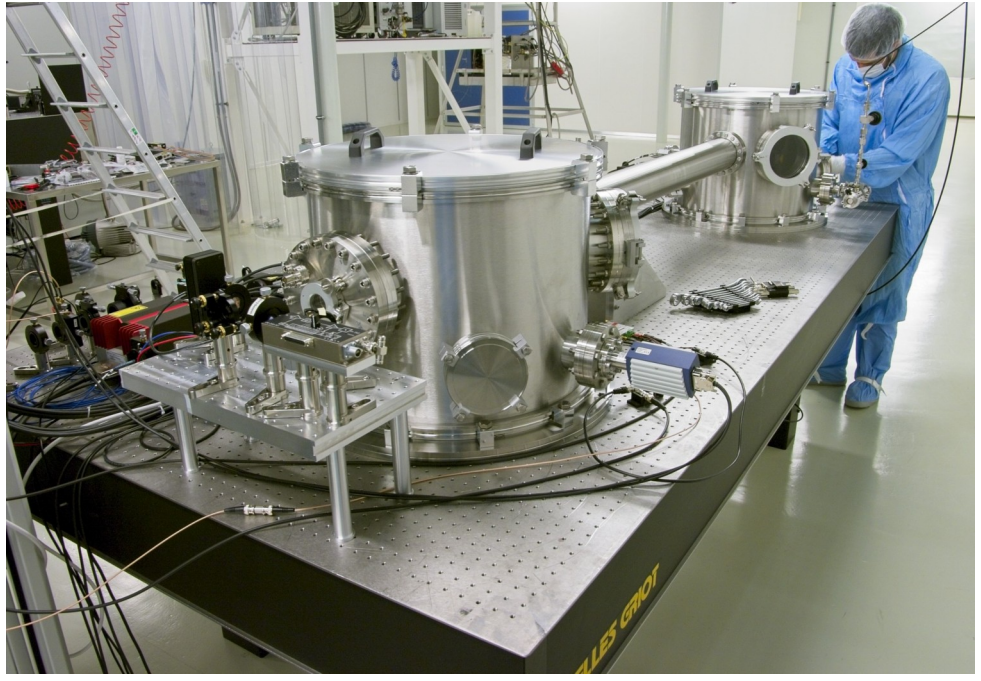
Inside and outside of the oven

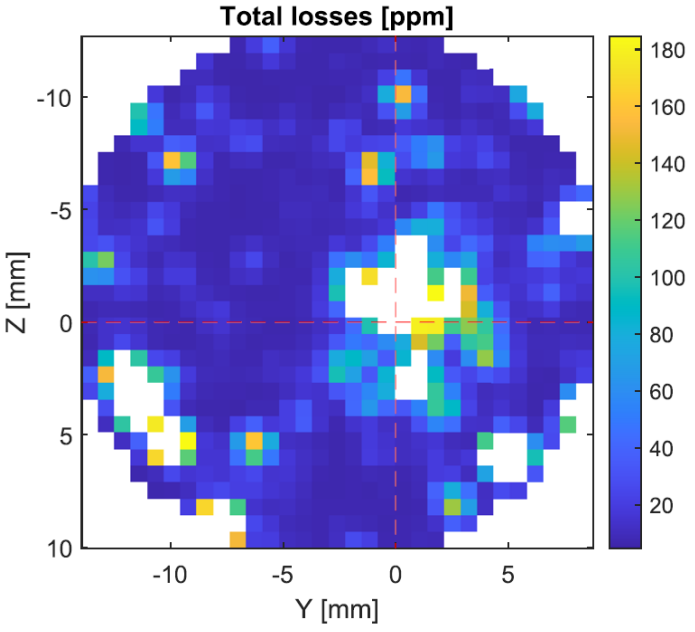
∅ 230 mm, 40 kg

Also Ti-doped sapphire

Results – optical loss

Demonstration of very low (optical loss) sapphire mirrors in a cavity (F ~ 250 000)





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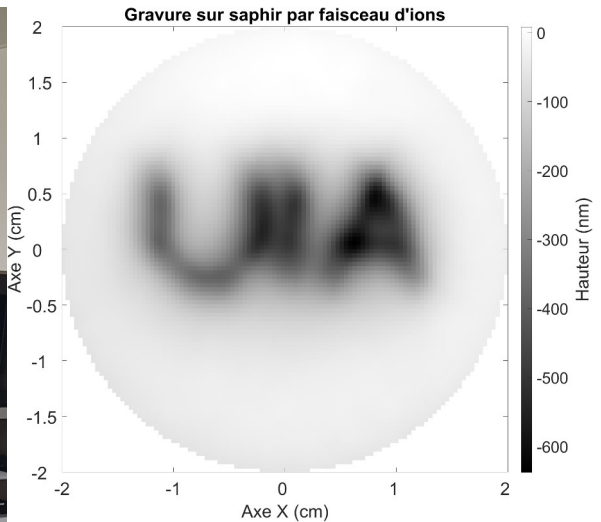
Optical loss inside the cavity while the position of the end mirror is scanned

Results – ion beam figuring

Refurbished an old vacuum tank

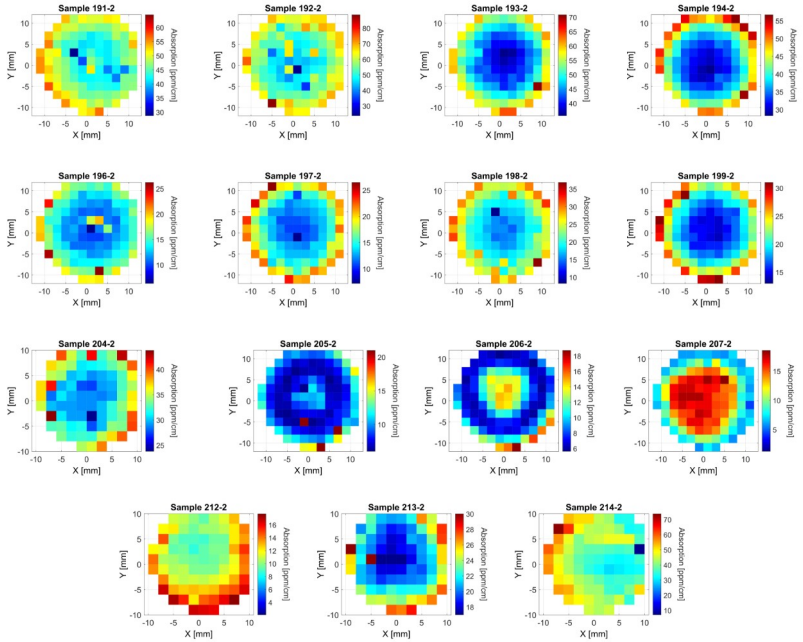


Engraving test on sapphire

- demonstration done
  (nothing new)
- asking for funding for a commercial machine

Results – optical absorption

Growth of around ~ 20 sapphire samples of Ø 30 mm with different growth parameters



Absorption mapping

- absorption under control (< 15 ppm/ cm)
- validate the raw materials
- birefringence too high but not the focus of this work

(under study how to reduce it)

Results – optical absorption

From the journal:
CrystEngComm

Enabling cryogenic gravitational wave detectors: growth of sapphire crystals with record low absorption in the near infrared

Check for updates

T. Aventin,[a] A. Nehari,[a] D. Forest,[b] J. Degallaix,[b] C. Dujardin,[a] G. Cagnoli[a] and K. Lebbou[a]

Author affiliations

doi

III
The short term

What we already know to do….

Crystal growth

Coating

The logical follow up to build a mirror

Mirror =

Crystal growth

+

Polishing

+

Coating

Require one new equipment

Raw glass → Cutting → Chamfering edges → Grinding → Polishing → Cleaning → Inspection

More difficult than expected to outsource

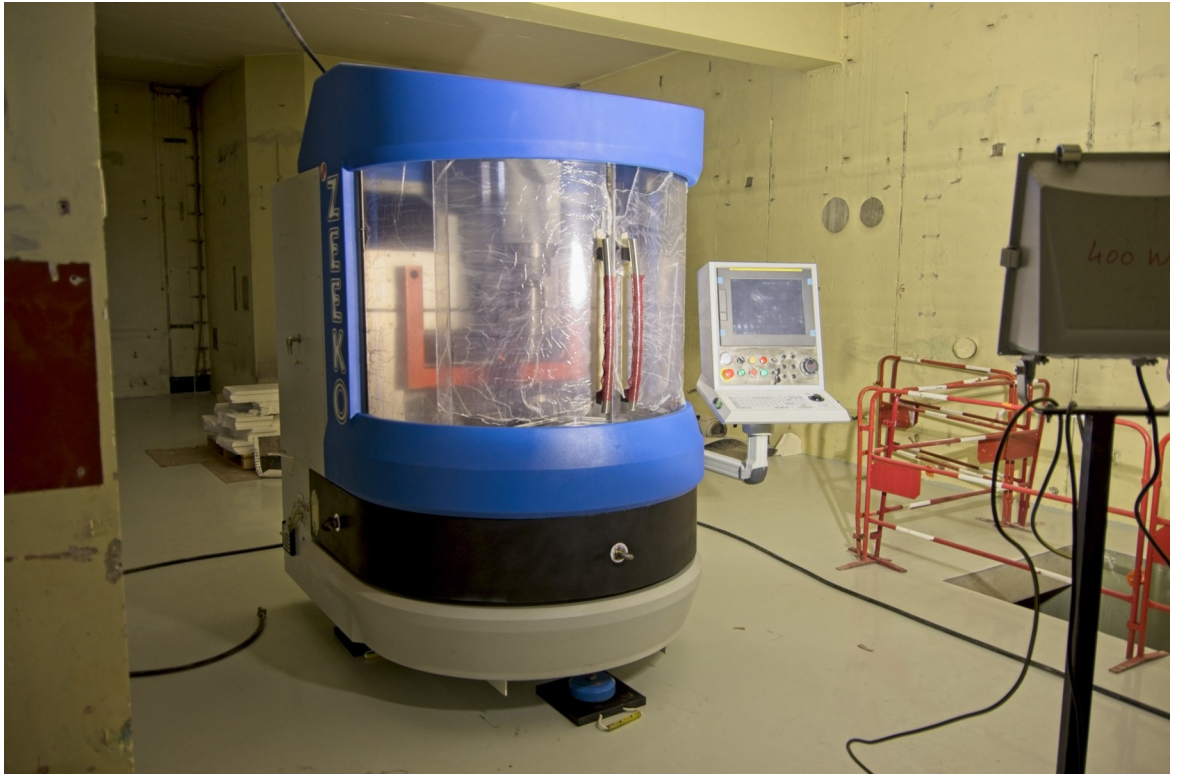
- mechanical polishing

(just delivered)

- ion beam figuring (need to acquire a new large machine)

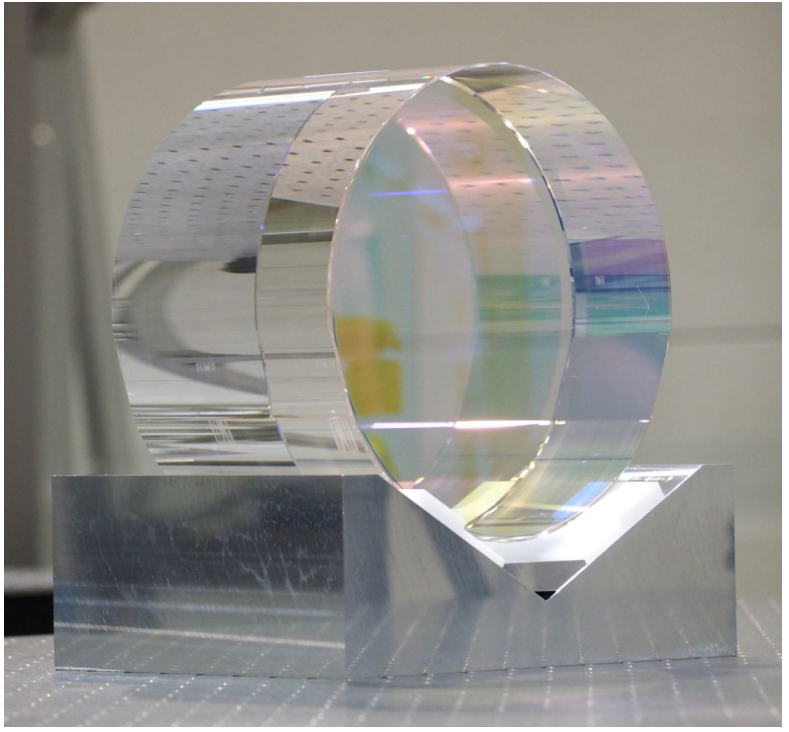
The new polishing machine

- for substrates up to Ø 400 mm, 50 kg
- process developed for sapphire (machine compatible other materials)



(in a temporary space in the lab in Lyon)

Ambition for the next 2-3 years



- find a way to do the cutting / polishing (develop internally or create collaboration)
- do a complete mirror in sapphire (Ø 300mm)
- if performance ok, propose it to KAGRA for an upgrade post O5

Conclusion

- New activities regarding the substrate development in Lyon, complementary to the coating work in LMA and iLM
- No competition at the global level to product large and very low optical loss sapphire
- First optical characterisation on large samples next year