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# Optical components in space environments: impact of optical performance measurements on the development of space instrumentation

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# Research motivations

- Future space missions are aimed at the exploration of increasingly inhospitable regions of our solar system
- Electrons and ions are considered among causes of potential damage of the optical coatings.
- The degradation of optical components can lead to a misinterpretation of the scientific data due to an uncontrolled change of the instrument response; in a more dramatic scenario, the failure of a component can affect the operational capacity of the whole instrument
- Definition of testing procedures to assess the suitability of the optical components to the operation environment is pivotal to prevent failures

# State of the art and open questions:

- The damage effects on coatings and their substrates depend on the ions species, their energy, the flux and the total fluence (or dose). Vice versa, given irradiation parameters, the damage depends on materials and coating structures.

1. **SCIENTIFIC KNOWLEDGE** Valuable experiments on the interaction of ions with coatings have been carried out, but usually these are not systematic; they are limited to specific values of energy and dose of selected ions species and they generally have more the character of a qualification of a specific component with respect to its space operational environment.

- Laboratory tests can be used to qualify the components by reproducing the operational conditions.

2. **GUIDELINES** We need to define guidelines for testing and network of accelerator facilities suitable for such test

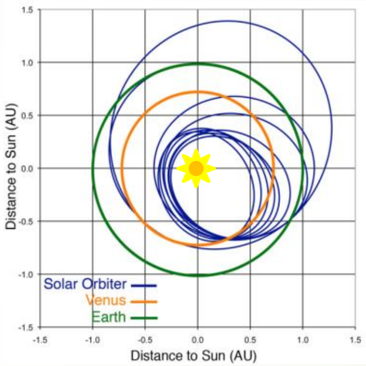
3. **OPERANTIONAL ENVIRONMENT** To carry out specific tests in view of a space mission we need to know the operational environments

# Example of definition of an OPERATIONAL ENVIRONMENT: Solar Orbiter

**Quite Solar wind particles:**

- **Protons: 1 keV**
- **Alpha particles: 4 keV**

- Input
  - Density/speed (i.e. at 1 UA)
  - Orbit r(t)
  - Scaling Model (i.e. $1/r^2$ )




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

- Outcome: fluence as function of mission lifetime

$$Total\ Fluence\ (\Delta T) = \int_{T_1}^{T_2} Flux(t)dt = \int_{T_1}^{T_2} \frac{Density_{1AU}}{scaling\_factor(r(t))} \cdot speed(t) \cdot dt$$

- Moreover, propagation inside the instrument is required

# Irradiation parameters for ground tests

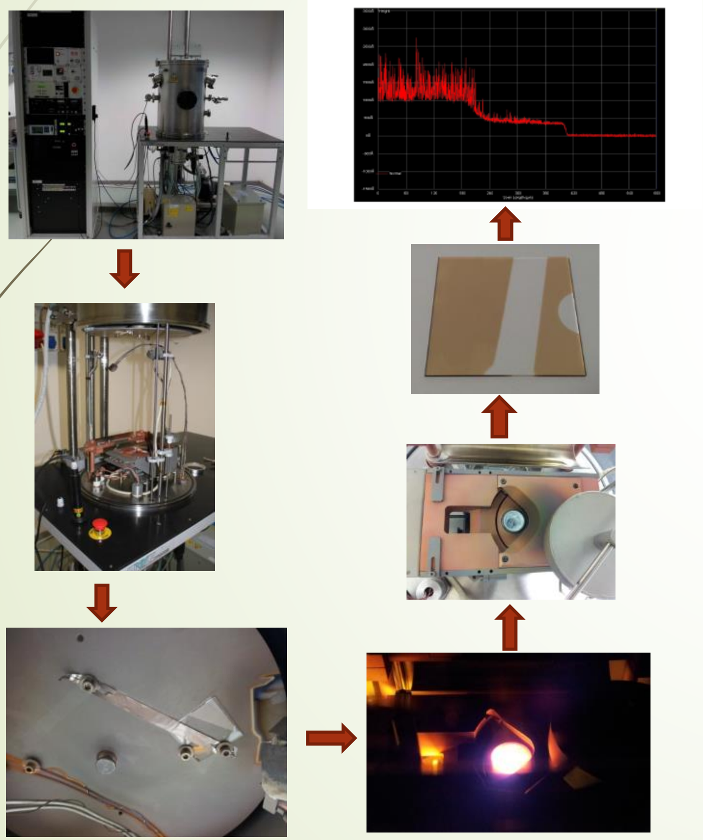
- The dependence of the damage from the particles flux parameter needs to be investigated, considering that fluxes used for testing in accelerator facilities on ground are always orders of magnitude higher than ones in space

- Fluences considered
  - Dose A: 1 years SOLO lifetime
  - Dose B: 2 years SOLO lifetime
  - Dose C: 4 years SOLO lifetime
  - Dose B: 6 years SOLO lifetime

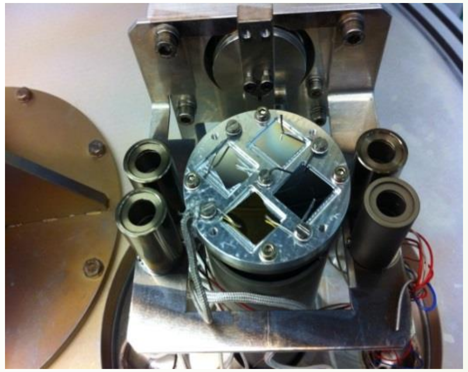
| Pt or Au Sample # | Fluence $He^+/cm^2$ | Flux $He^+/cm^2/s$ |
|---|---|---|
| 1 | $A=2.6\cdot10^{15}$ | $F1=1.5\cdot10^{11}$ |
| 2 | $A=2.6\cdot10^{15}$ | $F2=3.0\cdot10^{12}$ |
| 3 | $A=2.6\cdot10^{15}$ | $F3=8.8\cdot10^{12}$ |
| 4 | $B=5.2\cdot10^{15}$ | $F1=1.5\cdot10^{11}$ |
| 5 | $B=5.2\cdot10^{15}$ | $F2=3.0\cdot10^{12}$ |
| 6 | $B=5.2\cdot10^{15}$ | $F3=8.8\cdot10^{12}$ |
| 7 | $C=10.4\cdot10^{15}$ | $F1=1.5\cdot10^{11}$ |
| 8 | $C=10.4\cdot10^{15}$ | $F2=3.0\cdot10^{12}$ |
| 9 | $C=10.4\cdot10^{15}$ | $F3=8.8\cdot10^{12}$ |
| 10 | $D=15.6\cdot10^{15}$ | $F1=1.5\cdot10^{11}$ |
| 11 | $D=15.6\cdot10^{15}$ | $F2=3.0\cdot10^{12}$ |
| 12 | $D=15.6\cdot10^{15}$ | $F3=8.8\cdot10^{12}$ |
| Ref | - | - |

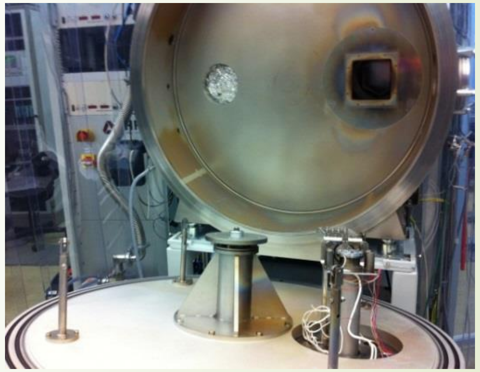
# Au and Pt single layer fabrication and He+ irradiation

E-beam Evaporator @CNR-IFN



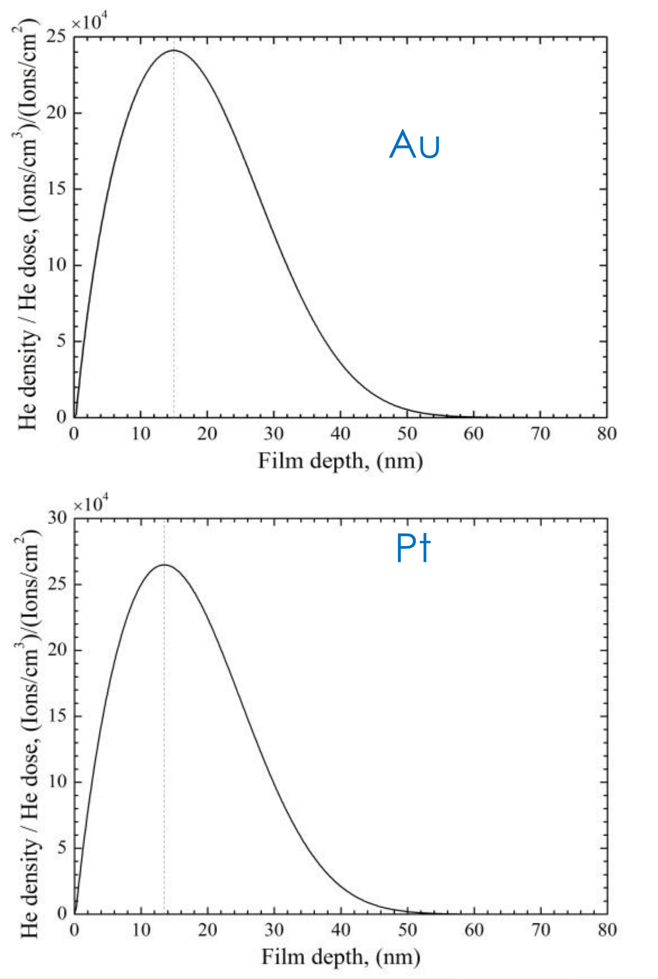
Ion Beam Center at the Helmholtz-Zentrum Dresden-Rossendorf
Ions delivery with energies in the range 200 eV - tens MeV



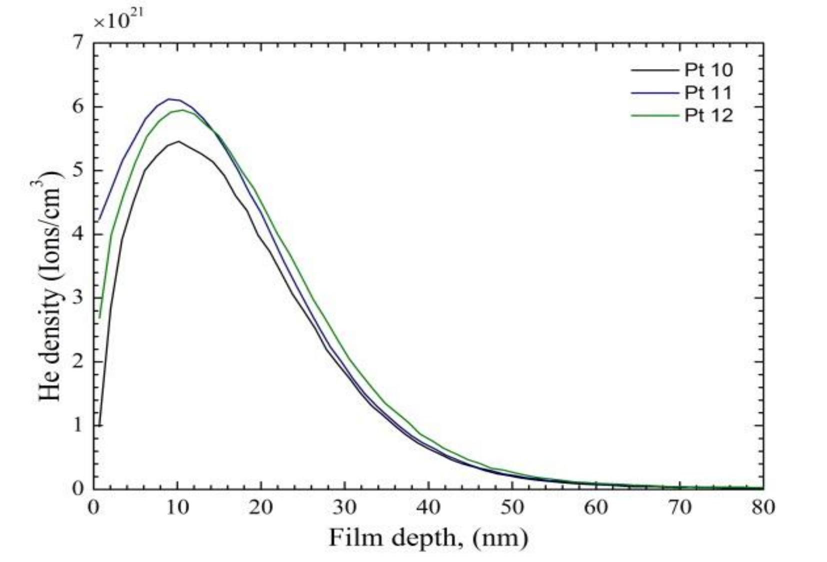


# Implantation profile analysis

TRIM/SRIM performs Monte Carlo simulations of elastic scattering interactions




He+ implantation profile in sample Pt 10, 11 and 12 as measured by Secondary Ion Mass Spectrometry(SIMS)




| Pt or Au Sample # | Fluence He+/cm$^2$ | Flux He+/cm$^2$/s |
|---|---|---|
| 10 | D=$15.6\cdot10^{15}$ | F1=$1.5\cdot10^{11}$ |
| 11 | D=$15.6\cdot10^{15}$ | F2=$3.0\cdot10^{12}$ |
| 12 | D=$15.6\cdot10^{15}$ | F3=$8.8\cdot10^{12}$ |

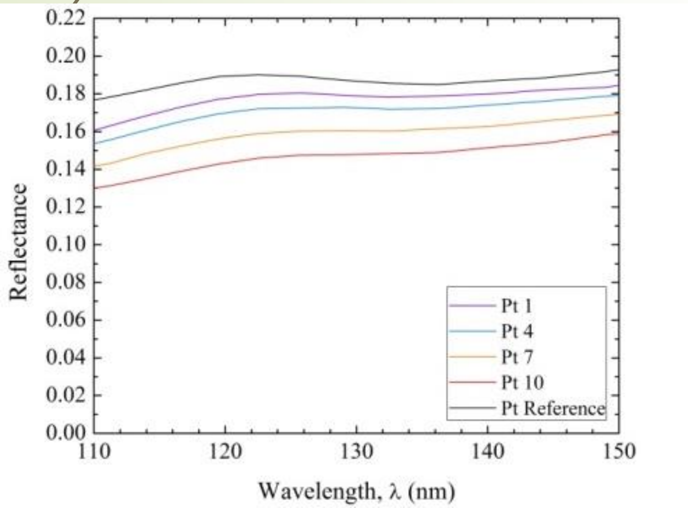
# Reflectance variation due to the flux rate

The dependence of the damage from the particles flux parameter needs to be investigated, considering that fluxes used for testing in accelerator facilities on ground are always orders of magnitude higher than ones in space

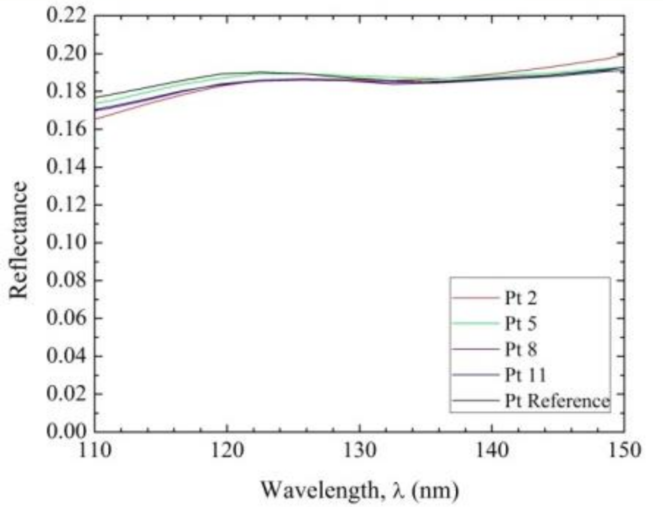
SIMS measurements demonstrate that the same implantation profile can be achieved regardless of the flux rate, thus suggesting the use of higher fluxes to reduce accelerator facilities occupation time.

However, it is still unclear while only samples implanted with low flux rates show a reflectance degradation with increasing dose at 121.6 nm.

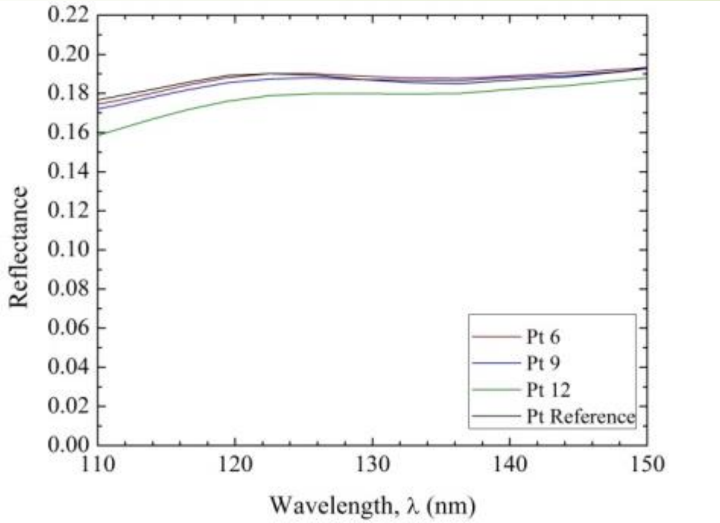
F1




F2



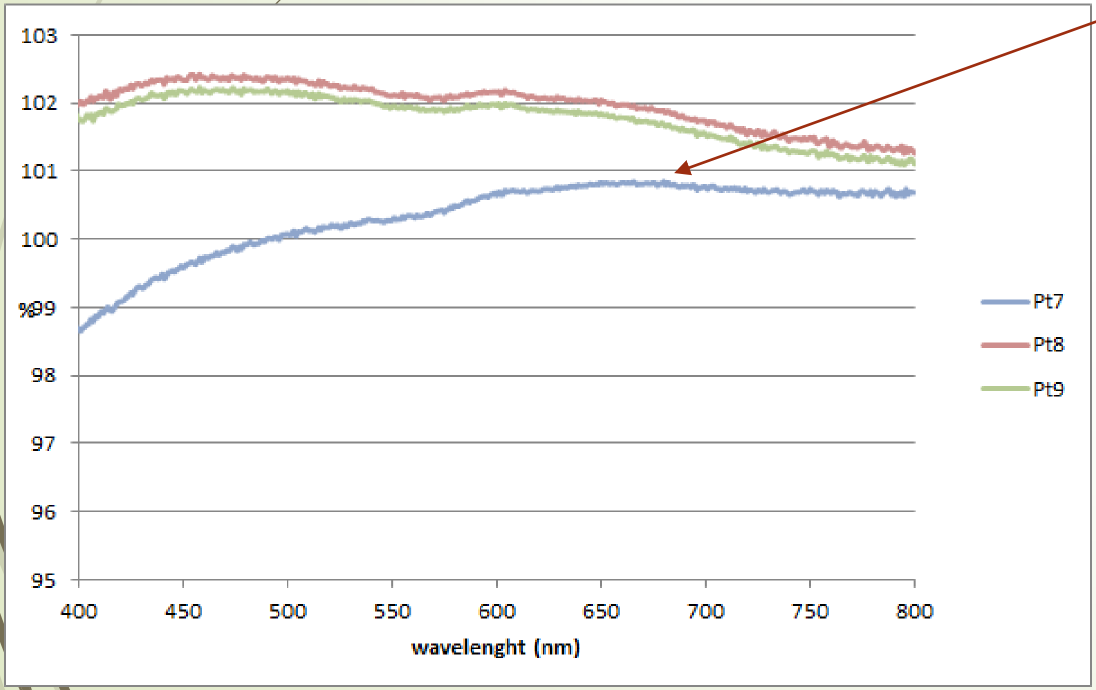

F3



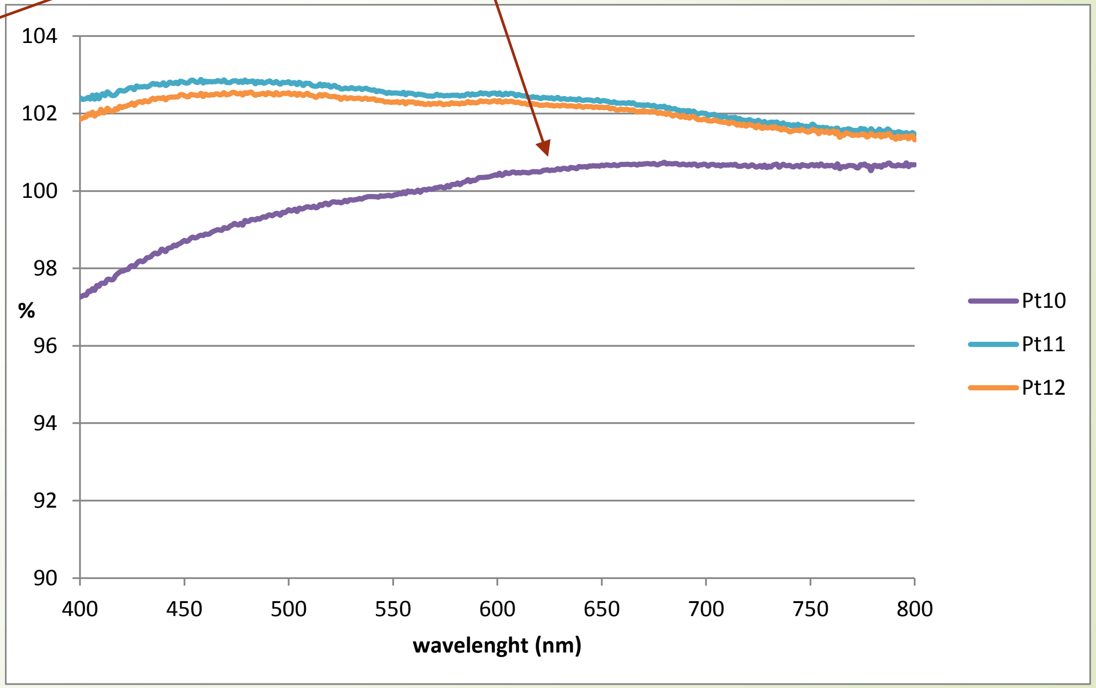
# VIS reflectance measurements

Reflectance measurements with VIS radiation at a fixed dose, the reflectivity lines are related to a R=100% of a Pt REF sample. Is possible to see that the lowest flux has the lowest reflectivity.

Dose C




Dose D



# Potential explanation on R variation

The sample have the same implantation profile, but only samples implanted with F1 show a decrease of reflectance in the Ly-alpha region

Potential explanations:

- presence of contamination due to longer exposure in chamber, including surface contamination; synergistic effects; carbon is considered one potential contaminant
- potential damage mechanisms or effects present at low flux (and not at higher ones) are also considered.

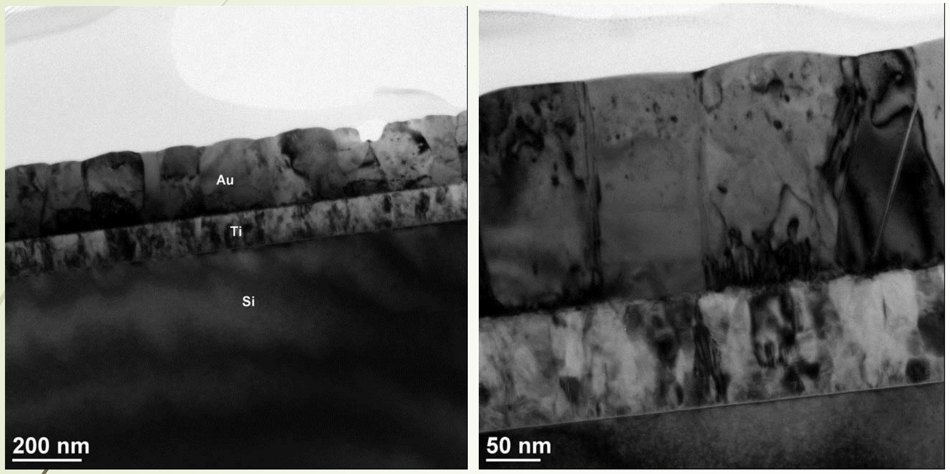
The sample have the same implantation profile, but samples implanted with F2 and F3 show a slight increase of reflectance in the VIS

Potential explanations:

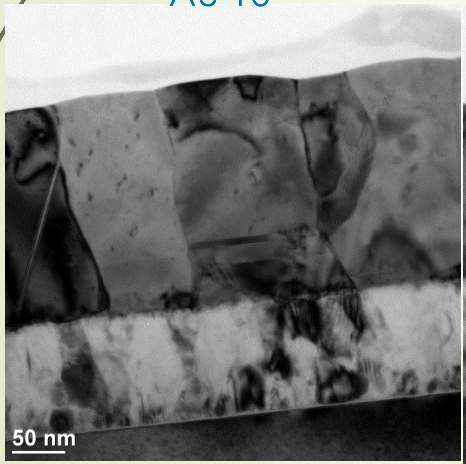
- Change of structural properties → **structural analysis are needed**!!

# Further studies (1)

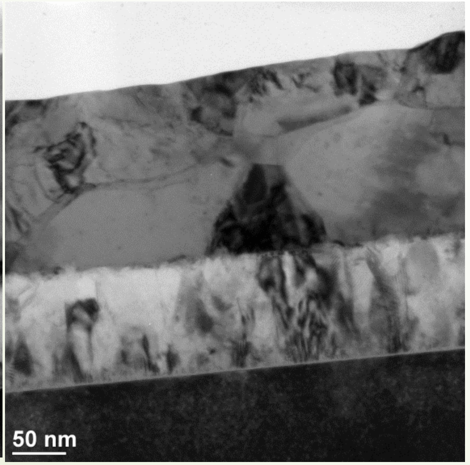
Au Ref TEM images



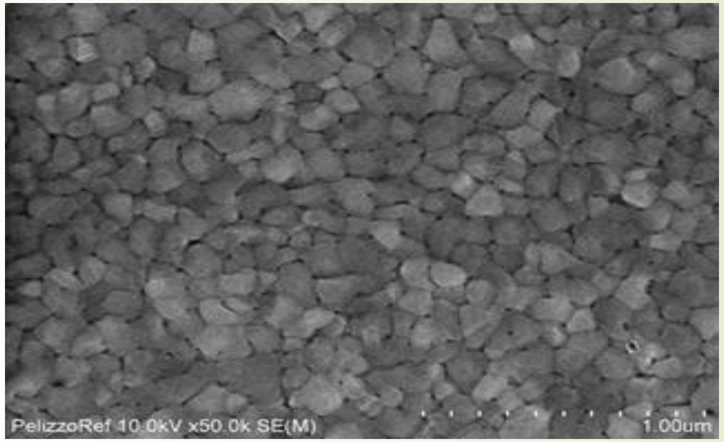

Au 10

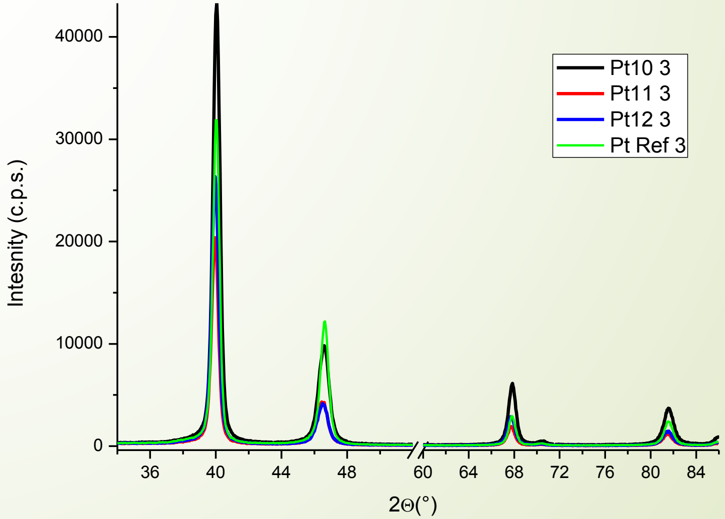



Au 12



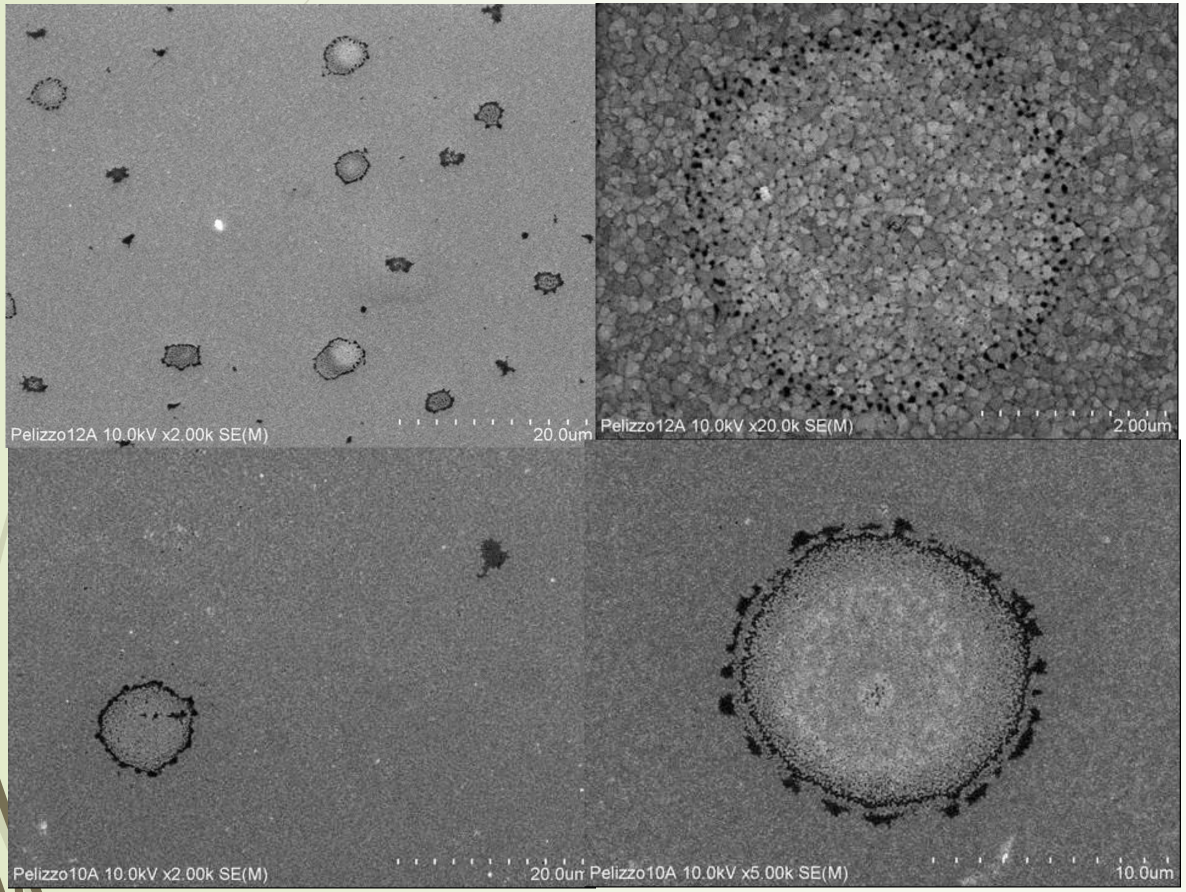

Au Ref SEM image



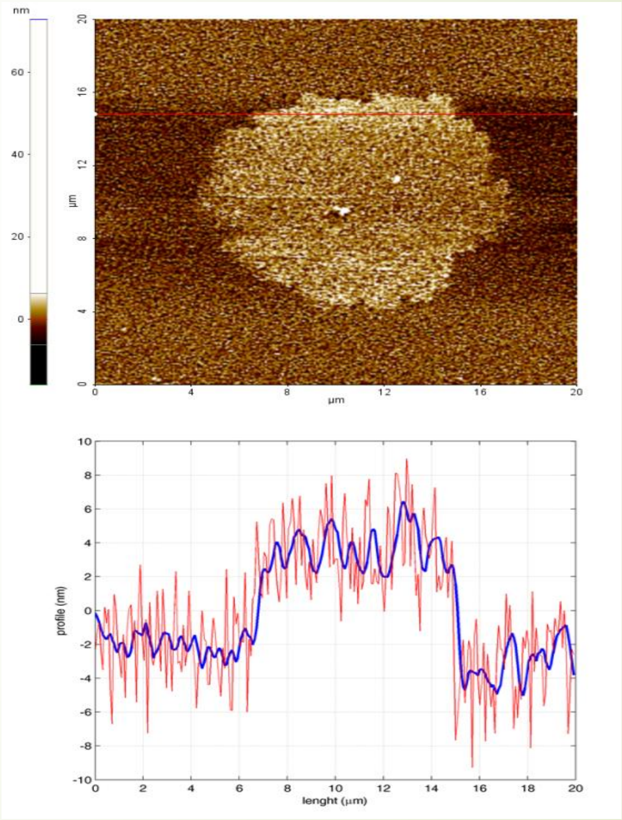



# Further studies (2)

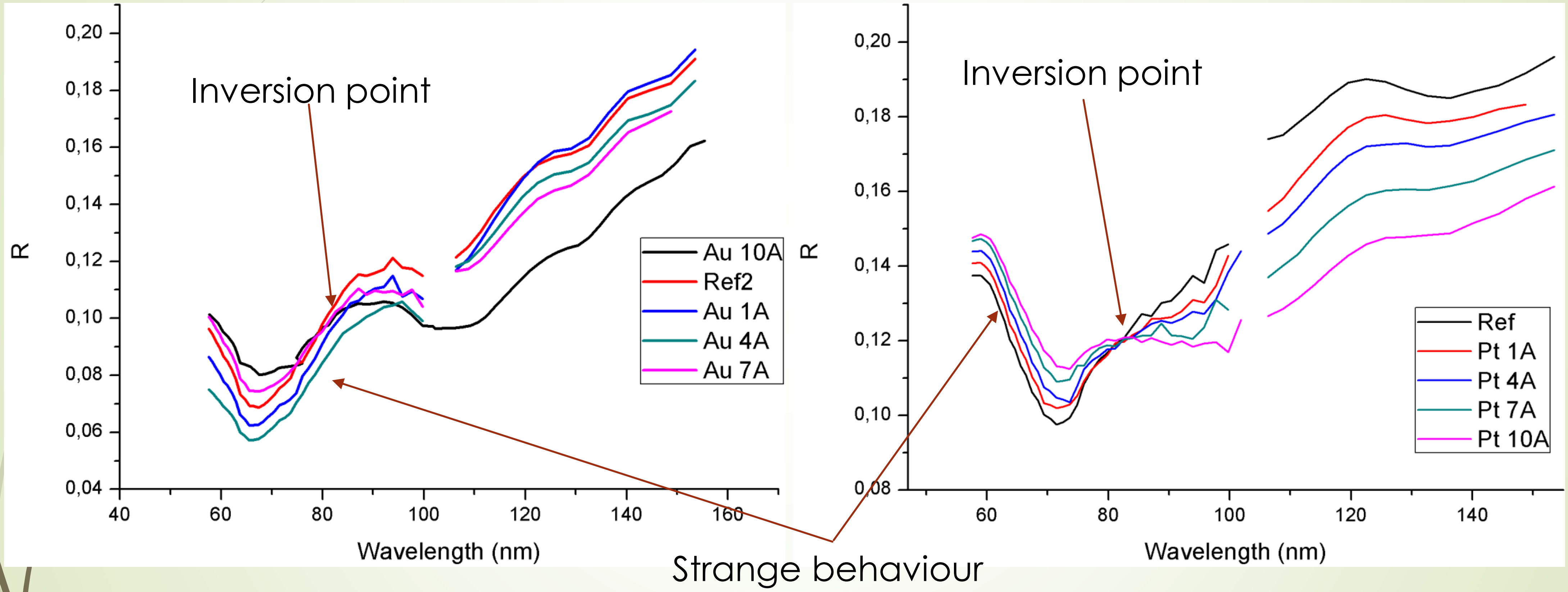
Au 12




Analysis of surface defects



# …All that glitters is not gold




**There are still open questions about the reflectivity variation induced by He ions!!**

# What has been done:

- Optical measurements of irradiates samples;
- Structural analysis like TEM/SEM, XRD, EDX, and SIMS of irradiated samples and not;
- The Numerical model (EMA) partially agree the experiment.

# What has to be done:

- In some spectral range the behavior of the reflectivity change vs dose is still not clear so the experiments will try to fully understand and predict the reflectivity change due to ion irradiation;
- Improve the empirical EMA model and extend it to more complex optical devices.

Thank you for your attention