Treatment of Polymers by Plasma Immersion Ion Implantation for Space Applications

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Outline

- Motivation
- Objectives
- Direct Al implantation
- Recoil Al implantation
- Analysis
- Results
- Conclusions and Future Work

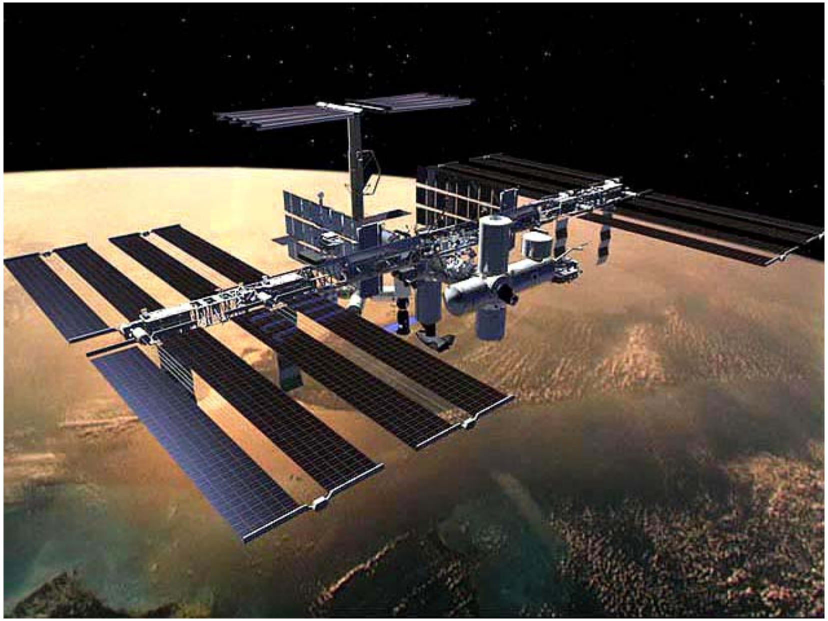
Motivation

Protection of Components for Spacecrafts Orbiting LEO

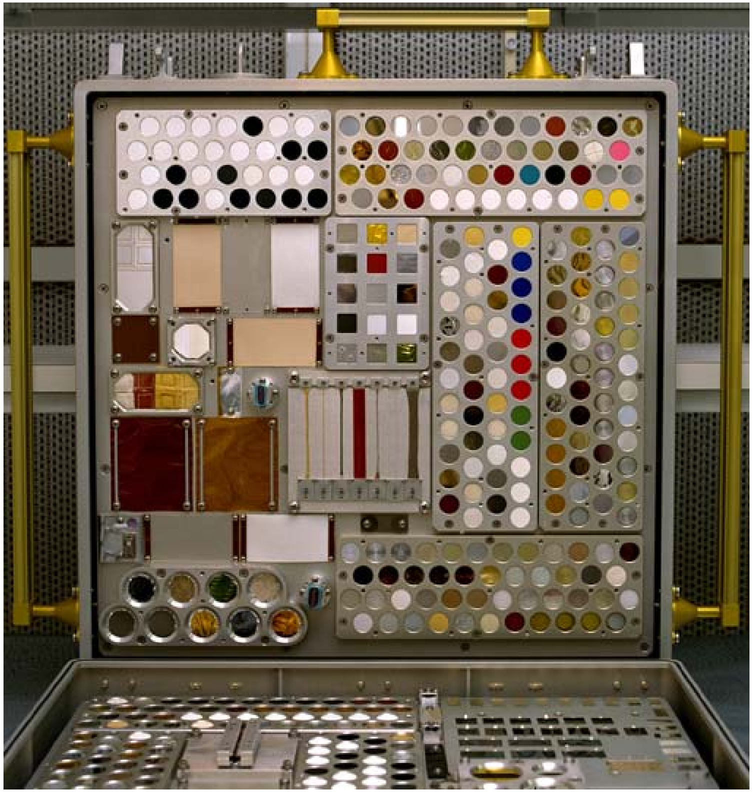
Low Earth Orbit (LEO) environment (180-650 km): rich in atomic oxygen, which degrades polymeric materials (such as Kapton, Mylar or Teflon) used in satellites.

May erode certain polymers by over 2 μm in 90 days

Oxygen resistant polymers could improve the lifetime of satellites and space stations and could find many applications in space, including huge fold-up antennas, inflatable mirrors & lenses, solar sails…



International Space Station orbiting LEO region (450 km)



Materials International Space Station Experiment – MISSE project

Trays of materials samples will expose 750 materials to LEO environment, for 18 months.

Oxidation protection: Thin layers of several metal oxides such as Al_2O_3, MgO, or SiO_2 are being studied as protective coatings for polymers in LEO

Thermal transients (-100° C to +100 ° C) : Superior adhesion of the thin film is required
→ Metal Plasma Immersion **Ion Implantation and Deposition**

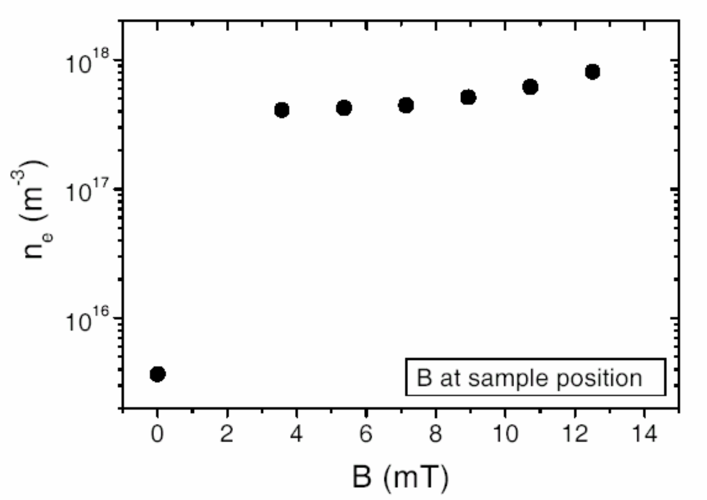
PIII in polymers: charging of the dielectric is proportional to plasma density

Typically for ~ 20 µm thick polymers:

$n \sim 10^{17}\ m^{-3} \rightarrow \Delta V \sim 7kV$ in 2µs

$n \sim 10^{15}\ m^{-3} \rightarrow \Delta V \sim 700V$ in 60µs

In metal plasmas generated by vacuum arcs:



Magnetic field increases plasma density by two orders of magnitude

Objectives

Aluminum implantation in Kapton® by three different methods

- Direct implantation in a magnetized Al plasma
- Direct implantation in an unmagnetized Al plasma
- Al deposition + implantation in nitrogen plasma (recoil implantation)

Resistance tests for space environment

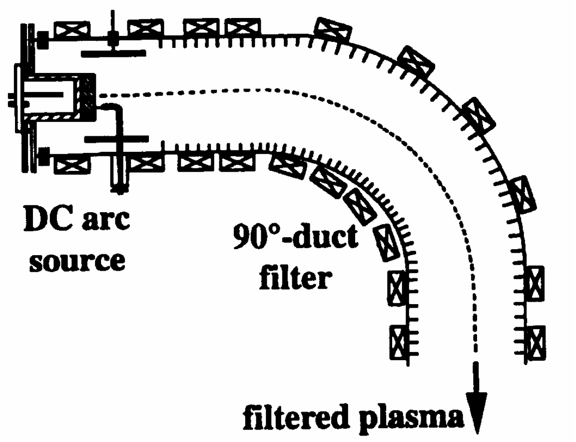
- Oxygen degradation (oxygen plasmas)
- Thermal cycling
- Adhesion test

Direct Aluminum implantation

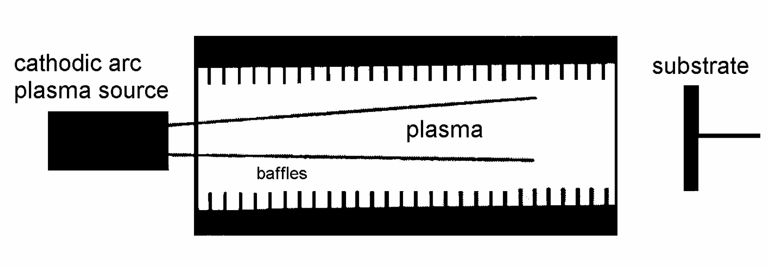
Vacuum Arc Plasmas: HV trigger: arc initiation
Plasma **drift velocity** ~ 10^4m/s

I_{arc} ~ (100-1k)A/50V
I_{ion} ~ up to (5 - 10)% I_{arc}

Macroparticle Filtering systems:



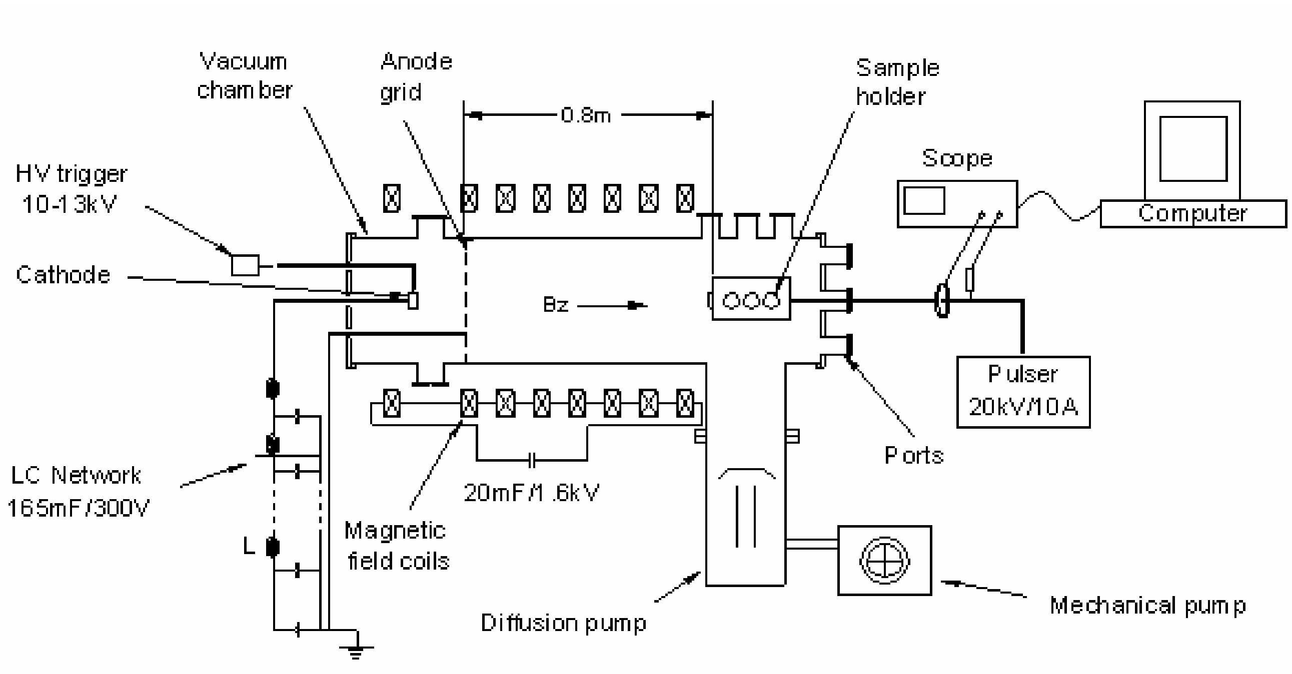
Curved magnetic filter
good filtering
not so good plasma transport



Straight magnetic filter
not so good filtering
good plasma transport

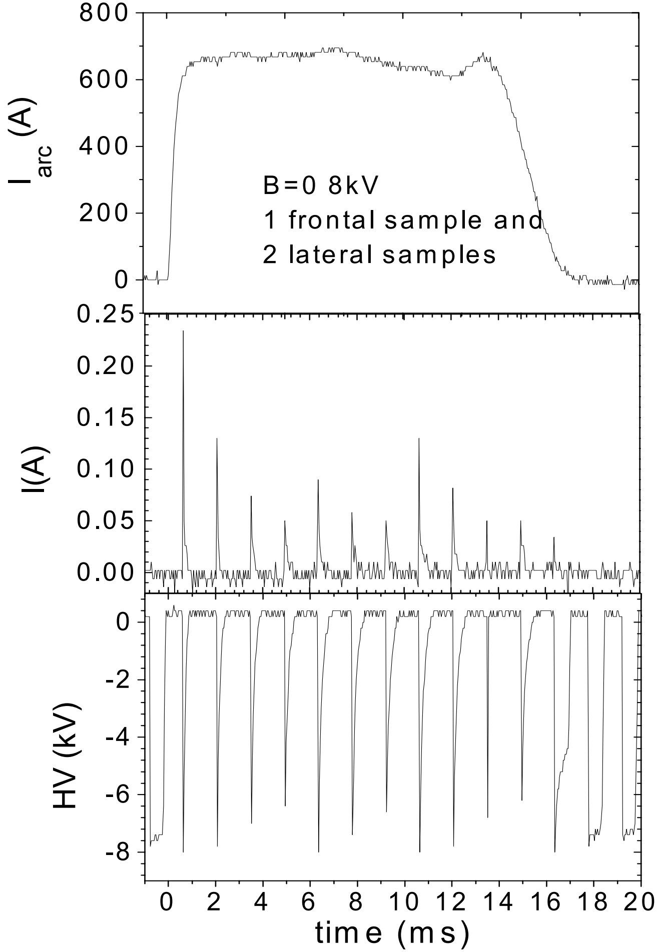
Macroparticles avoided and deposition minimized by orienting samples **parallel to plasma stream**

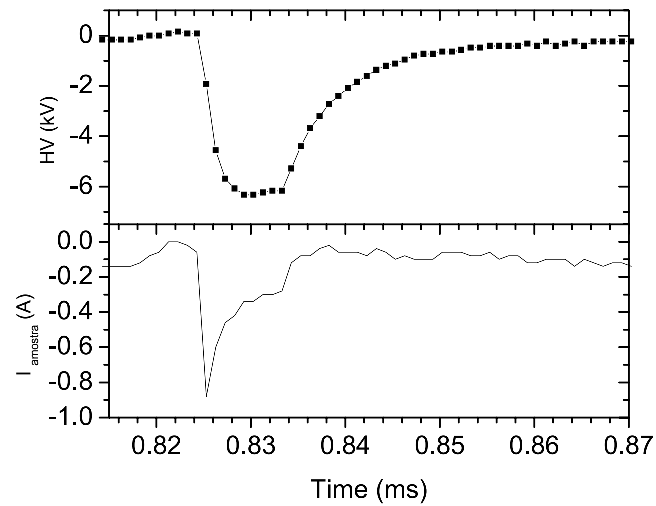
Experimental Set-up



Vacuum arc:	Al cathode	Tungsten grid anode	HV trigger: 10-13 kV
Vacuum chamber	ϕ=0.22m, L=1.05m		
	Base pressure ~ 1×10^{-4} Pa B field: 150G-7kG		
Sample holder:	85cm from cathode		

- # Implantation Conditions





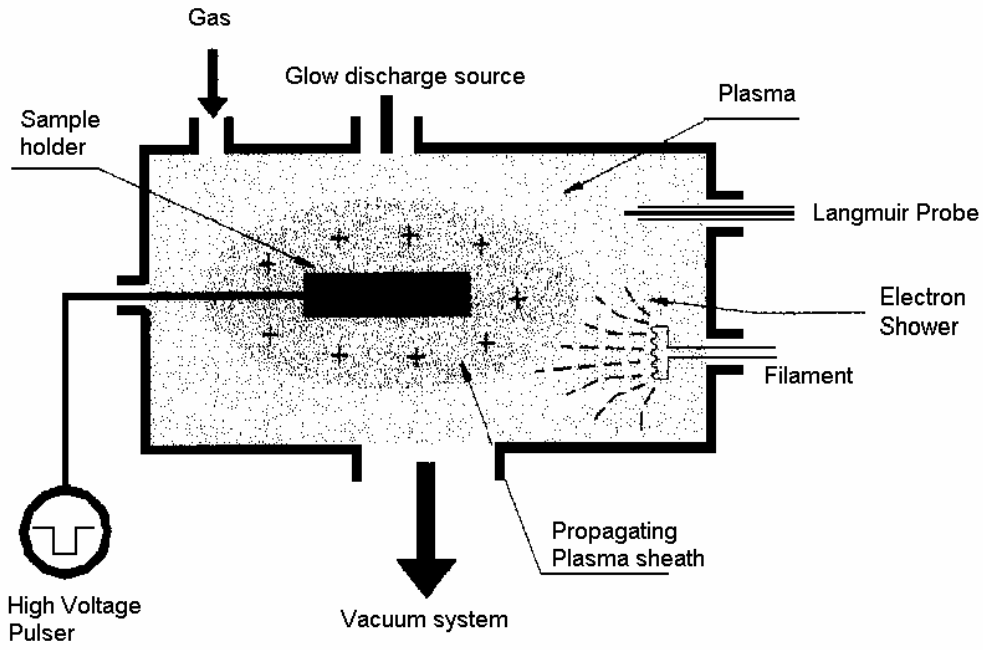
With B = 125 G Iarc = 1kA
7μs pulses, 2.5 kV,
900 Hz (13-14 pulses / discharge)
100 discharges

With B = 0 Iarc = 1 kA
7μs pulses, 6 kV, 900 Hz
800 discharges

Recoil Aluminum implantation

200 Å aluminum film deposited by electron beam on a Kapton sample (8.5cm×12cm) wound around sample holder. HV in contact with deposited film.

Implantation in **Nitrogen plasmas**: n ~ 10^{10} cm^{-3}, T_e < 10 eV
HV pulses: 5 μs, 100Hz, 5 kV
treatment time of 30 minutes



Analysis

Elemental composition and morphology

- RBS
- XPS
- SEM , EDS

Oxygen degradation

- Oxygen plasma: 40kHz parallel plate capacitive reactor
  200 mTorr, 200W $\rightarrow$ $n \sim 10^{10}$ cm^{-3} , $T_e \sim (1\text{-}2)$ eV
  ~ one hour exposure

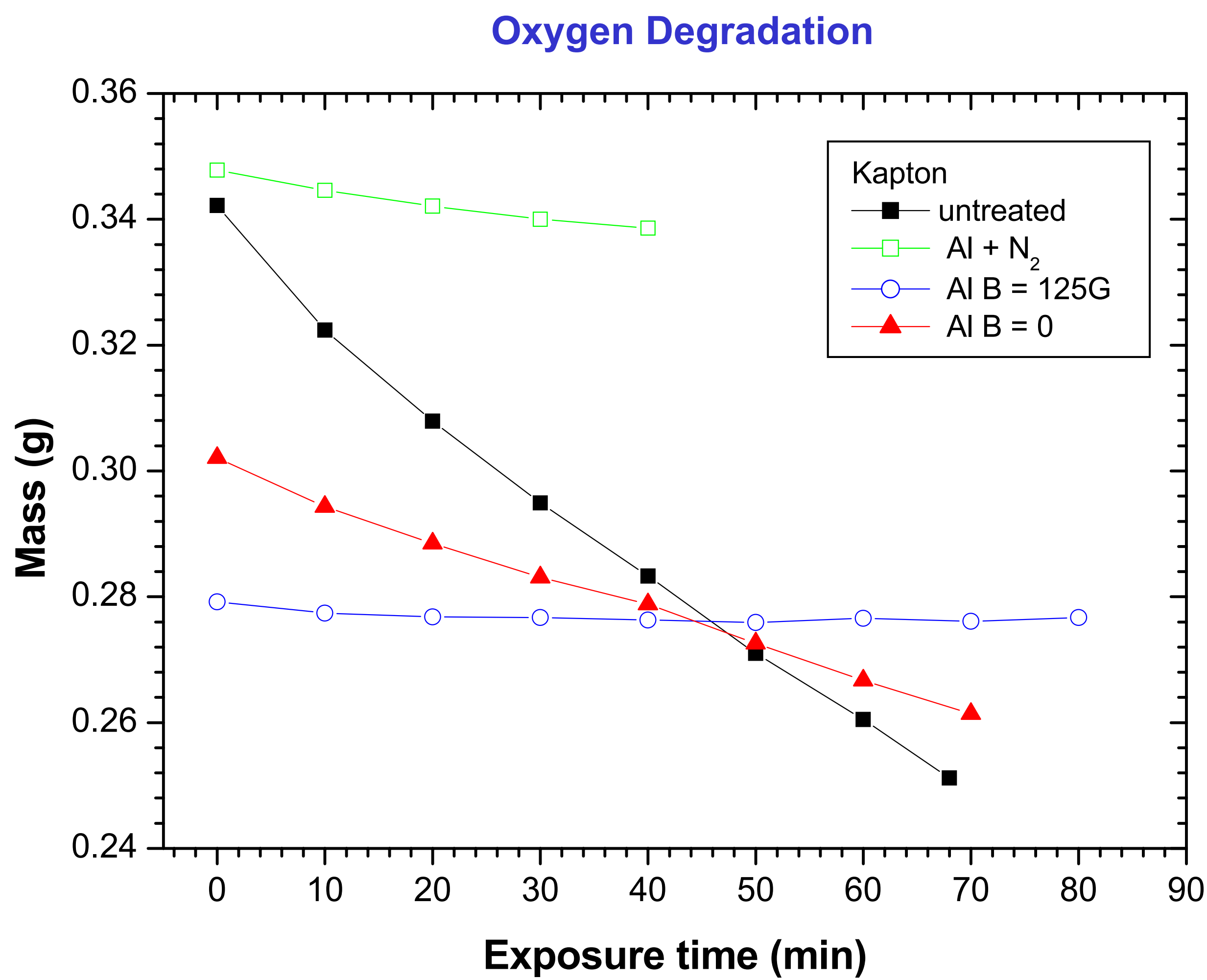
Thermal cycling

- 1 minute liquid nitrogen immersion (-196 °C)
- 1 minute pre-heated oven (100 °C)
- 15 cycles

Adhesion Test

- applying and removing a pressure sensitive tape + SEM

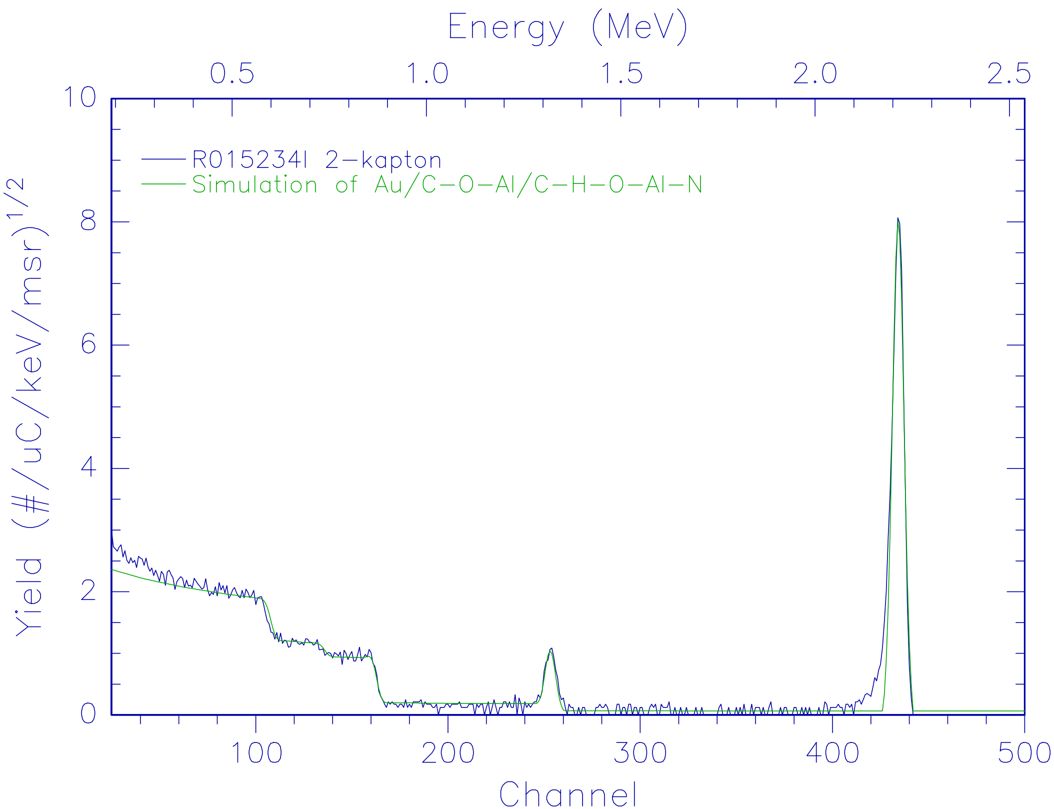
Results



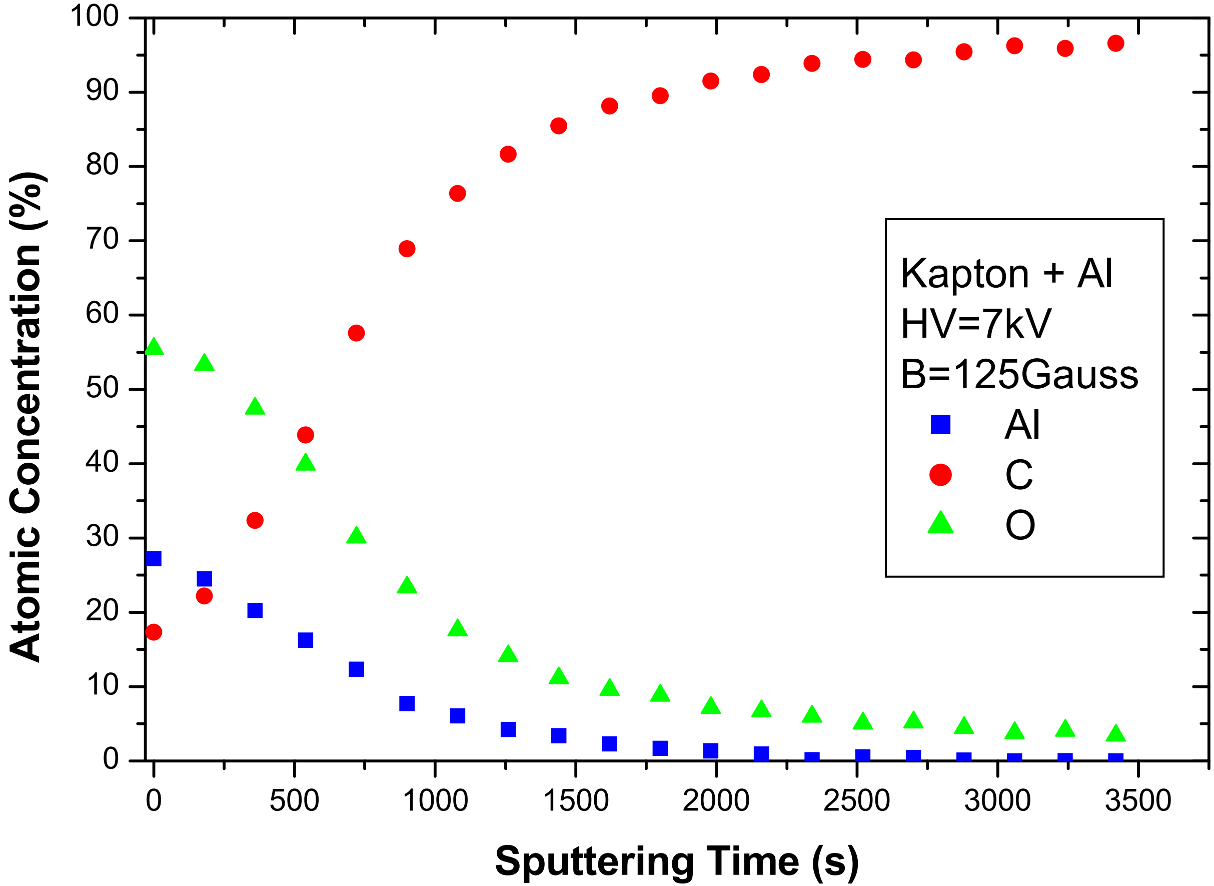
Oxygen Degradation
Mass (g)
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0
10
20
30
40
50
60
70
80
90
Exposure time (min)
Kapton
untreated
Al + N2
Al B = 125G
Al B = 0

Kapton sample implanted with Al in a magnetized plasma

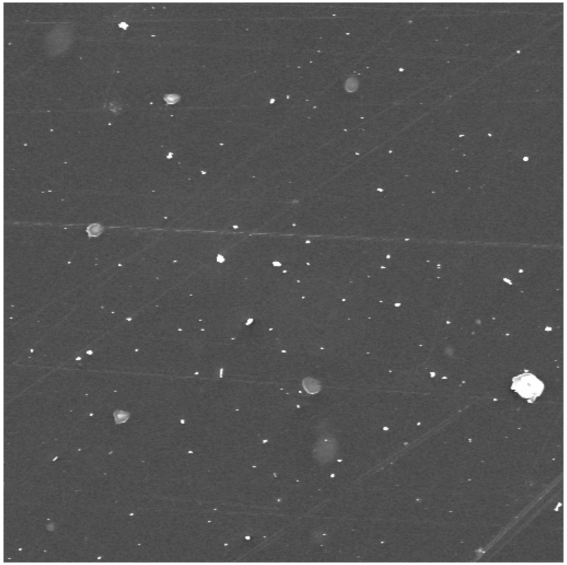
- **RBS** → retained doses of 10^{16} atoms/cm^2, but mostly at the surface



- **XPS** → formation of an ion mixing layer

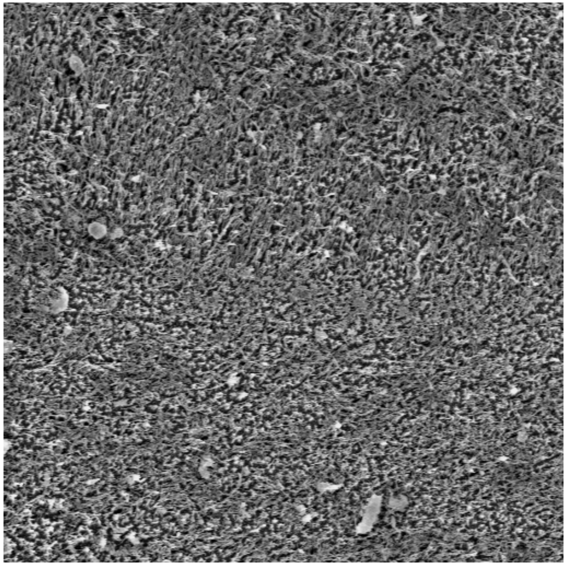


Kapton sample implanted with Al in a magnetized plasma

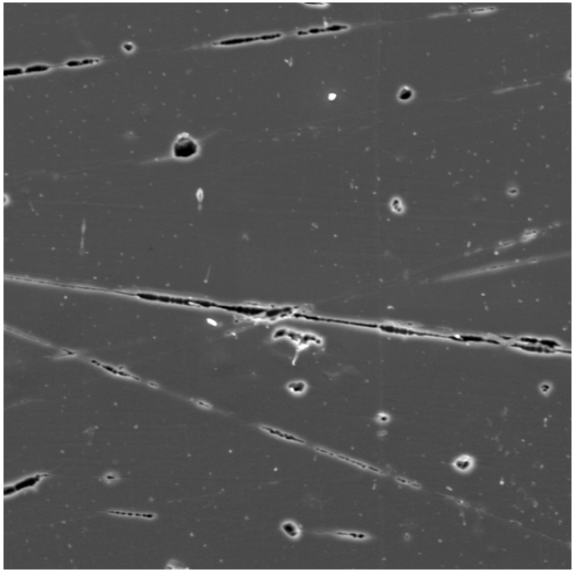


Without treatment

Without treatment after oxygen exposure →



Treated sample after oxygen exposure + thermal cycling → + adhesion tests

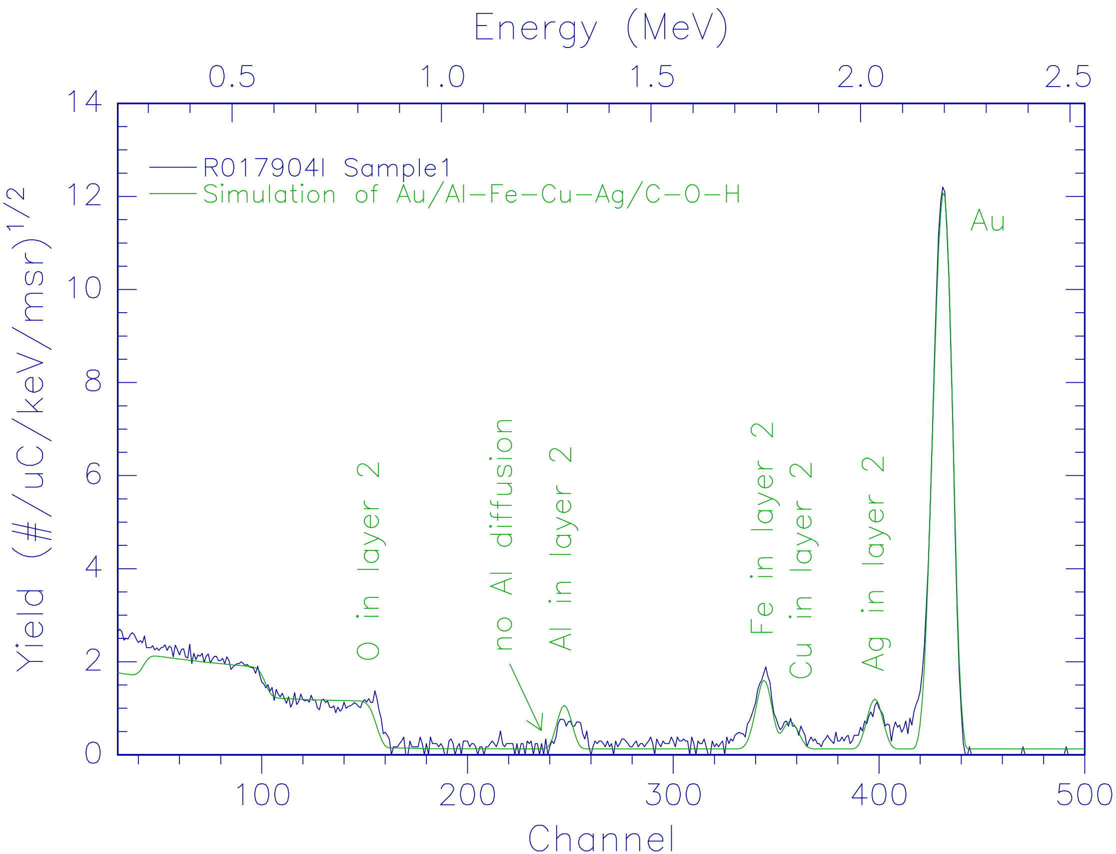


Kapton sample implanted with Al in an unmagnetized plasma

- Not uniform : good parts behave like magnetized case after exposure to O plasmas
  bad parts behave like untreated case after exposure to O plasmas

- Possible causes: Insufficient dose
  misalignment with
  plasma stream

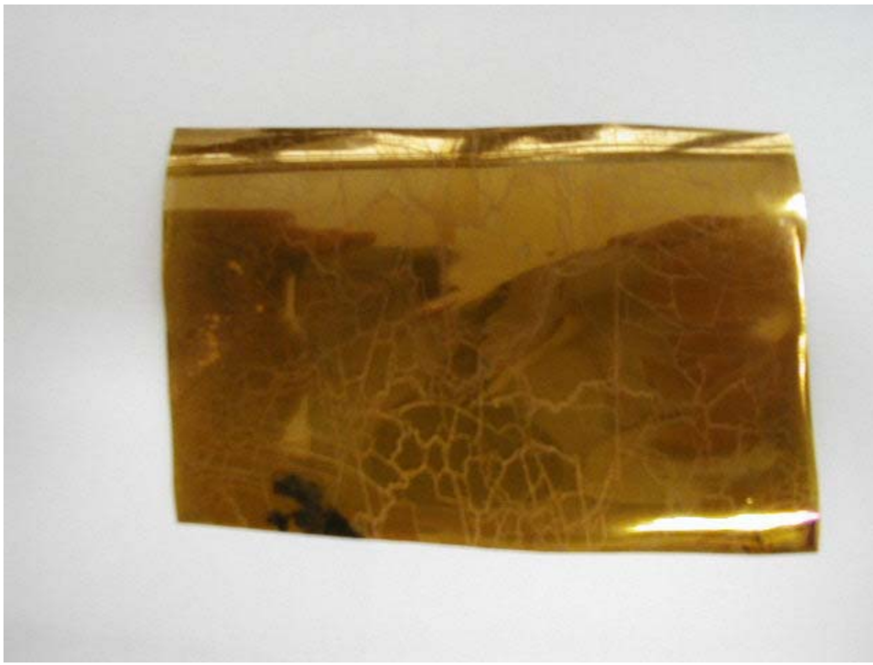
- **RBS** – “good” parts – about 100Å Al deposition mostly at surface

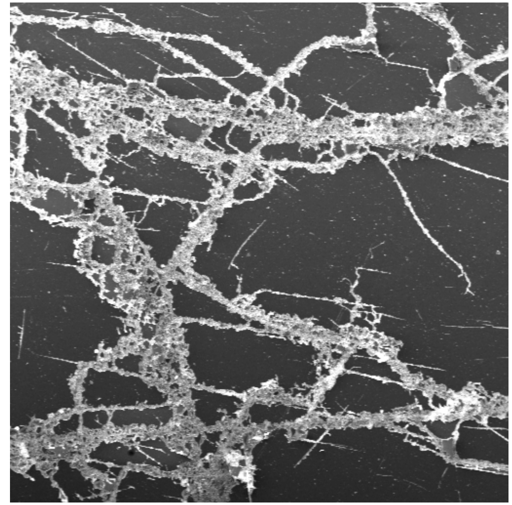


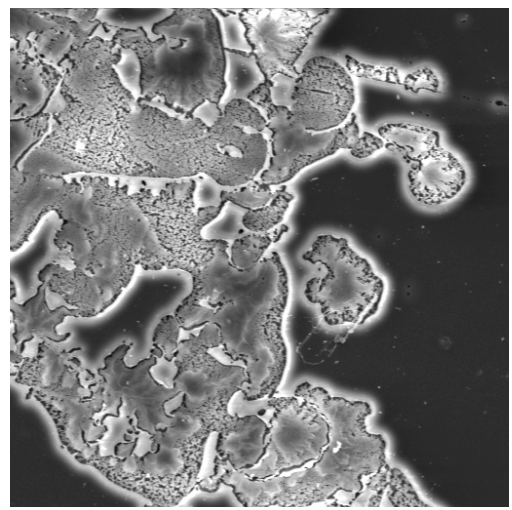
- **Adhesion tests after thermal cycling showed no delamination**

- **Kapton sample with Al deposition (200Å) + nitrogen plasma implantation**

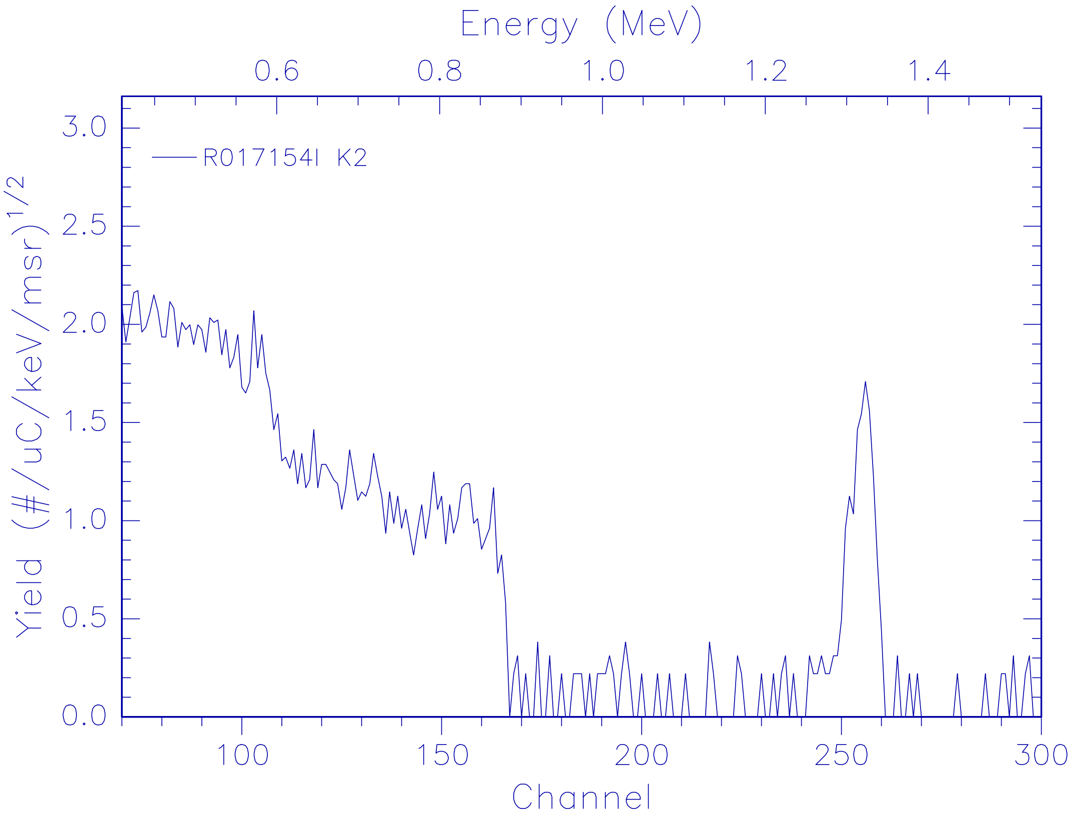
- Formation of cracked film → probably stressed aluminum nitride
- Loss of transparency







- **RBS** – Al deposited mostly at surface



- **Adhesion tests after thermal cycling showed no delamination**

Conclusions

- Kapton samples implanted with Al in a magnetized vacuum arc discharge resulted in excellent protection of the polymer against oxygen degradation.
- Retained doses of 10^{16} atoms/cm^2 were obtained, and although most of the atoms are concentrated on the surface, an intermediate ion mixing layer was formed.
- Adhesion test after thermal cycling shows good adhesion to the substrate.
- Implantation with Al in non-magnetized plasmas needs much longer treatment times, incompatible with present machine configuration.
- Al deposition by e-beam, followed by recoil implantation in a nitrogen plasma resulted in a cracked film, probably due to the formation of a stressed aluminum nitride film. Recoil implantation in an argon plasma is underway.

Acknowledgements:

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