Ion beam deposition and optical properties of mirror structures based on dielectric and metallic films

C. Bundesmann and H. Neumann

Leibniz-Institut für Oberflächenmodifizierung e.V.,
Permoserstraße 15, 04318 Leipzig, Germany

Outline

- Introduction
  - Motivation
  - Dual ion beam deposition
  - Single layer properties
- Simulation of optimized mirror structures
- Experimental results
  - Reflectivity
  - Stress
- Summary

Introduction

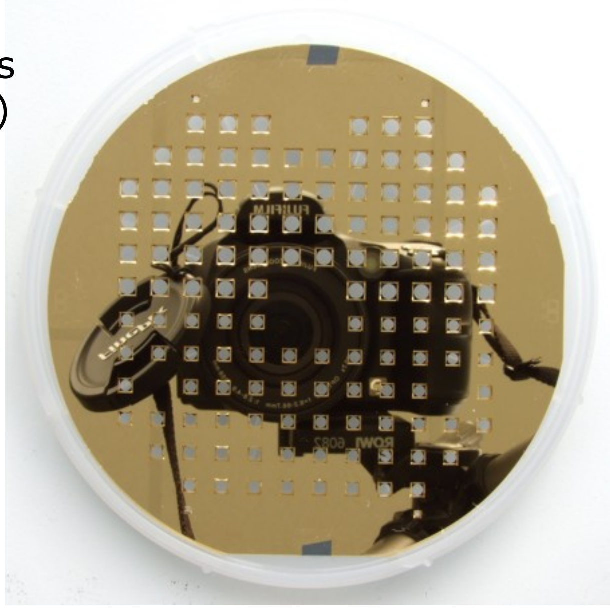
Our aim:

Laser mirror at λ = 1064nm

- high reflectivity
- minimal stack height
- low stress

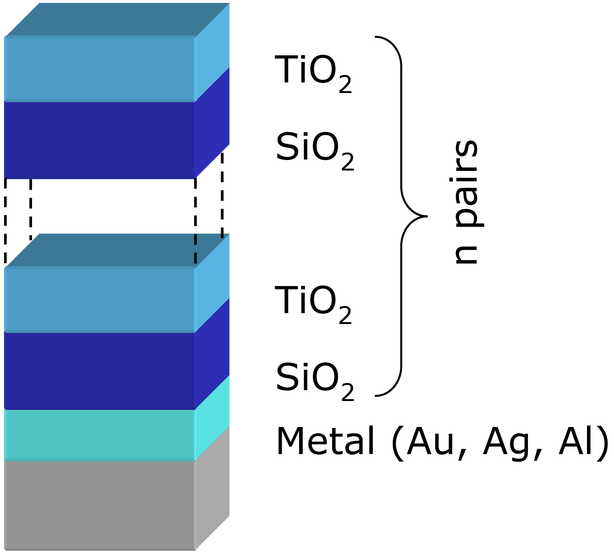
124 micro mirrors
(∅ = 2.3/3.0mm)
on 4” Si wafer

Deposition mask,
etched by
ZfM Chemnitz
(TU Chemnitz)



Solution:

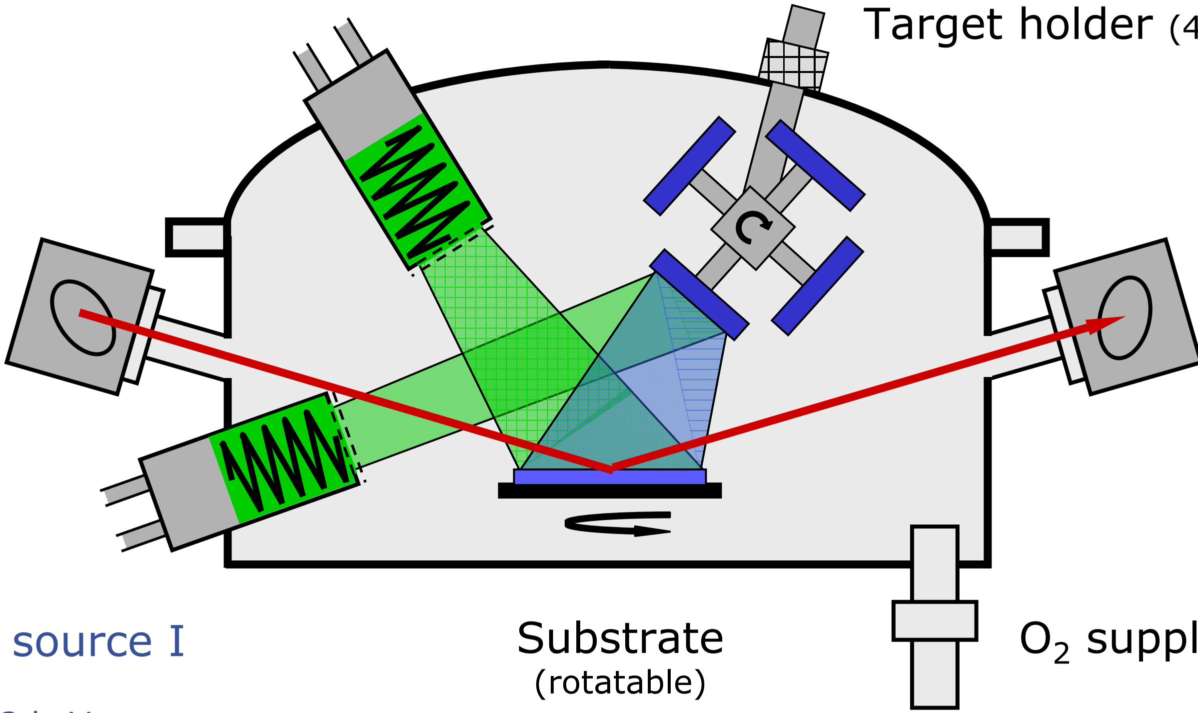
Combination of metal film and dielectric layer stack (Bragg mirror)



Growth technique:
Dual ion beam deposition

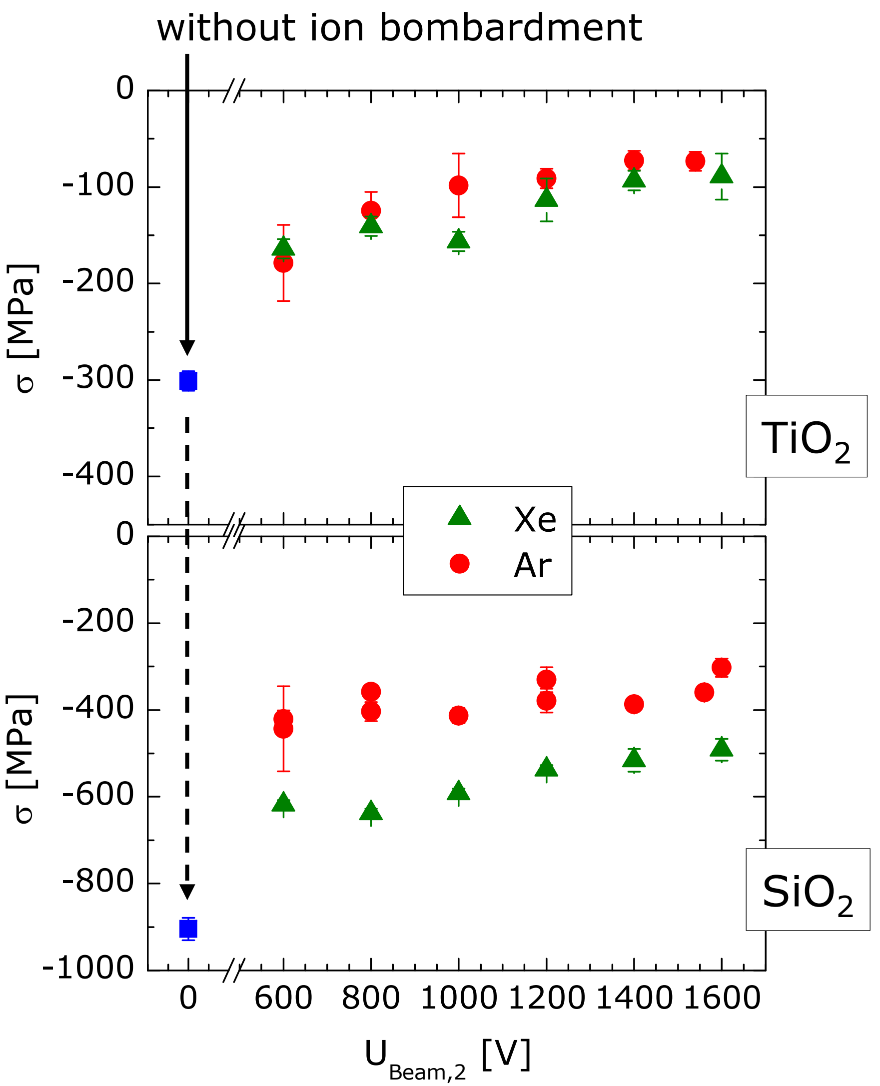
Dual ion beam deposition (DIBD): Setup

RF-Ion beam source II
(Assist source)
Ion energy up to 2 keV
Ion current controlled by pulse length modulation (PLM)



M. Zeuner, F. Scholze, B. Dathe, H. Neumann, Surf. Coat. Tech. 142-144 (2001) 39-48.

Single layers: Film stress



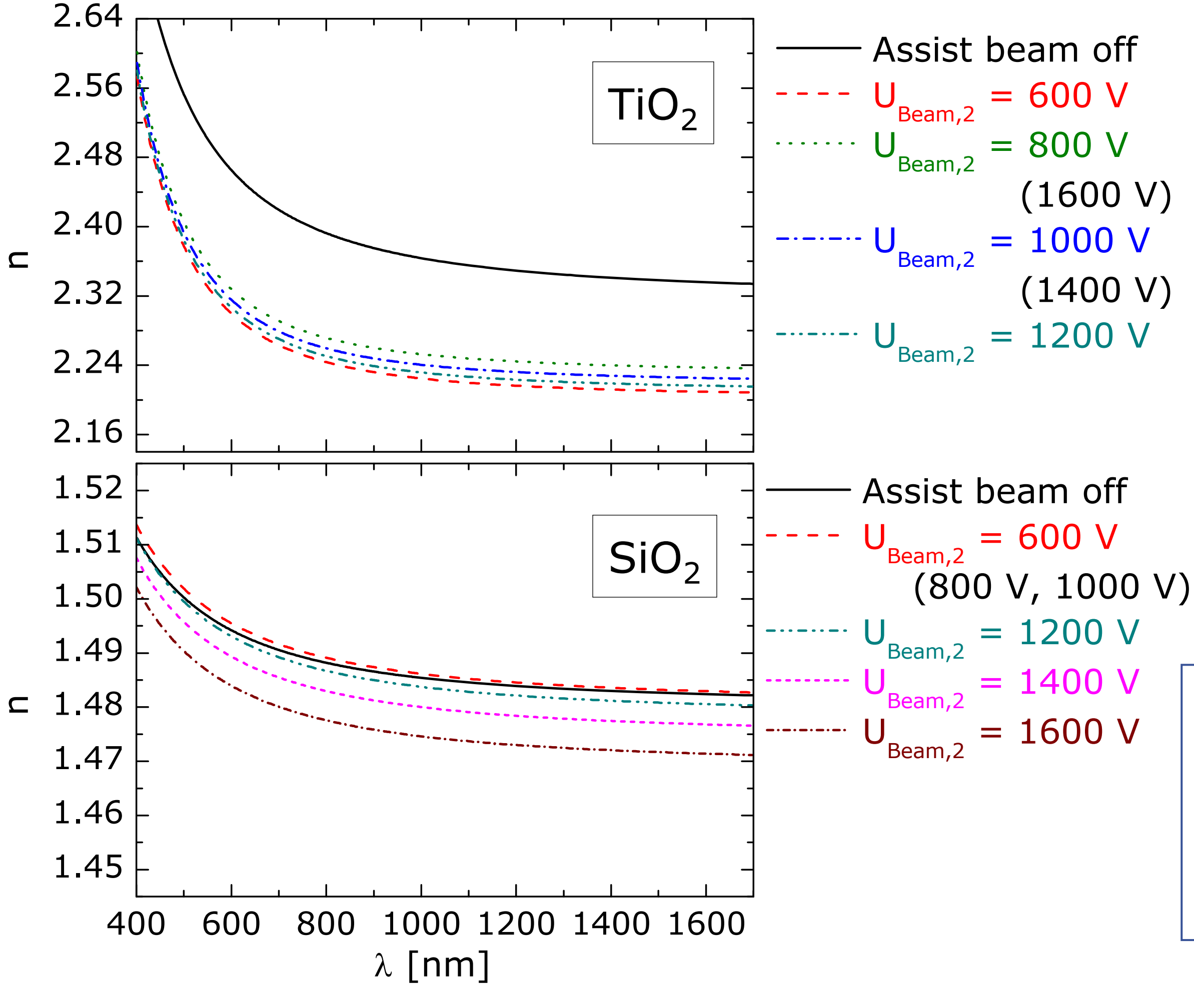
Stress relaxation by energetic ion bombardment

Increasing stress relaxation with increasing ion energy

Talk Mühlleiten 2007
I.-M. Eichentopf et al.
„Variation der Verspannung optischer dünner Schichten abgeschieden mit DIBD„

Single layers: Optical properties

Variation of ion energy of ion source II (Xe ion bombardment)



n decreases with increasing bombarding ion energy

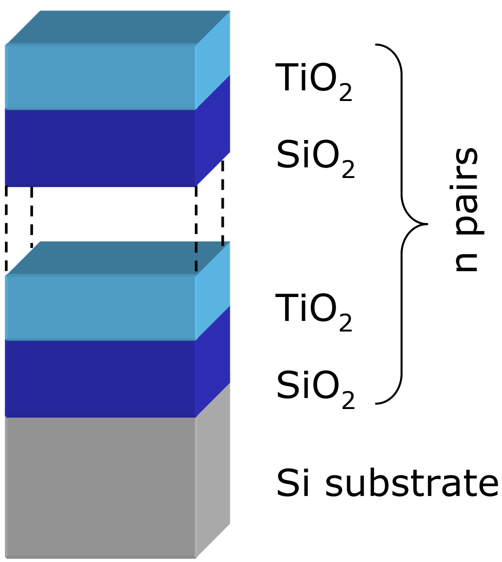
No absorption detected

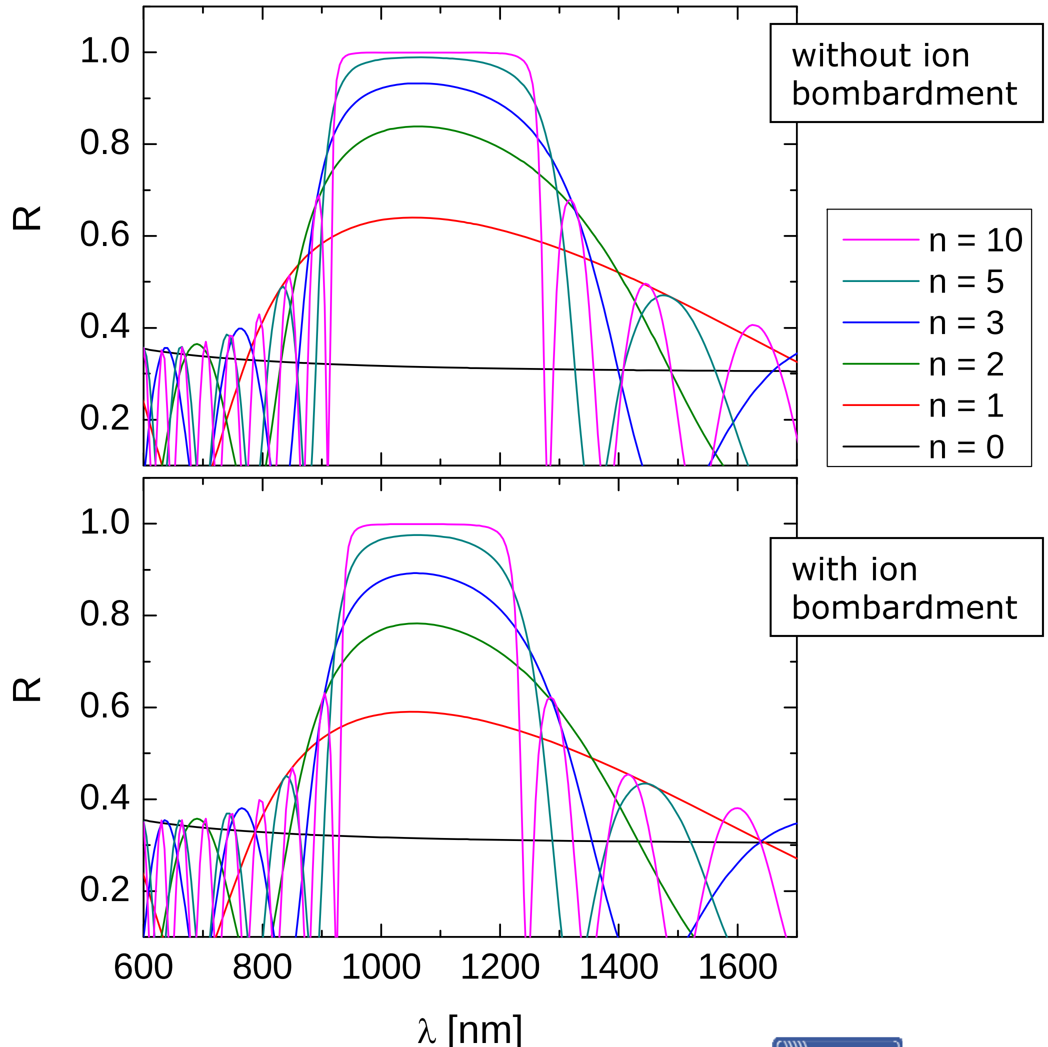
Talk Mühlleiten 2007
C. Bundesmann et al.
„Optische Eigenschaften metallischer und dielektrischer Dünnfilme bei der Ionenstrahlbeschichtung„

Simulation: Mirror structure without metal layer

Simulated reflectivity spectra without/with ion bombardment

- reflectivity band gets smaller
- reflectivity maximum decreases slightly





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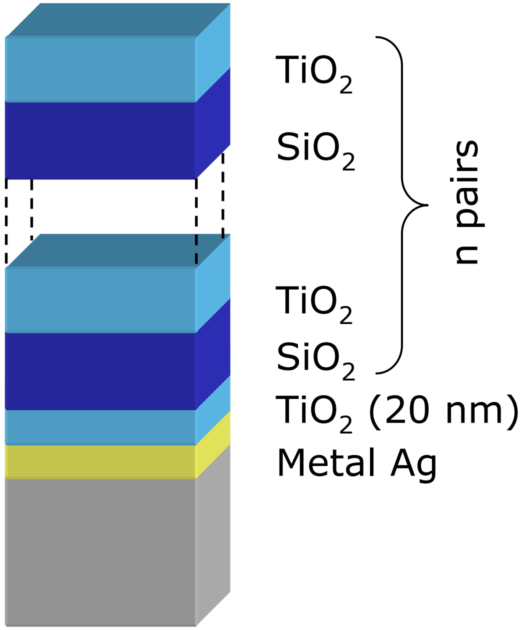
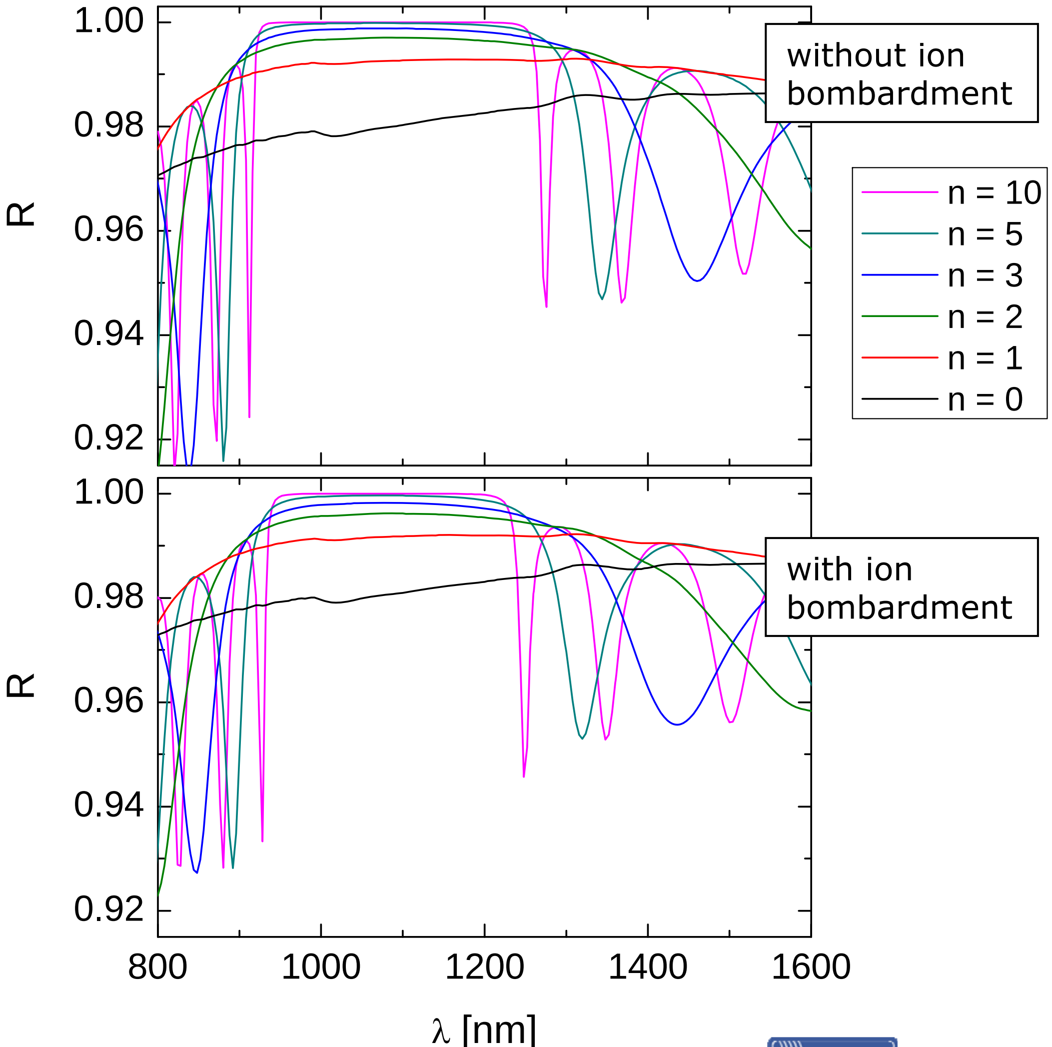
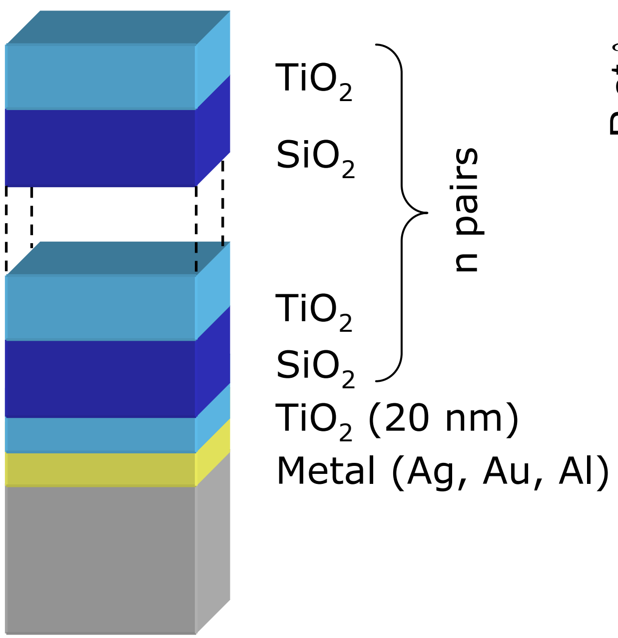
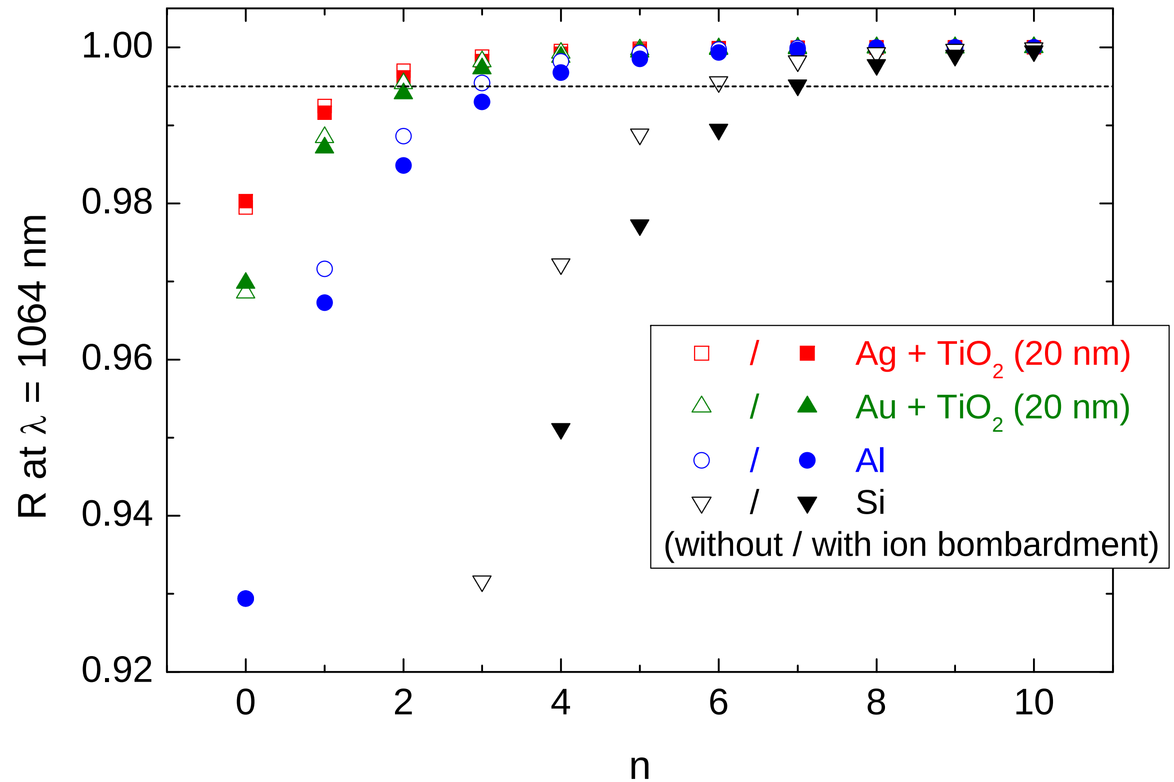




Simulation: Reflectivity maximum

Simulated reflectivity maximum at λ = 1064 nm





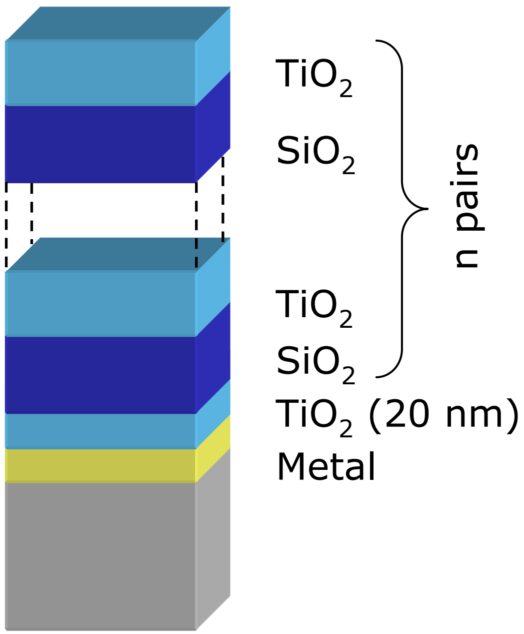
R maximum decreases with ion bombardment

Simulation: Optimized thicknesses of mirror structure

Optimized layer thickness
for reflectivity maximum
at λ = 1064 nm

at normal incidence
(no absorbtion):

$$n\,d = \frac{\lambda}{4}$$

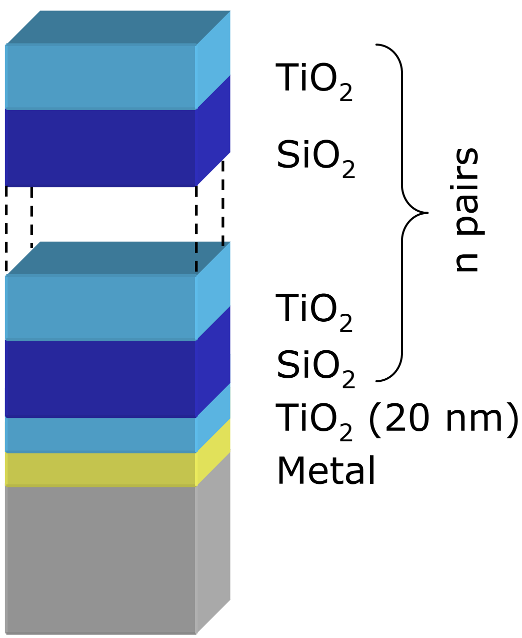


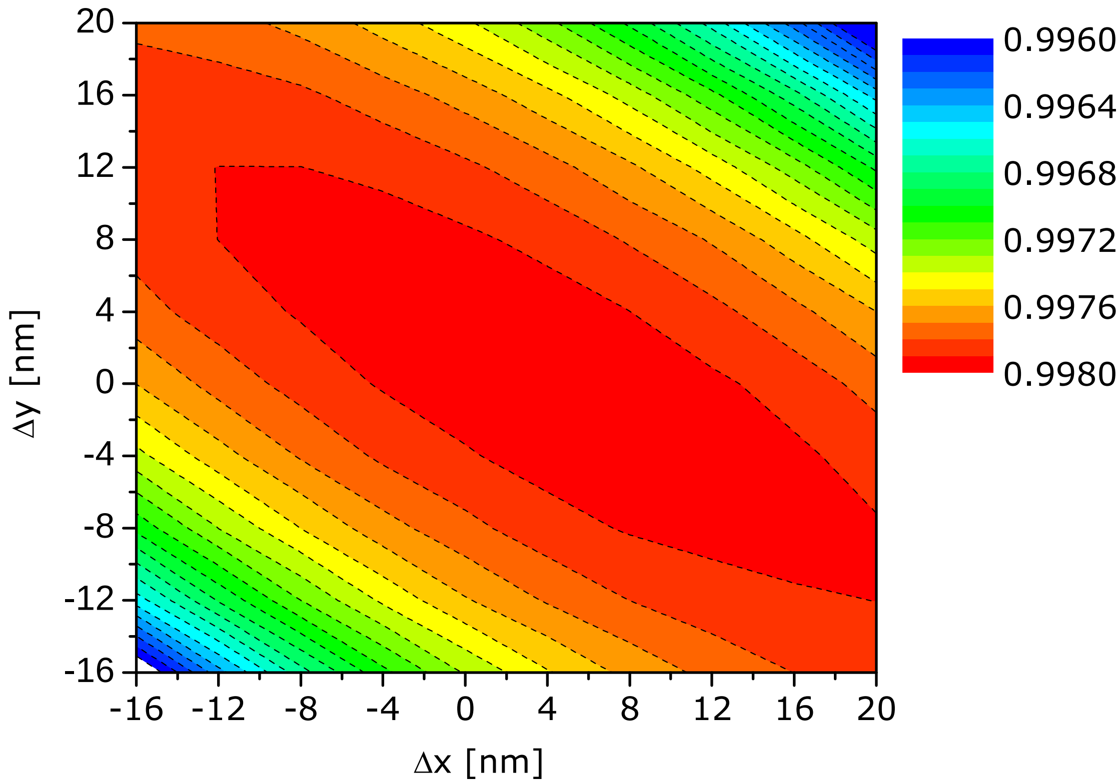
Metal	Ion bom-barment	TiO_2 buffer	SiO_2 1st layer	TiO_2	SiO_2
Ag	no	20	**133.9**	**113.3**	**180.4**
	yes	20	**135.9**	**122.7**	**181.7**
Au	no	20	**133.1**	113.3	180.4
	yes	20	**135.2**	122.7	181.7
Al	no	-	**163.2**	113.3	180.4
	yes	-	**160.0**	122.7	181.7
-	no	-	**180.4**	113.3	180.4
	yes	-	**181.7**	122.7	181.7

Simulation: Effect of thickness deviations on R

Deviation of thickness
from optimized thickness

SiO_2: $d_1 \pm \Delta x$
TiO_2: $d_2 \pm \Delta y$

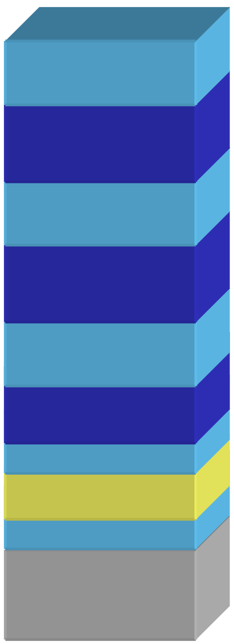




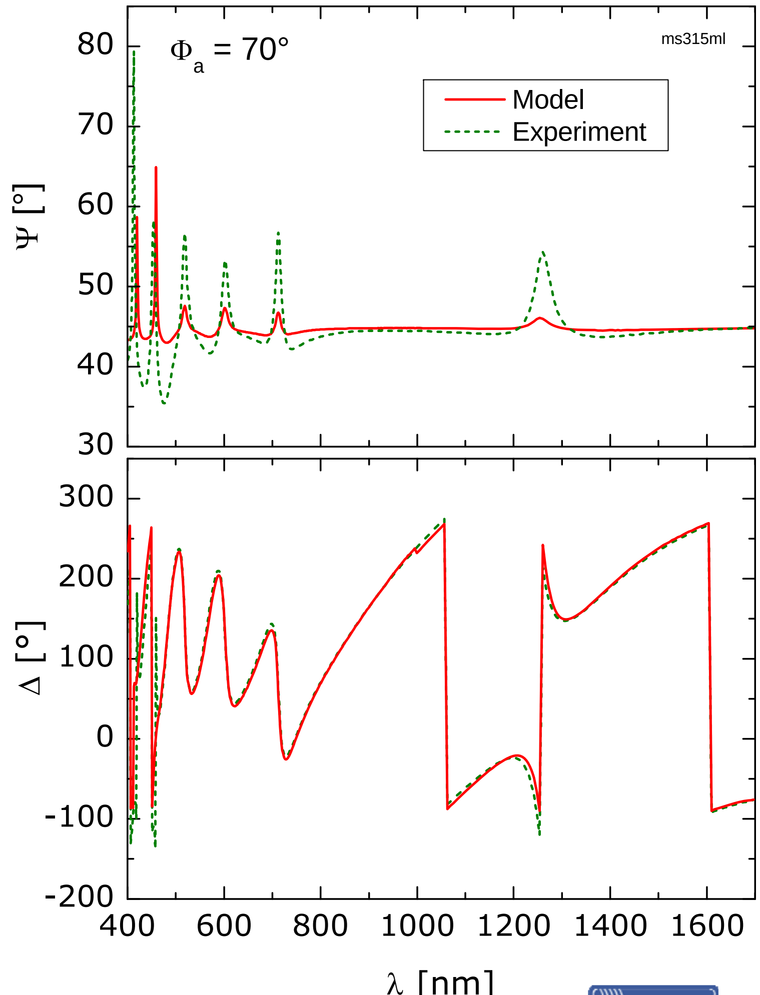
Thickness deviation of ± 10 nm reduces
reflectivity at λ = 1064 nm by 0.001

Ellipsometry analysis

Analysis I:
Cauchy term
without absorption



TiO_2	121.5 nm	122.7 nm
SiO_2	182.4 nm	181.7 nm
TiO_2	119.0 nm	122.7 nm
SiO_2	187.8 nm	181.7 nm
TiO_2	123.2 nm	122.7 nm
SiO_2	134.3 nm	135.9 nm
TiO_2	21 nm	20 nm
Ag	150 nm	
Ti	20 nm	



Large discrepancies for Ψ

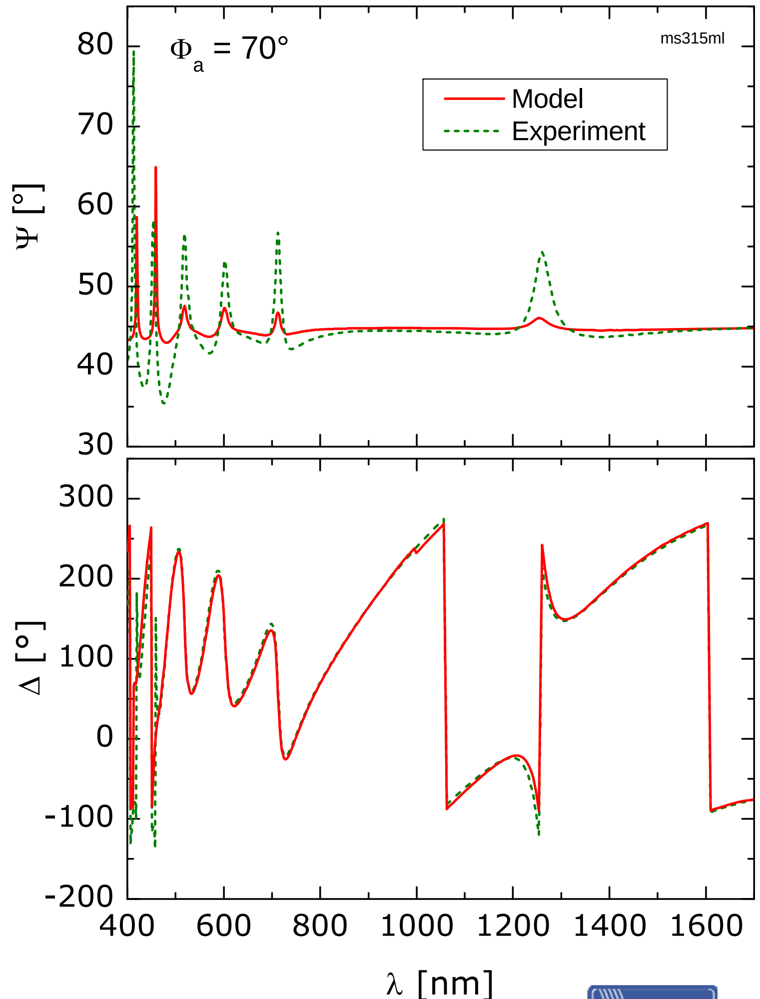
Ellipsometry analysis

What's the reason for the discrepancies in Ψ:

- Thickness inhomogeneity ?
- Interface roughness ?
- Interface mixing ?
- Absorption ?

SE analysis reveals absorption as reason for discrepancy !

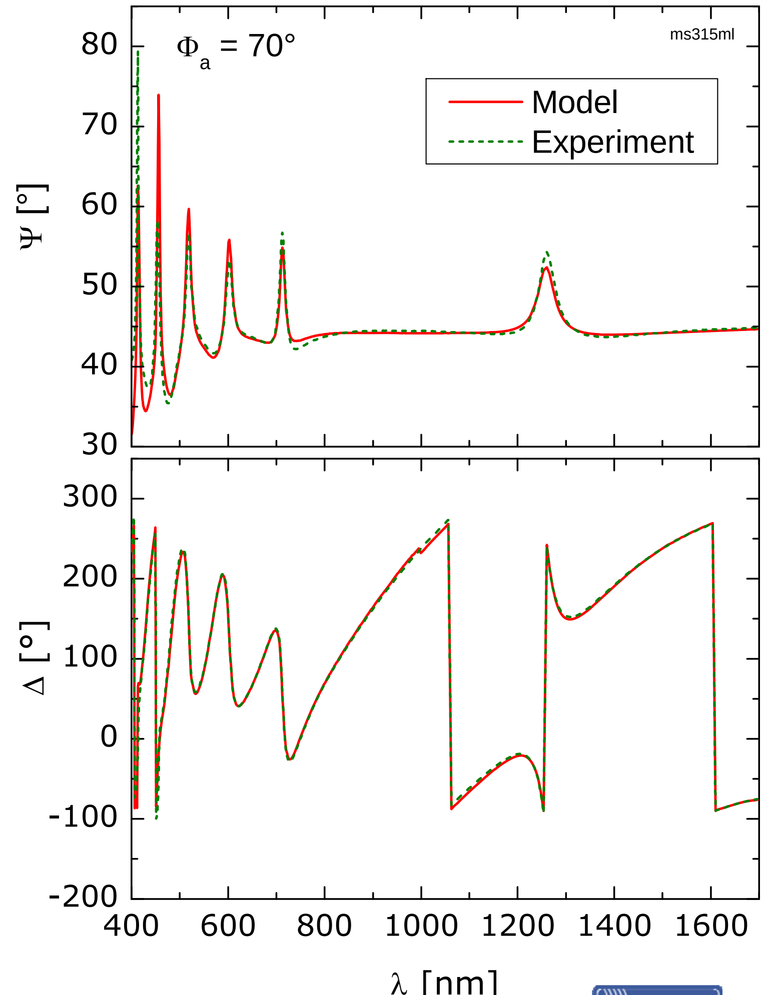
Localization of absorption ?



Ellipsometry analysis

Analysis II:
Cauchy term
with absorption

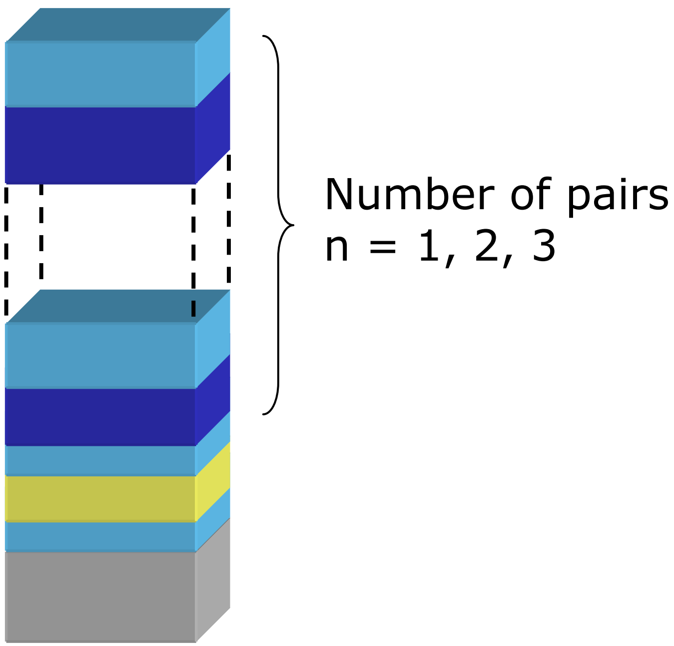
TiO_2	121.5 nm	122.7 nm
SiO_2	186.7 nm	181.7 nm
TiO_2	120.5 nm	122.7 nm
SiO_2	190.8 nm	181.7 nm
TiO_2	122.2 nm	122.7 nm
SiO_2	136.3 nm	135.9 nm
TiO_2	21 nm	20 nm
Ag	150 nm	
Ti	20 nm	

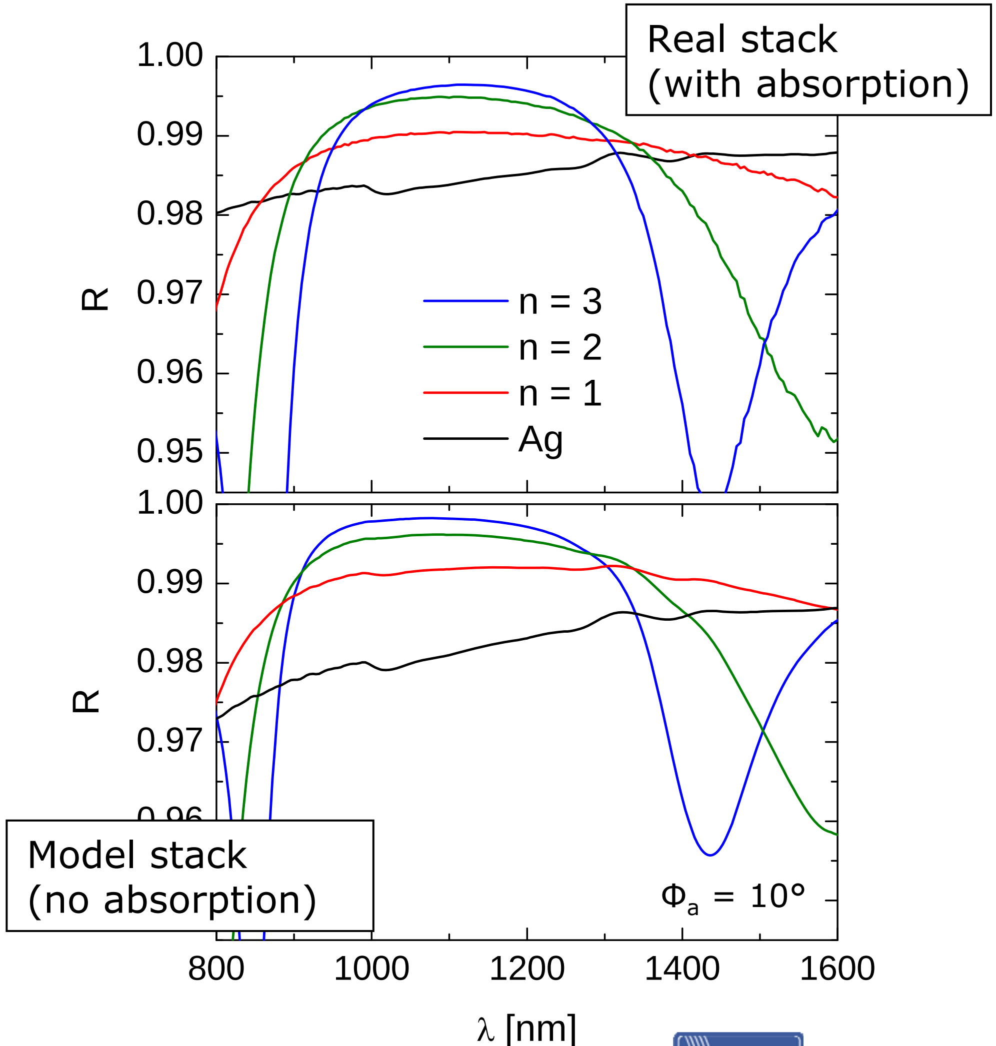


Modelled Ψ and Δ spectra match experimental data

Reflectivity

Reflectivity calculated from optical constants and thicknesses obtained by ellipsometry analysis





Experimental results of mirror stacks with Ag

Reflectivity

	Model thickness	1-Bragg-pair	2-Bragg-pairs	3-Bragg-pairs
TiO_2-Buffer	20 nm	15.9 nm	16.2 nm	18.9 nm
SiO_2 I	135 nm	140.4 nm	143.2 nm	142.7 nm
TiO_2 I	115 nm	120.1 nm	112.6 nm	111.5 nm
SiO_2 II	180 nm	-	203.1 nm	187.4 nm
TiO_2 II	115 nm	-	109.5 nm	119.4 nm
SiO_2 III	180 nm	-	-	179.2 nm
TiO_2 III	115 nm	-	-	115.2 nm
R at λ = 1064 nm				
Real stack		**0.990**	**0.994**	**0.996**
Model stack		**0.992**	**0.997**	**0.999**

Stress

Multilayers without ion bombardment: -550 … -700 MPa

Multilayers with ion bombardment: -150 … -250 MPa

Summary

Results:

- Model of mirror stack structure with optimized reflectivity at target wavelength based on results of properties of single layers
- Deposition of mirrors stacks by DIBD
- Ellipsometry characterization reveals absorption within dielectric layers
- Reflectivity losses due to absorption
- Stress relaxation in mirror structures grown with assisting ion beam (factor of 3 lower stress)

Tasks:

- Reduction of absorption within dielectric layers by optimization of growth process

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Thank you for your attention !

carsten.bundesmann[at]iom-leipzig.de

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