Study of ion damage on EUV light source collector mirrors

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Collector mirror lifetime

Main EUVL light source requirements (Throughput 100wfr/hr)

- EUV Power 115 W
- Long lifetime collector mirror

  Lifetime limitations :

  1) EUV exposure, heat load
  2) Cleanliness
  3) Fast ions

Development of collector mirror lifetime extension technology

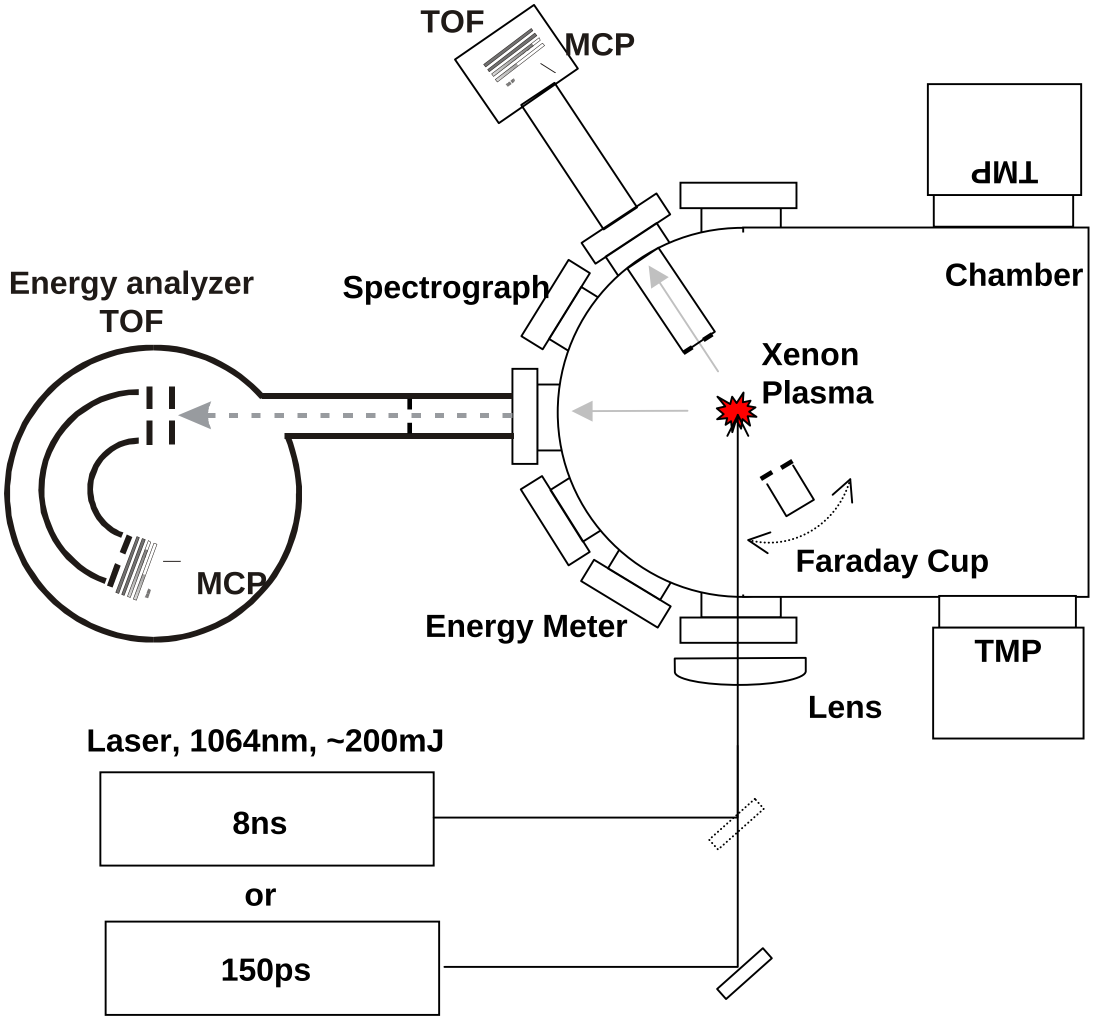
- Characterize ions from laser produced plasma using time-of-flight method (TOF)
- Clarify the damage mechanism of collector mirror caused by ions

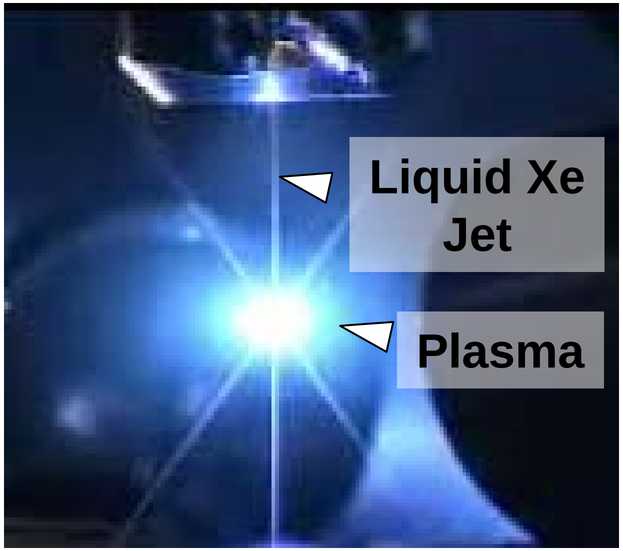
  Xe ion exposure test by :

  1) ion gun
  2) laser produced plasma
- Ion mitigation technology development

  Examine effective ion mitigation methods

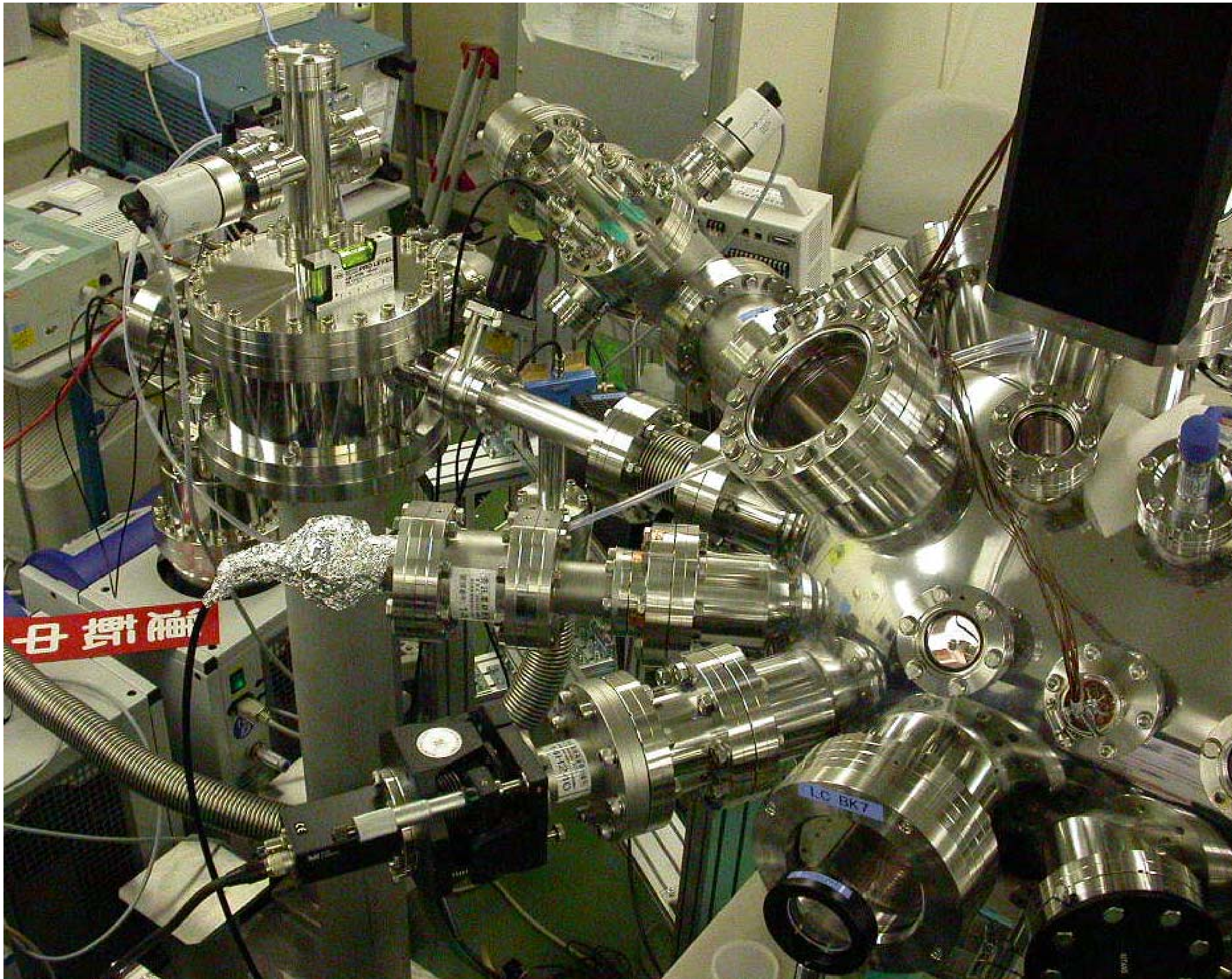
Experimental set up for ion energy measurement





Liquid Xe Jet and plasma

Experimental set up for ion energy measurement

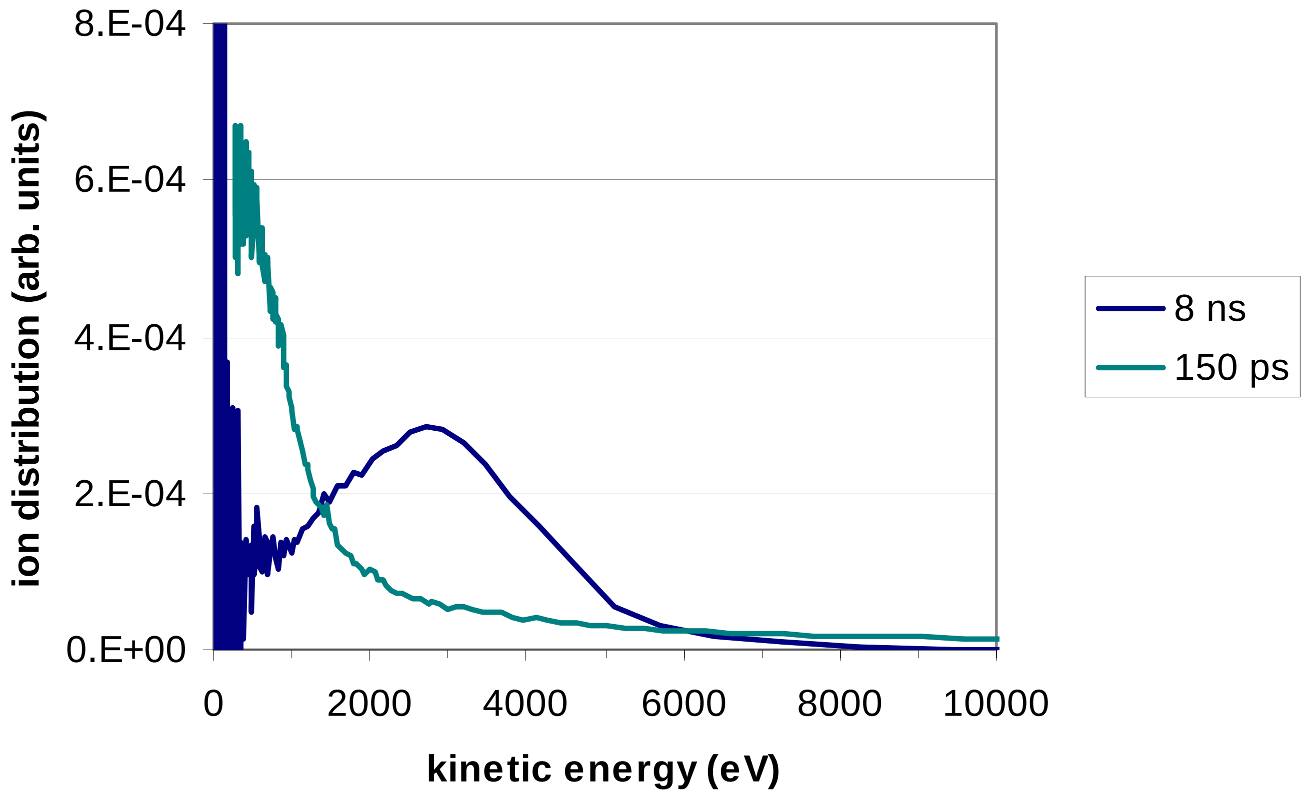


Xe ion energy measurement

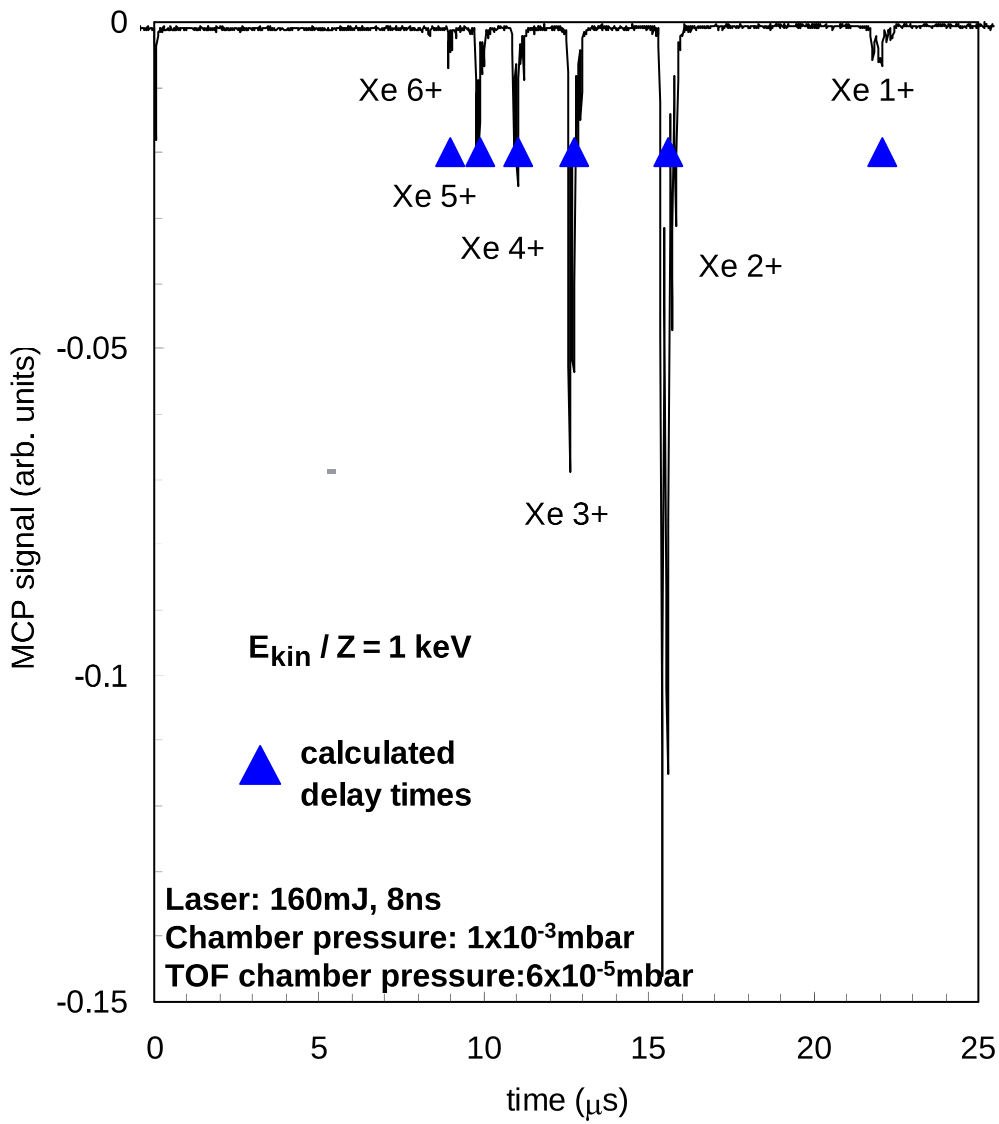
TOF measurement

-Xenon Ion Energy: 3 keV peak. 0.5 keV peak.
3 keV mean 7 keV mean

Laser Energy=200mJ,
Pulse Duration=8ns (fwhm), 150 ps (fwhm)
Intensity = 7.5x10^{11} W/cm^2 4x 10^{13} W/cm^2



Electro-static energy analyzer TOF signal



$Mv^2/R_0 = eZE(R_0)$

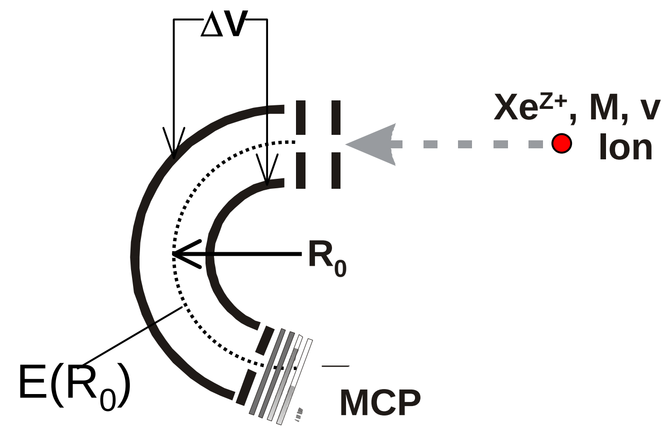
(Centrifugal force

=Charge x Electric field strength)

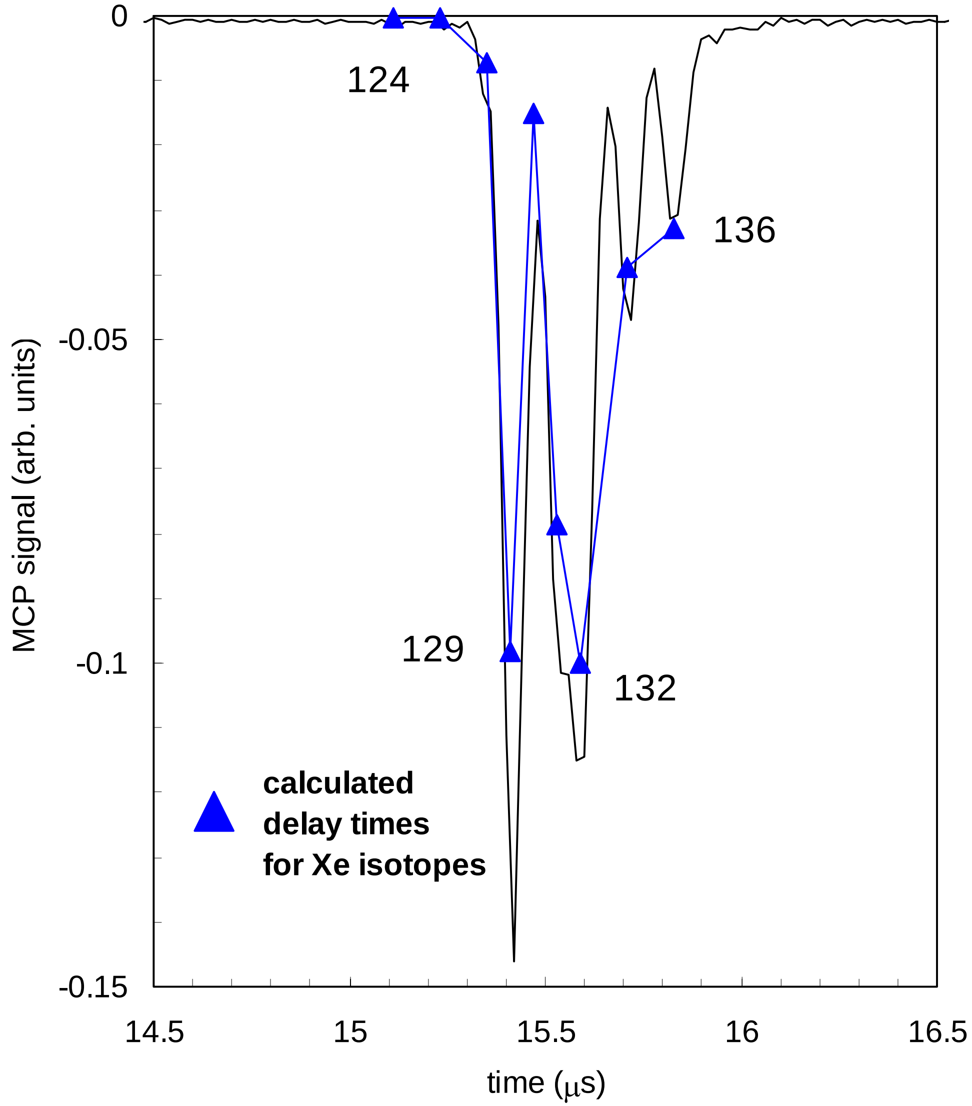
$E_{kin}/Z = Mv^2/2Z$

$= e R_0 E(R_0) / 2$

$= ke \Delta V$ [eV] : k=2.254



Fine structure of TOF signal



Laser: 160mJ, 8ns,
E_{kin}/ Z =1keV, Z=2;
avg 50 pulse

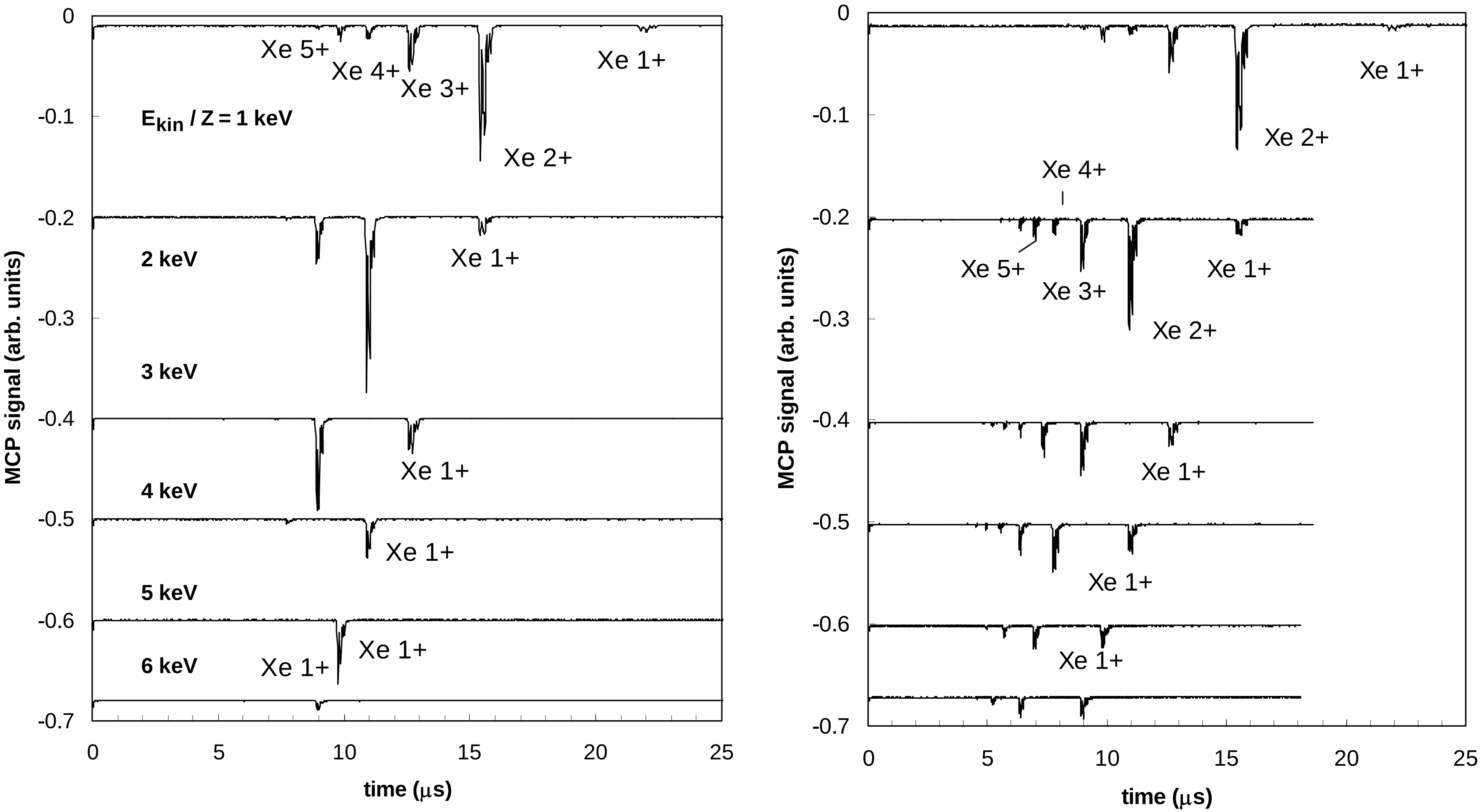
Xe isotopes

Mass Number Xe	Rel. Abundance (%)
124	0.1
126	0.1
128	1.9
129	26.4
130	4.1
131	21.2
132	26.9
134	10.4
136	8.9

TOF signal dependence on laser pulse duration

Laser energy: 100mJ

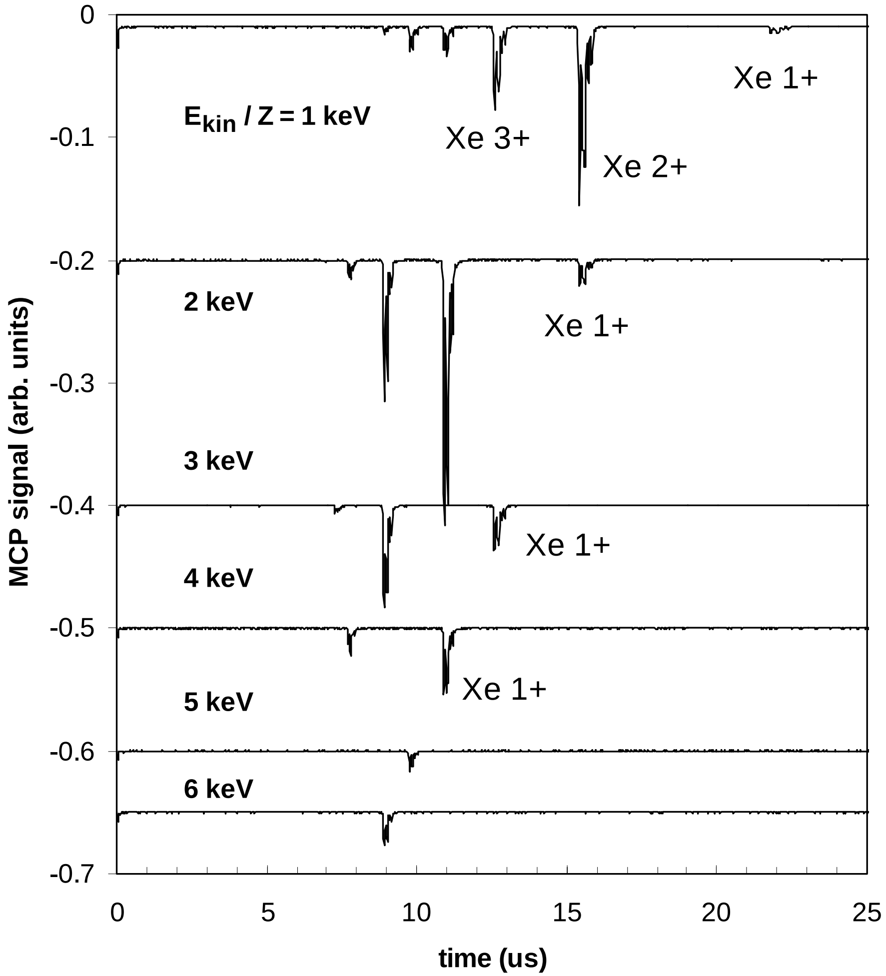
Pulse duration: 8 ns, Intensity: 3.8×10^{11} W/cm^2 150 ps, 2×10^{13} W/cm^2

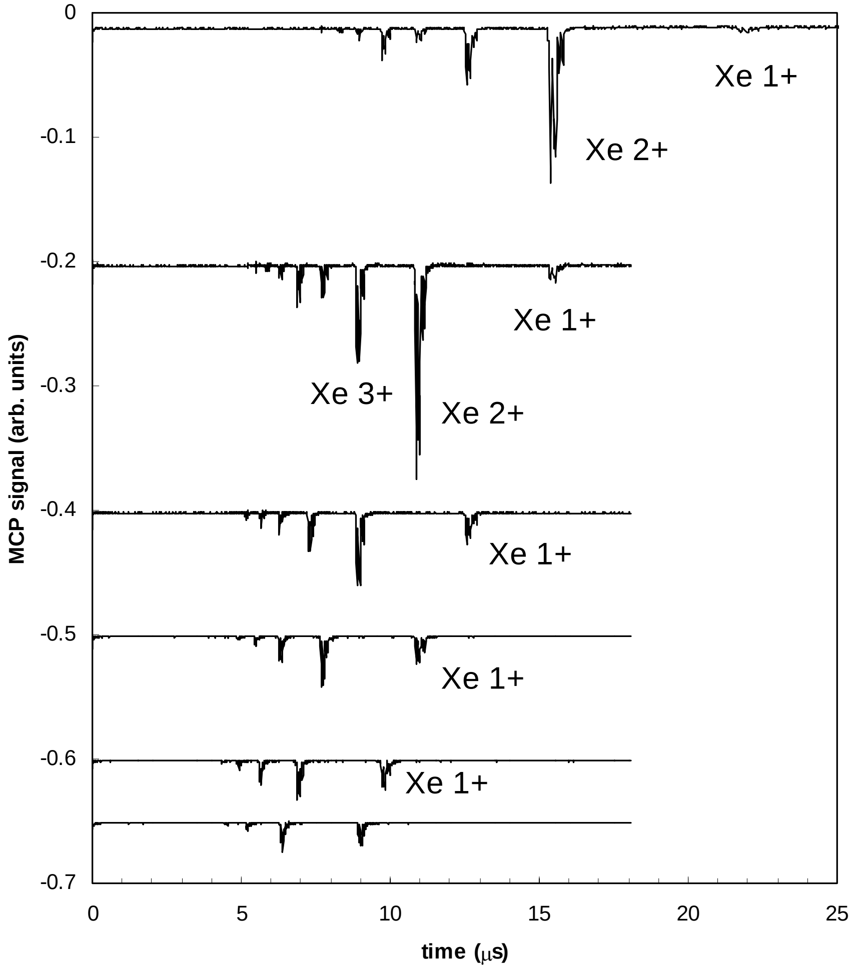


TOF signal dependence on laser energy

Laser energy: 160mJ

Pulse duration: 8 ns, Intensity: 6×10^{11} W/cm^2 150 ps, 3.2×10^{13} W/cm^2





Characterization of fast ions from LPP

Time-of-flight (TOF) ion measurement combined with electro-static energy analyzer.

•Xe^{2+} is the main ion from plasma.
•Up to Xe^{6+} ions are observed with 8-ns laser.
•Higher charge state Xe ions are observed with 150-ps laser.

Xe ion exposure measurement

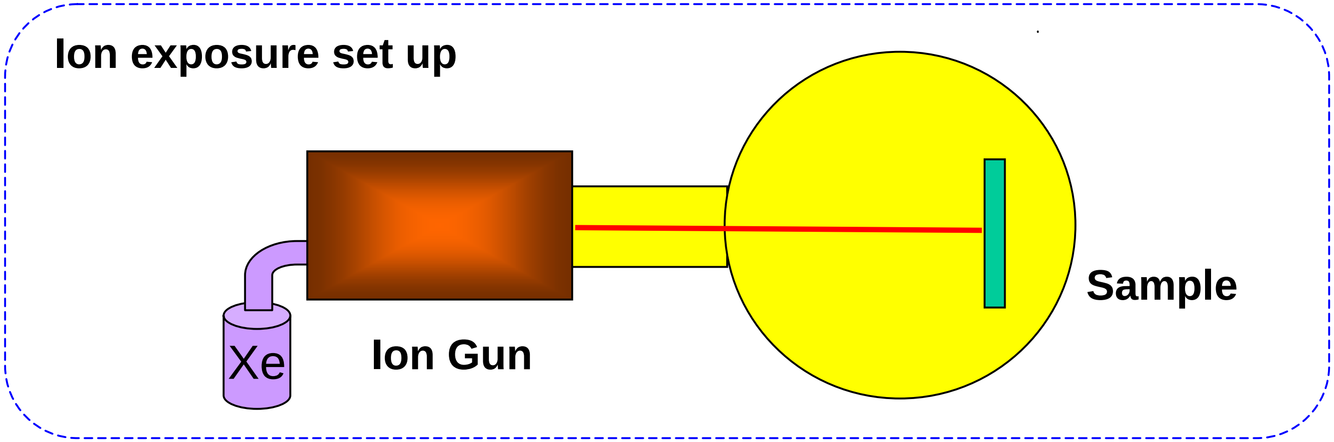
- Study of the influence of high-energy ions on Mo/Si multilayer mirrors

Xe ion exposure measurement with ion gun (5keV Max)

- Simplify the damage analysis
- Well defined ion energy

Exposure test by laser produced plasma

- Exposure test under real environment ex. EUV, Residual gas, Contamination
- Difference in charge state LPP Xe^{+}-Xe^{6+}



Conditions of Xe ion exposure measurement

Sample

•10 Mo/Si bilayer Si substrate mirror, λ=13.5 nm

Exposure conditions

•Ion energy 2 – 5 keV

•Ion dose 2.8 – 3.7 x 10^{16} ions/cm^2

•Normal incidence

Analysis

•Reflectivity measurement

•Depth profiles by Auger Electron Spectroscopy (AES)

•Cross sectional image by Transmission Electron Microscope (TEM)

Loss of multilayers

Increase of inter diffusion / Mixing

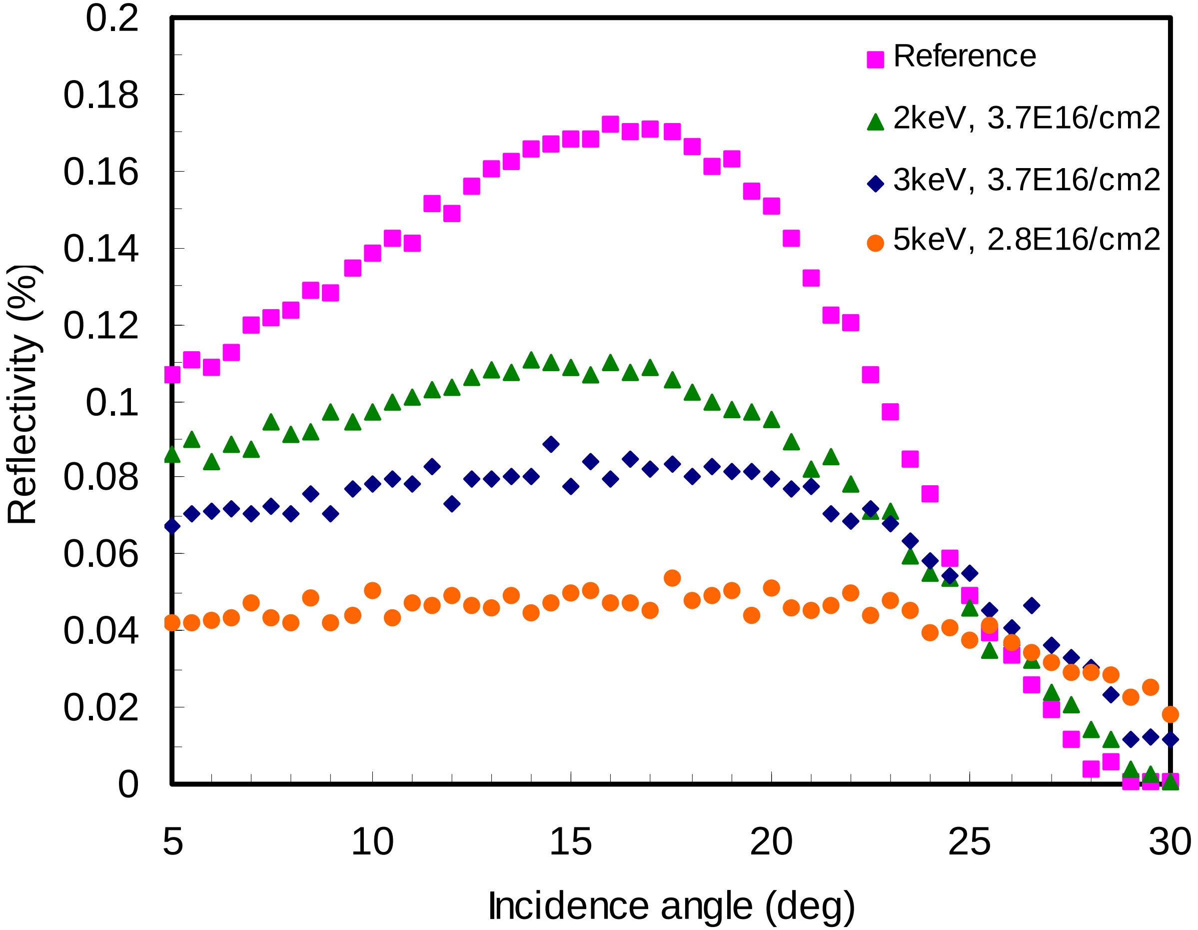
•Surface measurement by Atomic Force Microscopy (AFM)

Increase of surface roughness

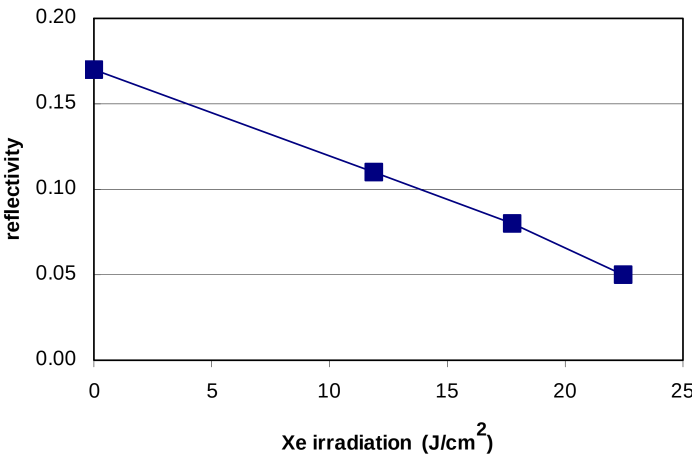
•Implanted Xe analysis by X-ray Photoelectron Spectroscopy (XPS)

Absorption by implanted Xe

Reflectivity measurement of exposed samples

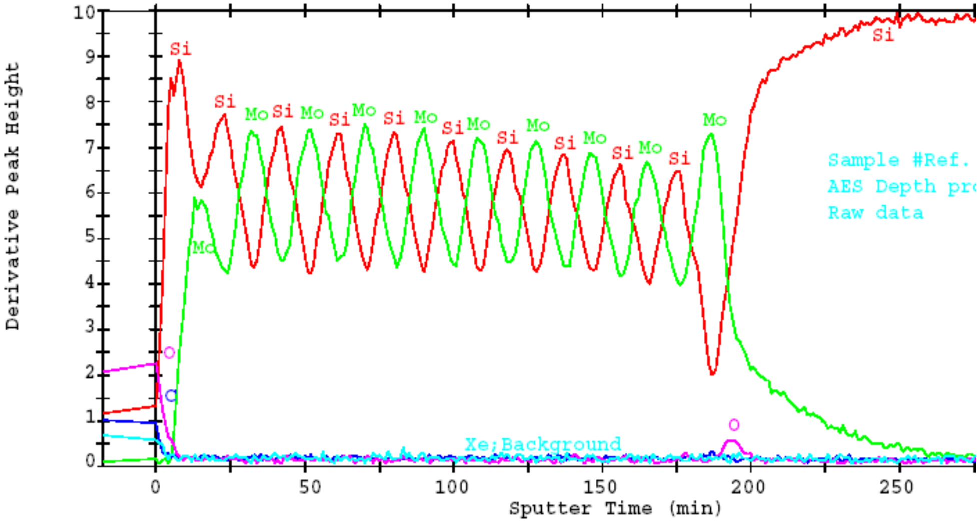


10 Mo/Si bilayer
Si substrate mirror
λ=13.5 nm

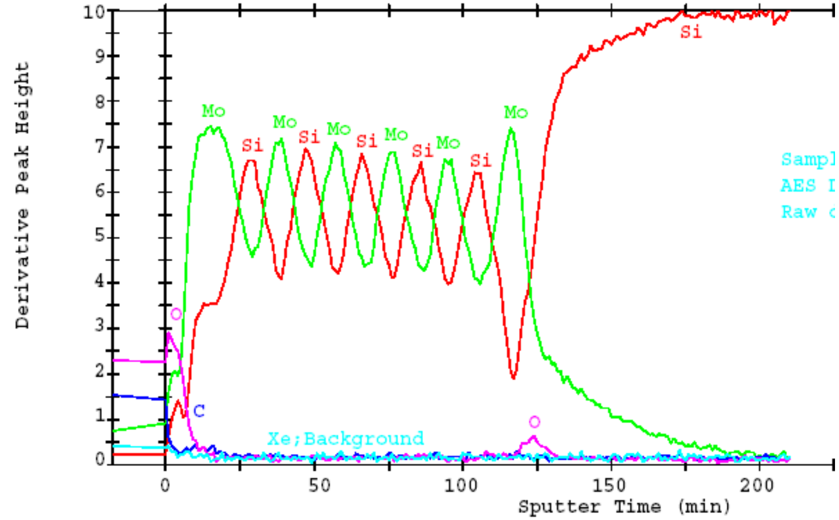


Ref: Noriaki Kandaka etal, Proceedings of SPIE Vol. 4343 (2001), 599

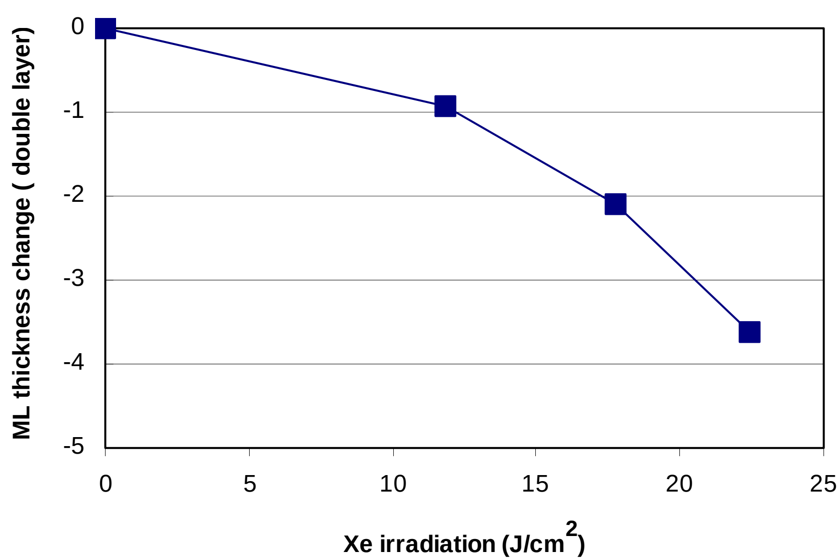
AES depth profiles of ion exposed samples



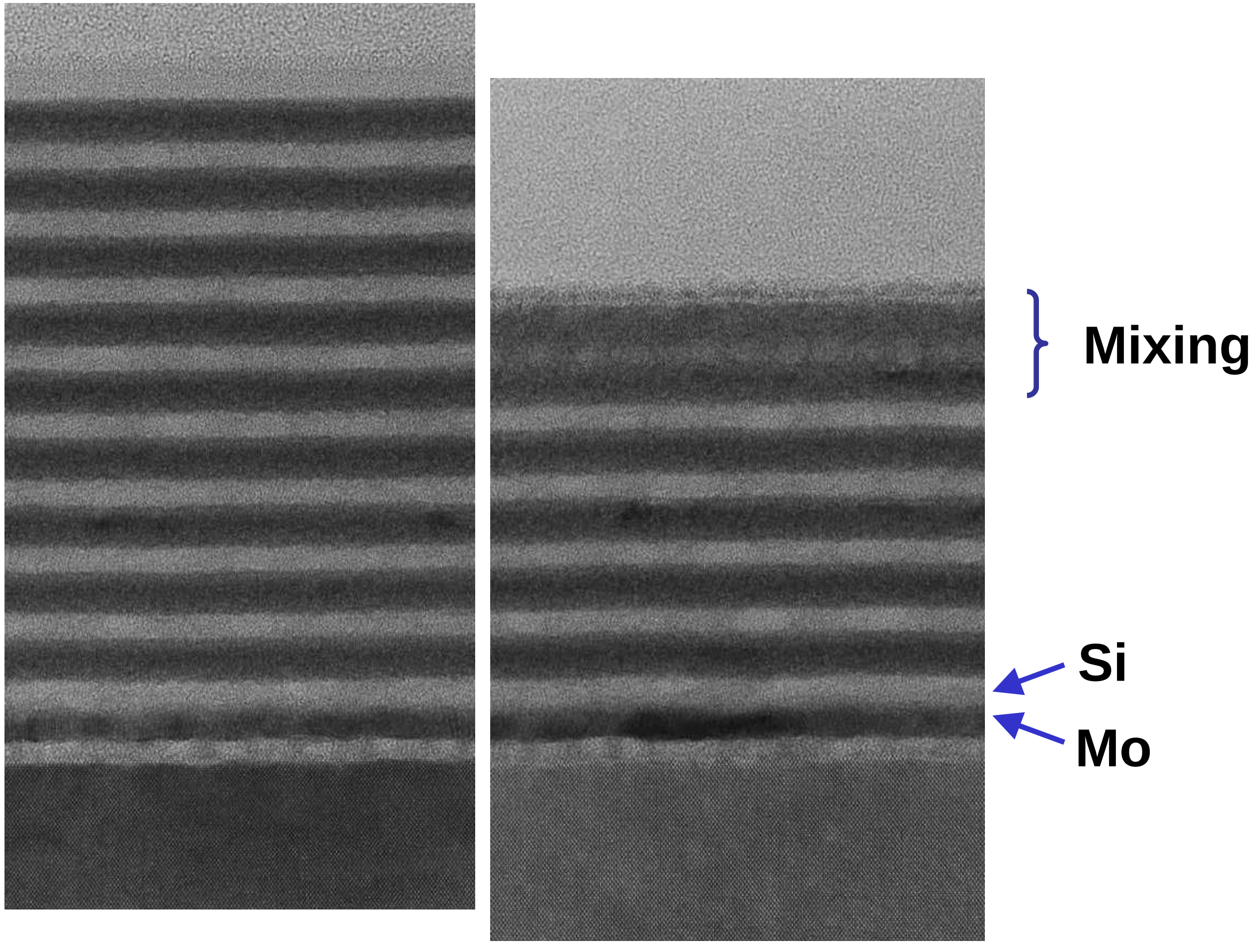
Reference



Ion energy 5 keV, Ion dose 2.8 X 10^{16} atoms/cm^2



TEM cross sectional image of multilayers

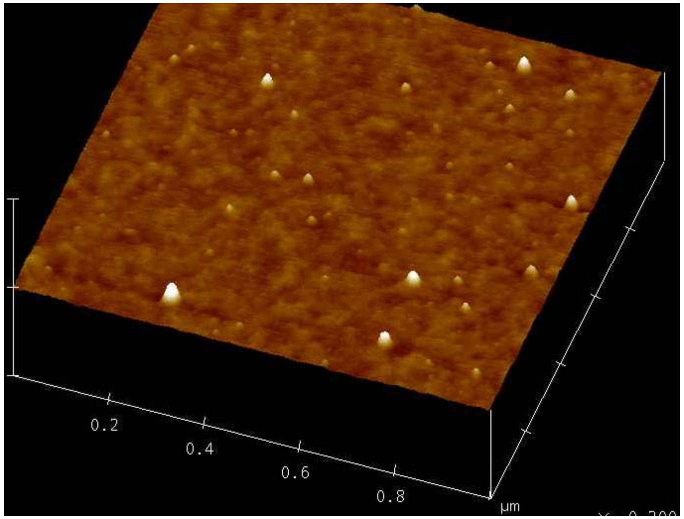


Reference

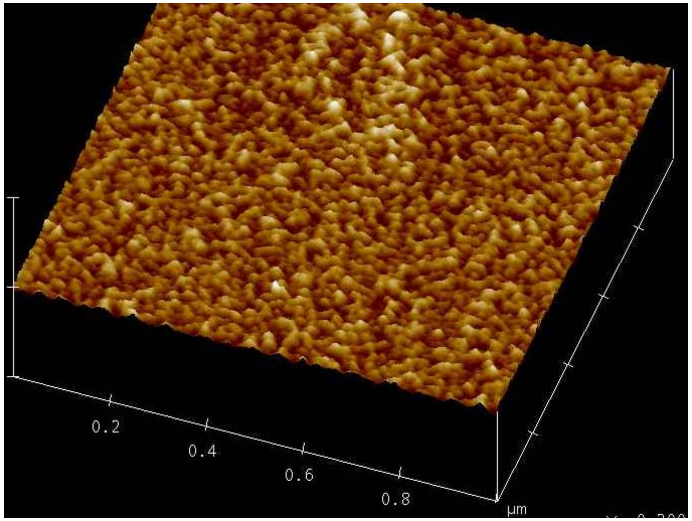
(10 Mo/Si bilayer
Si substrate mirror)

Ion energy 5 keV
Ion dose 2.8 X 10^{16} atoms/cm^2

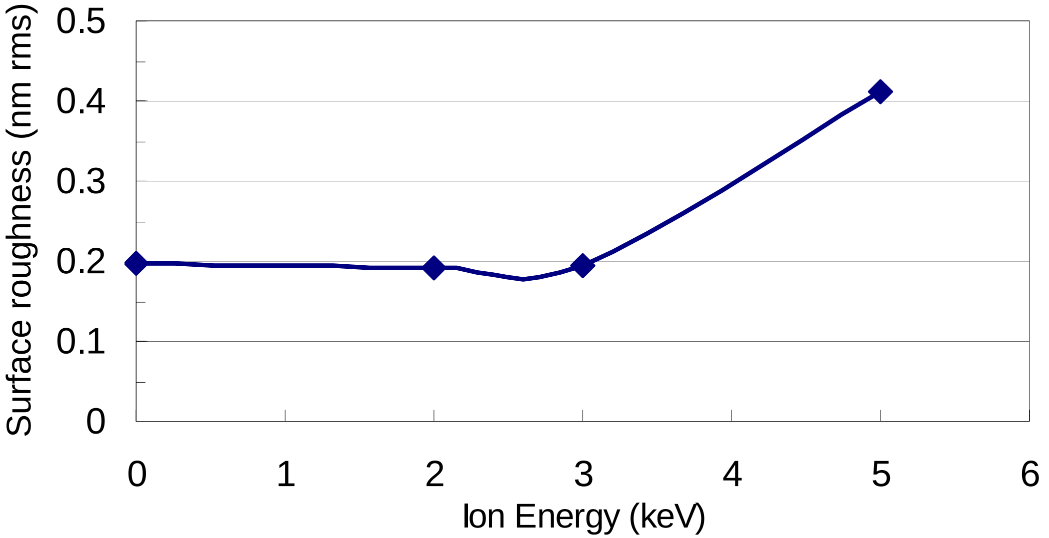
AFM scan image of multilayer surface



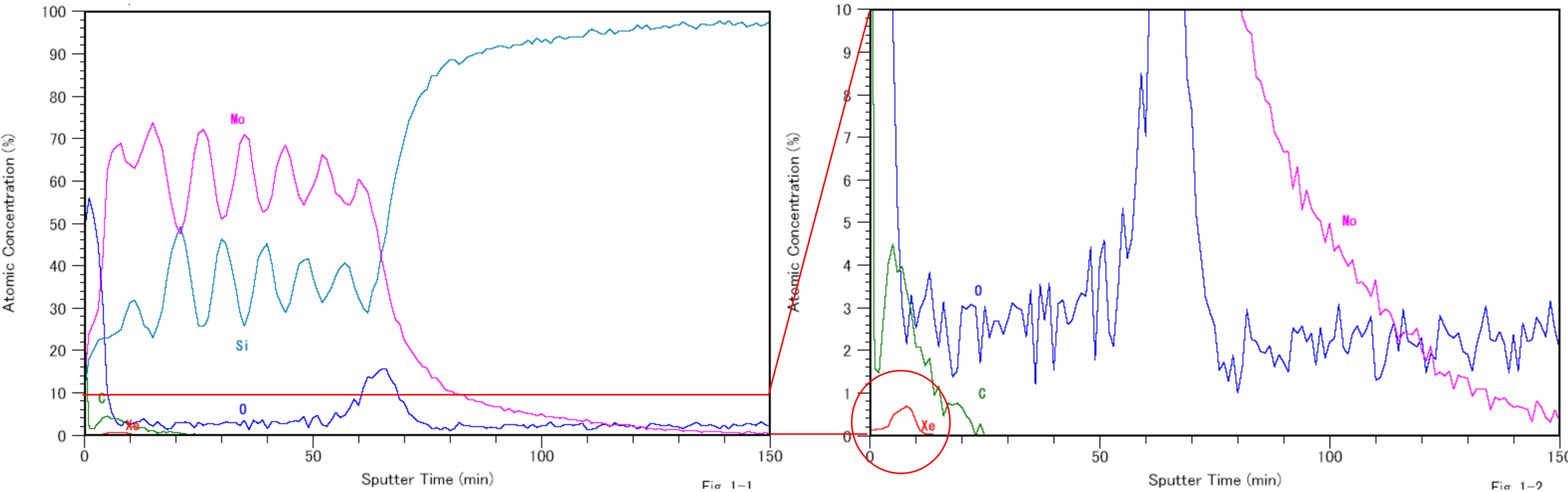
Reference Rms: 0.196 nm



Ion energy 5 keV, Ion dose 2.8 X 10^{16} atoms/cm^2
Rms: 0.411 nm



Implanted Xe analysis by XPS



Ion energy 5 keV

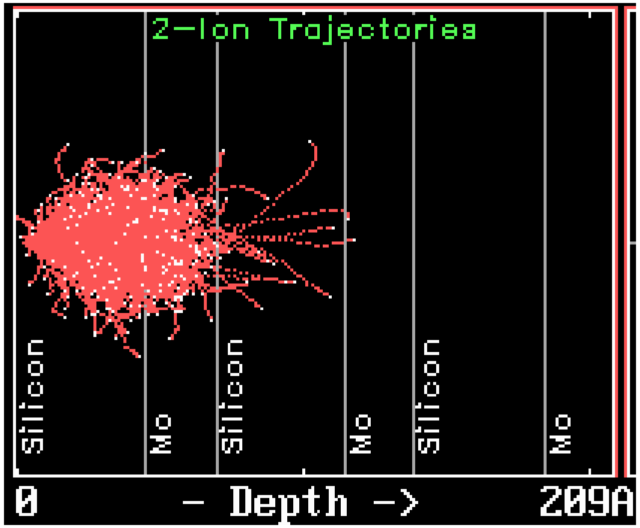
Ion dose 2.8 X 10^{16} atoms/cm^2

Xe atomic %: 0.7% peak

Total depth: 8 nm

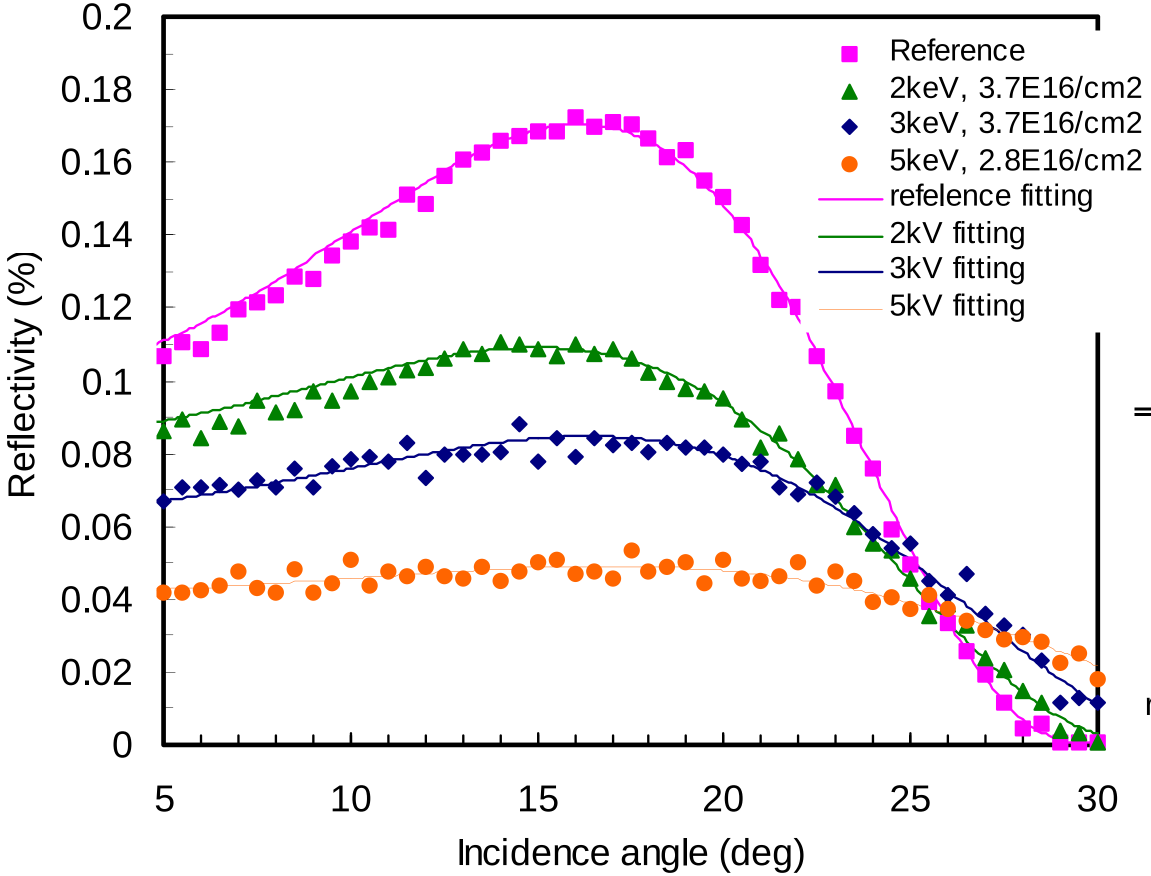
↓

Negligible absorption at 13.5 nm (<0.5%)



Monte-Carlo TRIM

Reflectivity fitting



Fitting parameters

Items	reference	2keV	3keV	5keV
Layer period (A)	69.6	69.15	69.55	69.55
Number of pairs	10	8	7	5
Thickness ratio	0.35	0.35	0.35	0.35
Interface layer thickness (A)	17.9	17.9	17.9	17.9
Interface roughness (Arms)	1.2	3.7	4.1	3.6

Ref: Noriaki Kandaka etal, Proceedings of SPIE Vol. 4343 (2001), 599

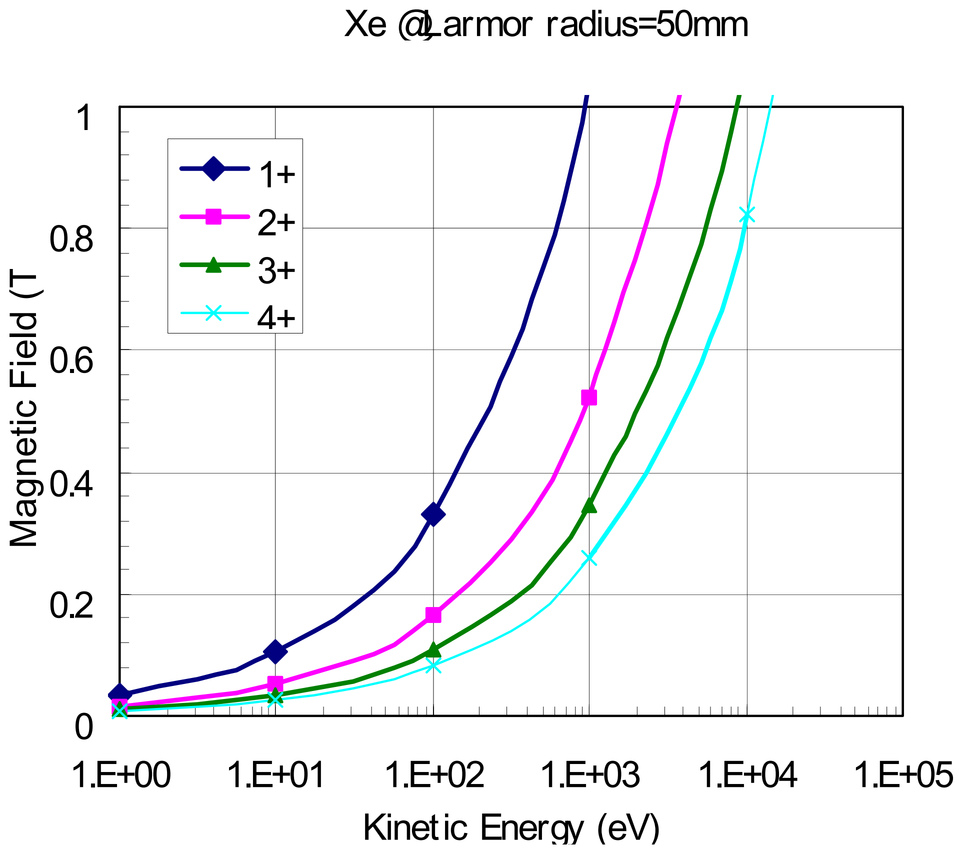
Damage mechanism of collector mirror

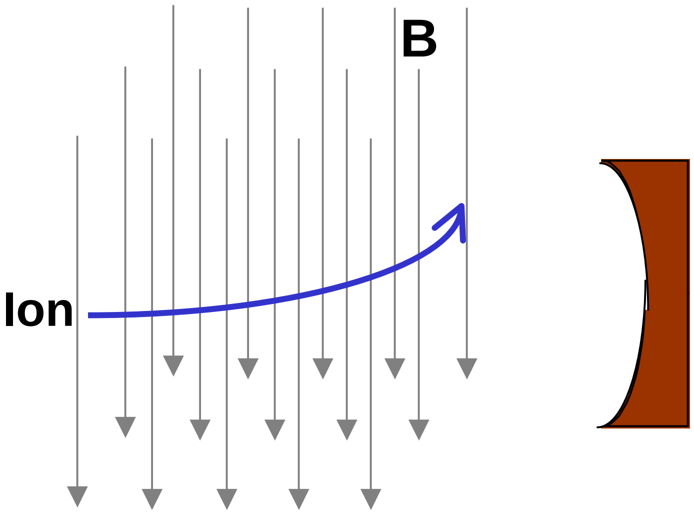
Clarify the damage mechanism of collector mirror by Xe ion exposure test with ion gun

- Ion sputtering of multilayer is the main mechanism.
- Multilayer boundary mixing and surface roughness increase is also observed.
- EUV absorption by implanted Xe is negligible.

Magnetic field for ion guide

Ion mitigation technology development
- Stop ions with buffer gas
- Magnetic field ion guide





Summary

Ions from laser produced plasma are characterized by time-of-flight measurement (TOF)

•Xe^{2+} is the main observed charge state.

•Up to Xe^{6+} ions are observed with 8-ns laser.

•Higher charge state Xe ions are observed with 150-ps laser.

Ion damage mechanism of the collector mirror has been clarified

•Multilayer sputtering by Xe ion is the main mechanism.

•Boundary mixing at surface bilayer and surface roughness increase is observed.

•EUV absorption by implanted Xe is negligible.

Ion mitigation technology development

Different schemes under investigation, e.g. Magnetic field ion guide

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