EUV MULTILAYER COATINGS FOR SPACE APPLICATIONS

P. Nicolosi

Dept of Information Engineering - University of Padova
CNR - National Research Council of Italy
Institute for Photonics and Nanotechnologies
Padova, LUXOR laboratory

COST Meeting 16-18 Nov 2011 Paris, France

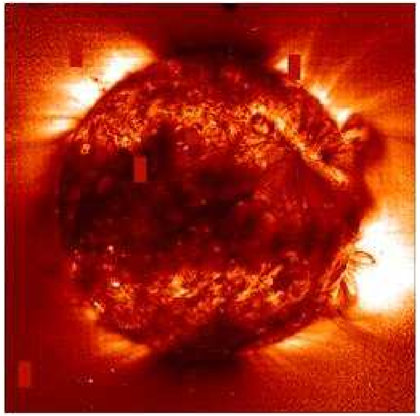
EUV multilayer coatings applications

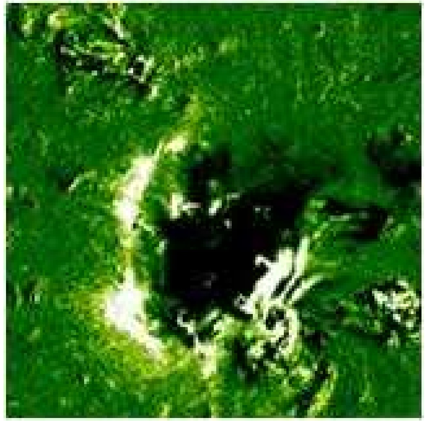
special and extreme

EUVL
HHG
SPACE
FEL

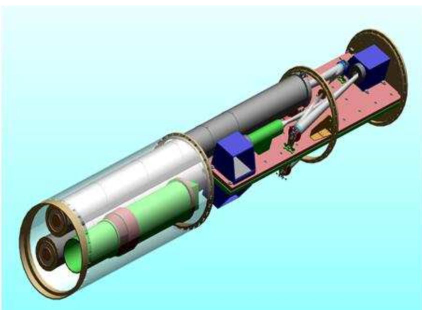
Application to solar physics

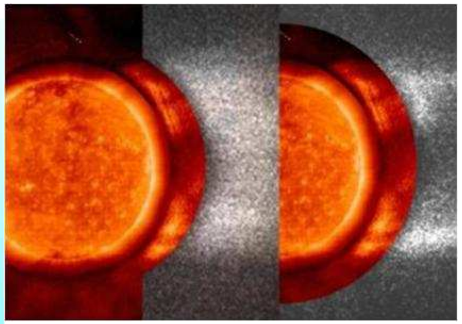
PAST: SOHO EIT, TRACE



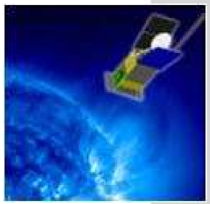


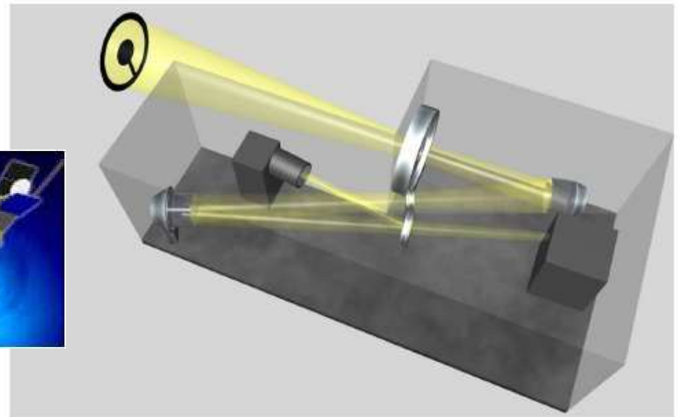
NOW: SCORE
SOUNDING ROCKET





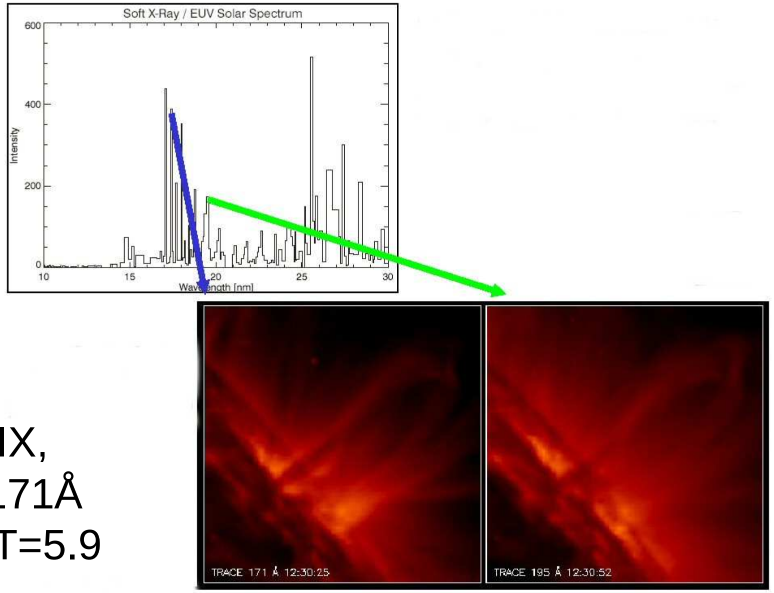
FUTURE: SOLO METIS





DEPARTMENT OF INFORMATION ENGINEERING
UNIVERSITY OF PADOVA

Application to Solar physics



Fe IX,
λ=171Å
logT=5.9

Fe XII,
λ=195 Å
logT=6.2

Solar telescopes need to be tuned to specific coronal emission lines to allow “monochromatic” high-resolution imaging.

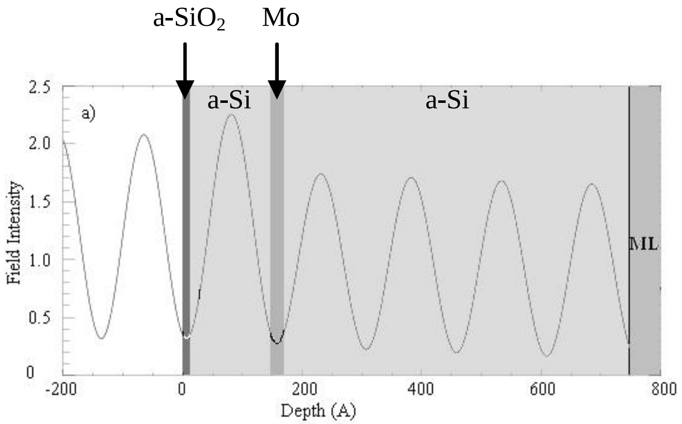
- Multilayer for solar line observations have been fabricated at Fe-IX (17.1 nm), Fe-XII (19.5 nm), Fe-XV (28.4 nm) and He-II (30.4 nm).
- Performance of such MLs have been evaluated in terms of **peak reflectivity** at working wavelength and **rejection capability** of unwanted lines
- Capping layer can be also important for lifetime

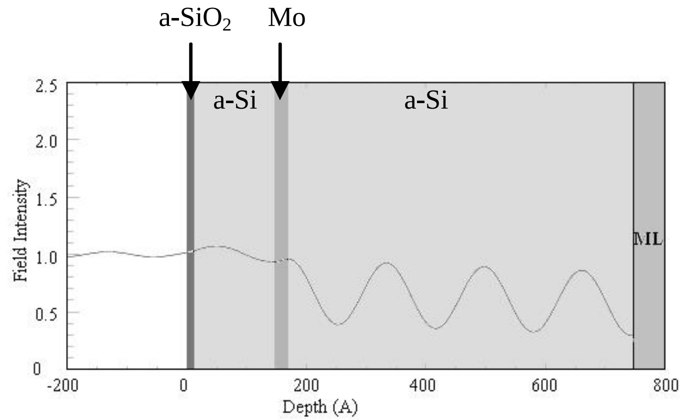
Application to Solar physics

$\lambda_{noise} \rightarrow$ 30.4 nm (He-II)

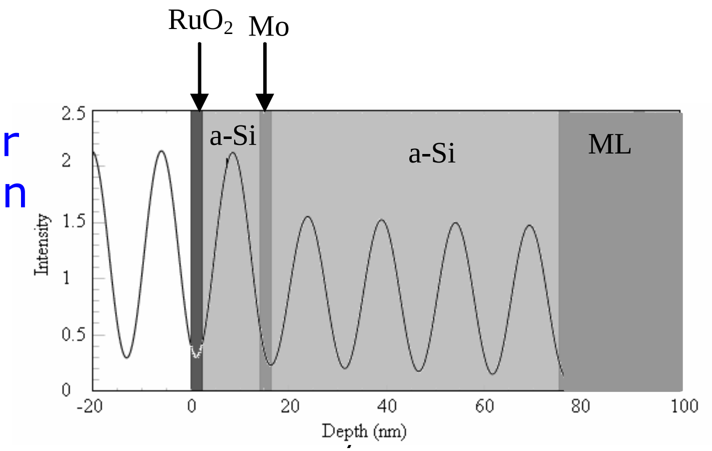
$\lambda_{peak} \rightarrow$ 28.4 nm (Fe-XV)

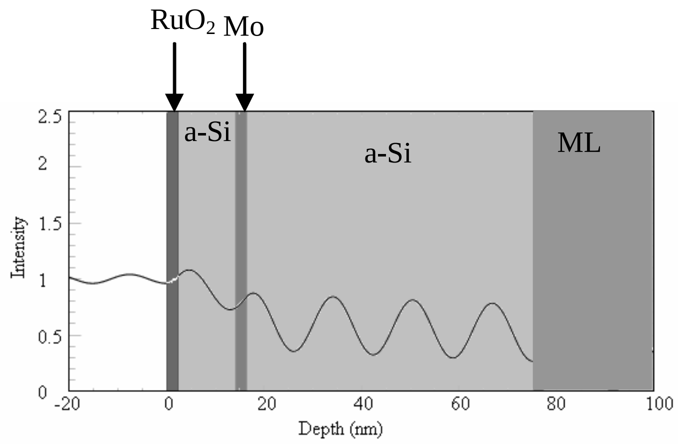
Mo/Si CL



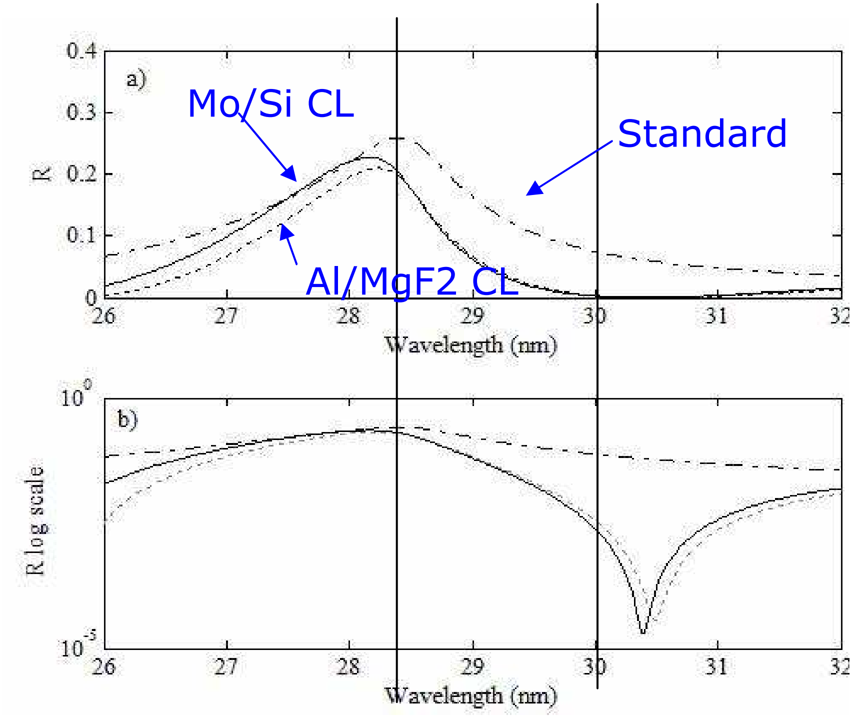


Mo/Si CL + Ru layer on top for protection

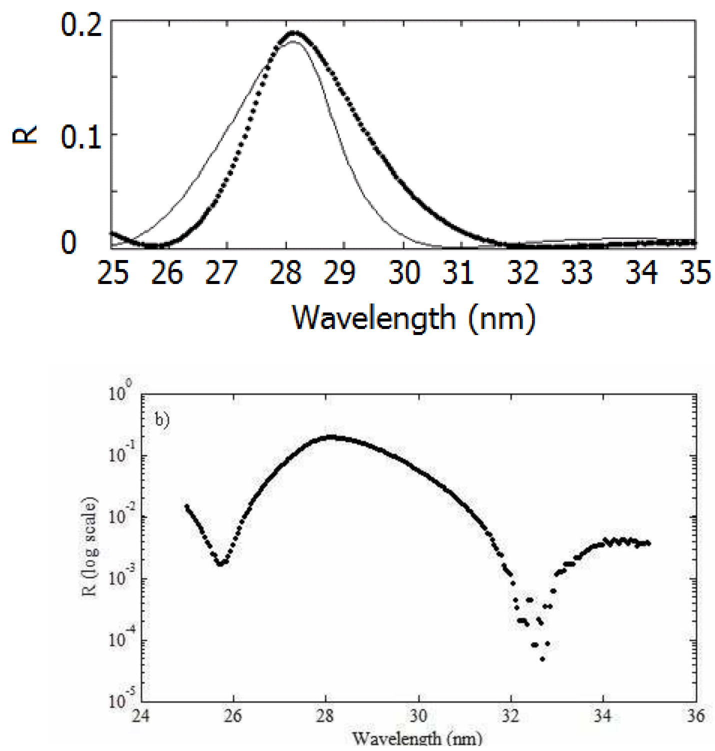




Application to Solar physics



Mo/Si CL



Application to Solar physics

SCORE sounding rocket experiment

ML for multiband observations (30.4, 121.6, 450-600)

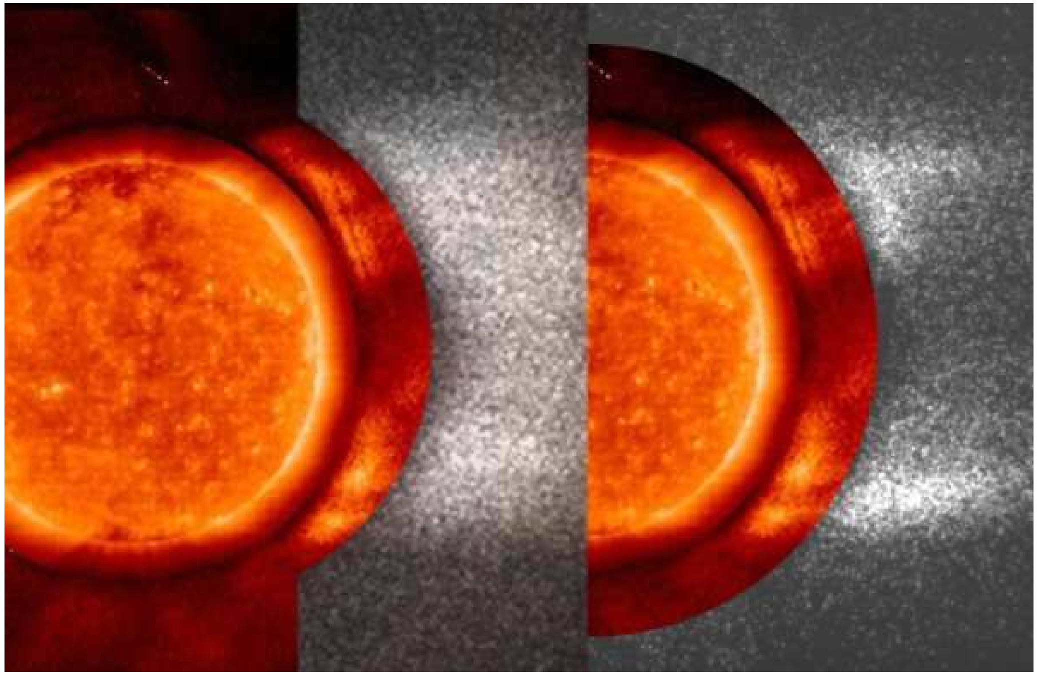
SiC/Mg
MLS

Application to Solar physics

SCORE sounding rocket experiment

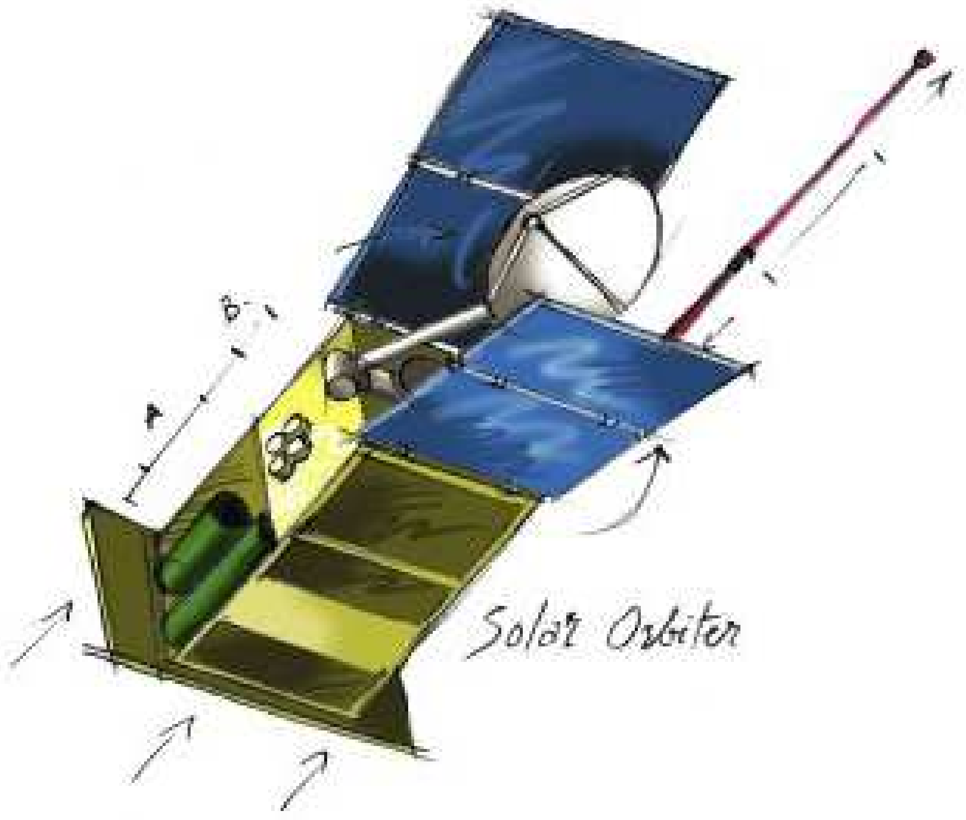
cromosphere (HEIT), inner corona (HECOR) @ He 304 A and outer corona (SCORE) @ HI 1216 A

cromosphere (HEIT), inner corona (HECOR) @ He 304 A and outer corona (SCORE) @ He 304 A



SOLar Orbiter (SOLO)

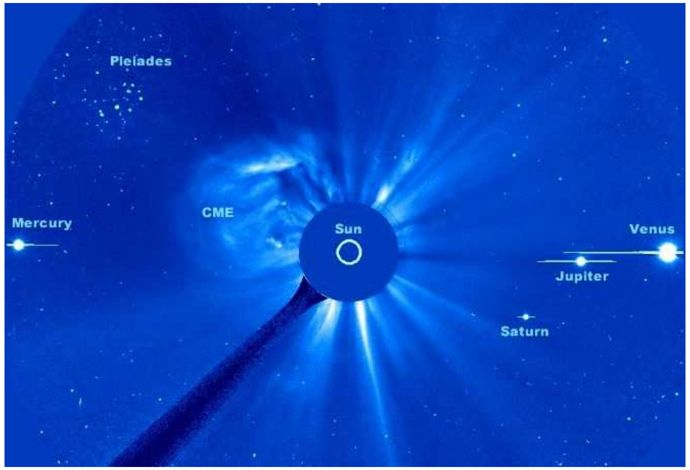
SOLar Orbiter mission is candidate for launch in January 2017. Its orbiting around the Sun will last about 7,5 years and will take it as close as 0,23 A.U, with increasing inclination up to more than 30° with respect to the solar equator, being able to view the solar atmosphere with high spatial resolution, covering the poles and the sun-side not visible from Earth.

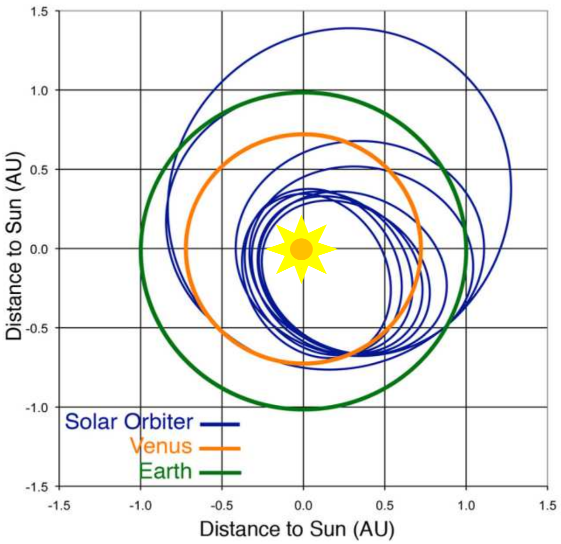


SOLO structure drawung

SOLO environment operation

- SOLO will be the closest mission to the sun
- Minimum perihelium will be 0.23 AU
- Temperature of MO: 236°
- Ion bombardment, H+ energy: 1 KeV



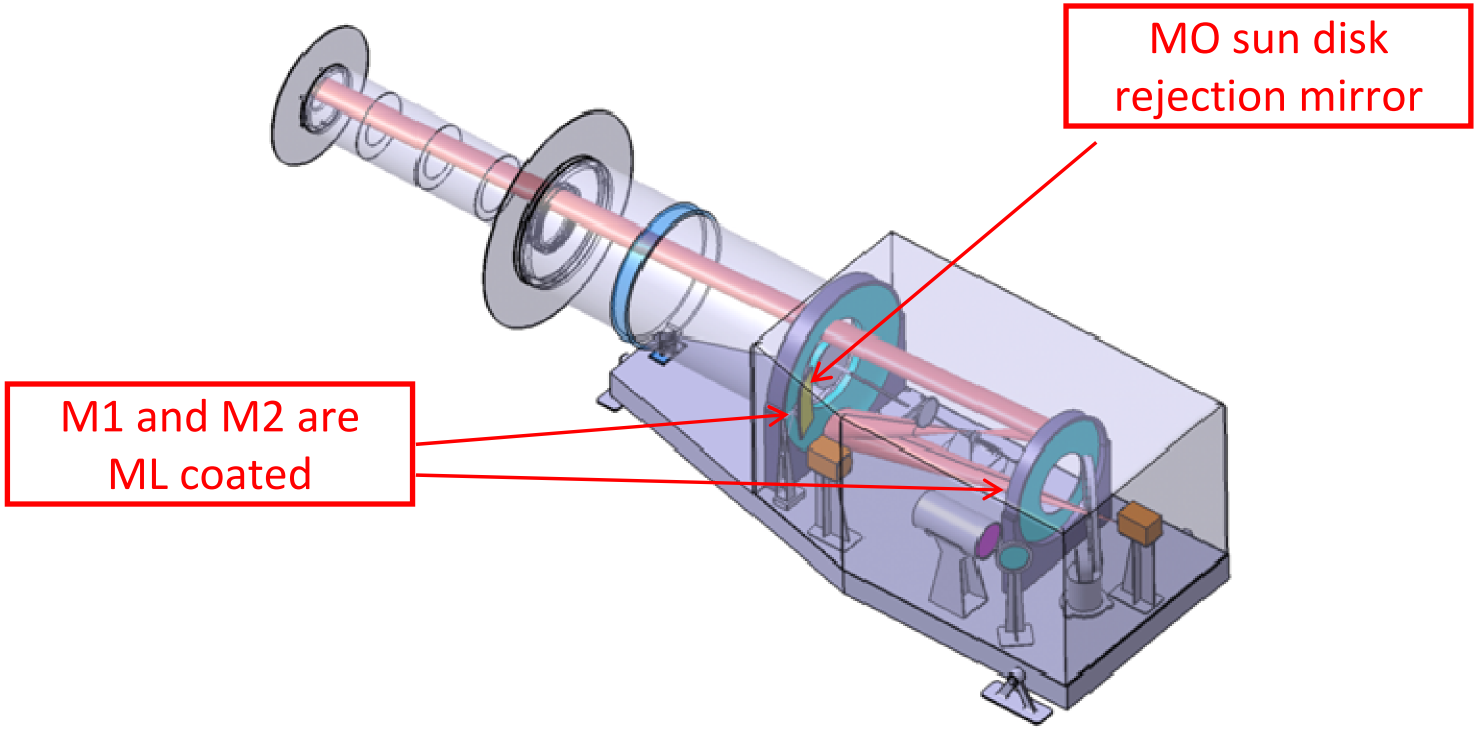


ESA Solar Orbiter Enviromental Specification, Issue2, 2008

	At 1AU (in the earth)	average
H+ Density (cm^{-3})	8,7	25
H+ Speed (km/s)	468	468
N_{alpha}/N_{proton}	0,047	0,047
N_{O}^{6+}/N_{proton}	0,0003	0,0003
N_{Fe}^{10+}/N_{proton}	$8,77 \times 10^{-6}$	$8,77 \times 10^{-6}$

METIS on board of SOLar Orbiter

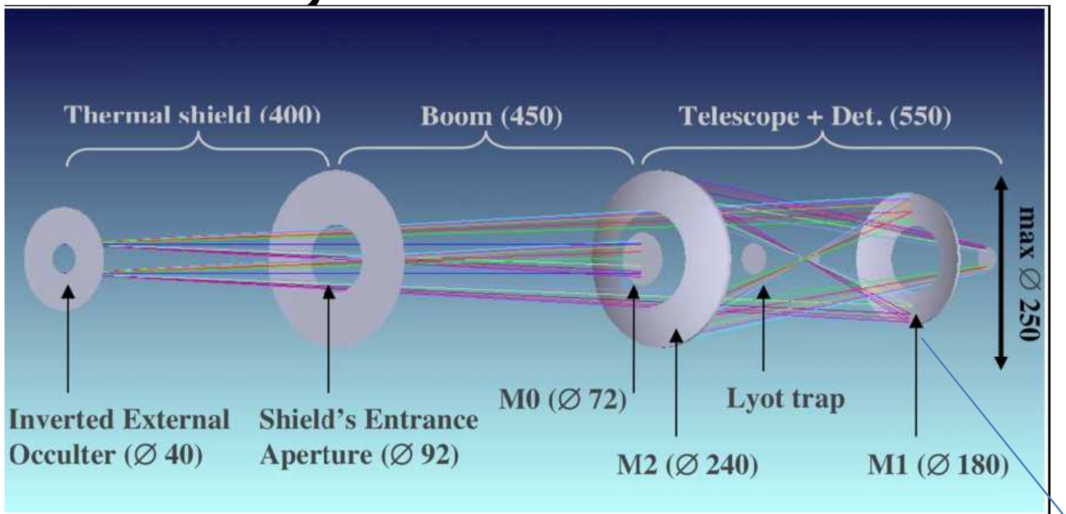
The Multi Element Telescope for Imaging and Spectroscopy (METIS) is an inverted – occultation coronograph on board of the SOLO payload. It is devoted to image the solar corona in three different spectral ranges at 30,4 nm (He-II Lyman – α line), 121,6 nm (H-I Lyman – α line) and in the visible range (450 – 600 nm) by using a combination of band pass filter and high – reflectivity multilayer mirrors.



METIS drawung

Multilayers for METIS

METIS optical drawung



The telescope design consists of two concave mirrors with ring shape. M0, M1 and M2 have to be multilayer coated.

M1 mirror

Requirements:

- High peak reflectivity at 30,4 nm, 121,6 nm, and in the visible range (450 – 600 nm)
- Stability over time
- Thermal stability
- High resistance to ion bombardments

Multilayers for METIS
State of art

- **Mo/Si** At wavelengths longer than the Si – L absorption edge at 12,4 nm, Mo/Si multilayer are conventionally used for their high stability and fairly high reflectivity. However, reflectivity of the Mo/Si multilayer decreases gradually when the wavelenght increases and the 30,4 nm reflectivity reduces to approximately 20%

- **Si/B_4C** Reflectance up to 25% can be obtained with **Si/B_4C** stack; however it has been verified to be unstable on the long term.

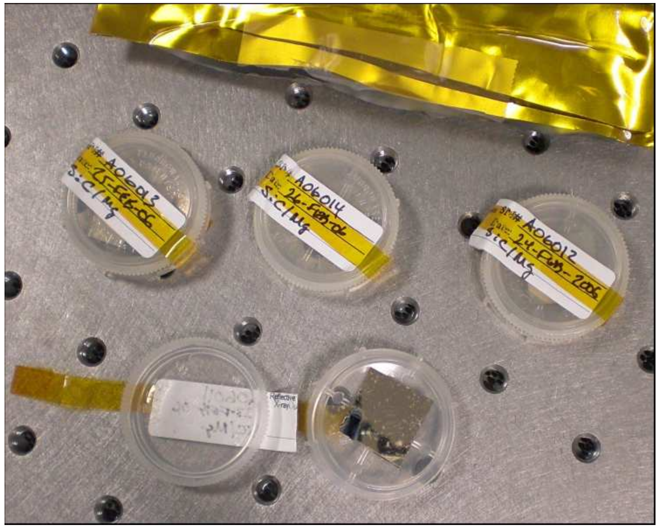
- **Mg/SiC** It could be a perfect candidate. It achieves up to 40% reflectance at 30,4 nm, and its stability has been deeply investigated. It has been selected to coat a mirror on board of the METIS prototype, the NASA Sounding – Rocket Coronographic Experiment (SCORE). …It could be a perfect solution…. But….

Multilayers for METIS
Mg/SiC … why not?

- Mg/SiC samples with different thickness ratio between the two materials and capping layers characteristics have been fabricated .

- They offer superior performances in terms of reflectivity, but from our experience not always in terms of stability on the long run.

- For example, the regular handling and the atmosphere exposure affect the performances of the coatings.



SiC/Mg samples

In this scenario, we have investigated alternative solutions.

Multilayers for METIS
Alternative solutions

•ML with different capping layer (CL) materials (4 different types):

1. Mo/Si + CL 1
2. Mo/Si + CL 2
3. Mo/Si + CL 3
4. Mo/Si + CL 4

(Samples fabricated on Si wafer)

- Ir/Si ML (Samples fabricated on Si wafer)

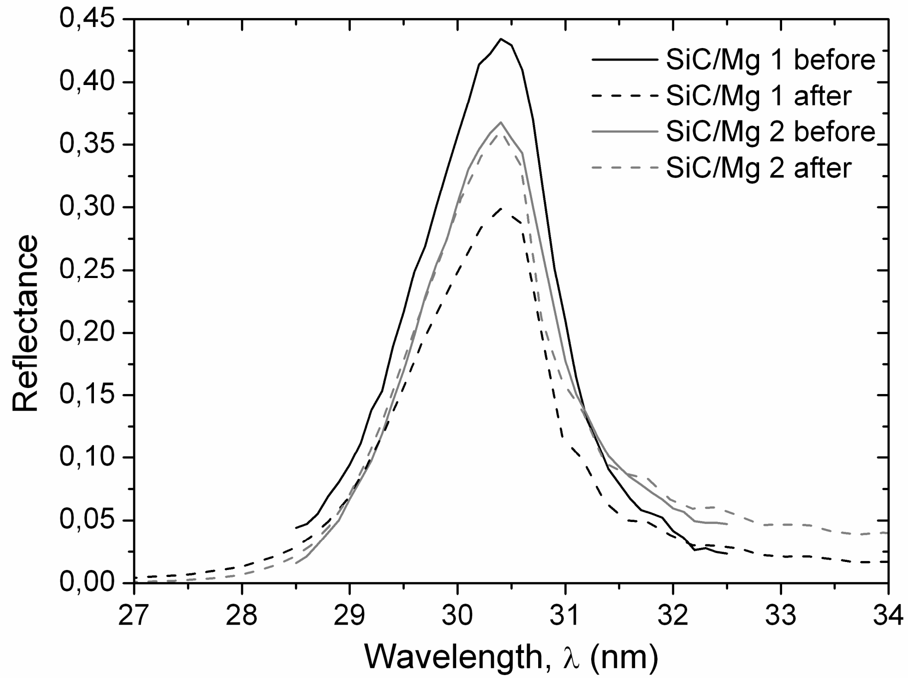
New samples

The samples have been designed at LUXOR Laboratory and deposited at Reflective X-ray Optics LLC (New York, USA) by DC magnetron sputtering onto polished Si (100) substrates*.

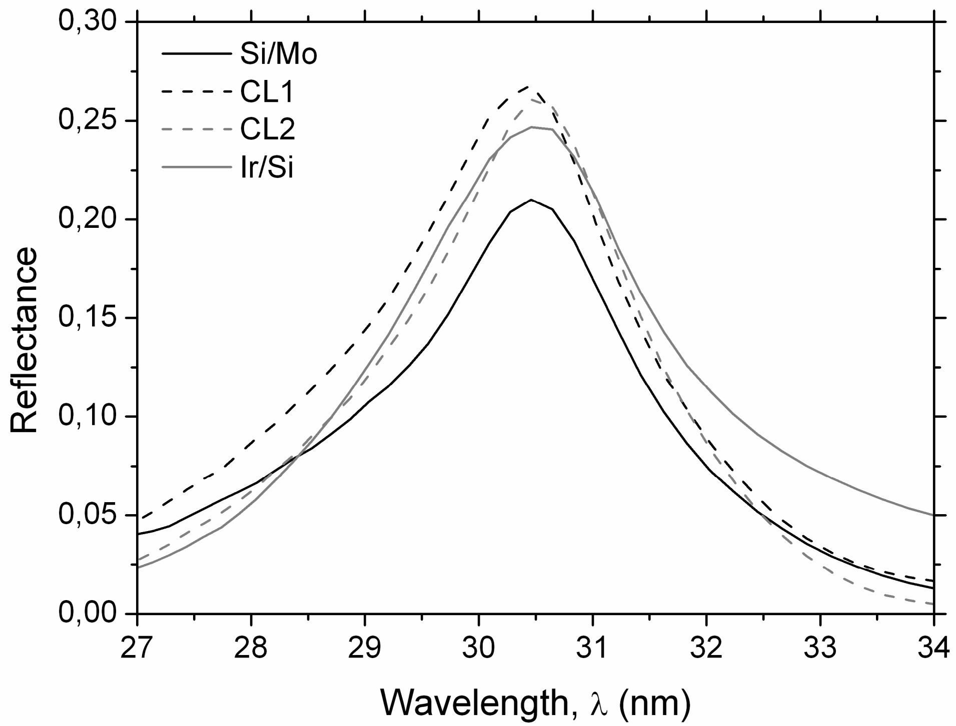
*Corso, A.J., Zuppella, P., Nicolosi, P., Windt, D.L., Gullikson, E., Pelizzo, M.G., "Capped multilayers with improved performances at 30,4 nm for future solar missions, Optics Express 2011

Multilayers for METIS
Measurements at 30,4 nm – Mg/SiC

The EUV measurements have been performed at BEAR beam line ELETTRA, Synchrotron - Trieste (Italy). Reflectance was measured at 5° from normal over the spectral range 27 – 34 nm. The figure refers to the reflectance of two different Mg/SiC samples after deposition and five years later.



Multilayers for METIS
Measurements at 30,4 nm – new samples



The reflectivity is stable over six months!

P. Nicolosi

Multilayers for METIS

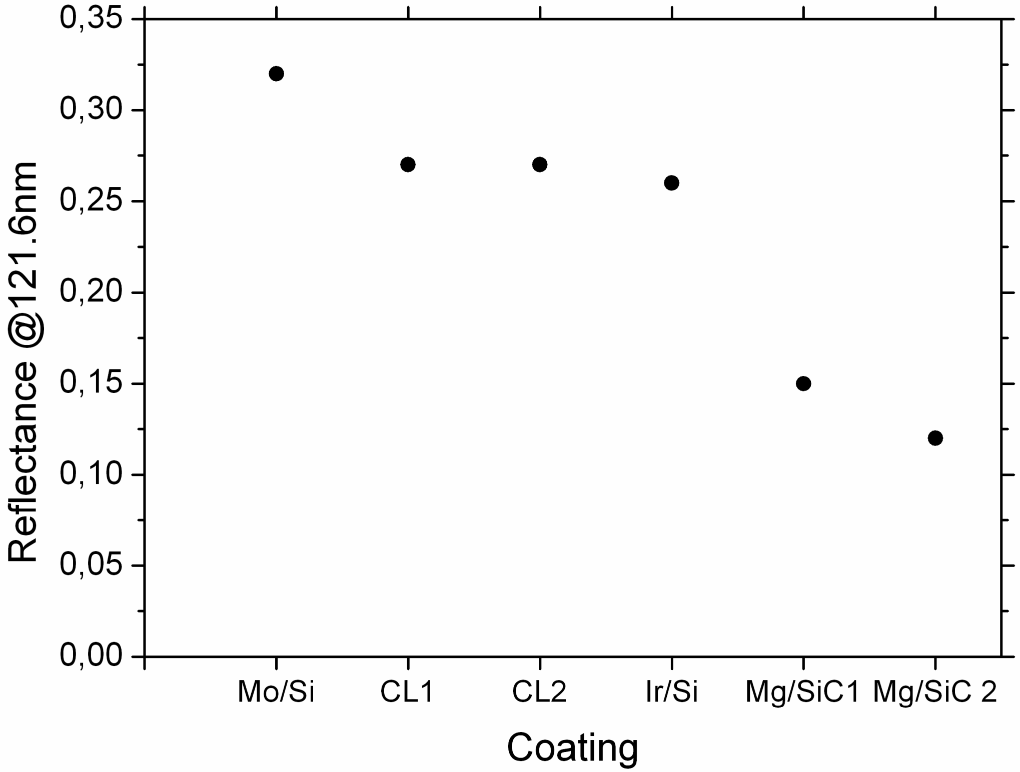
Measurements at 30,4 nm – considerations

- The new multilayers proposed perform better than the classical Mo/Si. The classical Mo/Si reflects 20% as expected , while the new structures proposed show better performances: 24% for Ir/Si multllayer and almost 27% for capping layers onto Mo/Si structures.
- After five years one of the Mg/SiC multilayers reflects 35%. However we can't fully explain the behavior of the Mg/SiC and foresee the total degradation of the refletivity by aging.

Then, the new multilayers can be considered valid candidates for their stability and significant peak reflectance over time. Further tests are in progress !

Multilayers for METIS
Measurements at 121,6 nm

The reflectance at 121,6 nm has been measured by using the normal incidence reflectometer at CNR – LUXOR (Padova, Italy)



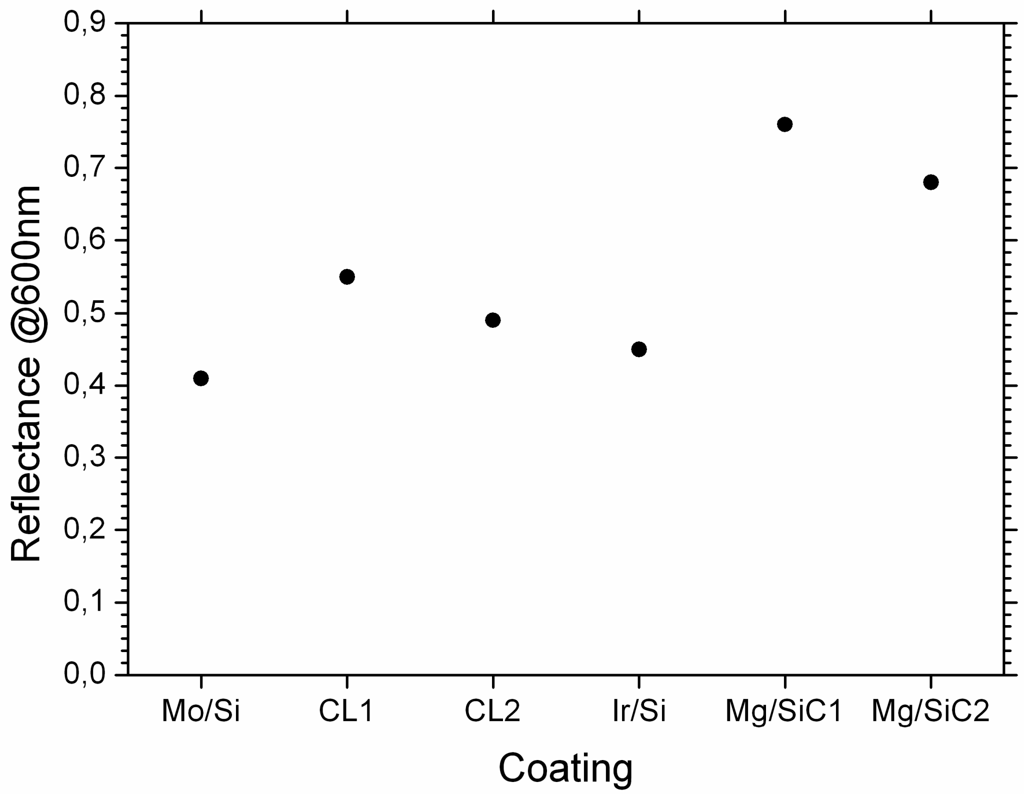
Notes:

•The Mo/Si performs better than the others multilayers: reflectivity of 32% has been maesured, on the contrary no better than 15% for the Mg/SiC coatings

•After five years the reflectivity of the Mg/SiC decreased of 30% . The reflectance at 121,6 nm depends on the first layer of the ML. We will expect further reflectance loss for normal handling operations.

Multilayers for METIS
Measurements in the VIS range

The VIS reflectance was carried on by using the Cary 5000 spectrophotometer in 250 – 800 nm spectral range. The figure below shows the experimental results at 600 nm.



Notes:

•The new samples are stable over time

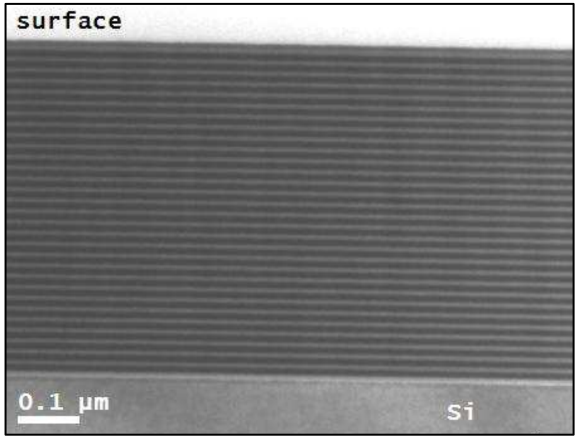
•By looking on the graph , the Mg/SiC seems to give superior performances, but the measurements have been done before the normal handling operations.

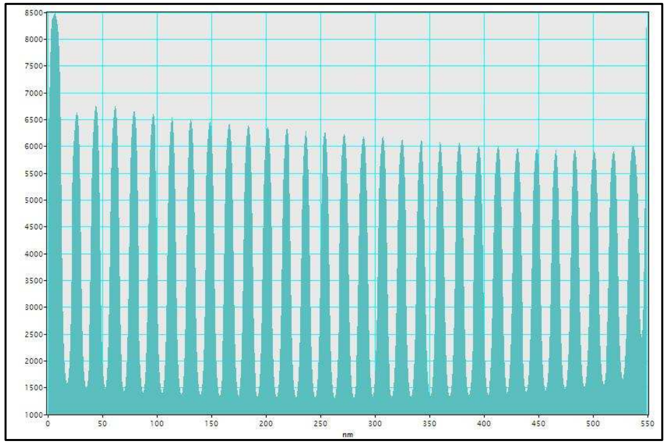
Multilayers for METIS
Structural analysis – Ir/Si

The structure and morphology of the innovative periodic Ir/Si multilayer have been investigated *.

Microscope:

FEI – Technai Field – emission Gun (FEG) TEM F – 20 Super Twin, operating at 200 KeV equipped with an EDX energy – dispersive X- ray spectrometer, and with scanning deflection coils that allow to form images in the scanning mode of operation (STEM)





Bright-Field cross-sectional image of the Multilayer and the corresponding intensity line scan.

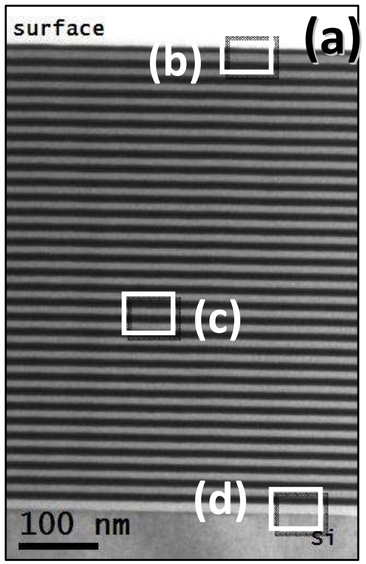
*Zuppella, P., Monaco, G., Corso, A.J., Nicolosi, P., Windt, D.L., Bello, V., Mattei, G., Pelizzo, M.G., "Iridium /Silicon multilayers for EUV applications in the 20 – 35 nm wavelength range", Opt. Lett. 36(7), 1203 – 1205 (2011)

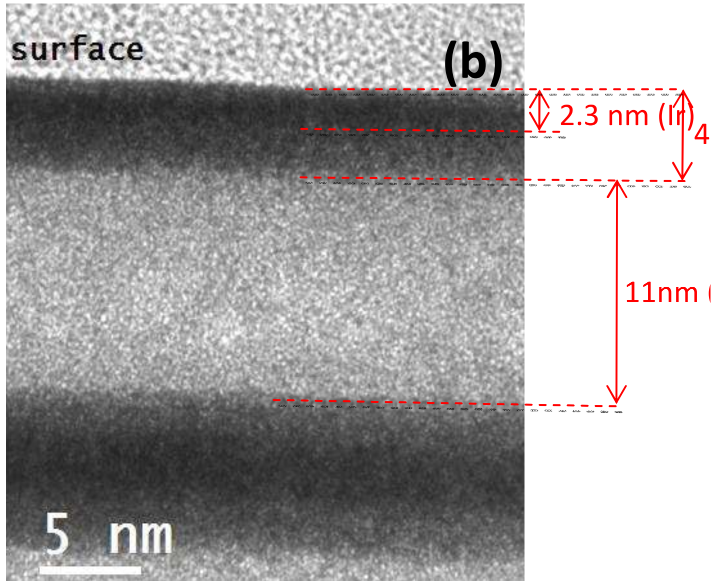
DEPARTMENT OF INFORMATION ENGINEERING
UNIVERSITY OF PADOVA

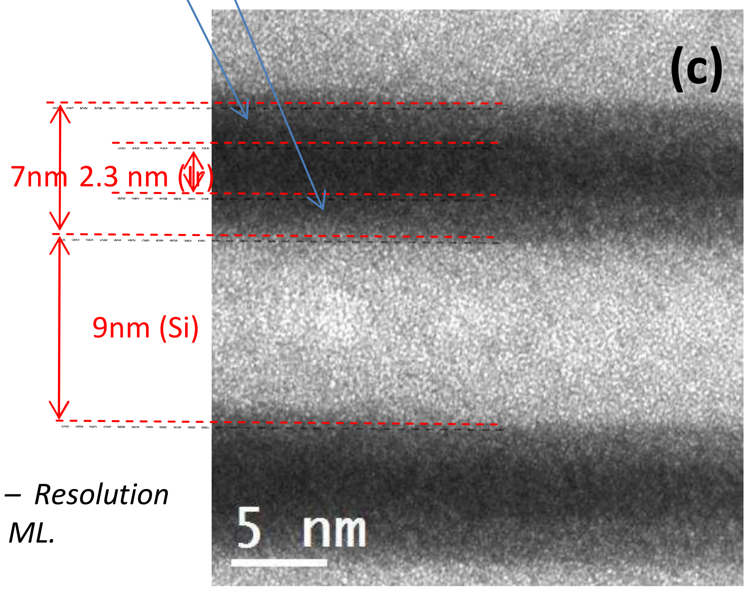
Multilayers for METIS

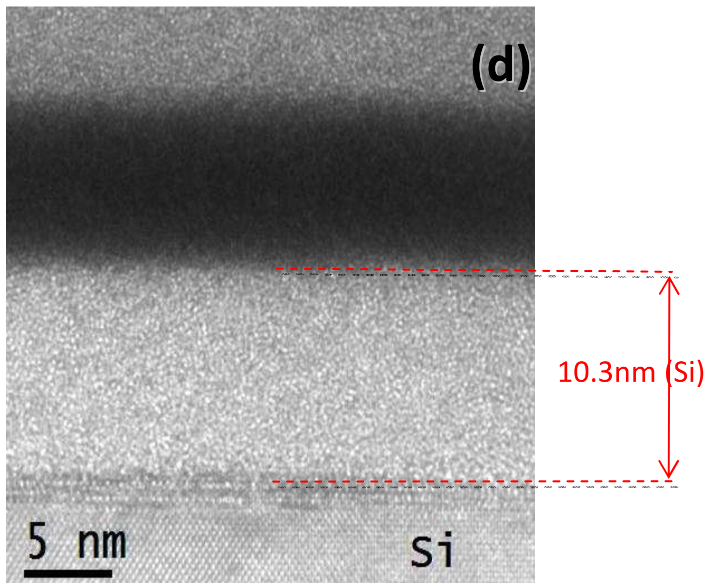
Structural analysis – Ir/Si

A mixed Si – Ir layer is present at each interface, the thickness is t_{Si_Ir}= 2,4 ± 0,4 nm





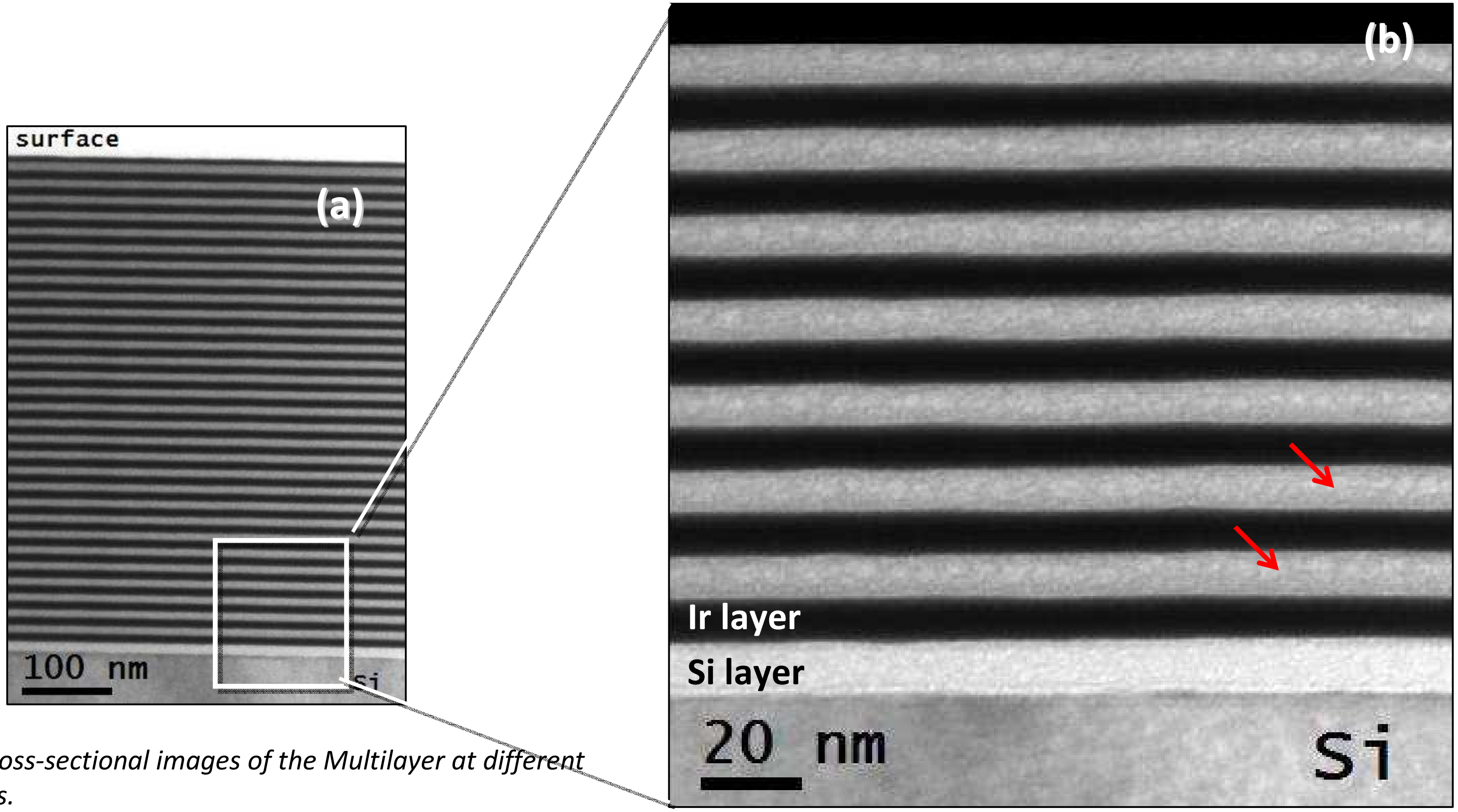




Bright – Field (a) and High – Resolution (b), (c), and (d) images of the ML.

Multilayers for METIS

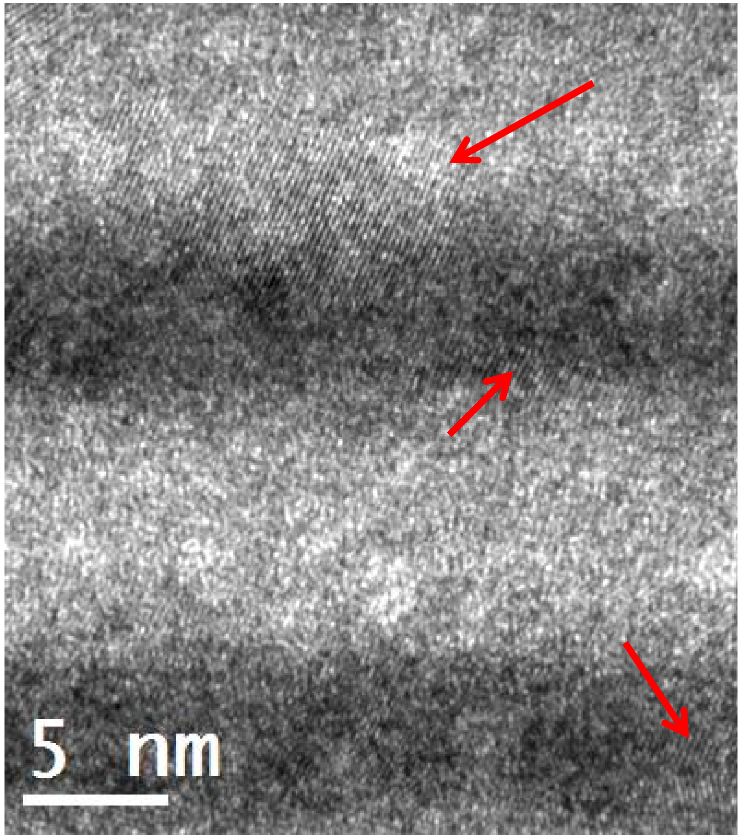
Structural analysis – Ir/Si



Bright-Field cross-sectional images of the Multilayer at different magnifications.

It is possible to observe modulations in the contrast within the a-Si layers, probably indicating that the a-Si layers are not perfectly densified (red arrows).

Multilayers for METIS
Structural analysis – Ir/Si



High-Resolution image acquired on a very thin region of the multilayer. Red arrows indicate Ir crystalline domains.

Experim. d(Å)	Ir-FCC d(Å)	Ir_3Si-Tetrag.d(Å)
2.17±0.05	2.22 (111)	2.18 (202)
1.91±0.03	1.92 (200)	

Tab.1 *Experimental interplanar distances found by FFT analysis of the HR-images compared with that of Ir-fcc and Ir_3Si Tetragonal phase, with the corresponding (hkl) indices.*

The HR-TEM image has been acquired on a thinner region: the red arrows indicate the presence of some crystalline domains with interplanar distances (reported in Tab.1) that could be attributed to an fcc-Ir phase. The last column of the tables show that an interplanar distance found by FFT analysis of HR images could be also attributed to the presence of a crystalline Ir_3Si phase.

Conclusions

- Multilayer design and development at LUXOR relative to ML's for Space Applications have been presented

ACKNOWLEDGEMENTS

- my colleagues:

  M.G. Pelizzo, P. Zuppella, A.J. Corso, G.Monaco, M. Suman

- D.L. Windt - RXO LLC

- METIS – SCORE team (E. Antonucci, S. Fineschi)

THANK YOU