Characterization of light scattering point defects in gravitational wave detector coating layers

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GWADW2021 Scattered light workshop

iP2i LYON

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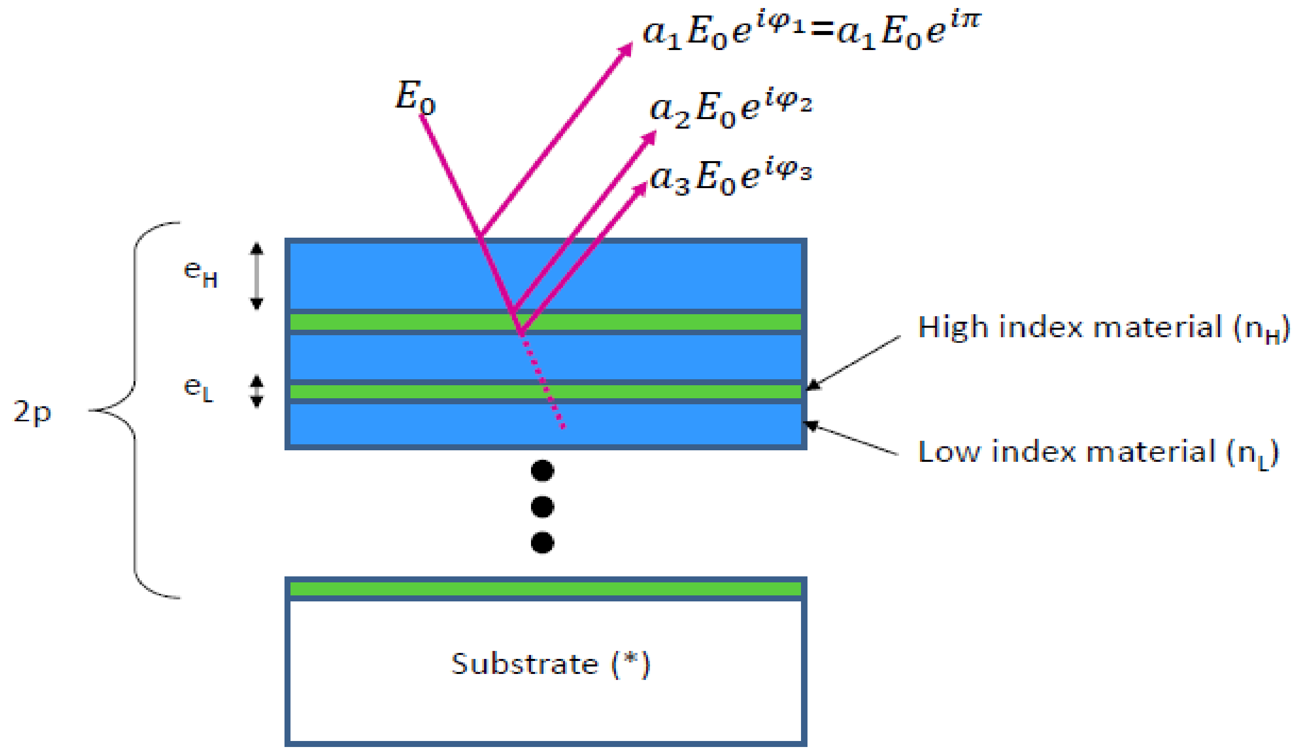
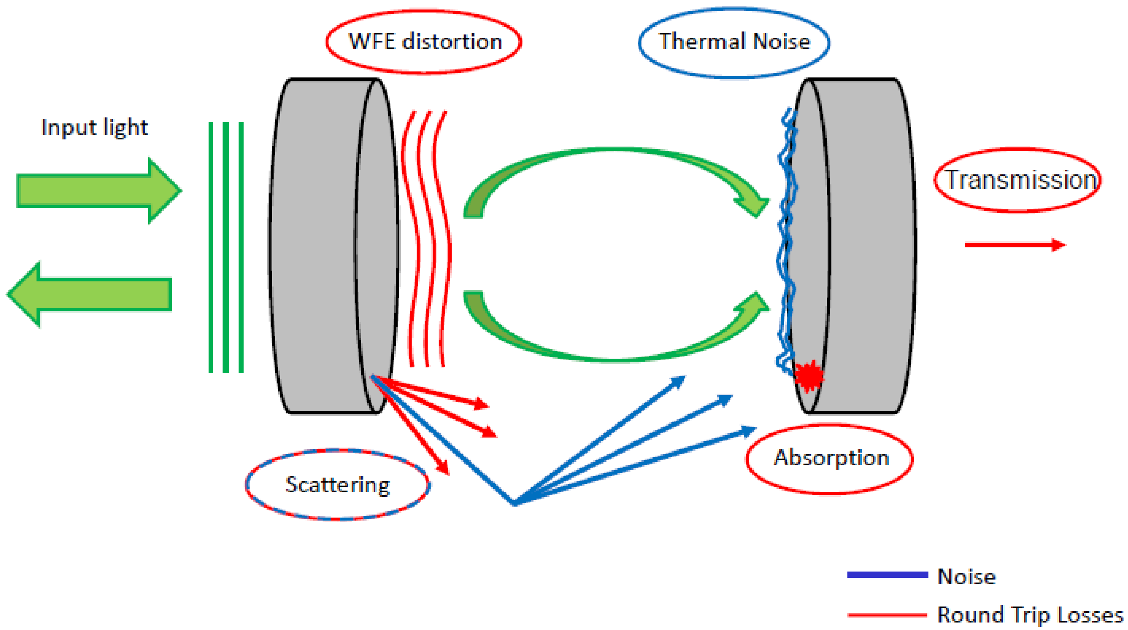
Mirror setup



Stack of thin films deposited by IBS :

- 2p layers
- 2 materials with different index of refraction n_H and n_L
- Constructive interferences in reflection
- Thicknesses of the layers $n_H\ e_H = n_H e_H = \frac{\lambda}{4}$; i.e Quarter Wave Layer (QWL)

The large mirrors of GW detectors



Major effects in mirror coating :

- Transmission of light through mirrors
- Absorption in the thin films
- Light scattering by the imperfections of the mirror.
  - The polishing of the substrate which adds defects
  - Point defects in the thin films due to the deposition technique.

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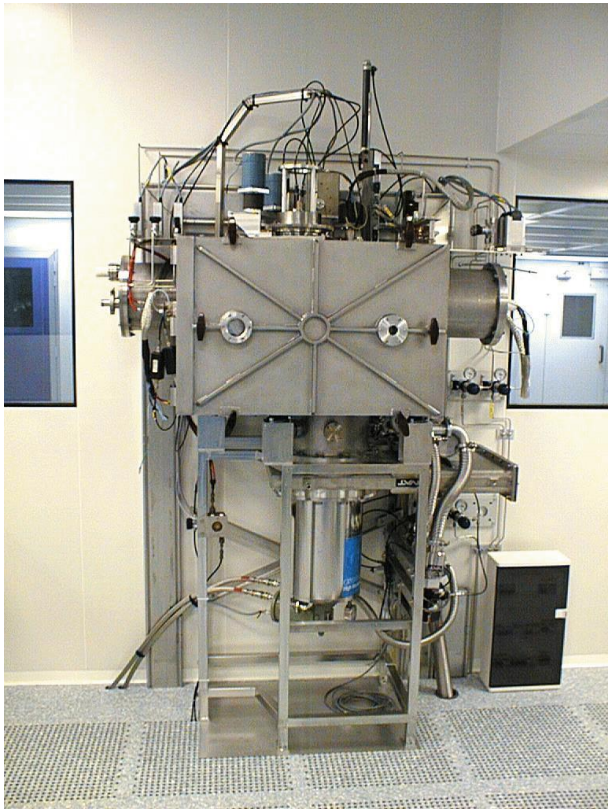
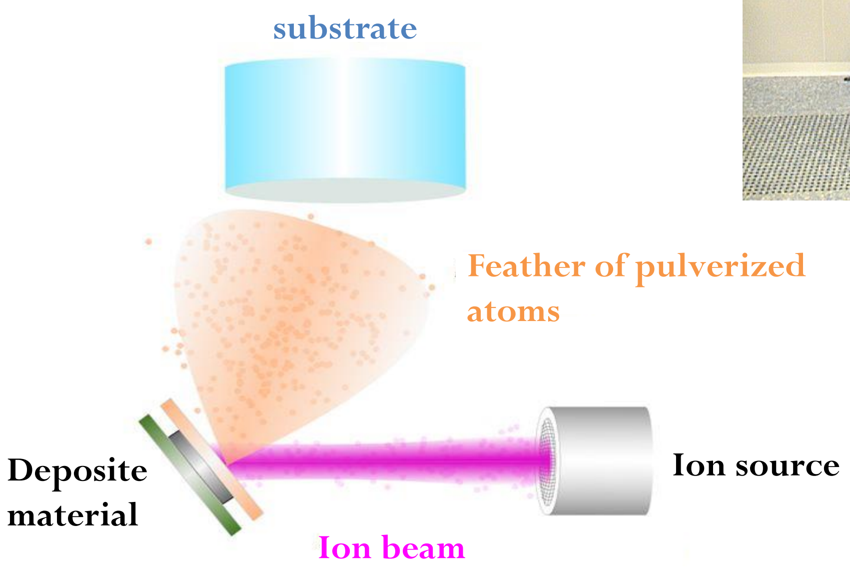
SAMPLE & EXPERIMENTAL PROCEDURE

Set up

For the study :

- Coating deposition using Ion Beam Sputtering (IBS) technique
- Micropolished fused silica substrate of 1" with low defect density ≈ 0,04 defects/mm² and defect size < nanometers
- RMS roughness smaller than 1 Å
- Materials: Tantala and silica





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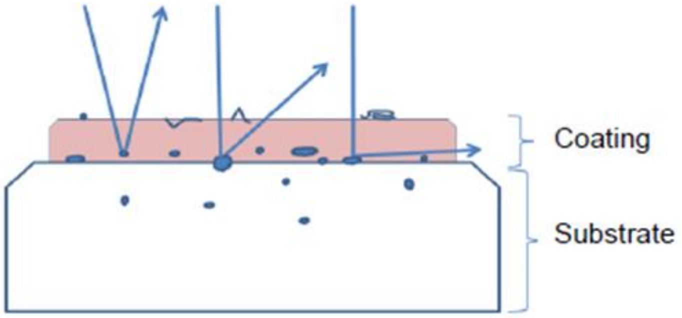
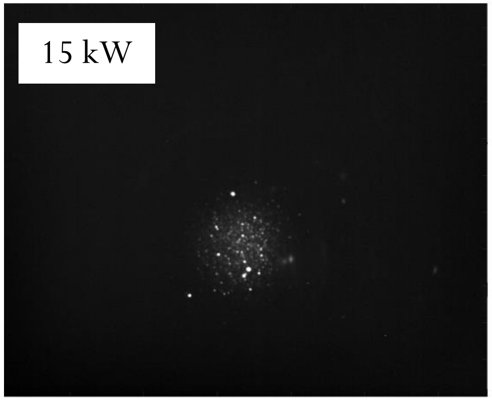
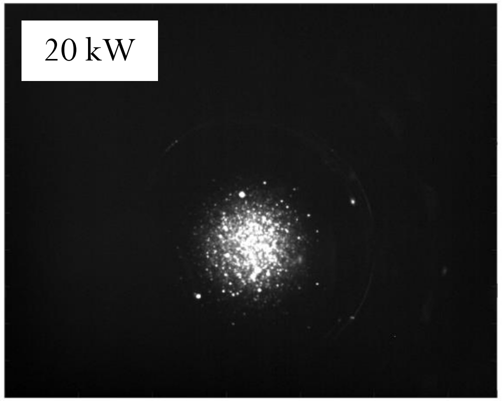
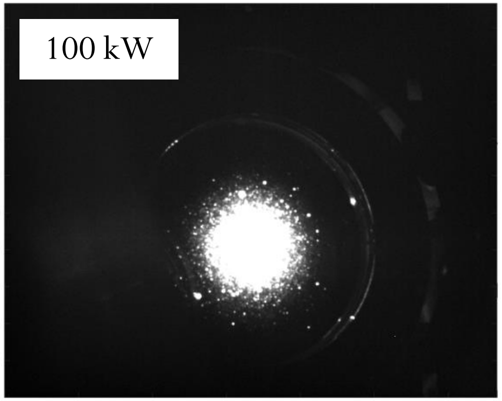
Point defects

- Some point-like defects present inside the coating
- Know since several years
- Limiting factor for future detectors
- Can be the origin of the extra-loss observed in Advanced LIGO and Advanced Virgo









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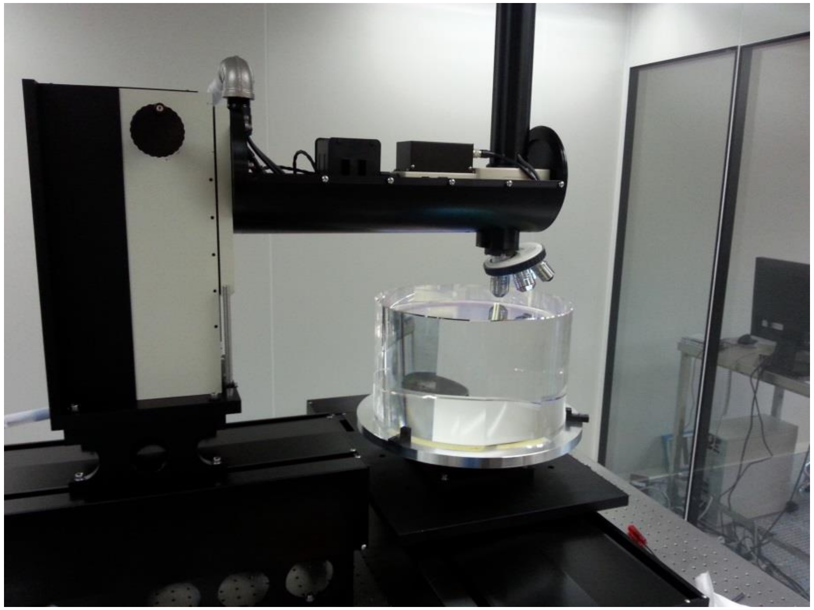
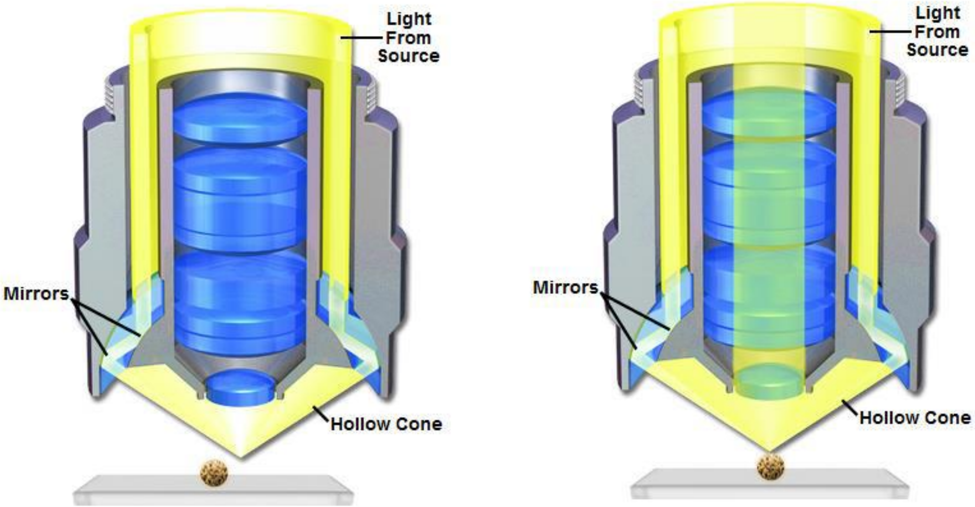
Defects detection : instrument

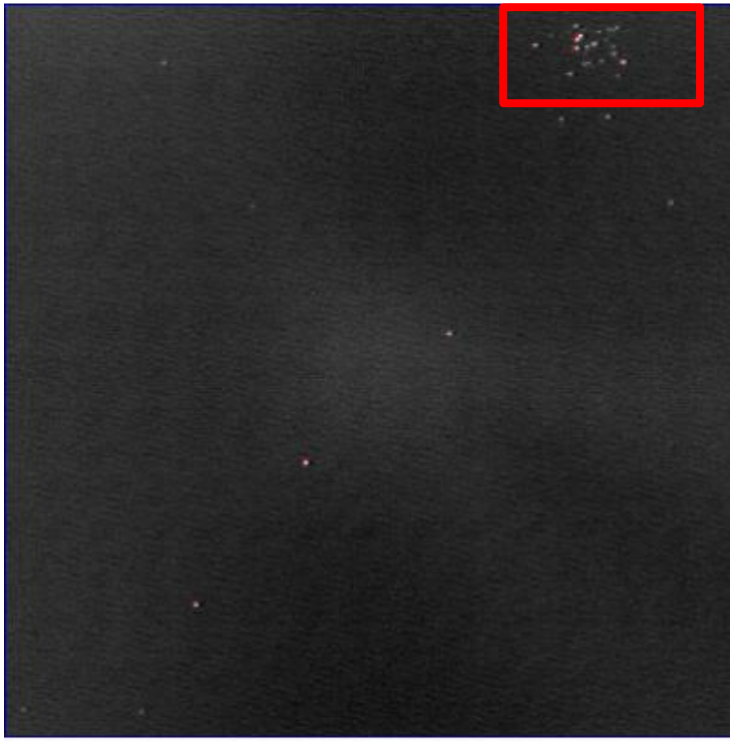
Detection defects done with the profilometer

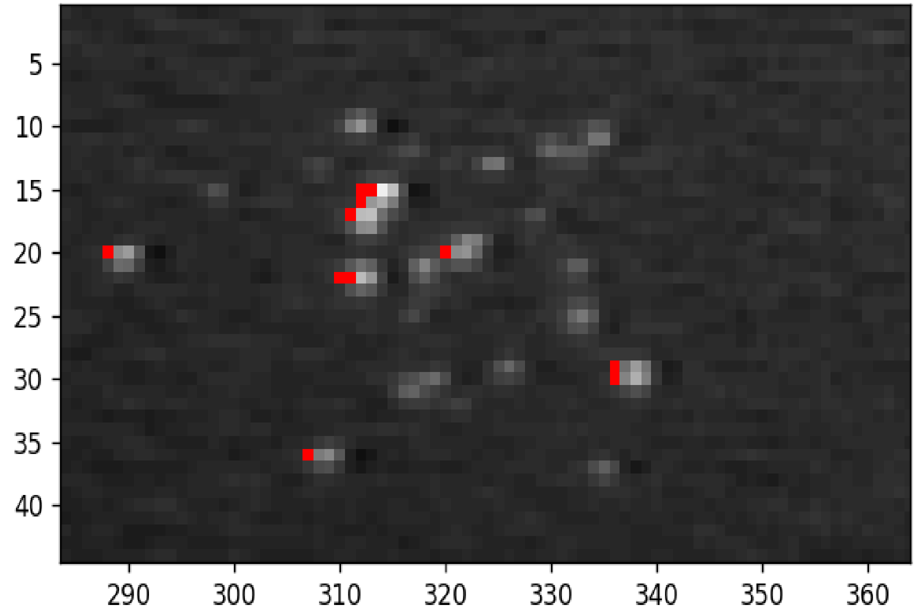
- Using dark-field
- 256 grey levels
- Mapping large surface, by squares of 513x513 μm^2
- Ø 18 mm on 1” sample

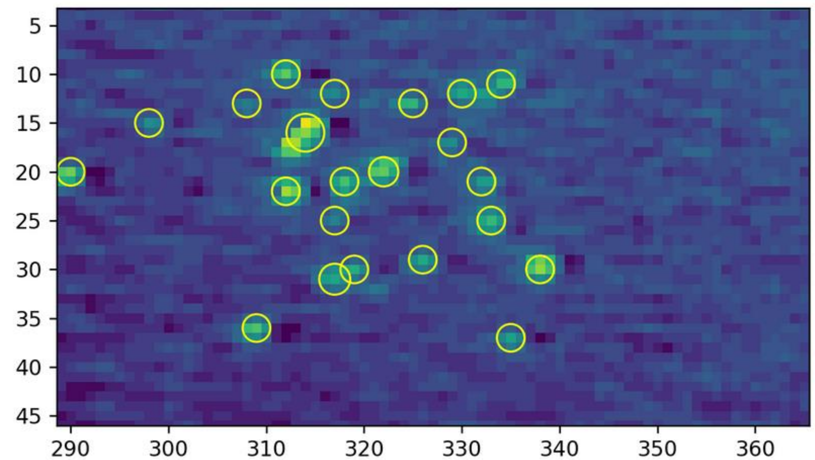




Crédits Olympus







<u>Offline image processing</u>

- Laplacian of Gaussian algorithm (scikit-image)
- Determines the number and size of defects

Van Der Walt et al., Scikit-image: imageprocessing in Python, PeerJ, 2:e453, (2014)

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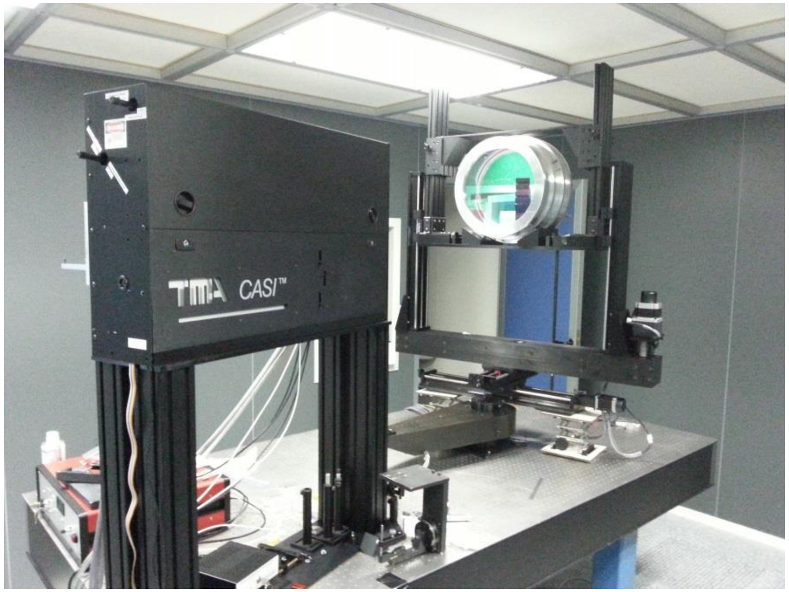
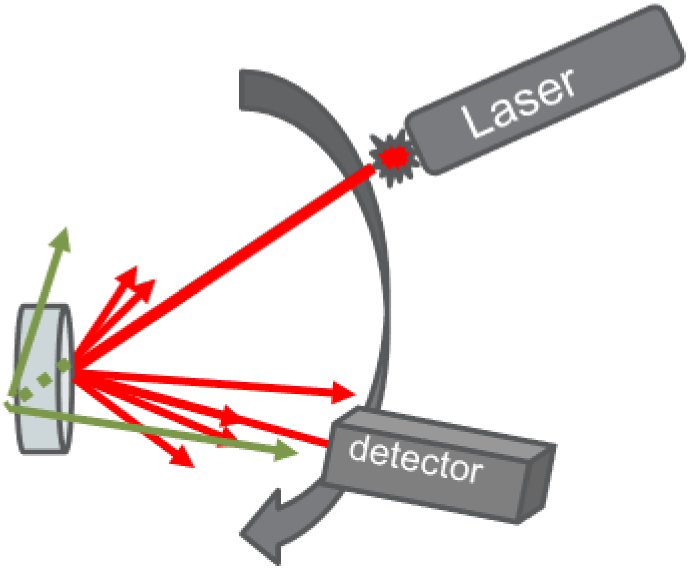
Optical Scattering



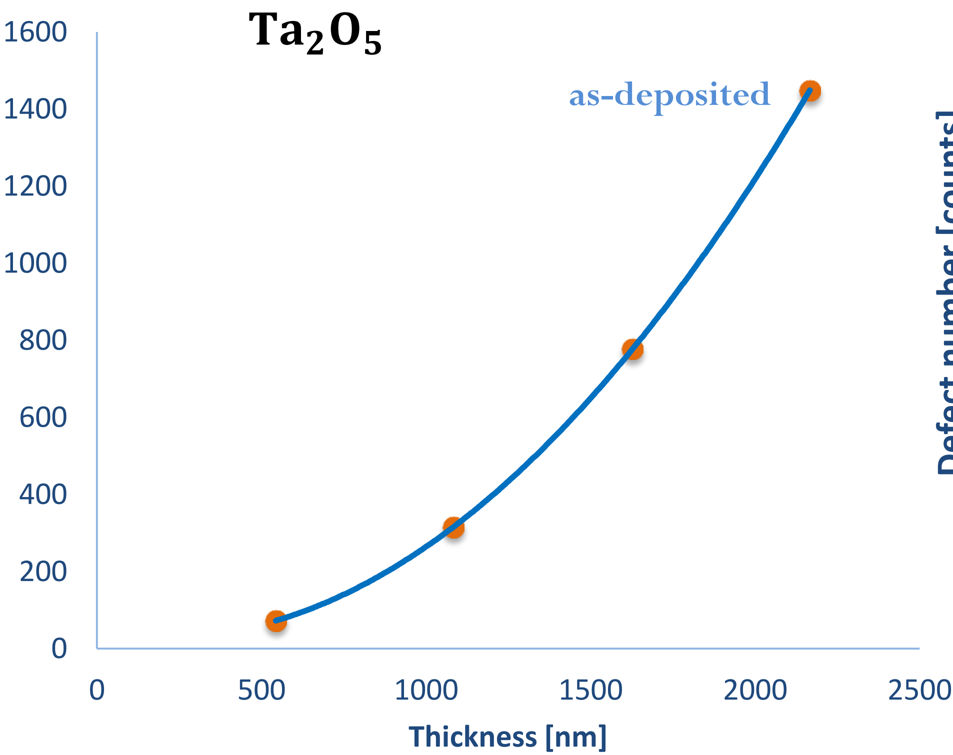


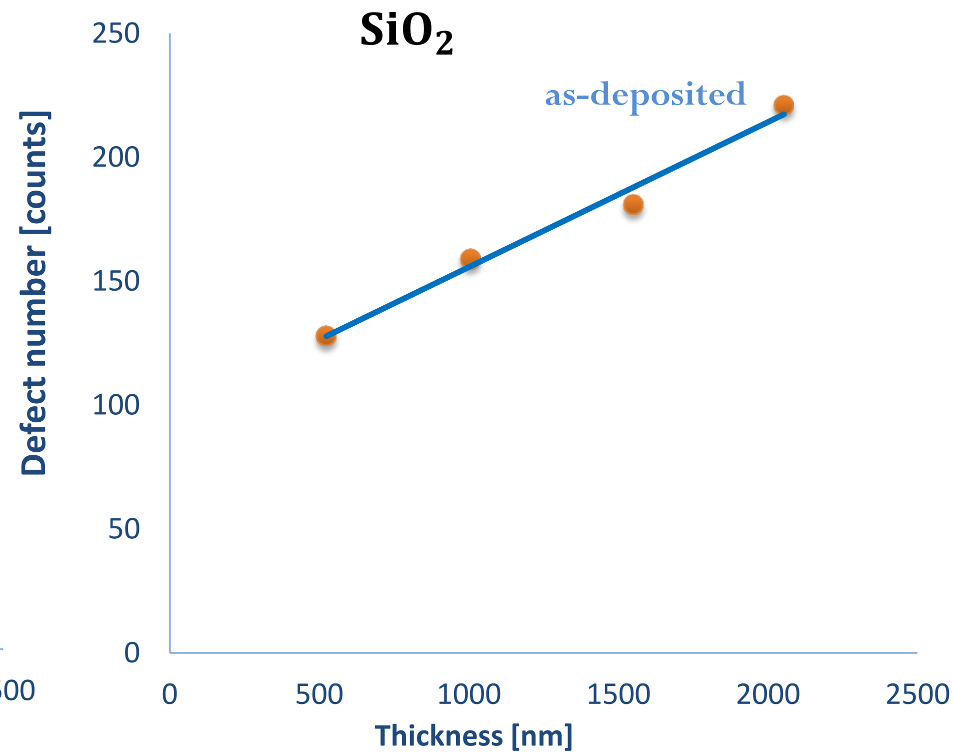
Scattering measurement done with a CASI (Complete Angle Scan Instrument) :

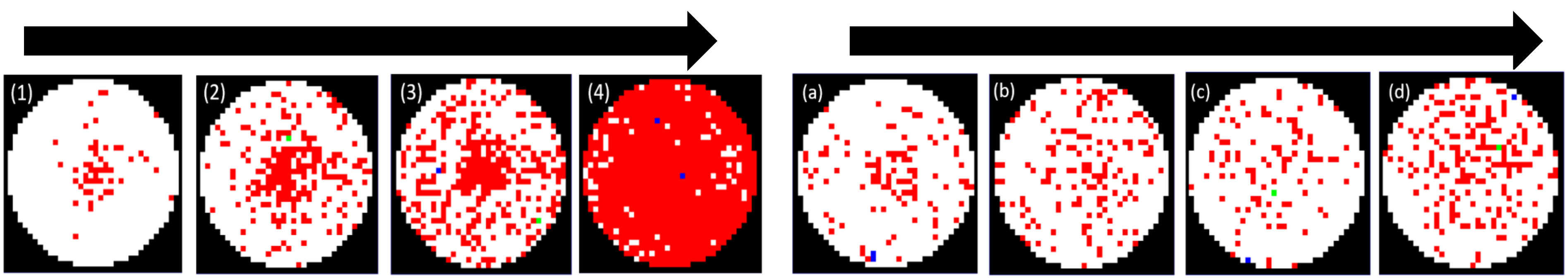
- Measurement of the BRDF
- Measurement of the reflection
- Specular transmission measurement
- $\lambda = 1064$ nm (as in the interferometer)
- Ø 16 mm of 1” sample

RESULTS

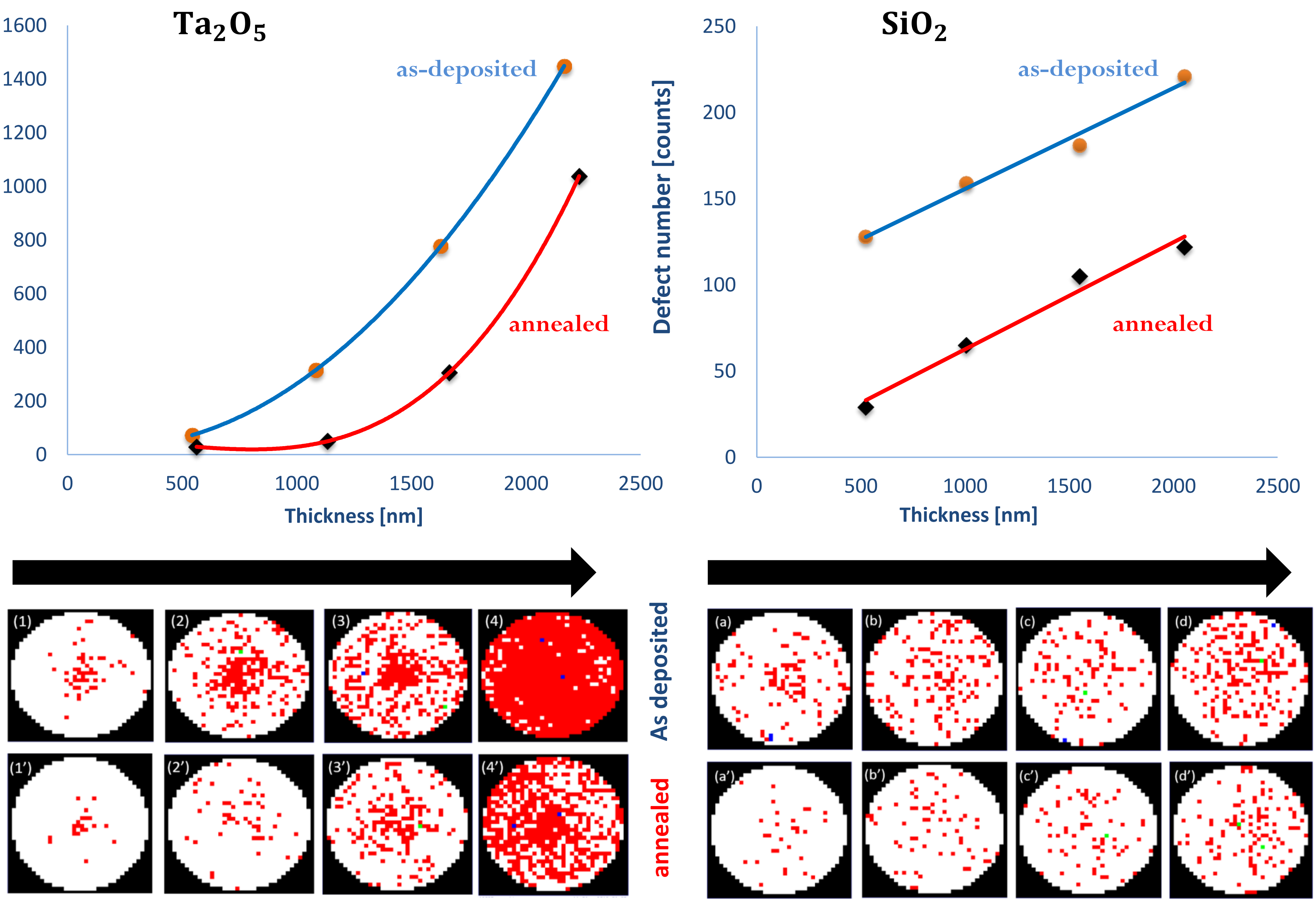
Optical Scattering





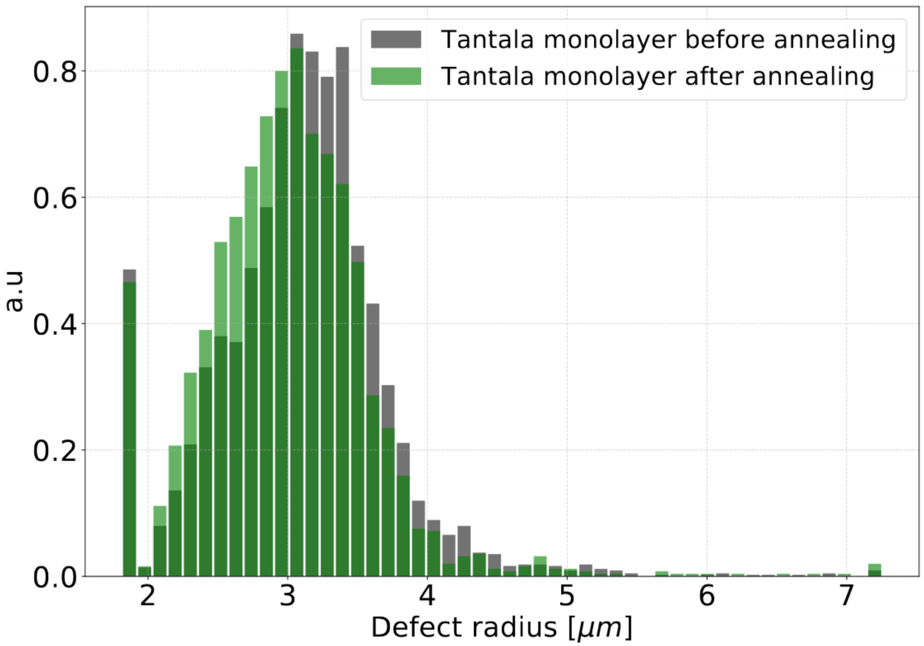


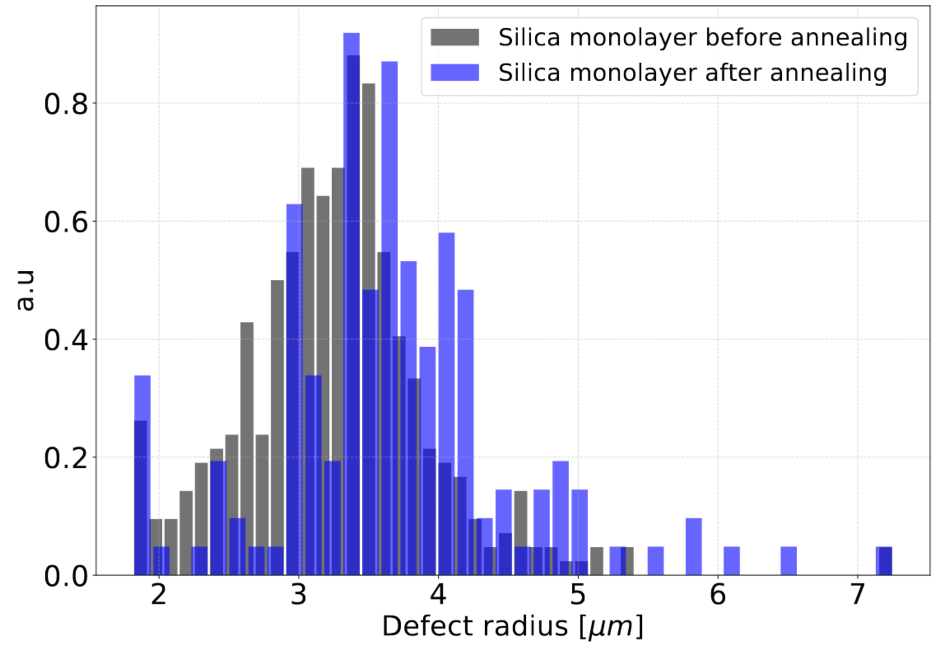
Defect density



Size of the defect

Study carried out with Ta2O5 and SiO2 monolayers for different thicknesses





- More defects inside the Ta2O5 than SiO2
- Median size defect ≈ 3 µm
- Post deposition annealing cure the defects (also observed by LIGO G2000374-v2)

S.Sayah et al., Appl. Opt. **60**, 4068-4073 (2021) https://doi.org/10.1364/AO.415462

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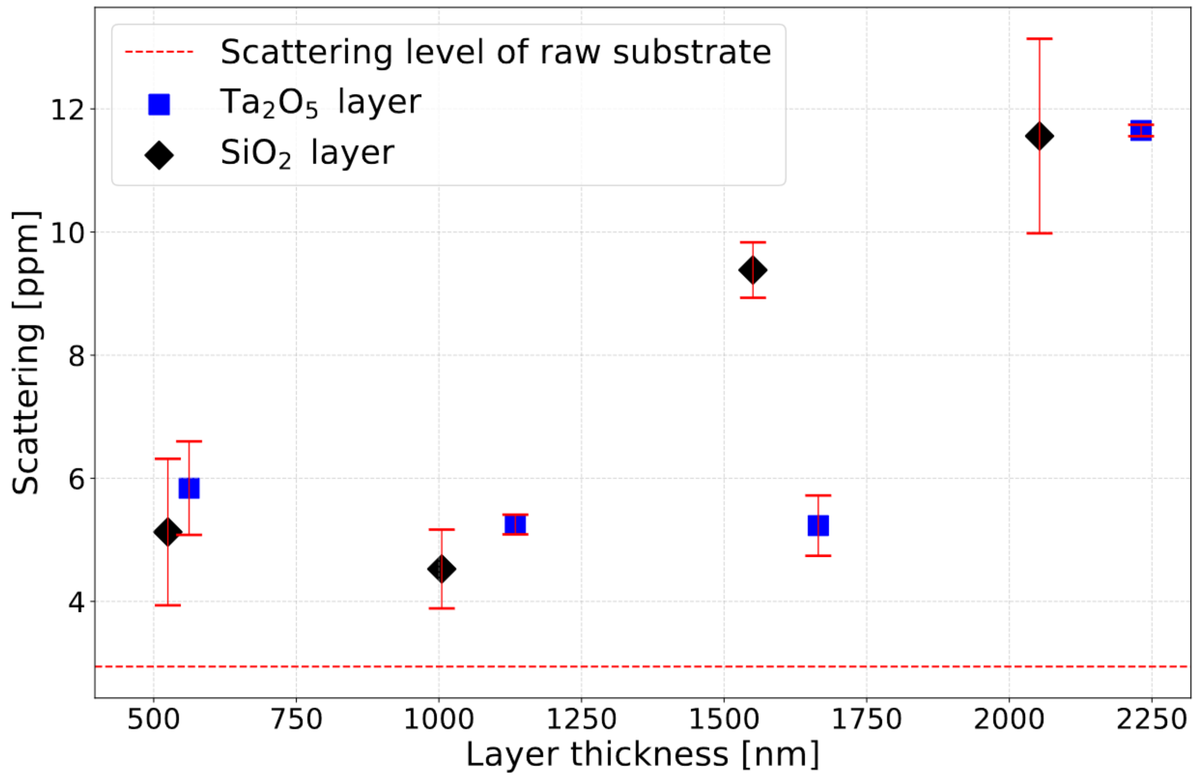
Optical scattering

Measured at 1064 nm



- Factor 10 on the number of defects between the thickest samples of silica and tantala but the scattered light is comparable.
- Scattering values suggest that the nature (size or optical properties) of the defects in silica scatters more than in tantala layers.

Conclusion

1. Development of a reliable image processing
2. We have more defect in tantala monolayers than silica monolayers (factor 10)
3. The defect density is dependant to the layer thickness
4. Annealing reduces by factor 2 the defect density
5. The defect size median is about 3 μm for each materials
6. Working on scattered light simulation

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