COATING RESEARCH & DEVELOPMENT @ LMA

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in collaboration with:

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Outline

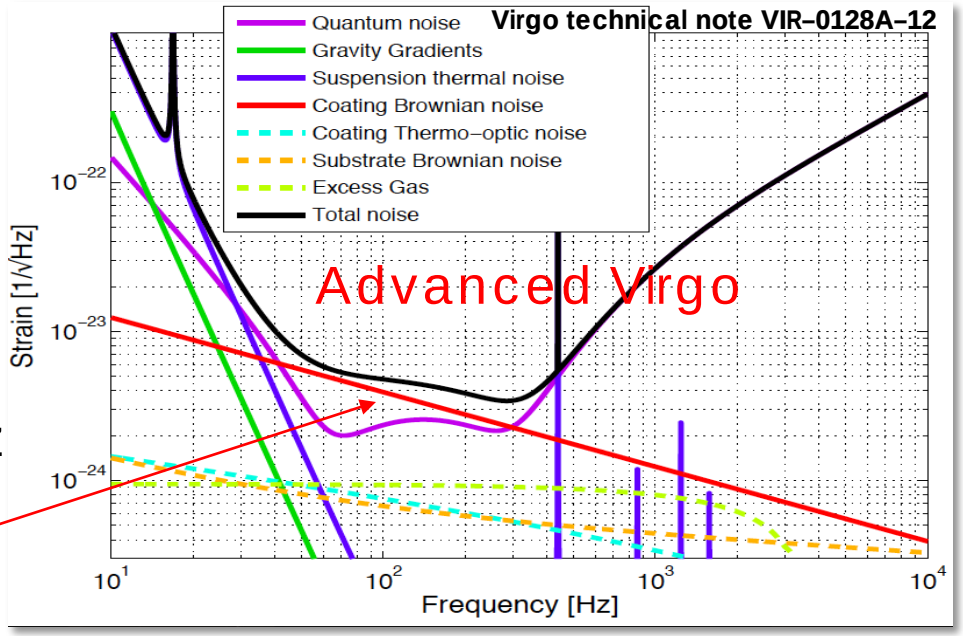
1. Investigation of Multilayer-Coating Loss
2. Updates on Atomic Layer Deposition

Investigation of Multilayer-Coating Loss

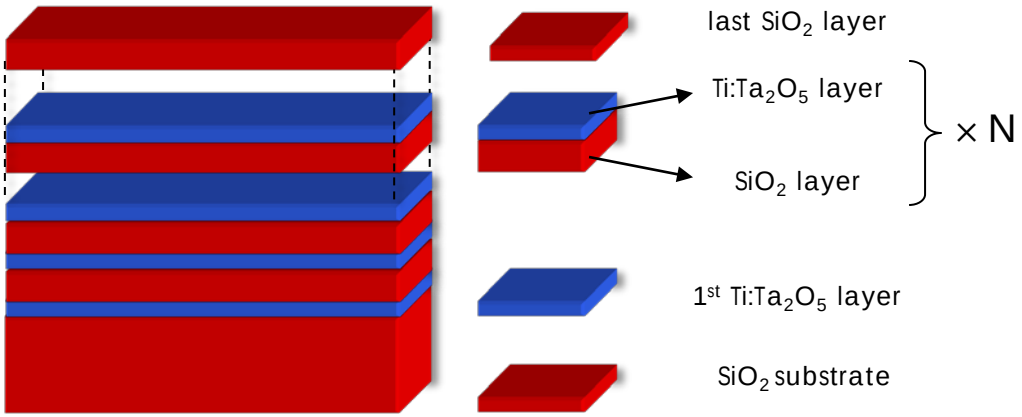
in collaboration with T. Epicier & B. Van de Moortèle, *CLYM*

Thermal Noise of Coatings

the sensitivity gravitational-wave interferometers of 2nd and 3rd generation will be limited by coating thermal noise around 10^2 Hz



coatings are multilayer stacks realized through Ion Beam Sputtering (IBS)



Ti:TaO_2O_5: HIGH (H) refractive index

SiO_2: LOW (L) refractive index

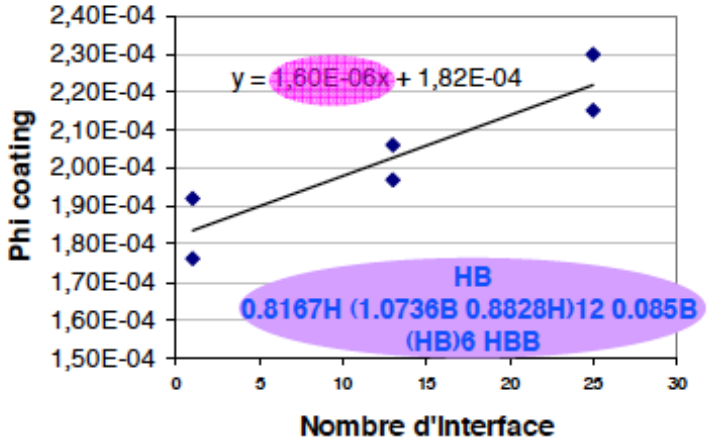
The Story So Far

- 1st c … tings
- new …]:
- cha…

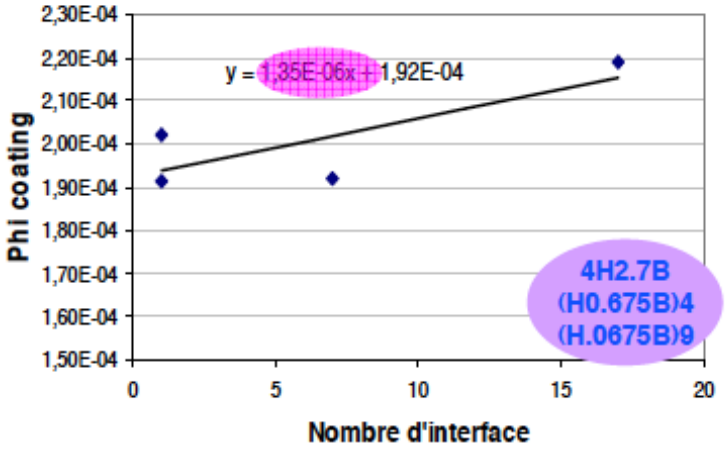
[*] LIGO tec…

Mechanical losses: multi-layers

- Dependence of coating multi-layers losses vs number of interfaces



Ratio Ti:Ta2O5/SiO2 ~ 0.6-0.7



Ratio Ti:Ta2O5/SiO2 ~ 1

- Estimate contribution to mechanical losses due to interfaces
- Deduce losses of Ti:Ta_2O_5 and SiO_2 from multi-layers
  - Ti:Ta_2O_5 ~ 2.4 ± 0.2 10^{-4} ; SiO_2 ~ 1.3 ± 0.4 10^{-4}
- Even if error is large, losses of silica remain significantly larger than what is measured on monolayers. Why?
  - Error in the measurement?
  - Silica behaving differently when stacked?

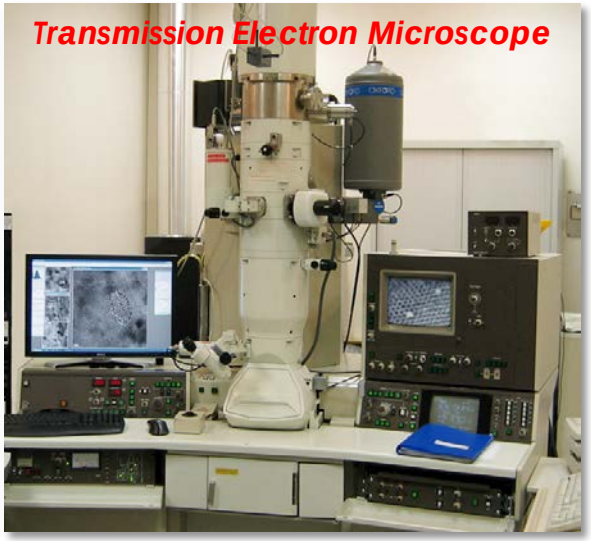
credits: R. Flaminio

Amaldi 9, Cardiff, 2011 6

Later Developments

physico-chemical characterization of SiO_2/Ti:Ta_2O_5 interfaces:

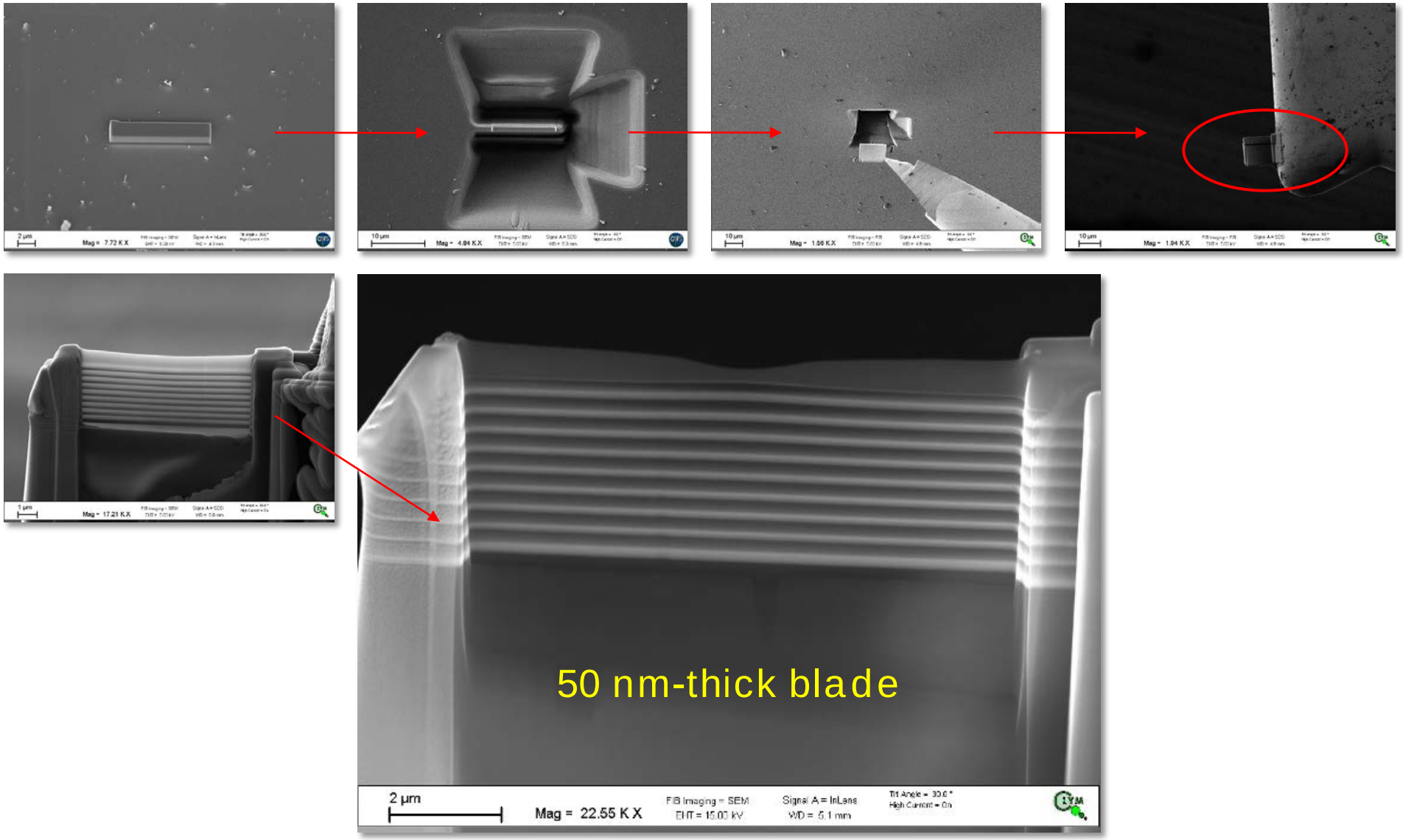
- sample: ITM-HR coating, 1.031H(1.3927L 0.5854H)8 1.199L [18 layers]
- Scanning/Transmission Electron Microscopy (SEM/TEM) @ CLYM: study at atomic scale



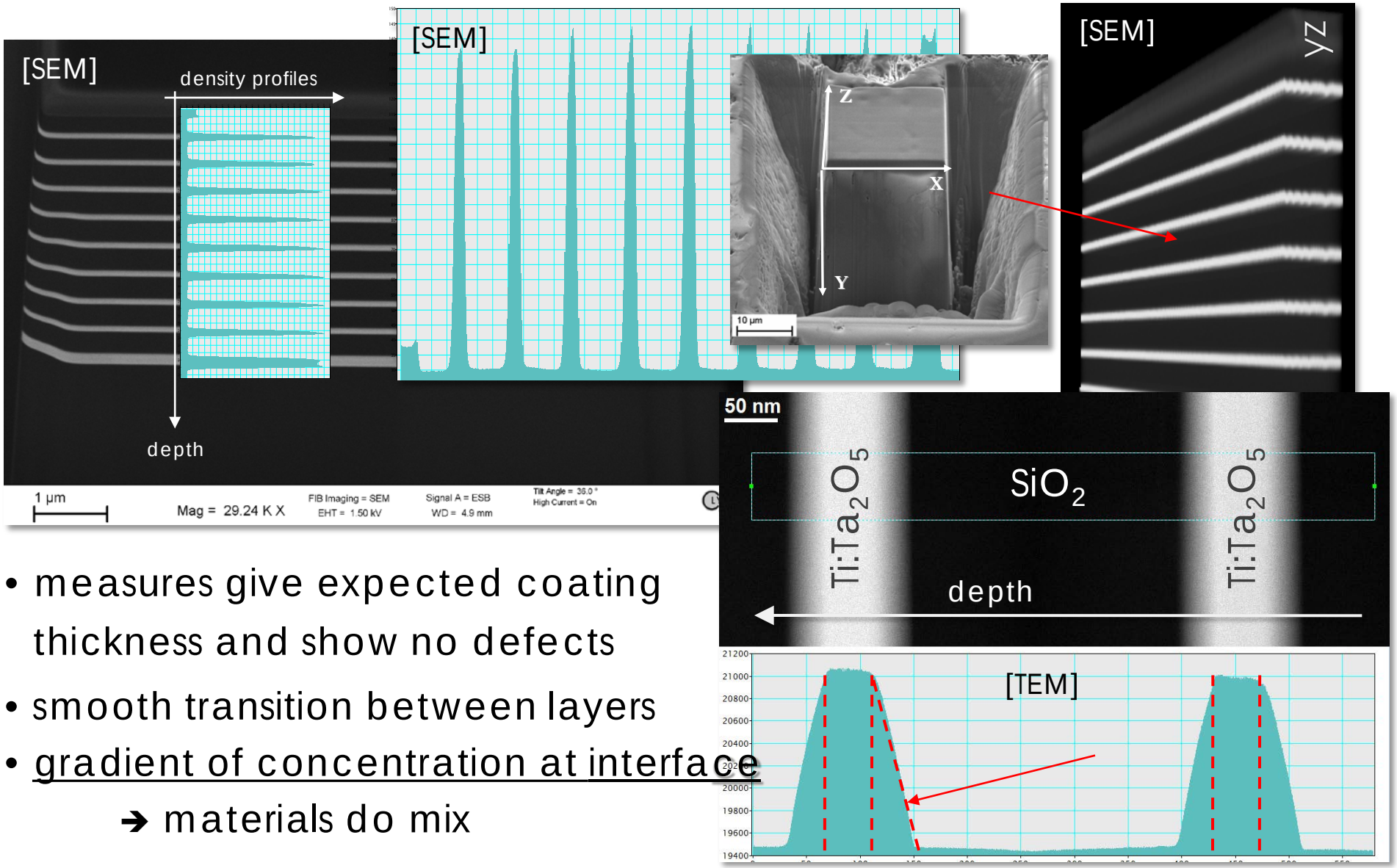
- ➢ imagery
- ➢ density profiles
- ➢ energy-dispersive X-ray analysis (EDX) ➔ atomic contentration

hypothesis: interdiffusion of materials?

Preparation of the Sample



Tomography & Density Profiles

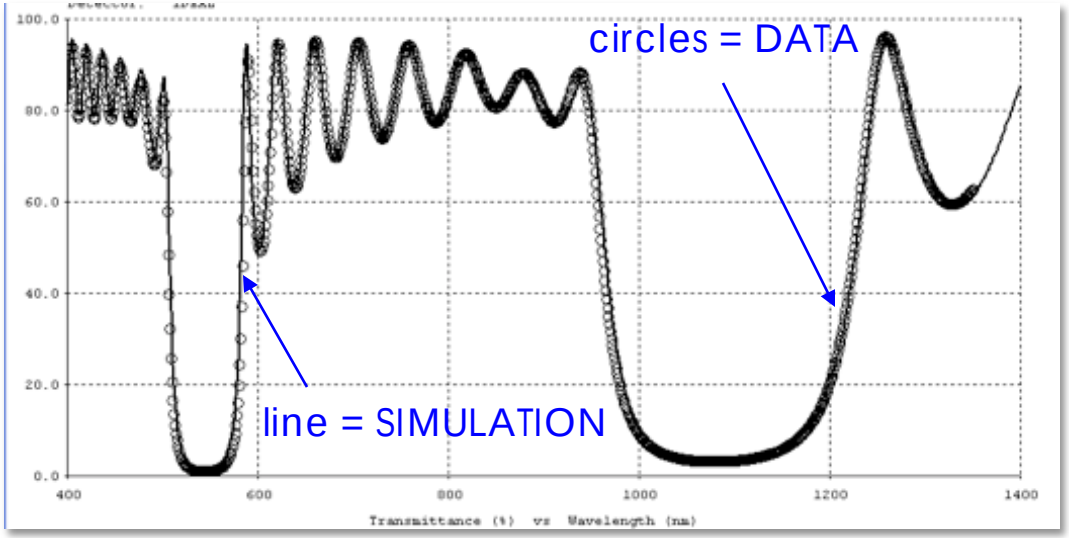


- measures give expected coating thickness and show no defects
- smooth transition between layers
- <u>gradient of concentration at interface</u>

  ➔ materials do mix

The Picture

- no cristalline phase observed in layers
- analyses reveal a mixing interface of 20 to 35 nm
- simulated optical spectra of multilayer coatings with mixed materials at interfaces are compatible with measures on 1" substrate
- optical simulations also show that gradients should be symmetric: Ti:Ta_2O_5 and SiO_2 diffuse into each other
- analyses of atomic concentrations are not conclusive ➔ new measures in progress



Mixed Materials

- could mixed interfaces explain exceeding loss?
- simple model of the interface: discrete gradient

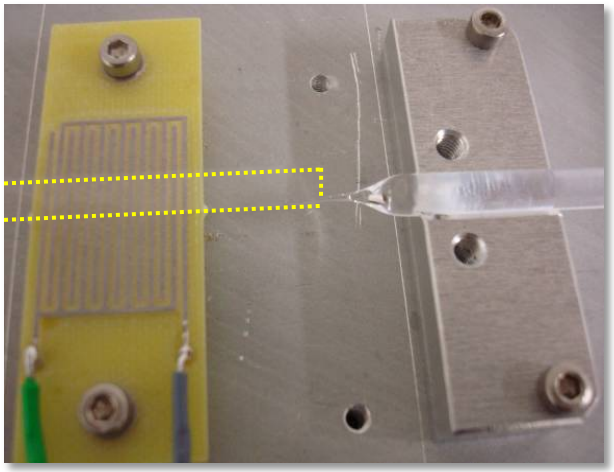
  mixed material 1 = 65% SiO_2 + 35% $Ti:Ta_2O_5$

  mixed material 2 = 65% $Ti:Ta_2O_5$ + 35% SiO_2
- coating of a SiO_2 blade with mixed material 1
- measure of loss of mix1:

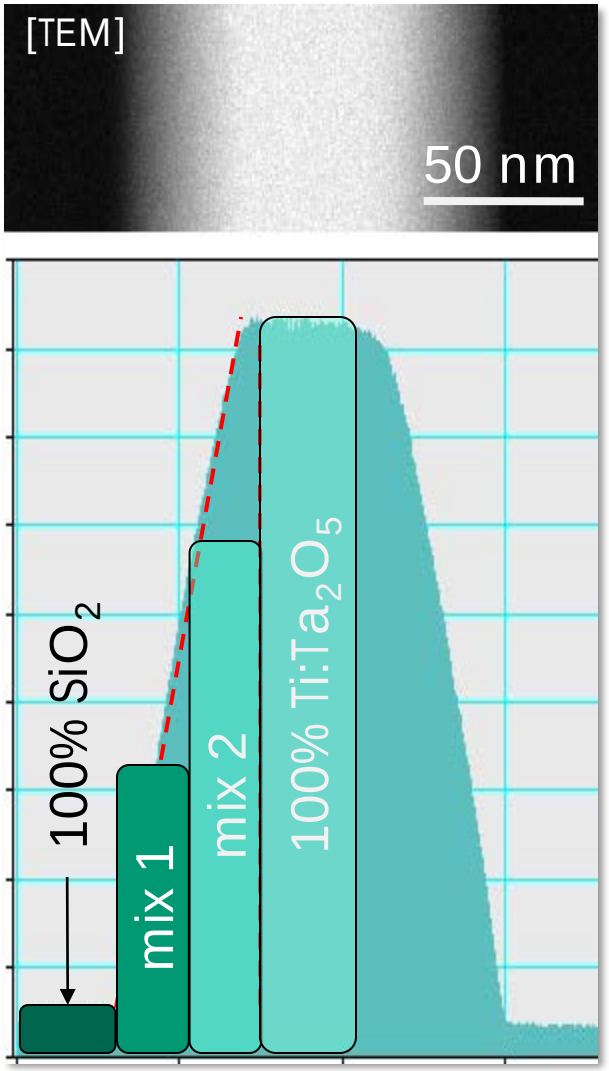
$\Phi_{mix1} = (2.7 +/- 0.2) \times 10^{-4}$

loss similar to $Ti:Ta_2O_5$

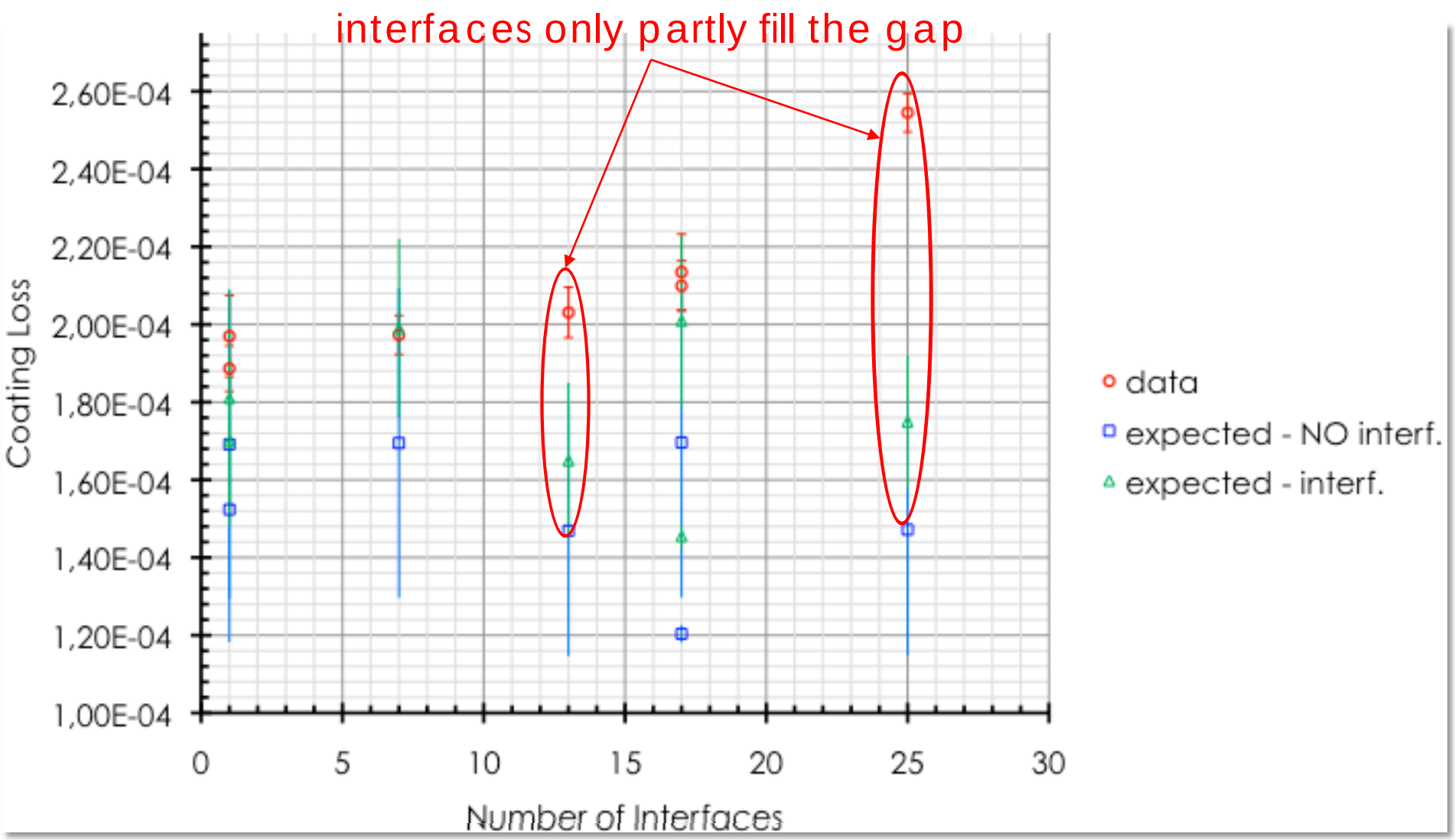
- to be done: deposit and measure mix 2



setup for ringdown technique



Interfaces – Results



Interfaces – Conclusions

- excess of mechanical loss is observed in multilayer coatings, depending on the number of interfaces between layers

- interfaces have been characterized
  - ➔ analyses revealed a mixing zone with gradients of atomic concentration

- loss of a mixed material (65% SiO_2 + 35% $Ti:Ta_2O_5$) has been measured
  - ➔ loss is similar to that of $Ti:Ta_2O_5$ …

- … but the presence of mixing interfaces only *partially* explains the exceeding loss [mixed material 2 has to be measured]

do we need a more complex model of the gradient?

Updates on Atomic Layer Deposition

in collaboration with E. Härkönen, M. Ritala & M. Leskelä *University of Helsinki*

Atomic Layer Deposition (ALD)

the idea:

investigation of new techniques to improve quality of coatings

➔ we want lower mechanical losses

↓

test of ALD realized @ University of Helsinki

advantages: ✓ self-limiting mechanism of film growth
✓ excellent coating uniformity - even on large areas
✓ homogeneous stoichiometry
✓ high reproducibility

➔ coatings of good quality factors[*] and optical properties

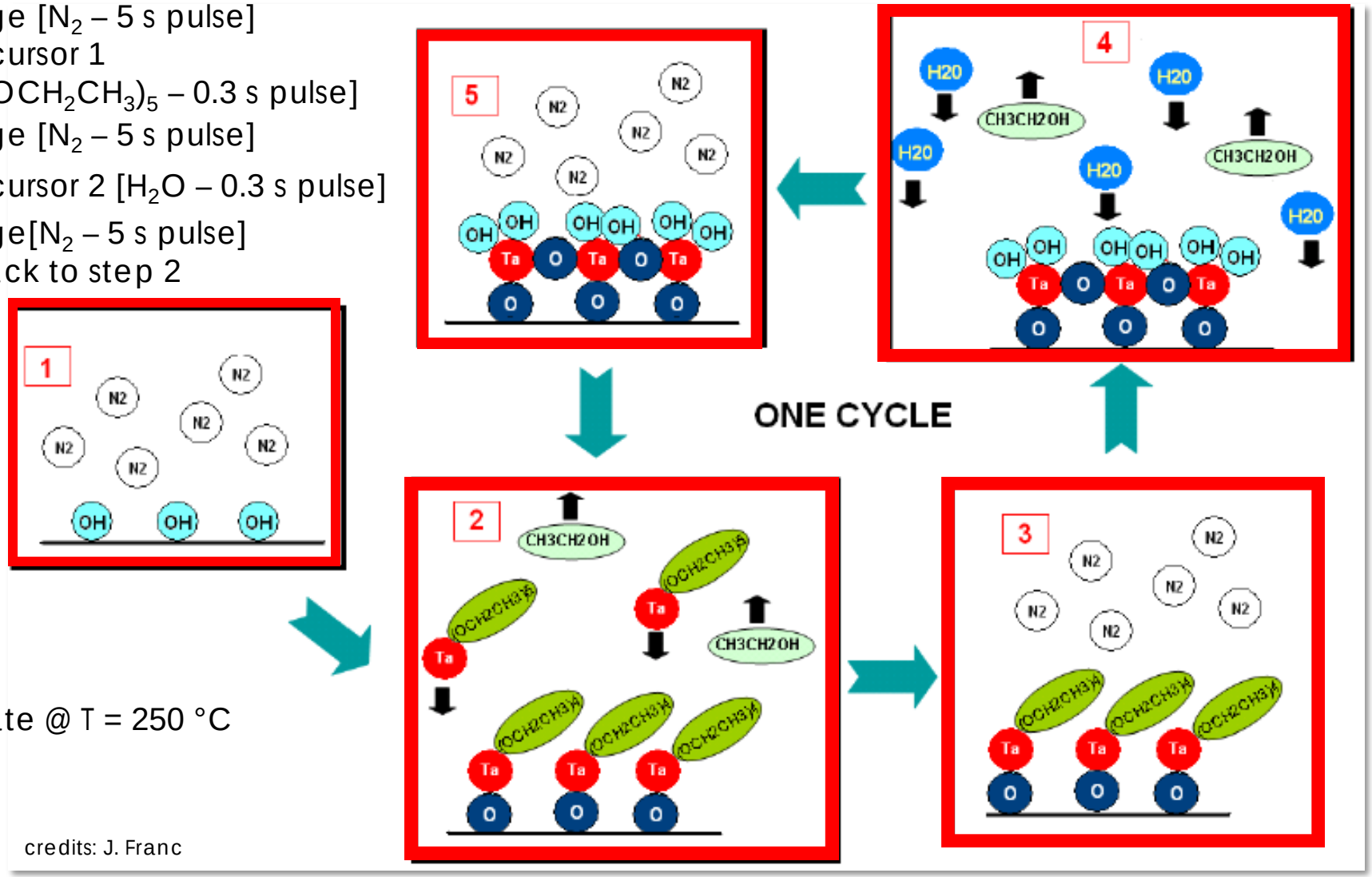
major concern: x low deposition rate

[*] **O Hahtela & al., *J. Micromech. Microeng.* 17, 2007**

Reminder

method based on alternate saturative surface reactions

1. purge [N_2 – 5 s pulse]
2. precursor 1 [$Ta(OCH_2CH_3)_5$ – 0.3 s pulse]
3. purge [N_2 – 5 s pulse]
4. precursor 2 [H_2O – 0.3 s pulse]
5. purge[N_2 – 5 s pulse]
   ➔ back to step 2

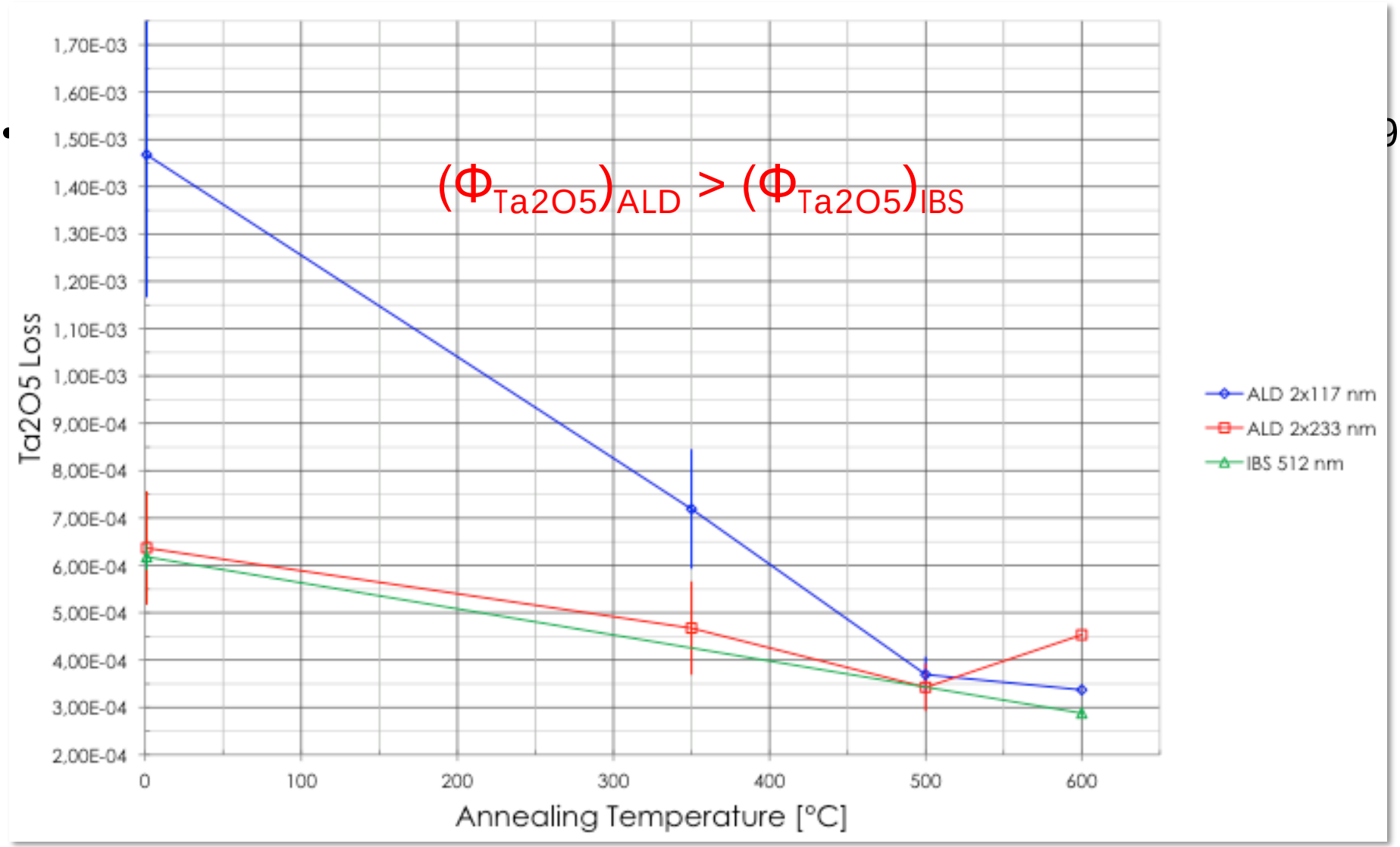


substrate @ T = 250 °C

credits: J. Franc

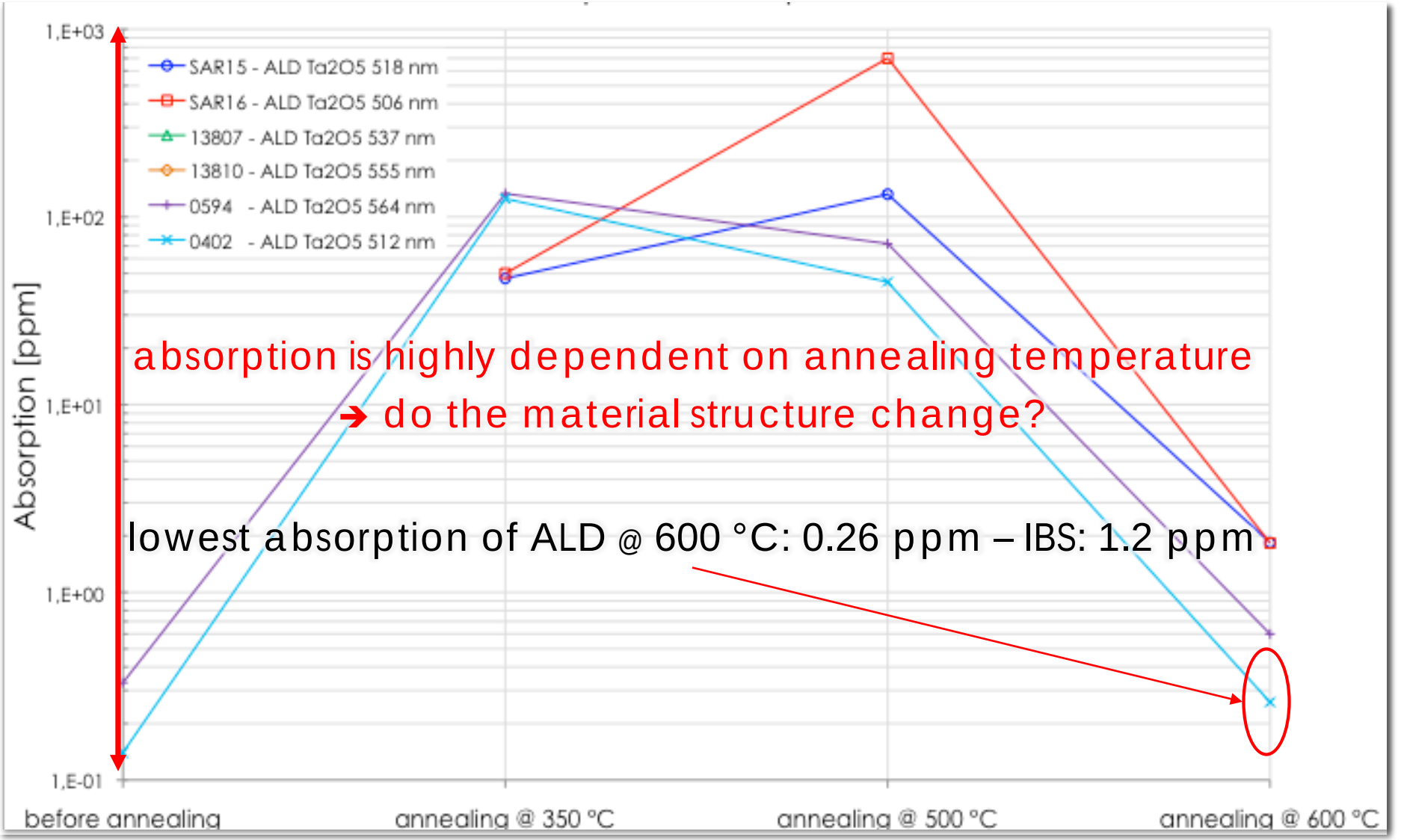
ALD – Results

monolayer coatings of undoped Ta_2O_5 on SiO_2 cantilever blades



ALD – Results

monolayer coatings of undoped Ta_2O_5 on 6 SiO_2 substrates of 1"



ALD – Conclusions

✓ ALD is a well-estabilished technique to realize high-quality coatings

x deposition rate is low

x mechanical losses of ALD coatings are larger

➔ no specific advantage in using ALD instead of IBS

✓ ALD coatings show good optical absorption

➔ unusual behavior wrt annealing might be worth further investigation

Summary

- the structure of multilayer coatings has been characterized
- analyses revealed interfaces of mixed materials
- mixed interfaces can only partly explain the gap between predicted and measured losses

- ALD coating technique has been investigated
  - x losses are larger compared to IBS coatings
  - ✓ optical absorption seems lower for $T_{annealing}$ > 600 °C

- next step: further characterization of optical absorption wrt $T_{annealing}$

Thank you for your attention.