Magnetron Sputtered Hydrogenated Amorphous Silicon Coatings for Einstein Telescope Mirrors

Diksha[1,2], Alex Amato[1,2] , Jessica Steinlechner[1,2]

Gianluigi Maggioni[3,4], Hanna Skliarova[3], Marco Bazzan[3]

Speaker : Diksha

1. Maastricht University, P.O. Box 616, 6200 MD Maastricht, The Netherlands
2. Nikhef, Science Park 105, 1098 XG Amsterdam, The Netherlands
3. Padova University , Via 8 Febbraio, 2 - 35122 Padova, Italy
4. INFN-LNL , **Viale dell'Università, 2 – 35020- Legnaro (PD) , Italy**

Diksha (d.diksha@maastrichtuniversity.nl)

Introduction

Amorphous silicon

➉ Padova University

- Hydrogenation during deposition by radio frequency magnetron sputtering
- Compositional Analysis with annealing temperature

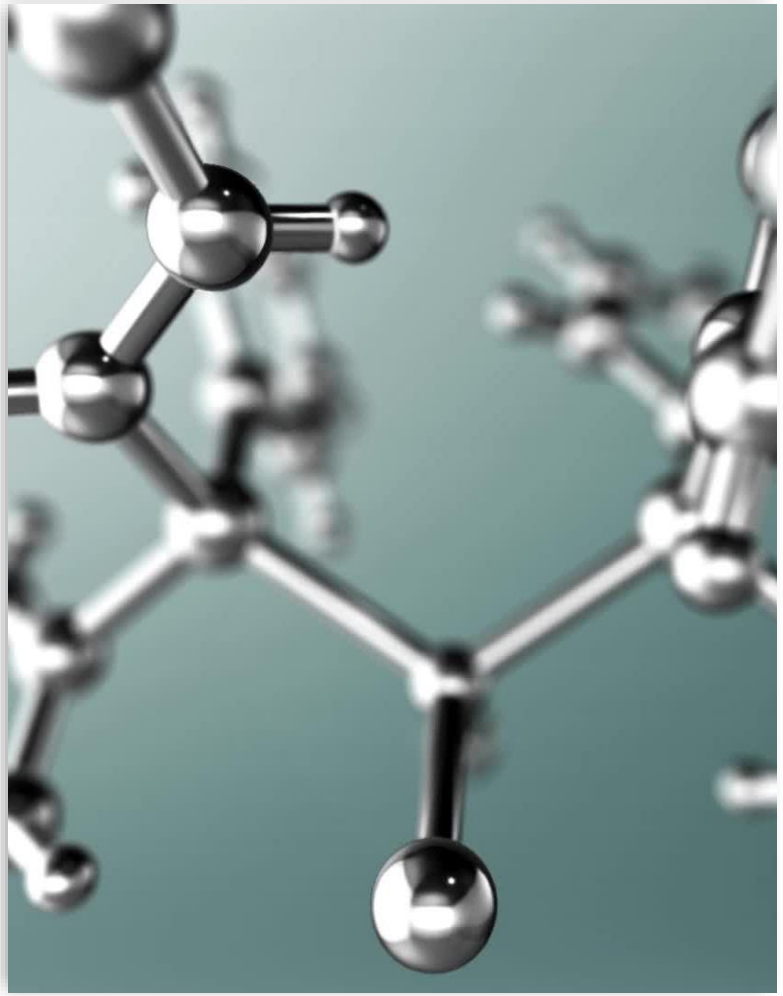
➉ Maastricht University

- Refractive index vs annealing temperature
- Optical absorption vs annealing temperature

Limitations of Amorphous Silicon

High optical absorption

- Exceeds acceptable levels for gravitational-wave detectors
- Studies related the absorption in the NIR region of aSi to the dangling bonds (unpaired electron-spin density) [1]
- Hydrogenation can help reducing dangling bond and hence absorption [2]
- H terminates dangling bonds; rearrangement of hydrogen sub lattice can affect concentration and distribution in defects thus facilitates a-Si structural rearrangement



[1] Phys. Rev. Lett. 131, 256902
[2] Phys. Rev. Lett. 121, 191101

Amorphous silicon coatings

Deposition setup @LNL-INFN

Target Si 99.999%
Radio Frequency Magnetron Sputtering

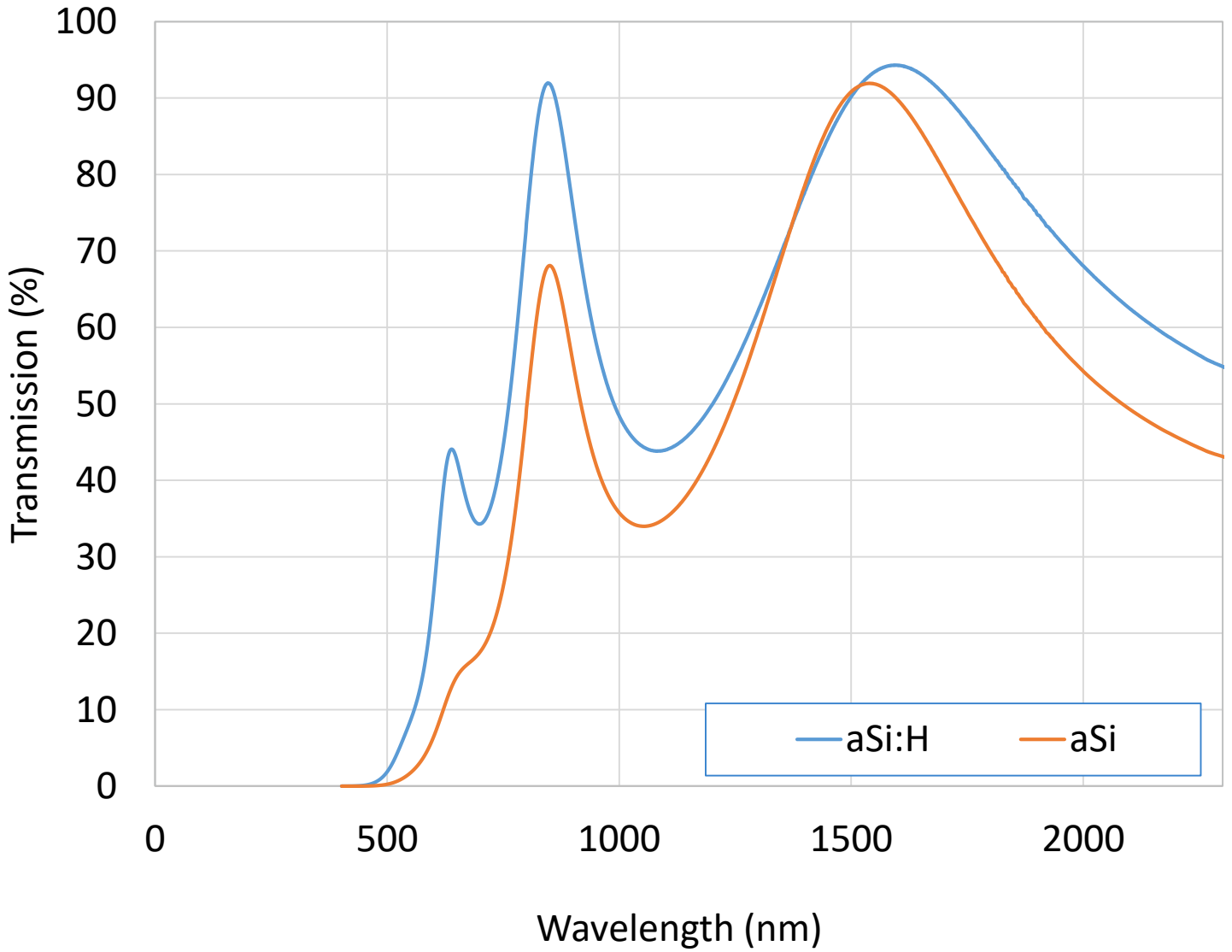
Deposition	aSi	aSi:H
Sputtering gas	Ar	Ar+5%H2
Substrates	2 SiO_2 disks (C7979), 2 Si wafer one side polished	2 SiO_2 disks (C7979), 2 Si wafer one side polished

Optical Characterization

Maastricht University

Diksha (d.diksha@maastrichtuniversity.nl)

Transmission Spectra for as deposited coatings



Transmission spectra

Annealing steps

100°C steps from as deposited to 600 °C.

Transmission spectra

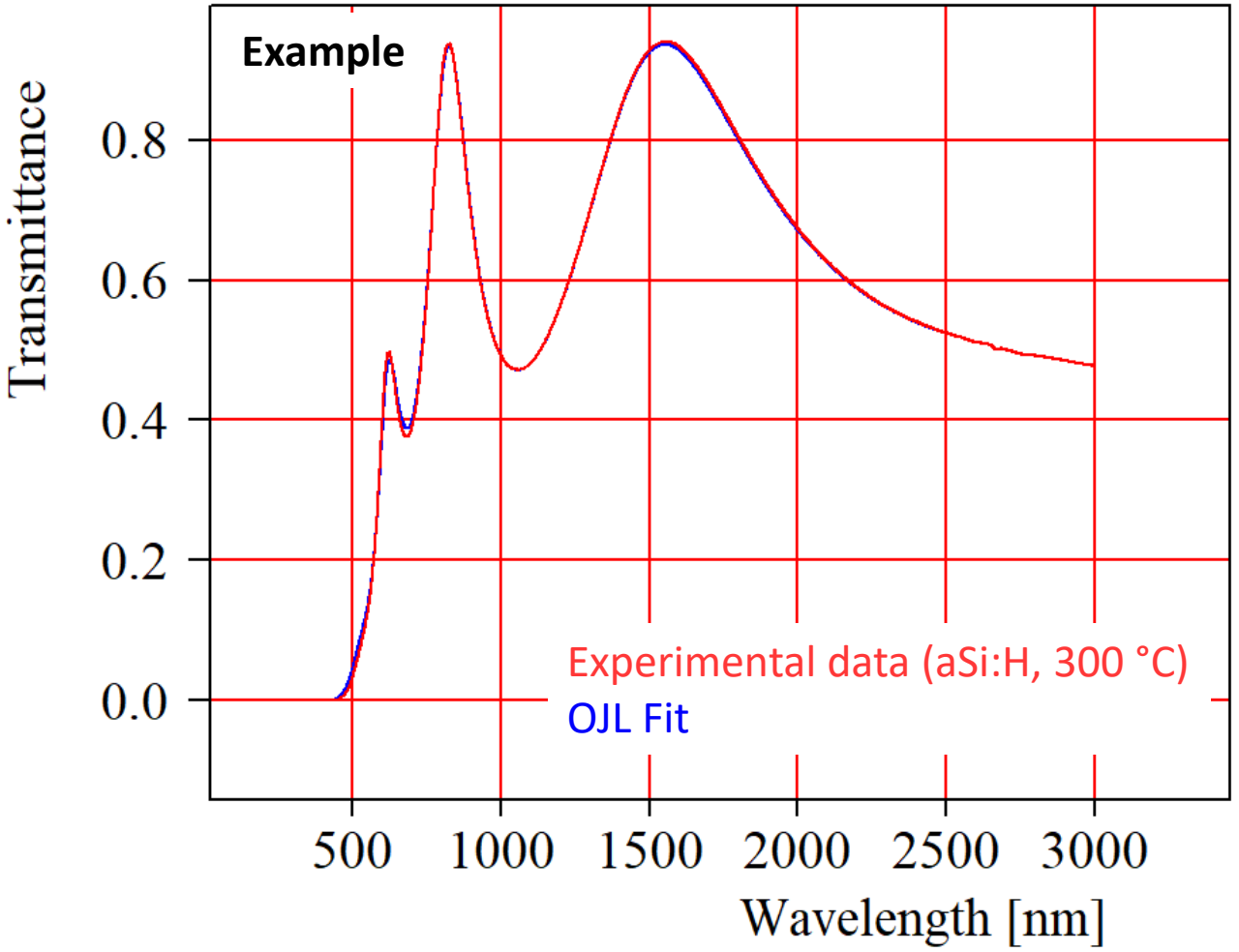
measured with the help of a Cary 5000 spectrophotometer.

Optical properties

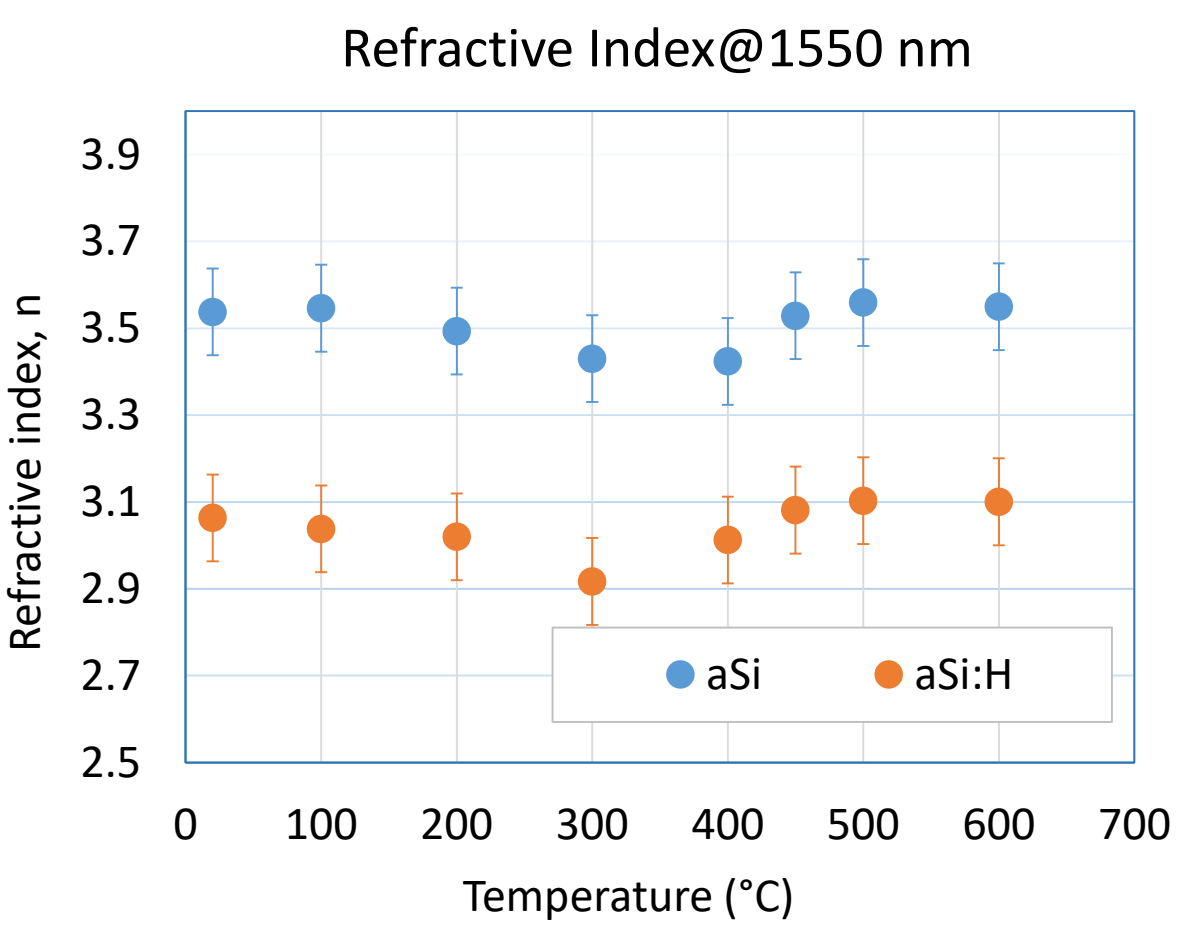
analyzed using two Kramers-Kronig consistent models:

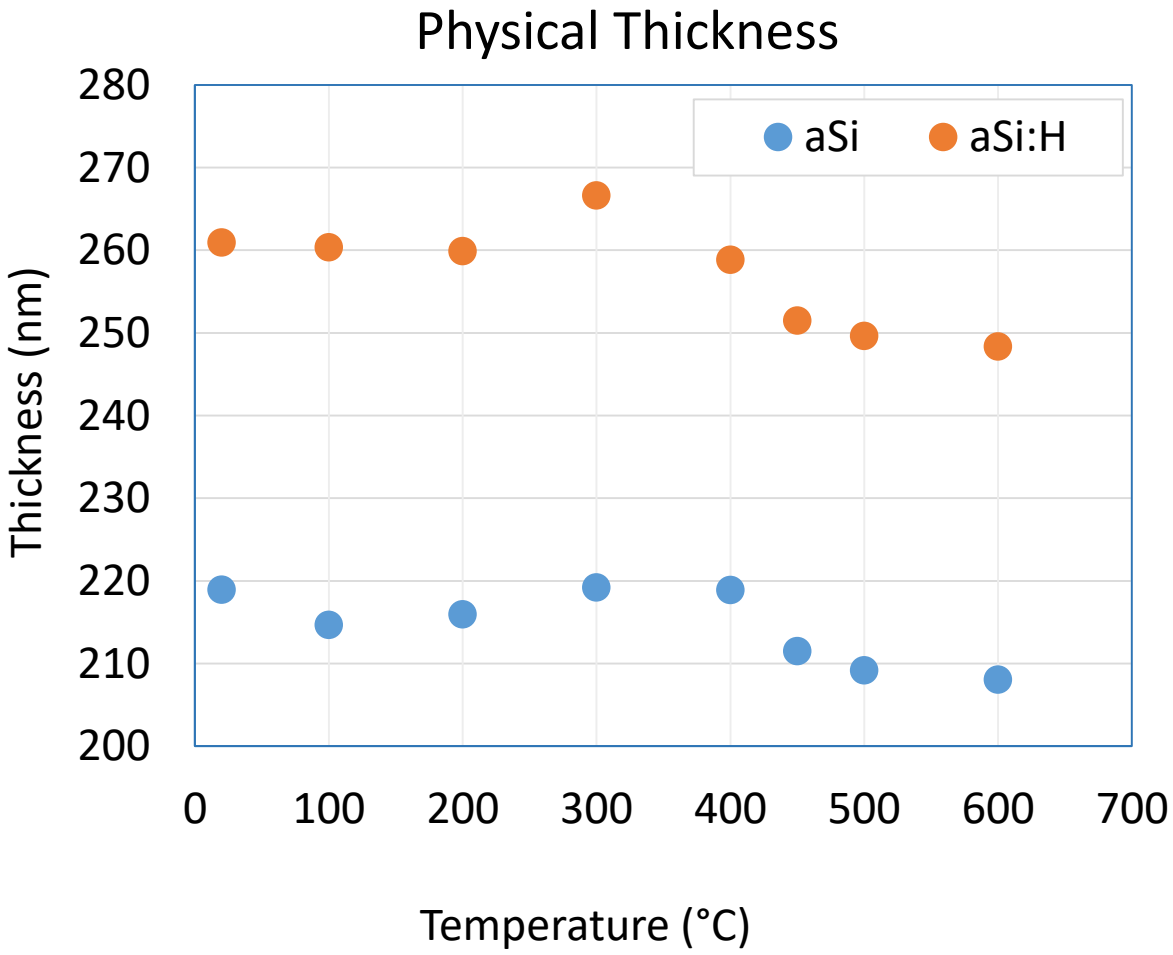
Tauc-Lorentz and OJL models.

(both are considered for final results)

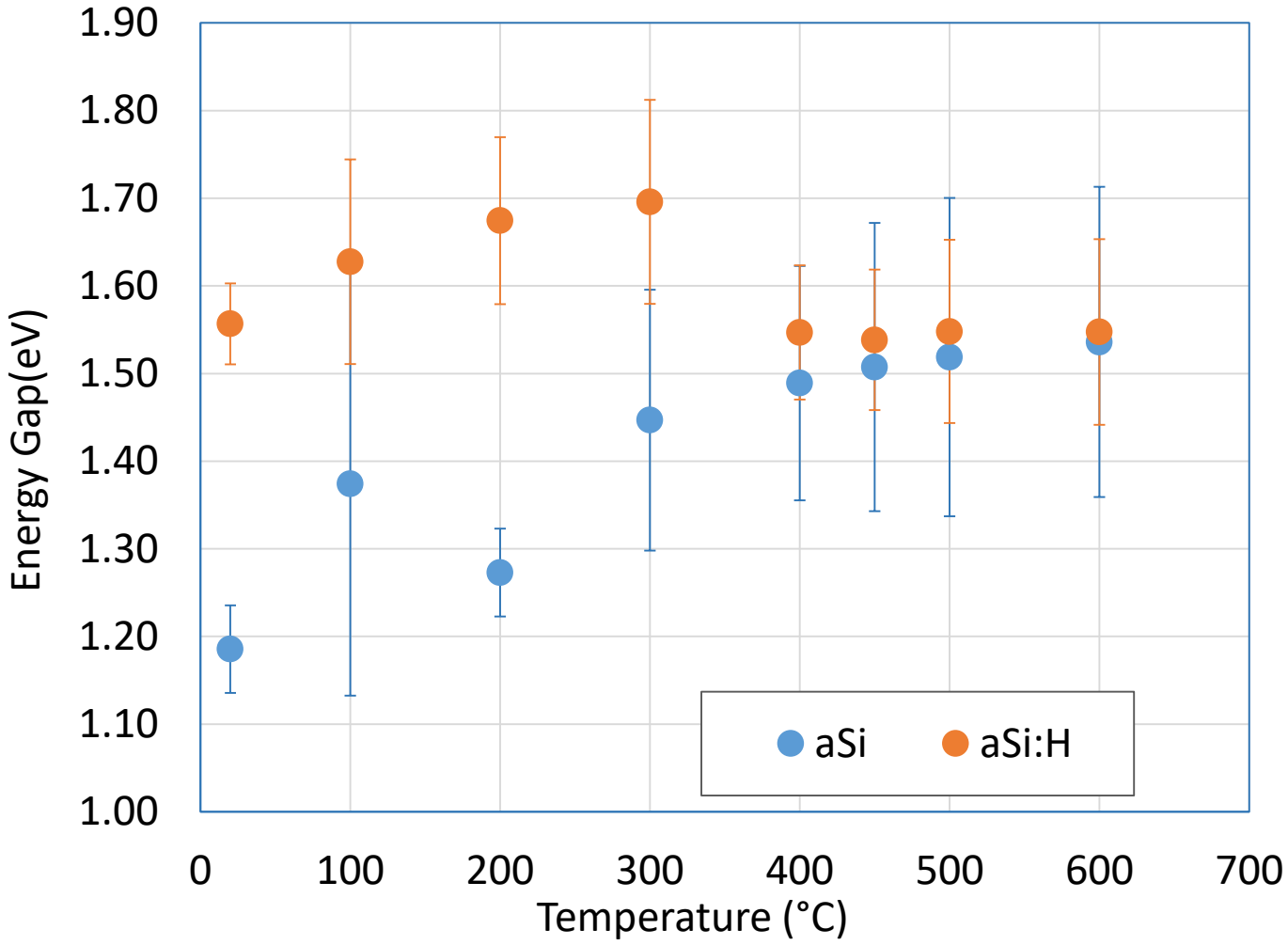


Refractive Index and thickness vs heat treatment





Energy gap vs heat treatment

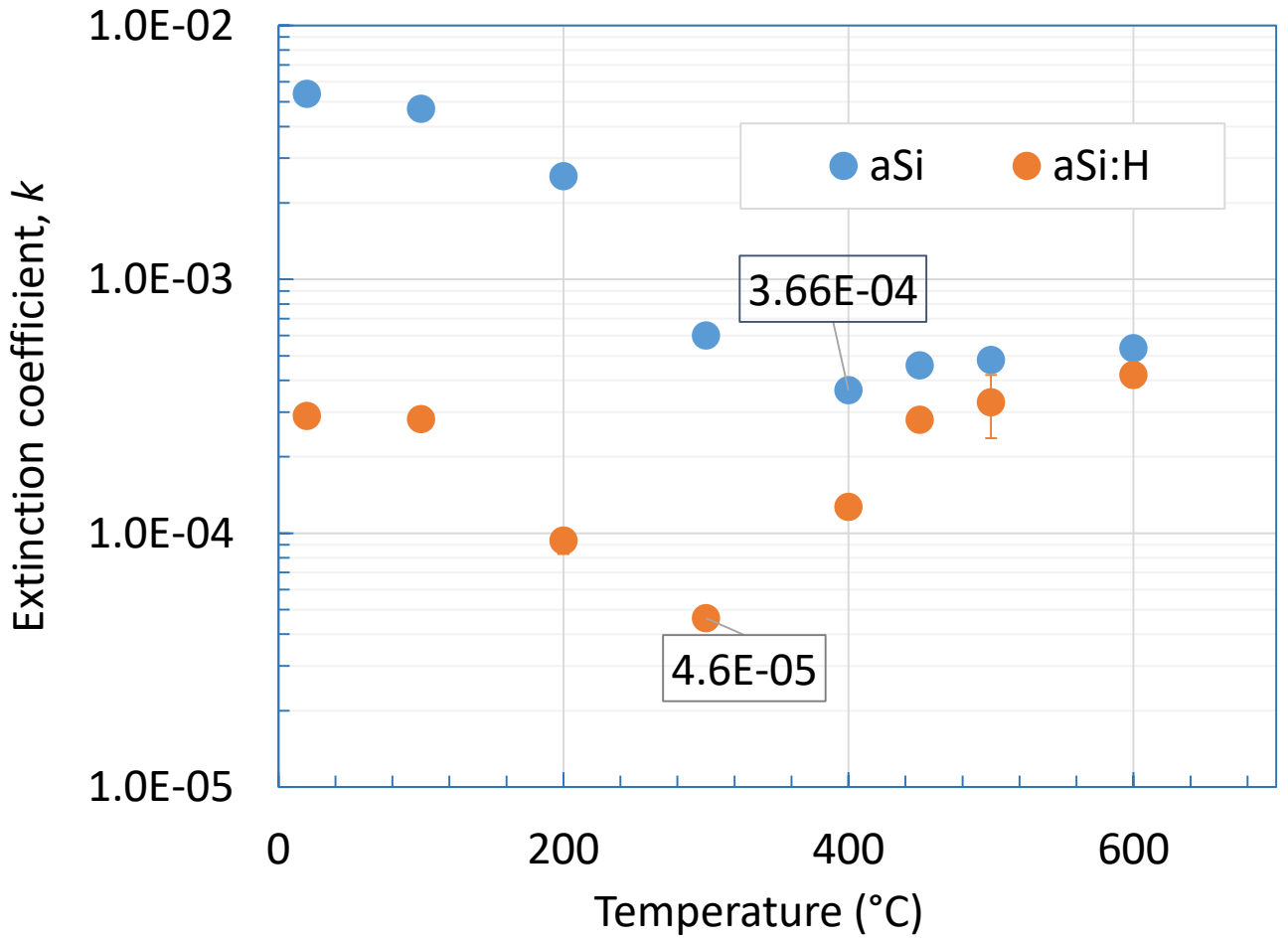


Extinction Coefficient @ 1550 nm

Results obtained in our study

1. Absorption measurements done with PCI (photo thermal common path interferometer) technique.

2. Absorption values were used to extract extinction coefficient values with the help of Tfcalc software.



Results from other studies conducted before in LVK

https://dcc.ligo.org/LIGO-G2400542 (LVK March 2024)
Phys. Rev. Lett. 131, 256902

RBS and ERDA analysis

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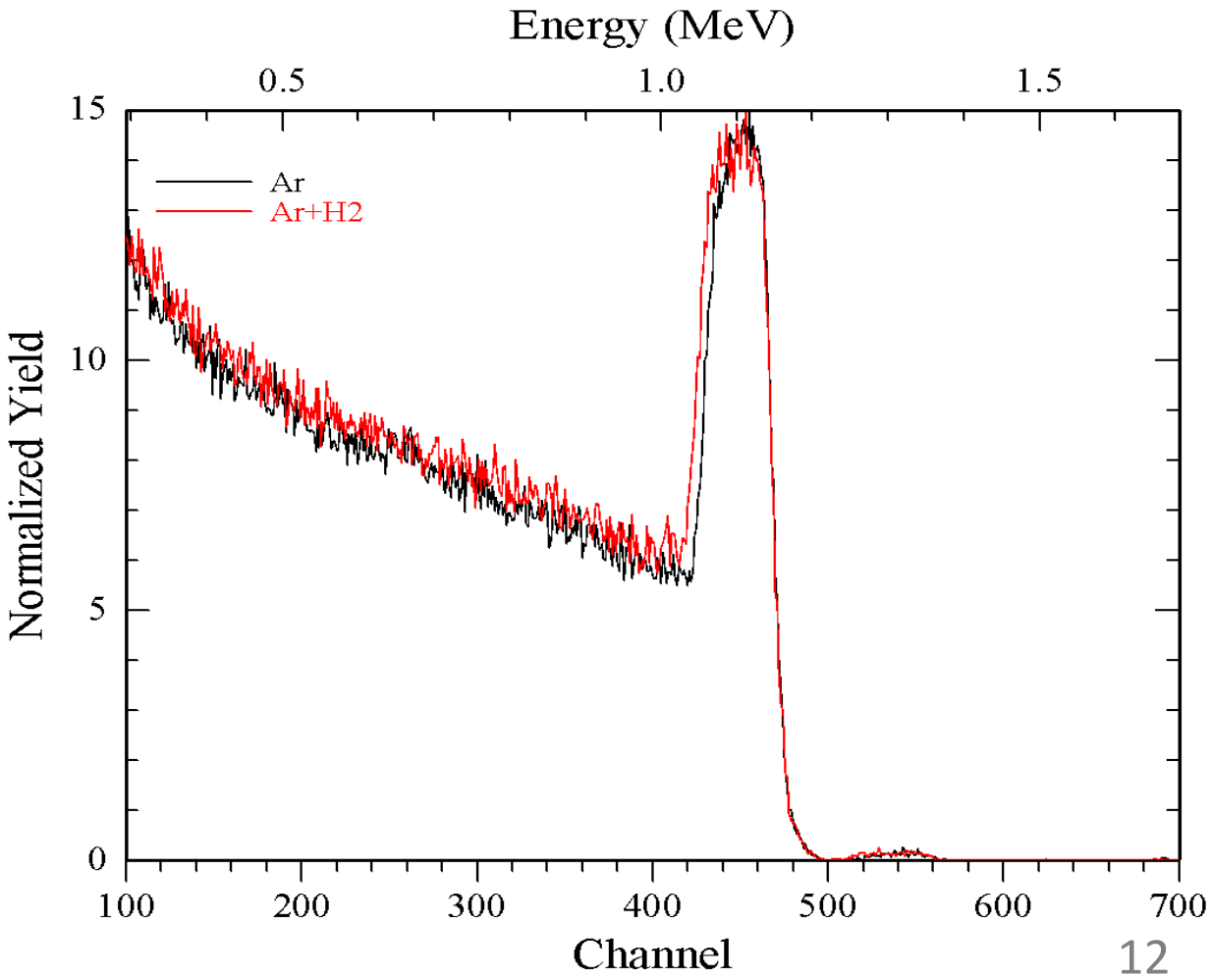
RBS - Rutherford backscattering spectrometry

ERDA - Elastic recoil detection analysis

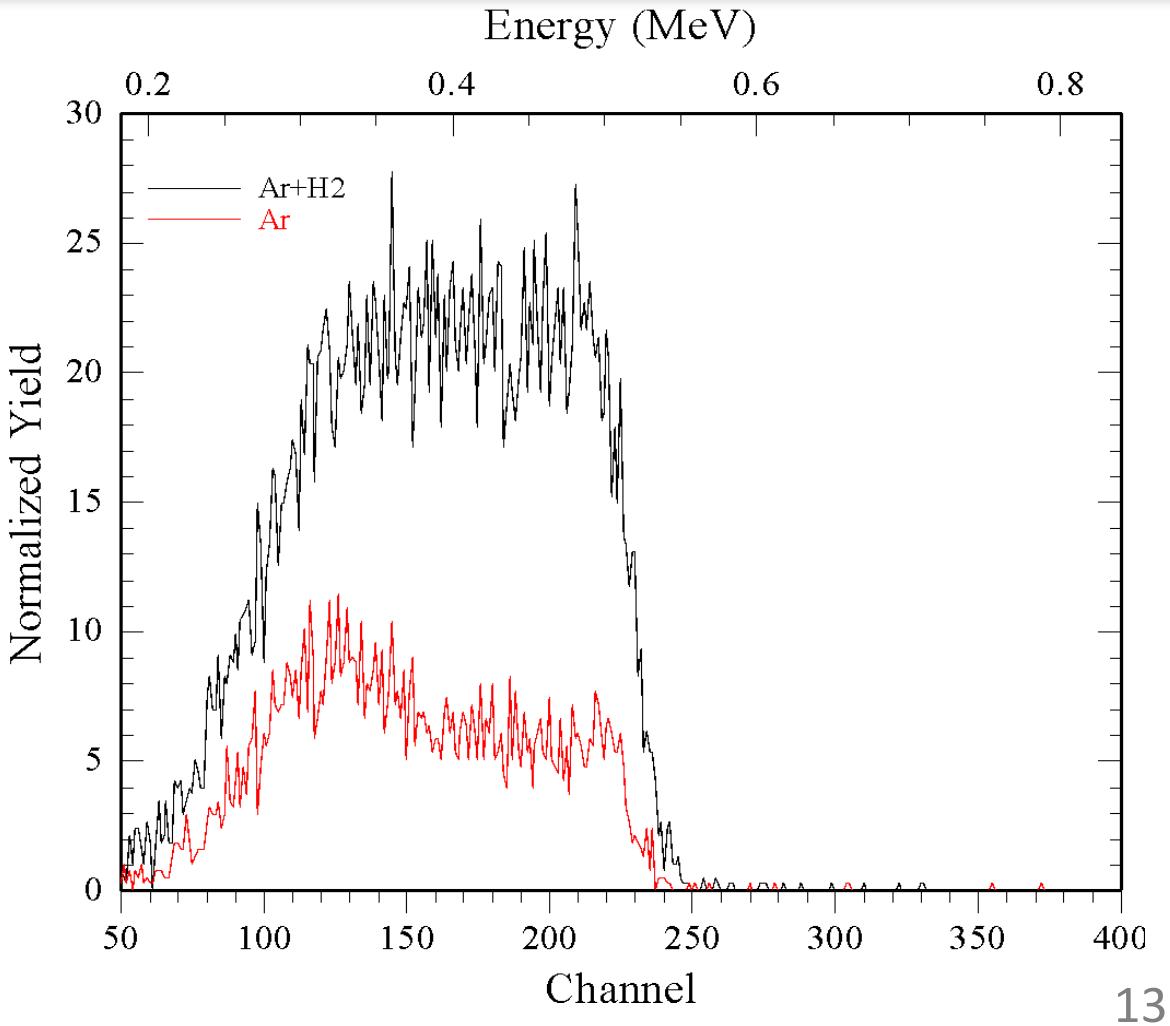
RBS measurements

Film Atomic Combination		
Sample	**Si dose (atom cm^{-2})**	**Film Thickness**
aSi	9.3e17	191
aSi:H	9.7e17	215



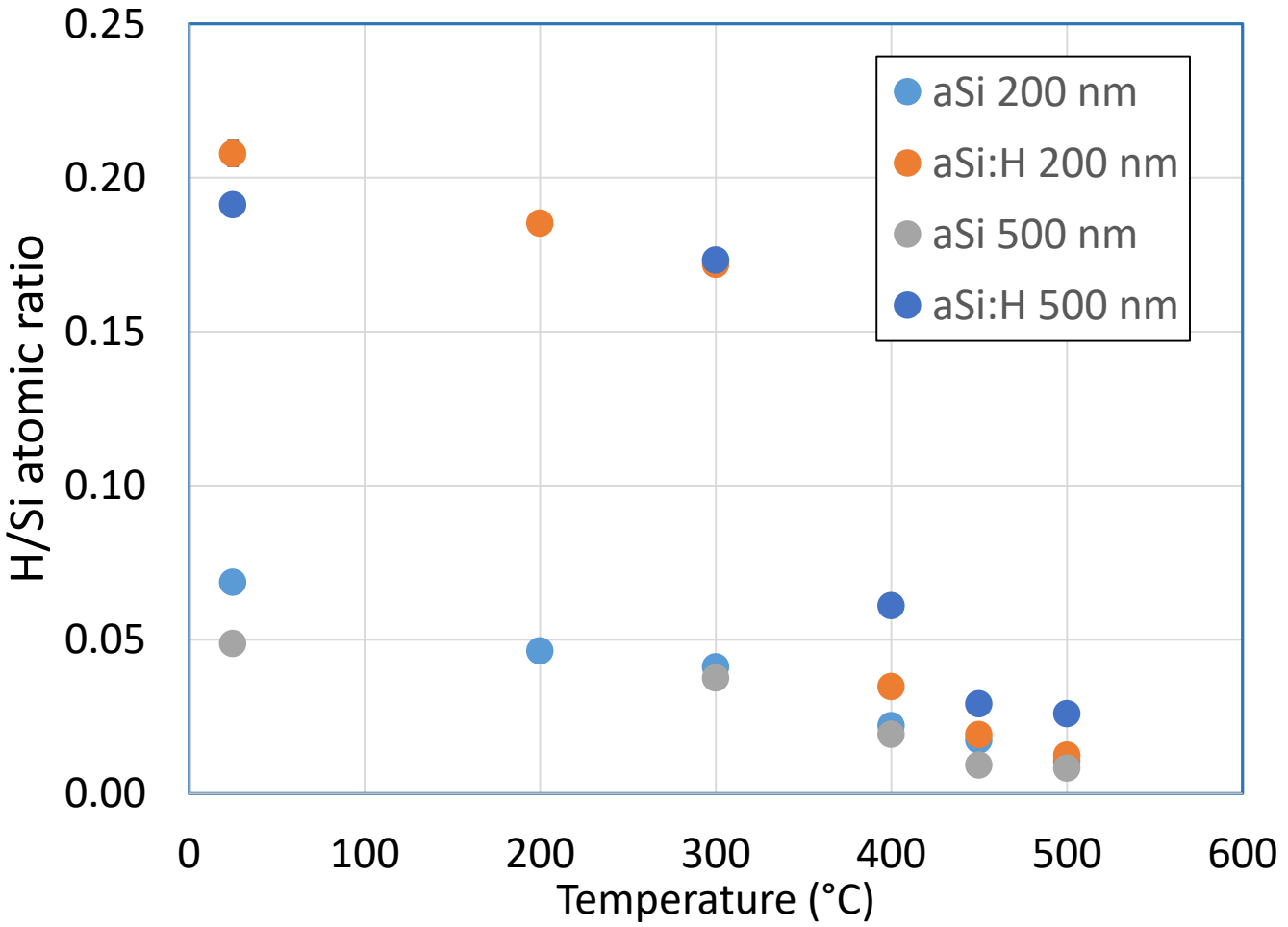
ERDA Measurements

Film Atomic Combination		
Sample	**H/Si**	**Ar/Si**
aSi	0.07	0.004
aSi:H	0.21	0.006



Diksha (d.diksha@maastrichtuniversity.nl)

RBS+ERDA after annealing



H/Si atomic ratio obtained by ERDA+RBS has similar **trend** in respect to Si-H bonds concentration obtained by FTIR

There is **significant decrease** of H/Si atomic ratio in aSi 937 sample **sputtered in 5%H_2+Ar after 300^{0}C**

FT/IR analysis

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Diksha (d.diksha@maastrichtuniversity.nl)

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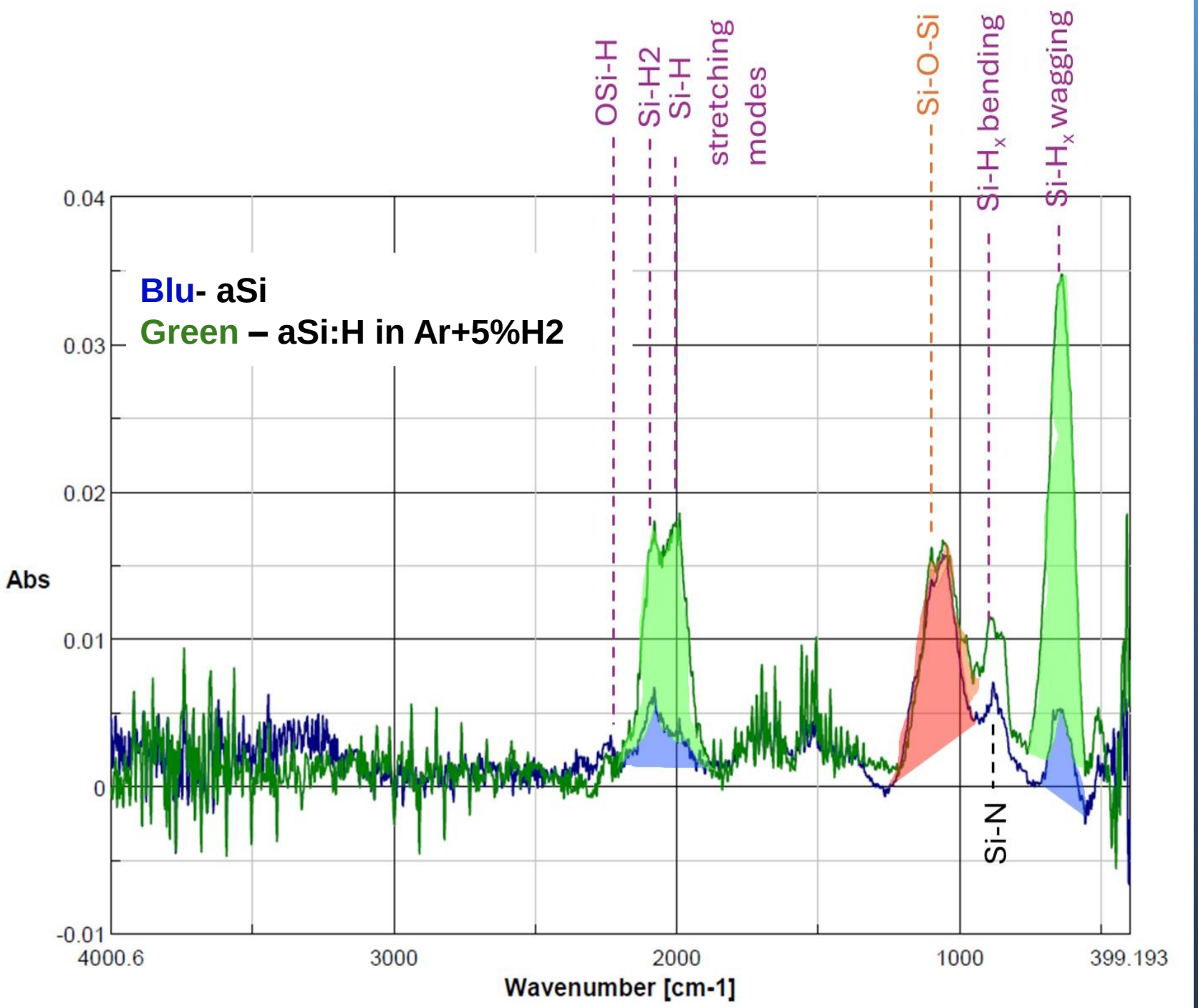
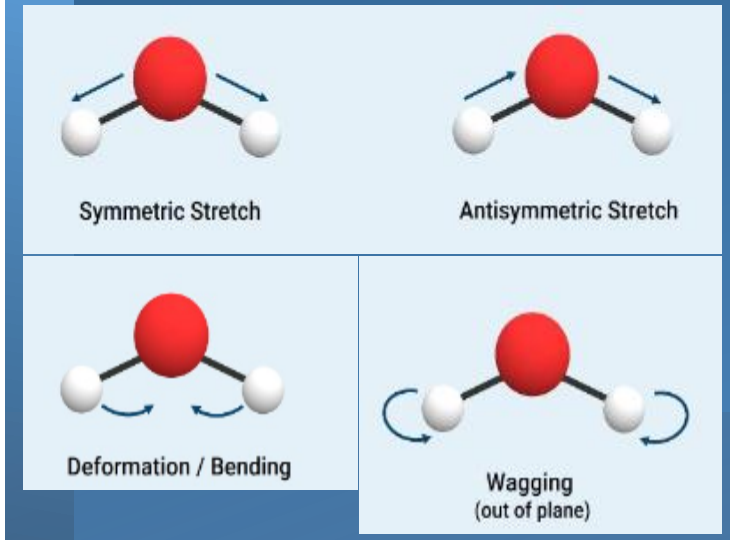


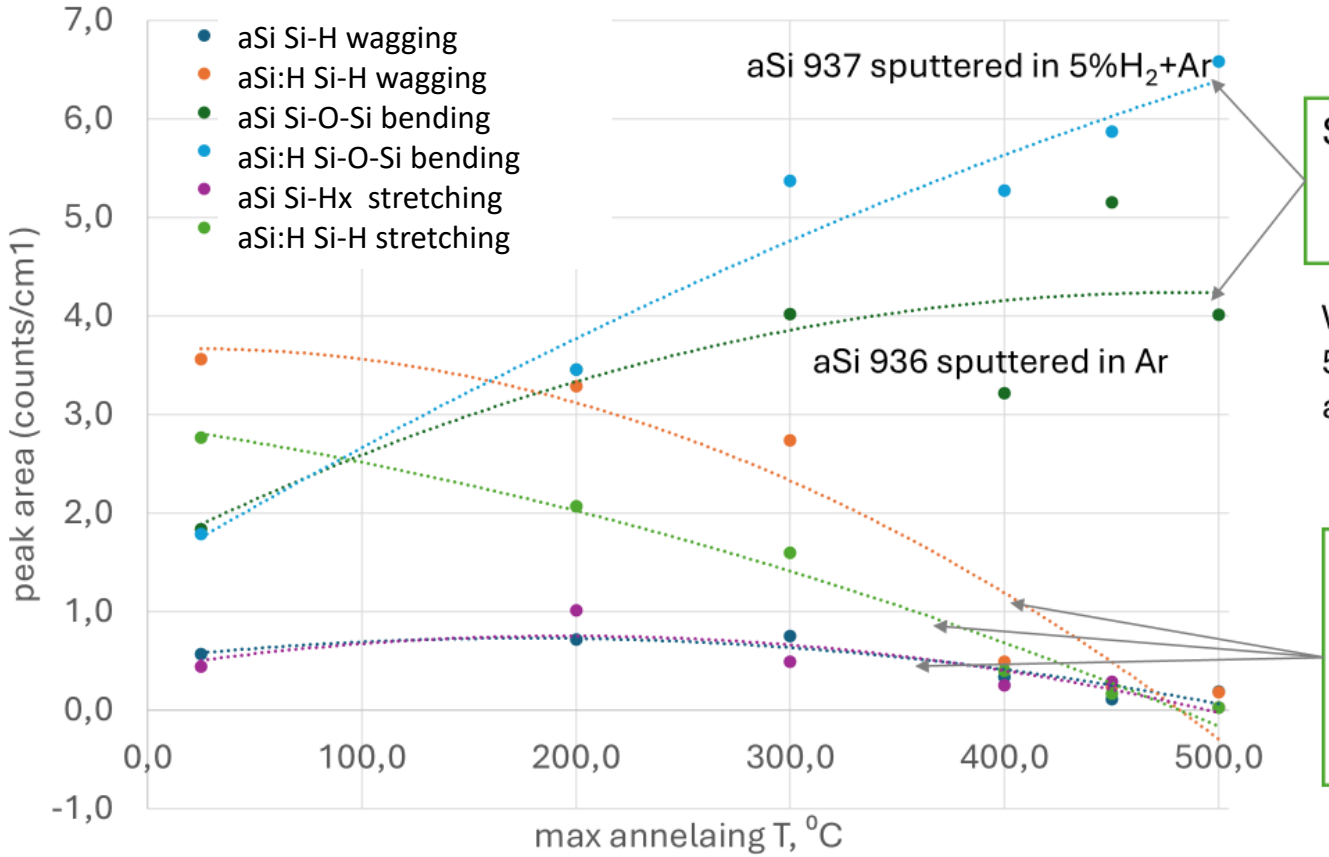


Measuring area under the peaks correlated to

- Si-H2 Si-H stretching modes
- Si-Hx wagging mode
- Si-O-Si single or multiple band

Proportional to “concentration” of the bond in the film

FTIR: peak area evolution (trend) on annealing

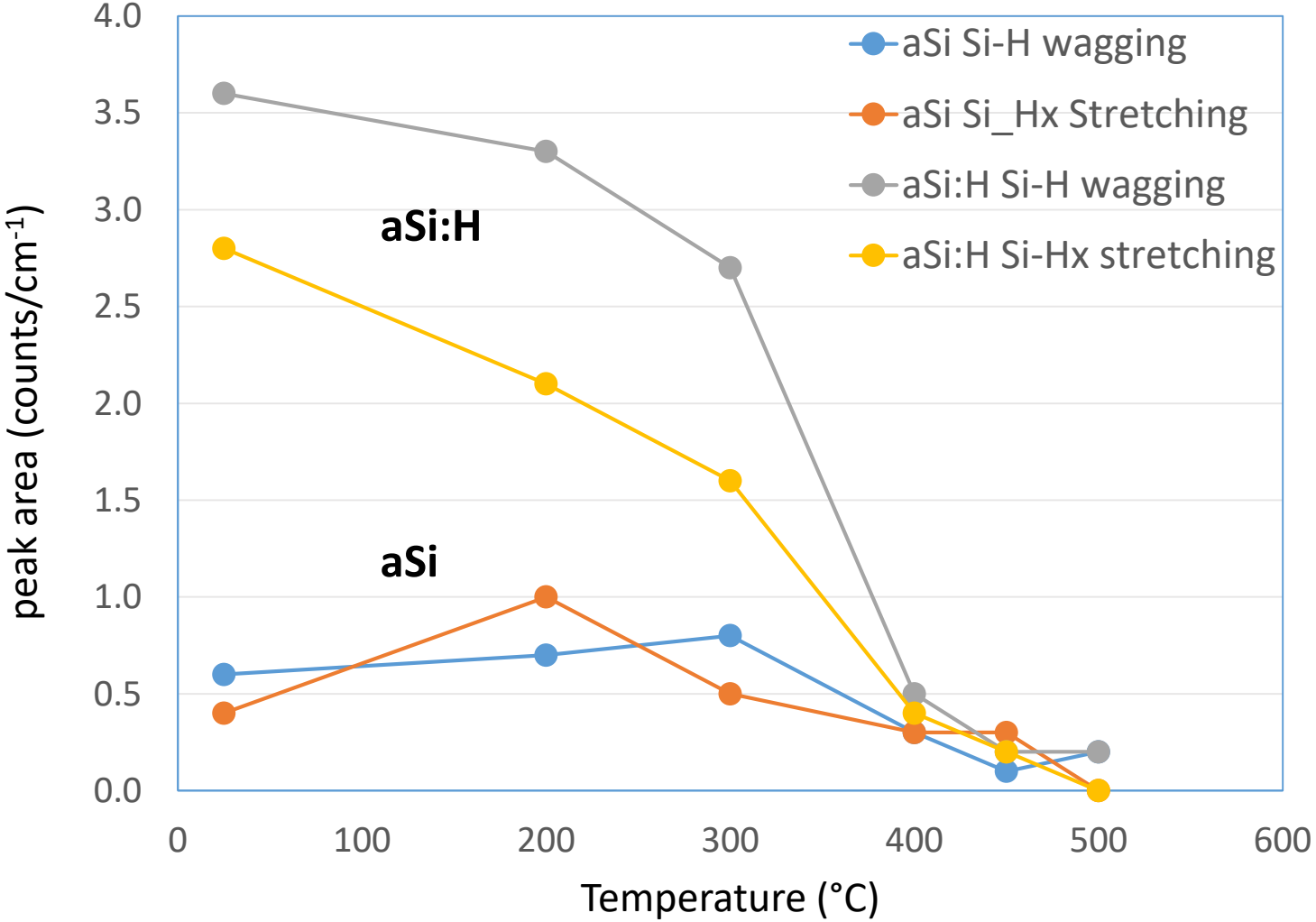


Si-O-Si bonds "concentration" increase
=
oxidation

We observe that aSi 937 deposited in $5\%H_2$+Ar is more oxidized on annealing then aSI 936 deposited in Ar

Si-H bonds "concentration" decrease
=
Si-H bonds decomposition,
=
H content decrease

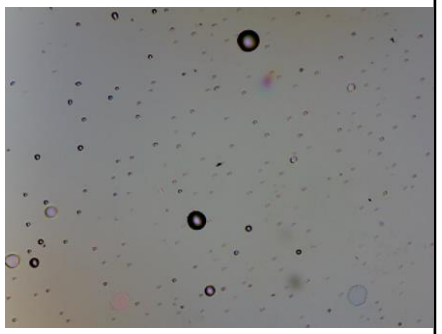
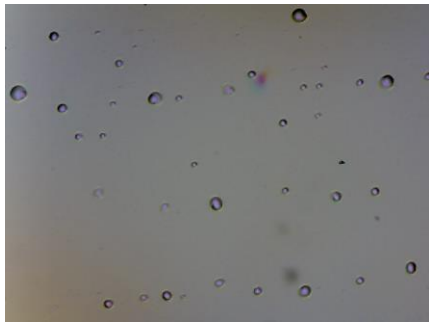
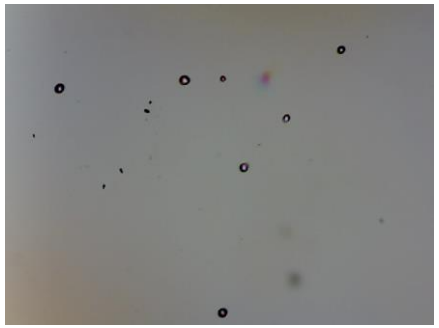
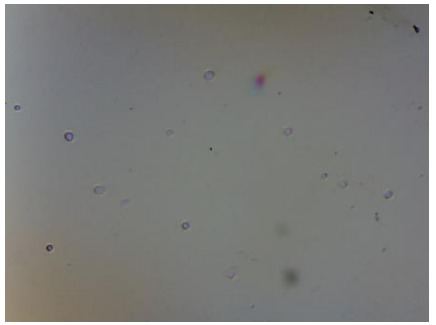
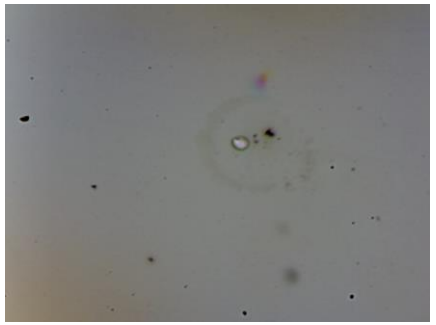
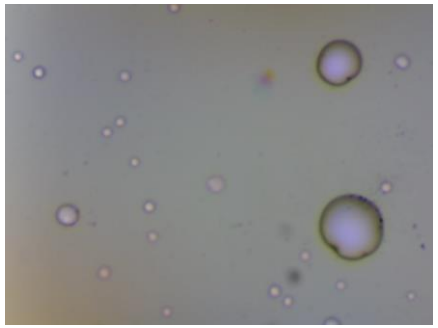
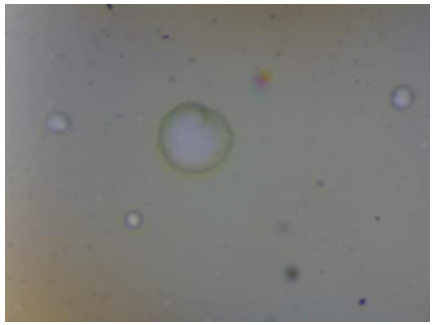
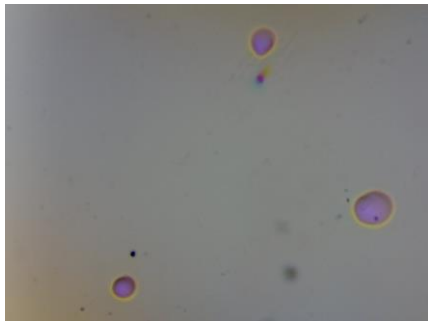
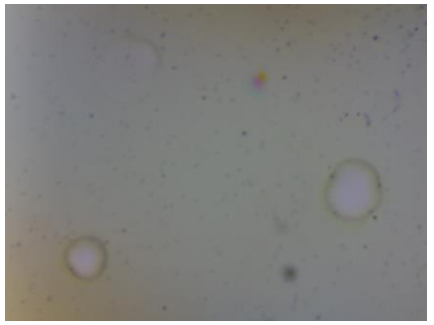
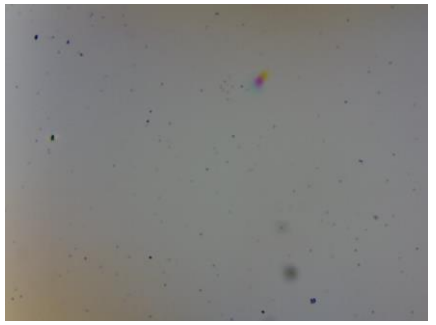
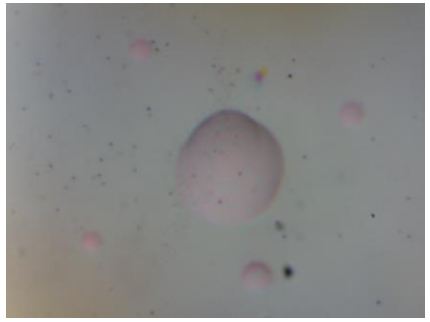
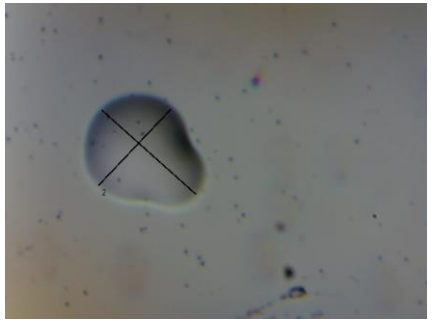
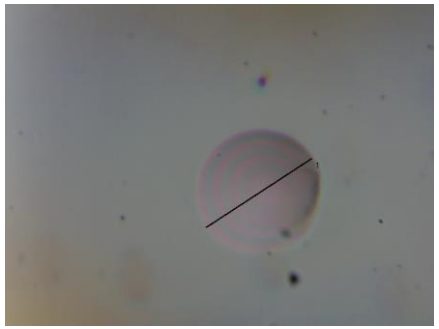
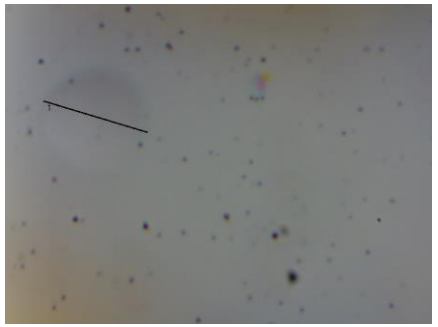
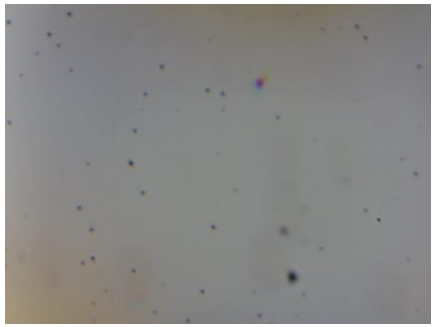
FTIR: peak area evolution (trend) on annealing



It is **evident the change of the trend** of hydrogen release (decomposition of Si-H bonds) in aSi 937 sample **sputtered in 5%H_2+Ar**

In aSi 936 sample **sputtered in pure Ar** the release of hydrogen on increasing annealing temperature seems to have a softer trend

After annealing at 450ºC all samples show blistering. Ar deposited samples have more bubbles

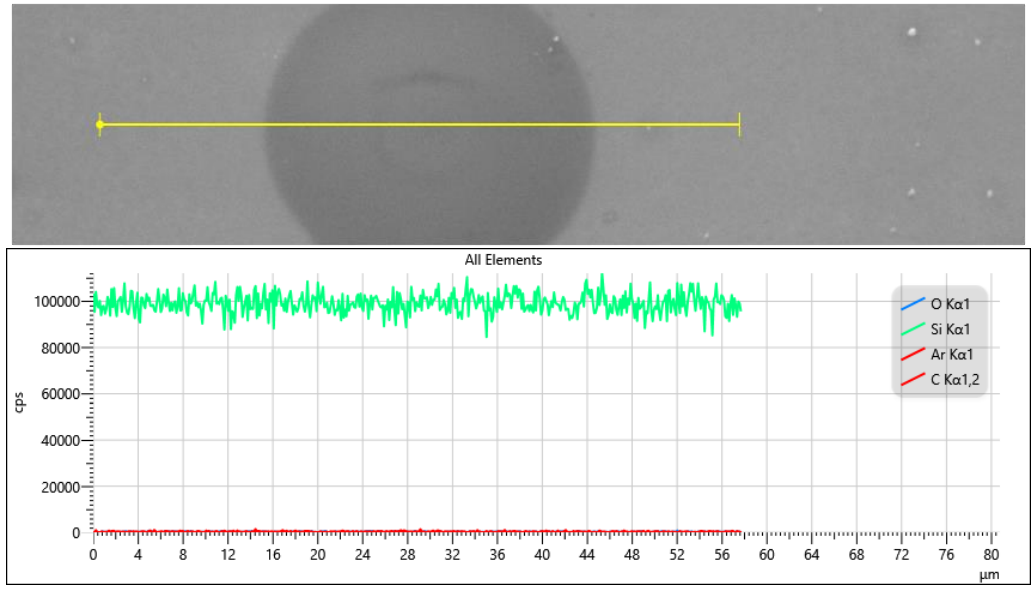
Opt. mic. magnification	Ar		Ar+5% H_2		
	200 nm	500 nm	200 nm	500 nm (set 1)	500 nm (set 2)
x5					
x20					
x50					

SEM_EDS measurement of bubbles

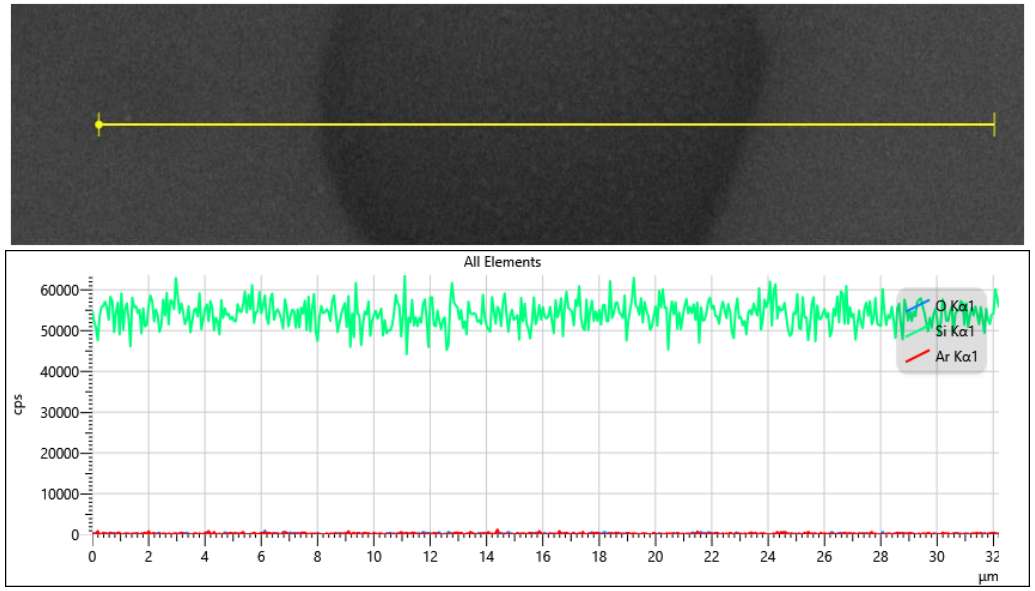
30kV e-beam

Hypothesis: bubble is full of Ar

aSi_ 300ºC, 400ºC, 450ºC, 500ºC



aSi:H_ 300ºC, 400ºC, 450ºC, 500ºC



No Ar variation through line scan was observed

Summary

The lowest extinction coefficient was observed for magnetron sputtered aSi:H (5% H2) at 300 °C was 4.6E-05

It is almost a factor of 12 times with the non hydrogenated sample at the same temperature and 8 times to the lowest at 400 °C

The hydrogen content rapidly falls after 300 °C observed from the ERDA measurments . It is also observed that the Si-H bond “concentration” from area under the peaks in FT/IR analysis also seems to decrease.

Lower refractive indices observed for hydrogenated samples (3.01 (aSi:H) and 3.42 (aSi) at 300 °C) (12% less than aSi at 300 °C)

Further steps for amorphous silicon

Measure 500 nm thick single layers for characterization

Development of multiple layer stack of amorphous silicon and silicon nitride and it’s study

Thank you for your attention!