CISAS Università degli studi di Padova
Consiglio Nazionale delle Ricerche

Enrico Tessarolo, STASA XXX PhD Course

Optical components in space environments: fabrication, characterization and performance degradation

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Outline

- Introduction on space environment considered and potential damages induced on optical coatings
- Experiment layout
- Damage results in single layer coatings
- Damage results in bilayers coatings
- Conclusion and next steps

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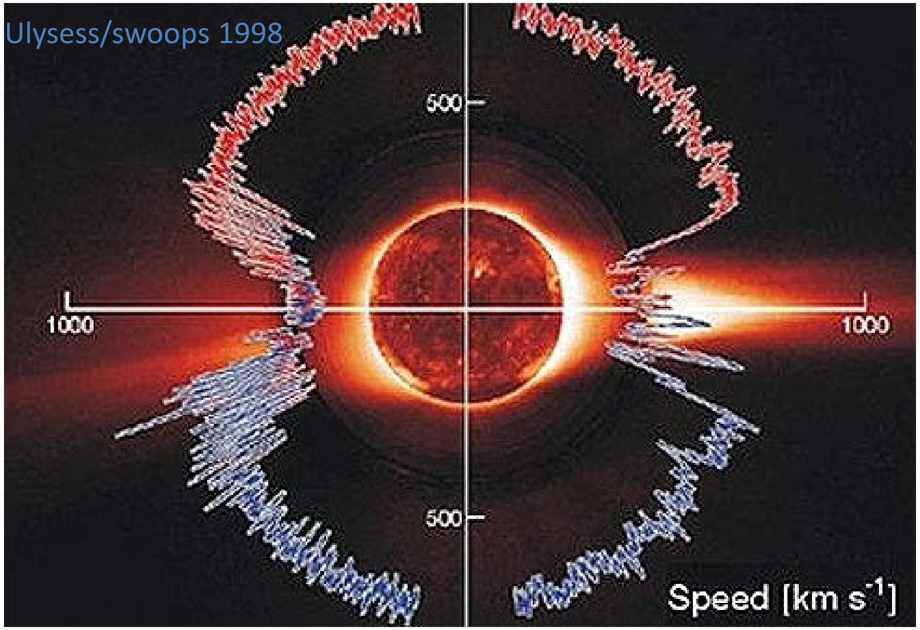
Solar Environment and the solar wind particles



Slow solar wind		
Species	**Energy (avg)**	**Composition %**
p	1 keV	95
He+	4 keV	5
Fast solar wind		
p	4 keV	95
He+	16 keV	5

Solar wind speed distribution:

Slow speed around ecliptic ~ 400 km/sec

Fast speed around poles ~800 km/sec

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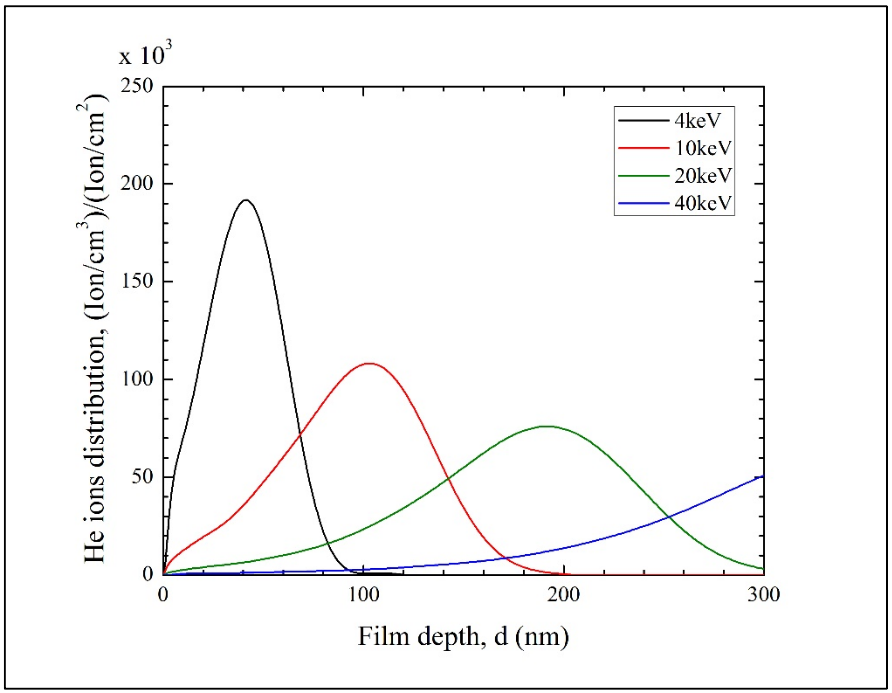
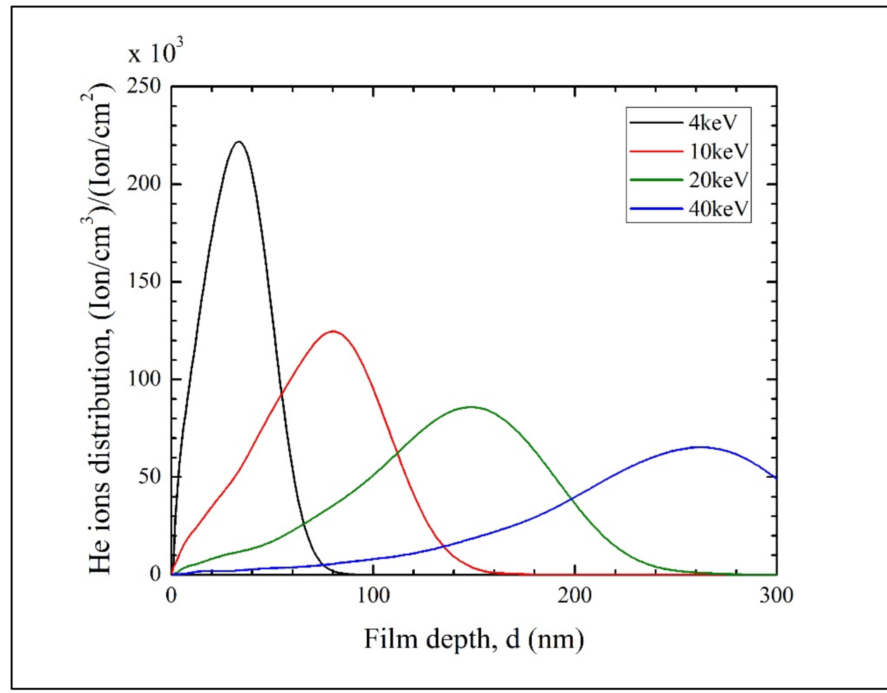
SRIM simulations in SiO_2 and TiO_2 single layers

He+ 300 nm SiO_2 layer



He+ 300 nm TiO_2 layer



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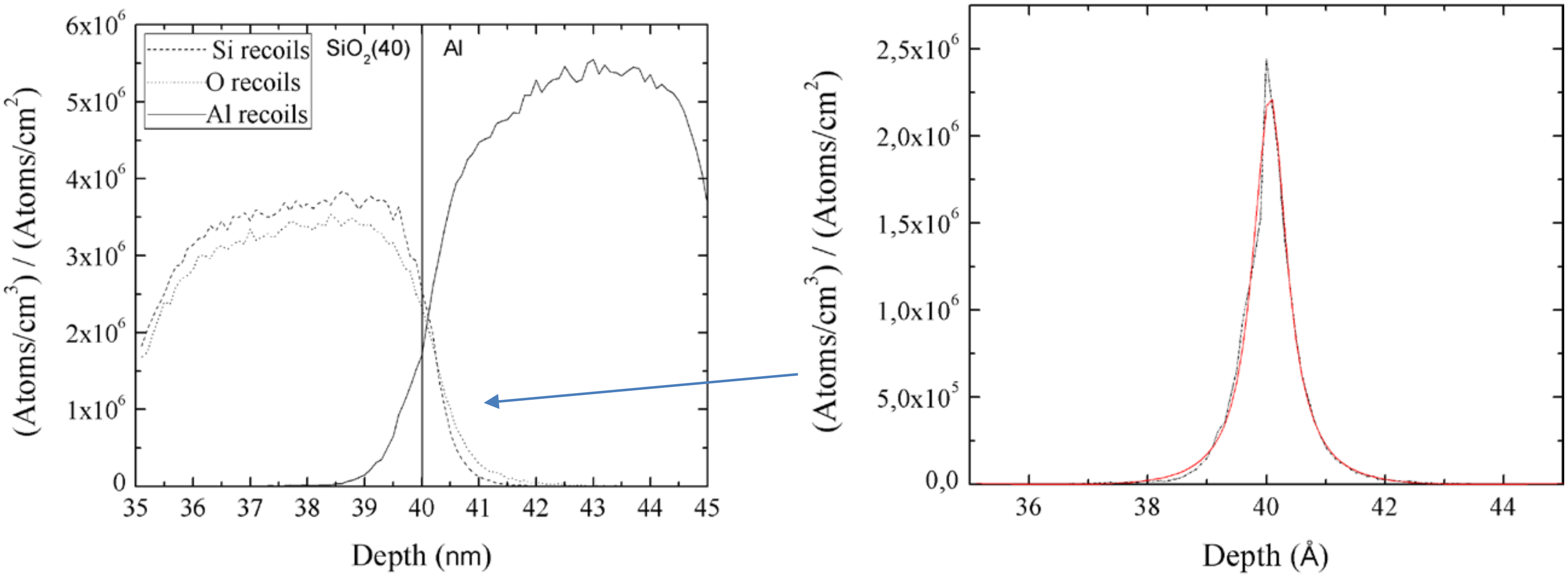
SRIM simulations in a SiO_2/Al bi-layer



Low dependence of the intermix width with respect to energies considered

SiO_2 Thickness (nm)	Energy (keV)	Intermix width (nm)	SiO_2 Thickness (nm)	Energy (keV)	Intermix width (nm)
10	He @ 4 keV	0,87	20	He @ 50 keV	0,71
40	He @ 4 keV	0,88	130	He @ 16 KeV	0,82
70	He @ 4 keV	0,80	200	He @ 50 keV	0,76

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Potential damages in optical coatings

a) When the energy is very low, ions highly concentrate close to the surface. Depending on irradiation doses (and fluxes) the following damages can be observed:
   - Optical properties changes (doping)
   - Morphological changes (superficial roughness)
   - Delamination in case of multilayers (blistering)
   - Enhanced intermixing at interfaces

b) As the energy increases, the ions spread in a larger portion of the film
   - The same damages occurs at higher doses

c) As the energy increases further, the ions overcome the coating

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Experimental layout

Sample Name	Ion Energy He+	Flux ($cm^{-2}s^{-1}$)	Dose (cm^{-2})	Session Code
Au	4 keV	L : $1.6\cdot10^{12}$	L : $4\cdot10^{16}$	**4LL**
	4 keV	H : $1.6\cdot10^{13}$	L : $4\cdot10^{16}$	**4HL**
	4 keV	H : $1.6\cdot10^{13}$	L : $4\cdot10^{16}$	**4HL**
SiO_2(20)/Al	4 keV	L : $1.6\cdot10^{12}$	L : $4\cdot10^{16}$	**4LL**
	4 keV	H : $1.6\cdot10^{13}$	L : $4\cdot10^{16}$	**4HL**
SiO_2(40)/Al	4 keV	L : $1.6\cdot10^{12}$	L : $4\cdot10^{16}$	**4LL**
	4 keV	H : $1.6\cdot10^{13}$	L : $4\cdot10^{16}$	**4HL**
SiO_2(140)/Al	16 keV	H : $1.6\cdot10^{13}$	H : $4\cdot10^{17}$	**16HH**
TiO_2(30)/Al	4 keV	L : $1.6\cdot10^{12}$	L : $4\cdot10^{16}$	**4LL**
	4 keV	H : $1.6\cdot10^{13}$	L : $4\cdot10^{16}$	**4HL**
TiO_2(95)/Al	16 keV	H : $1.6\cdot10^{13}$	H : $4\cdot10^{17}$	**16HH**

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Ions implantation facility

Ion Beam Center at the Helmholtz-Zentrum Dresden-Rossendorf

Ions delivery with energies in the range 200 eV - tens MeV

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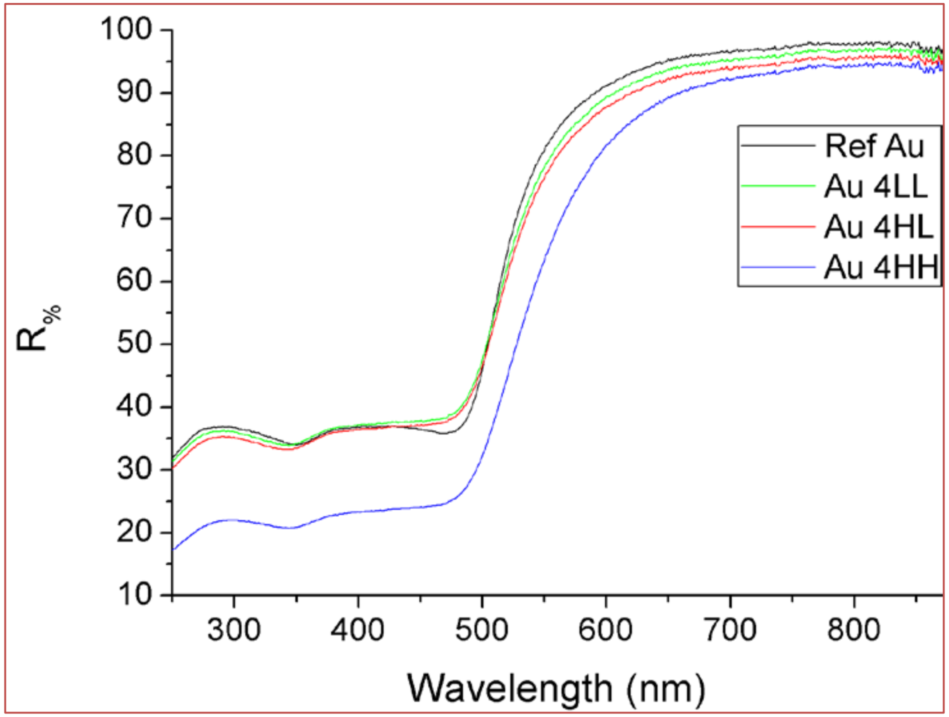
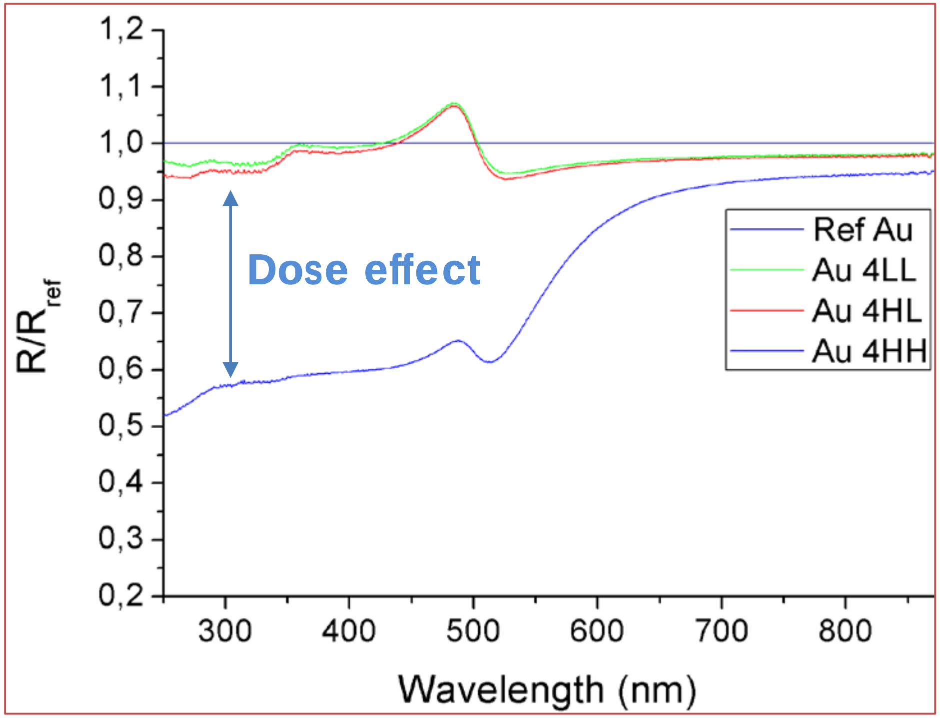
Damage results in single layer coatings (1)

Au single layer
Absolute specular reflectance
5° incidence angle



Au single layer
Relative total reflectance
8° incidence angle



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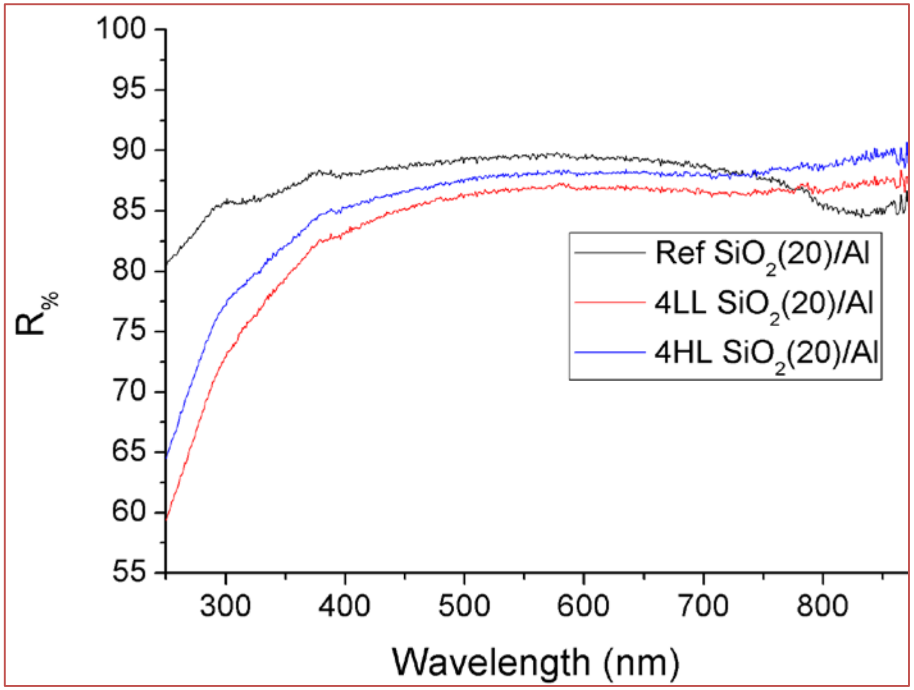
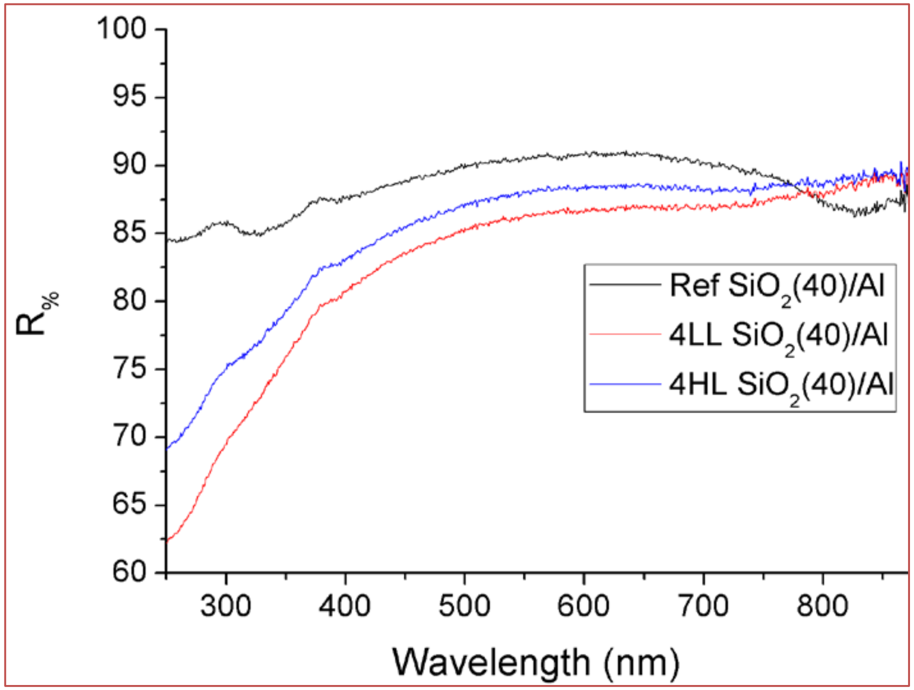
Damage results in bi-layer coatings – role of flux





- Similar behaviour of the reflectance drops
- The 4LL irradiated samples have a higher reflection drop than 4HL irradiated samples → given a dose, low fluxes induce more damage

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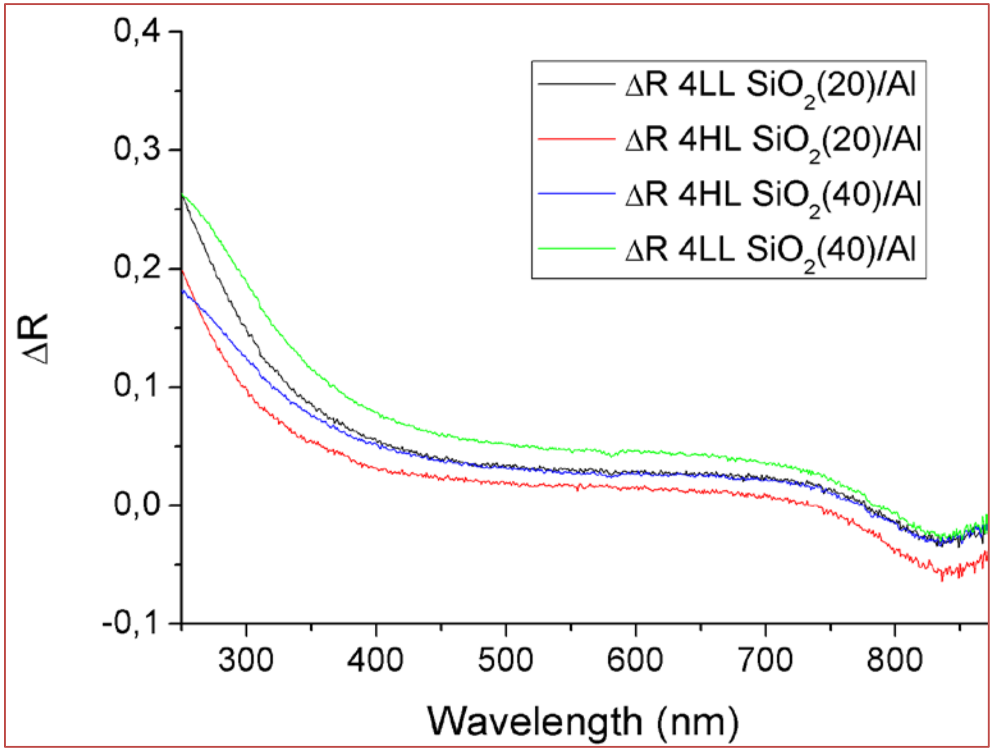
Damage results in bi-layer coatings – role of flux (2)

$$\Delta R = (R_{ref} - R_{irradiated})/R_{ref}$$



- ΔR depends on the flux;
- ΔR depends on the capping layer thickness;
- Varying flux, the ΔR drop in sample $SiO_2(40)/Al$ is the same as in $SiO_2(20)/Al$.

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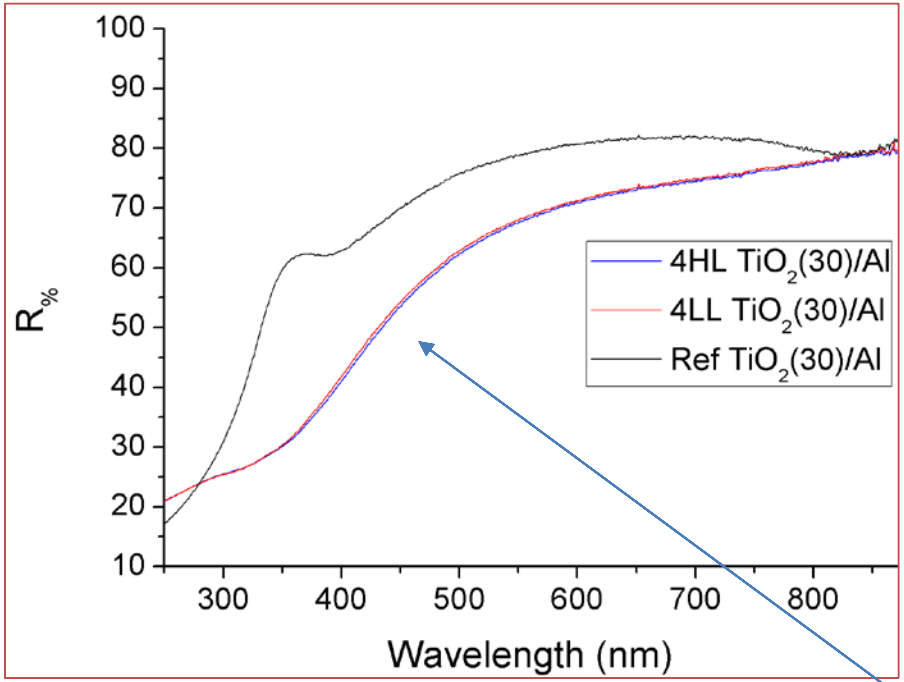
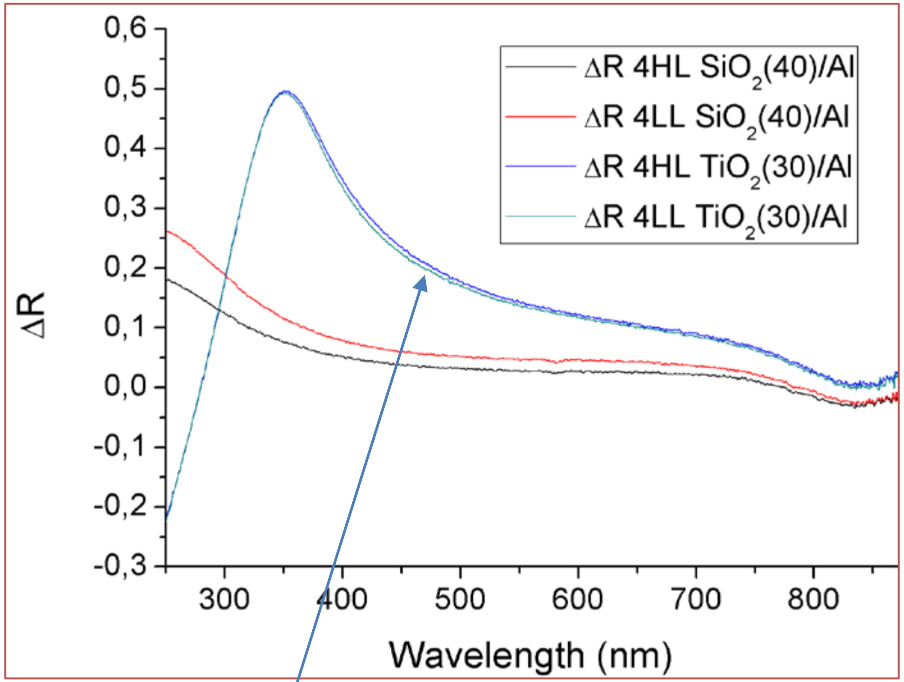
Damage results in bi-layer coatings – role of capping layer material





Slight flux dependence for TiO_2 capping layer

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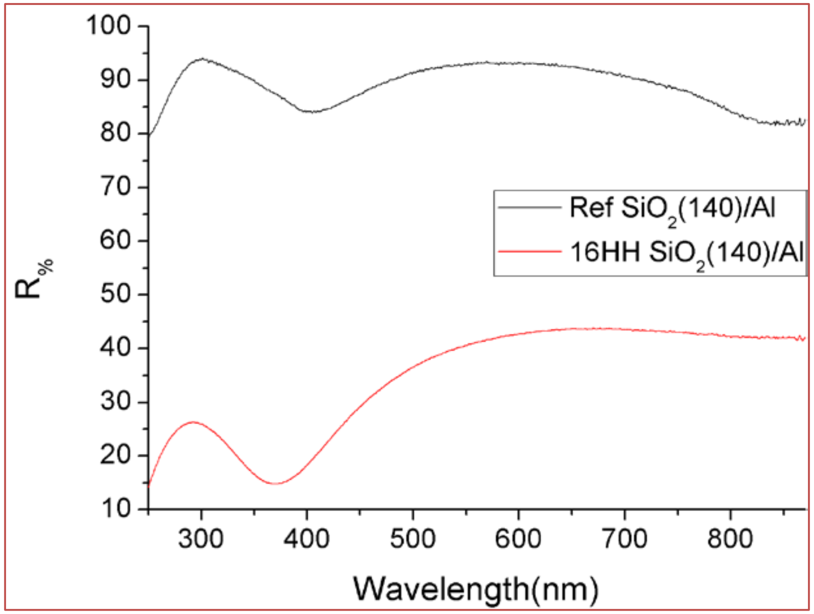
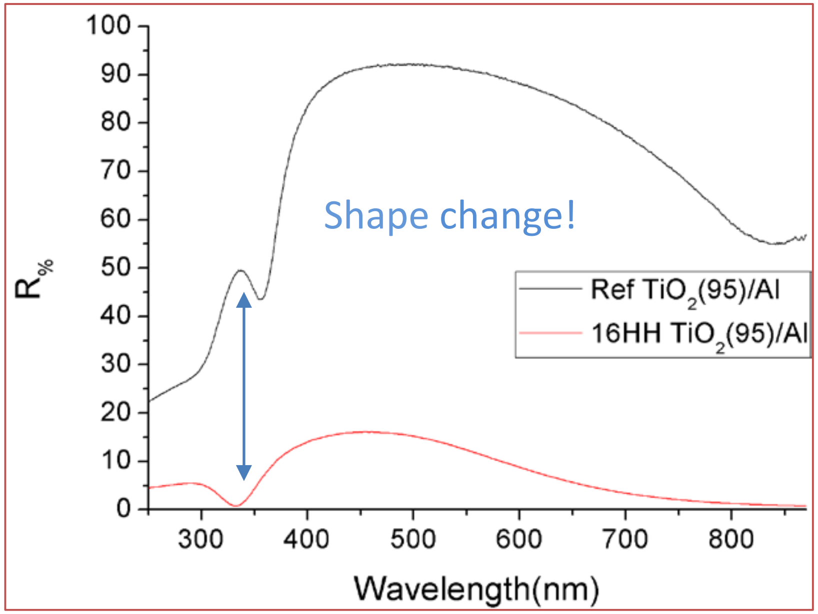
Damage results in bi-layer coatings – role of ions energy





- Irradiation session with 16 keV He ions show a dramatic reflectance drop!
- The TiO_2(95)/Al sample show also a different reflectance behaviour

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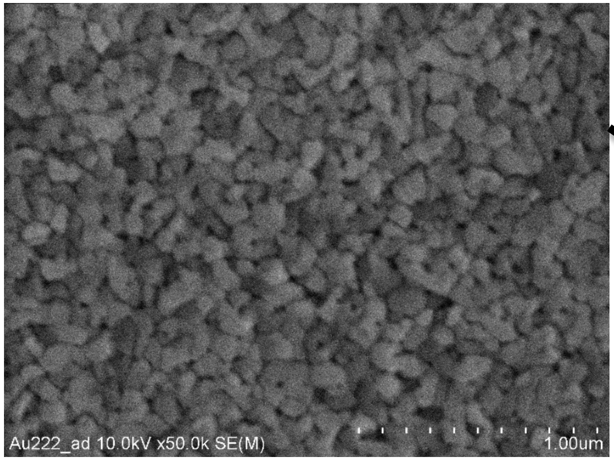
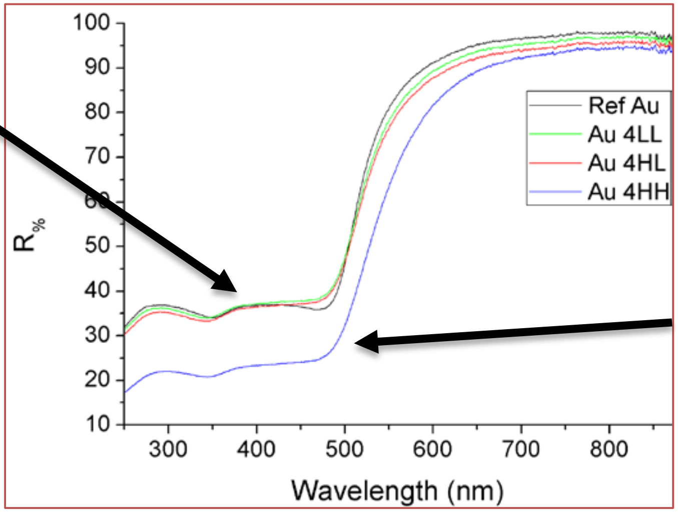
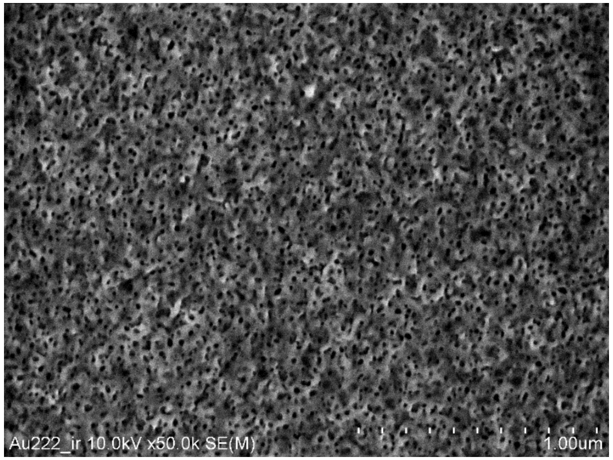
Damage results in Au thin film – HR-SEM







Comparison between surface SEM images of Au irradiated with 4 keV He+ ions
The material nanostructure is completely modified by the ion irradiation:

- Surface amorphization,
- Pours structure with consequent reduced density.

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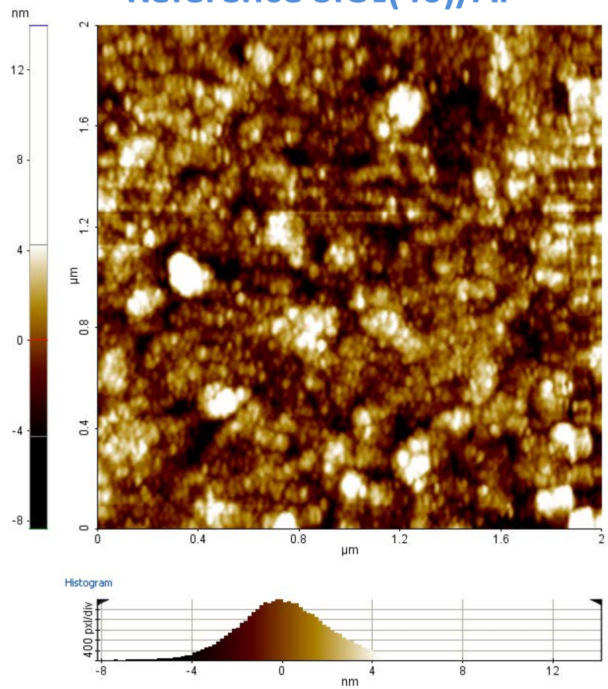
Damage results in bi-layer coatings – surface morphology (1)

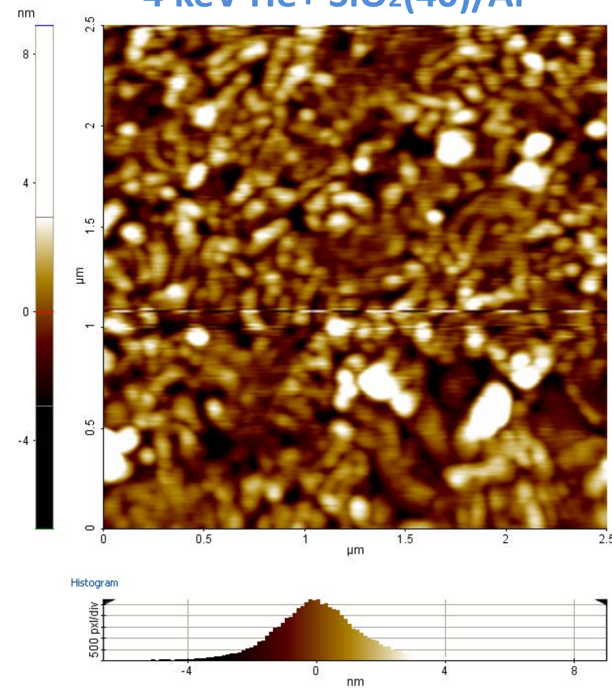
Reference SiO_2(40)/Al



Statistics

Region	Min(nm)	Max(nm)	Mid(nm)	Mean(nm)	Rpv(nm)	Rq(nm)	Ra(nm)
Whole	-8.355	13.974	2.809	0.000	22.329	2.165	1.661

4 keV He+ SiO_2(40)/Al



Statistics

Region	Min(nm)	Max(nm)	Mid(nm)	Mean(nm)	Rpv(nm)	Rq(nm)	Ra(nm)
Whole	-6.736	8.888	1.076	0.000	15.624	1.494	1.112

No evident change of surface roughness for low fluences

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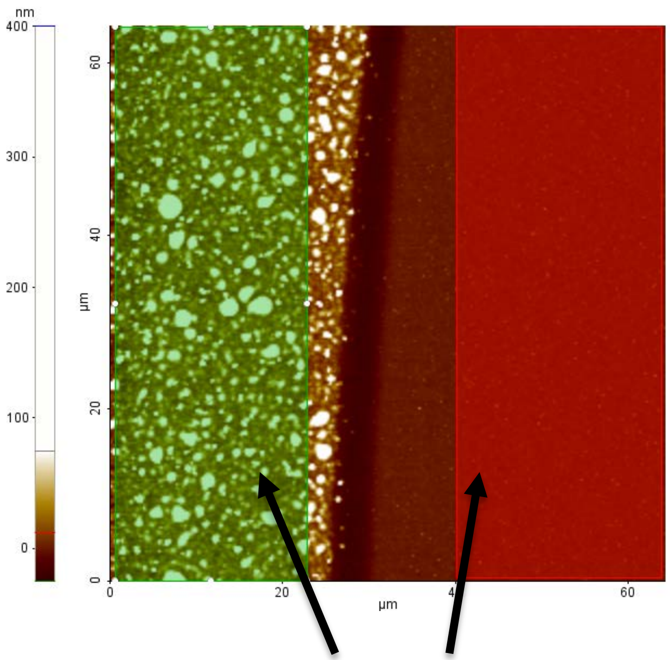
Damage results in bi-layer coatings – surface morphology (2)

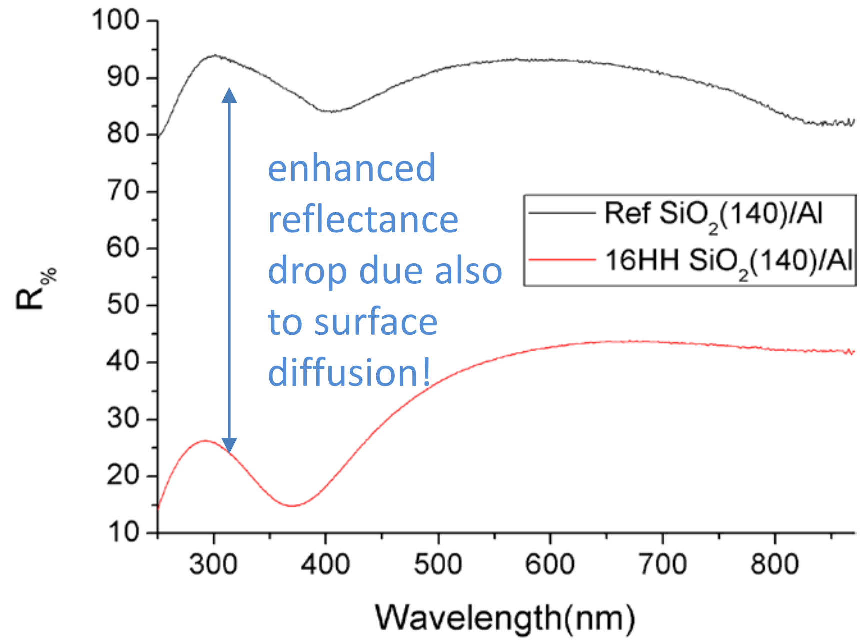


Evident change of surface roughness for high fluences

Sample SiO_2(140)/Al irradiation session 16HH:

Green → Irradiated area roughness ~41 nm

Red → Not irradiated area roughness ~2 nm



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Ph.D. Outcomes

- The effects of ion irradiation on thin film, and thin film structures has been studied along this 3-years Ph.D. project;
- Irradiation key-factor has been studied: fluence, flux, ion energy and type;
- Guidelines for space qualifications of optical components has been determined;
- Different surface and bulk analysis (AFM, XRR, SEM, TEM) has allowed connect optical performance degradation to surface/bulk modifications.
- An Effective medium model has been proposed to predict the optical performance degradation of irradiated optics

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Ph.D. Outcomes: publications

1. Pelizzo, M. G., Corso, A. J., Tessarolo, E., Martucci, A., Donazzan, A., Böttger, R., ... & Napolitani, E. (2017). Qualification tests of optical coatings in space environment. In Metrology for AeroSpace (MetroAeroSpace), 2017 IEEE International Workshop on (pp. 228-233). IEEE.

2. Tessarolo, E., Corso, A. J., Böttger, R., Martucci, A., & Pelizzo, M. G. (2017). Ions irradiation on bi-layer coatings. In Astronomical Optics: Design, Manufacture, and Test of Space and Ground Systems (Vol. 10401, p. 104010A). International Society for Optics and Photonics.

3. Corso, A. J., Tessarolo, E., Martucci, A., & Pelizzo, M. (2017). Systematic investigation of the optical coatings damages induced in harsh space environment. In Astronomical Optics: Design, Manufacture, and Test of Space and Ground Systems (Vol. 10401, p. 104010B). International Society for Optics and Photonics.

4. Pelizzo, M. G., Corso, A. J., Tessarolo, E., Zuppella, P., Böttger, R., Huebner, R., ... & Foggetta, L. (2016). Optical components in harsh space environment. In Planetary Defense and Space Environment Applications (Vol. 9981, p. 99810G). International Society for Optics and Photonics.

5. Zuccon, S., Napolitani, E., Tessarolo, E., Zuppella, P., Corso, A. J., Gerlin, F., ... & Pelizzo, M. G. (2015). Effects of helium ion bombardment on metallic gold and iridium thin films. Optical Materials Express, 5(1), 176-187.

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Thank you for you attention!

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