Study of EUV Source Collector Damage Mechanism

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Part of this work funded by ISMT under LITH152

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Highly Charged Ions: how they are different from ordinary ions, and why you should care.

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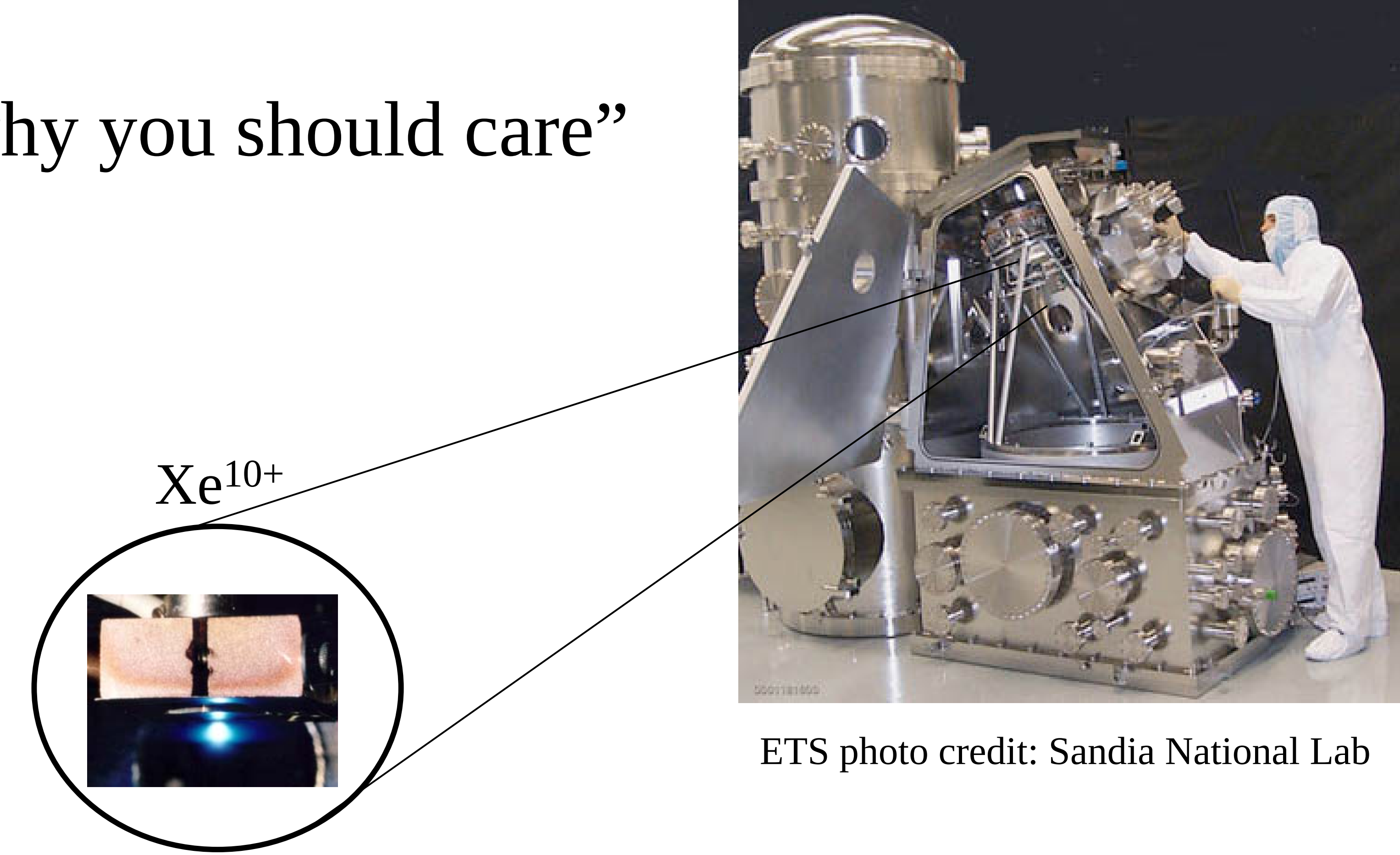
“. . . and why you should care”



ETS photo credit: Sandia National Lab

- Collector mirror damage data show confusing features which don’t fit well with conventional models.
- The so-called “potential energy sputtering” that is unique to highly charged ions may be able to explain some of these features.
- Potential energy sputtering is a relatively new discovery that is largely unknown within the lithography community..

Fundamental premise: Highly charged ions damage surfaces through an unconventional, and relatively unexplored, mechanism.

Conventional Ions

(Q=1)

Kinetic Energy

$$+1/2\ m\ v^2$$

(“Bowling balls”)

Highly Charged Ions

(Q>>1)

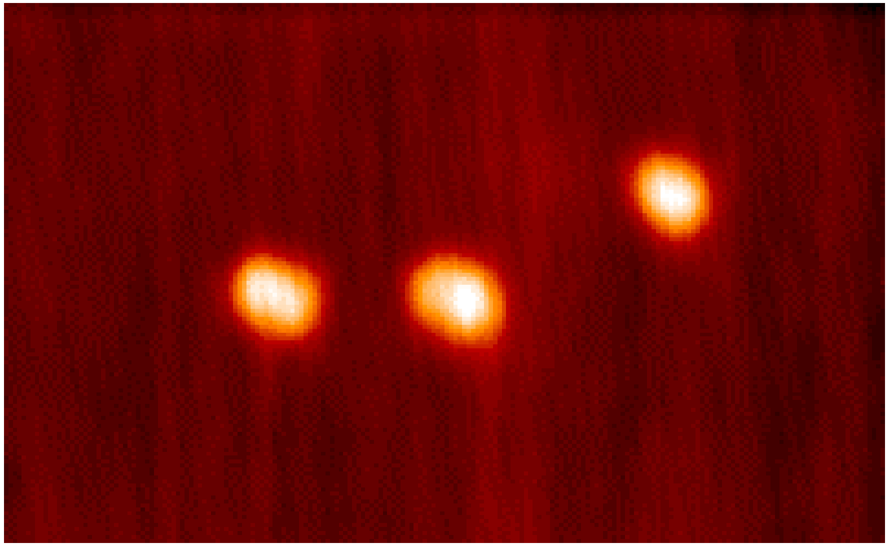
Potential Energy

$$-\ Q/r$$

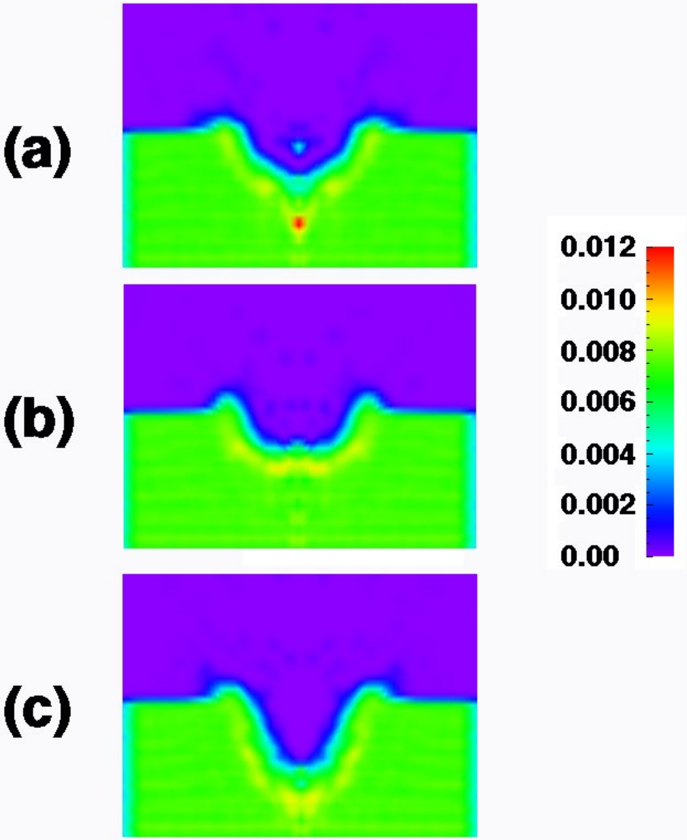
(“Bombs”)

Extreme case: A single Xe^{44+} ion can efficiently (100%) and severely (10 nm) damage a surface, even in the v=0 limit!

Experiment (HOPG)

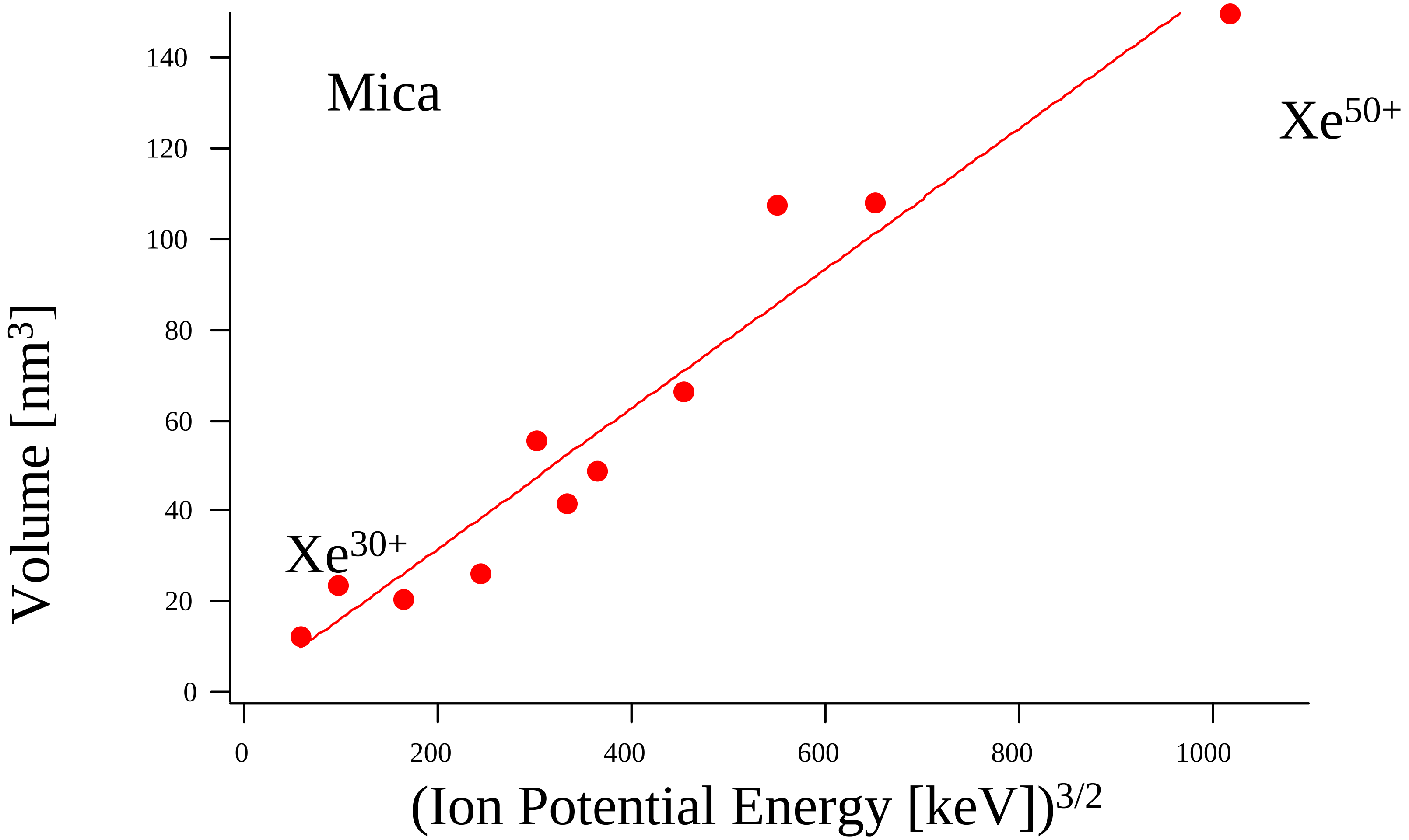


7 nm diameter dots



Theory (v=0)

Extent of the damage can be adjusted by varying the ion charge.



(extrap to 0.001=10 eV; 10^6 vertical gain!)

An example more relevant to EUVL:

Kinetic sputtering for Xe^{1+} ions on a ruthenium coated mirror:

60 eV ions: S<0.2 atoms/ion

[M. Kaminsky, Atomic and Ionic Impact Phenomena on Metal Surfaces, p. 155]

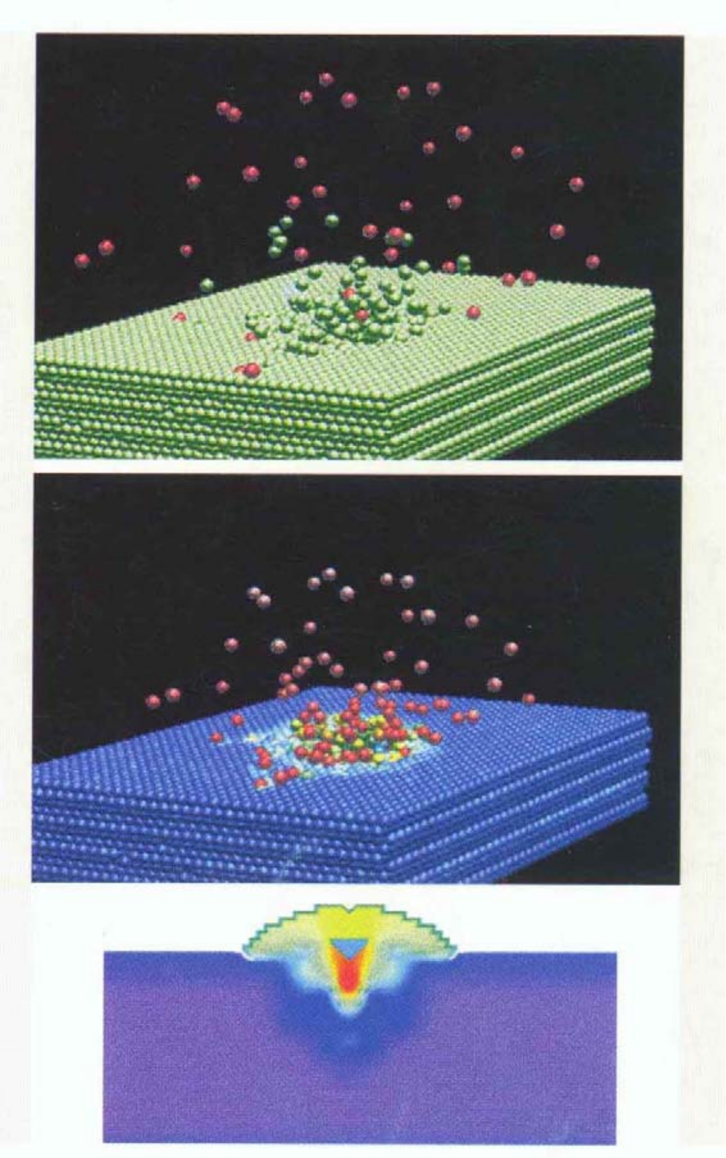
Potential sputtering (estimate):

Xe^{10+} ions: S>8 atoms/ion (80 atoms/ion upper bound)

Factor of over 40-400x larger!

Even if only a small fraction of ions that reach the collector are in high charge states, they may dominate the damage.

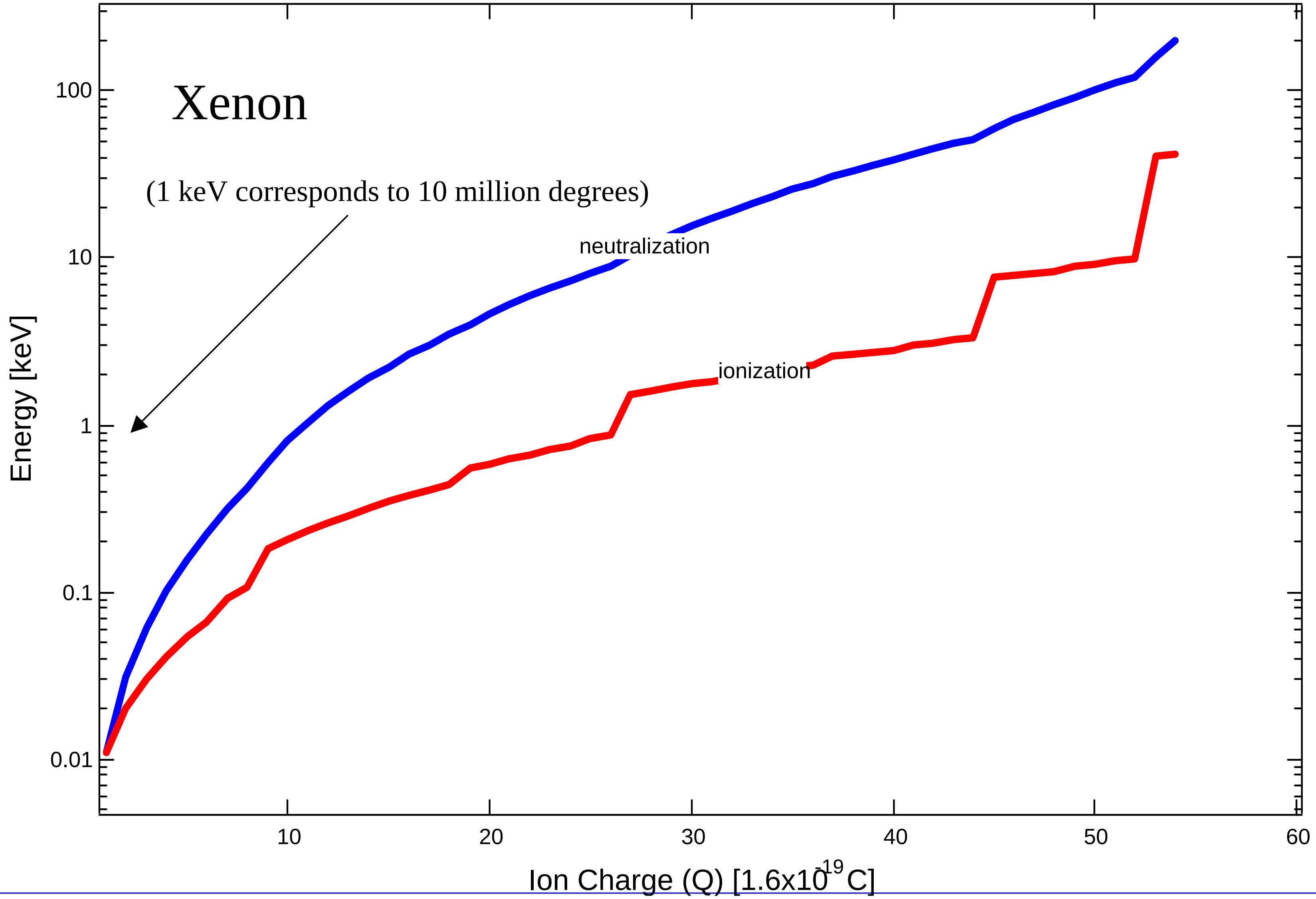
Erosion of source hardware and secondary debris formation is also a concern.



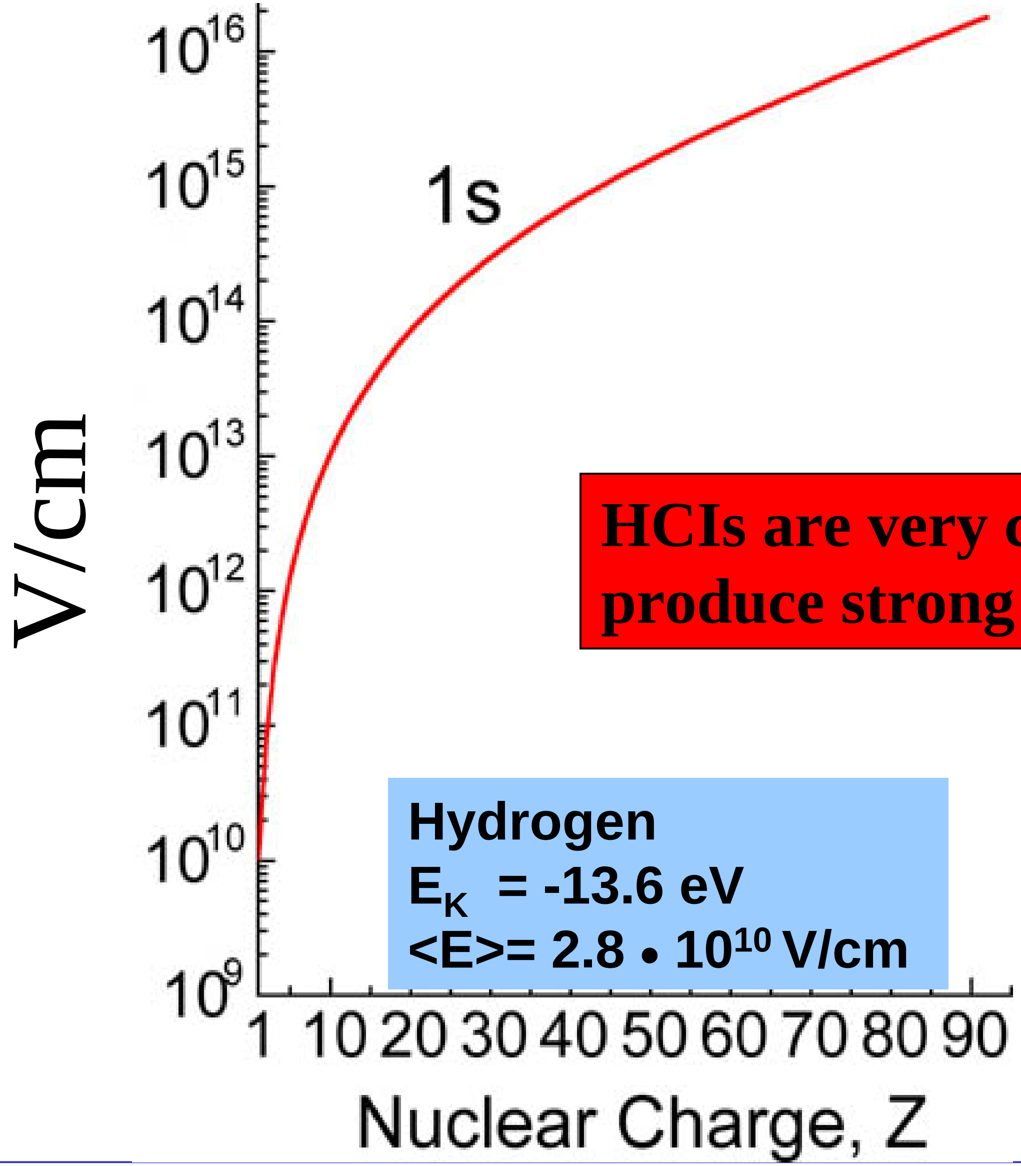
Sputtering yields are dramatically enhanced as Q is increased.

H.-P. Cheng and J. D. Gillaspy, Comp. Mater. Sci. **9**, 285, (1998). Cover.

The underlying mechanism (part I):



The underlying mechanism (part II):



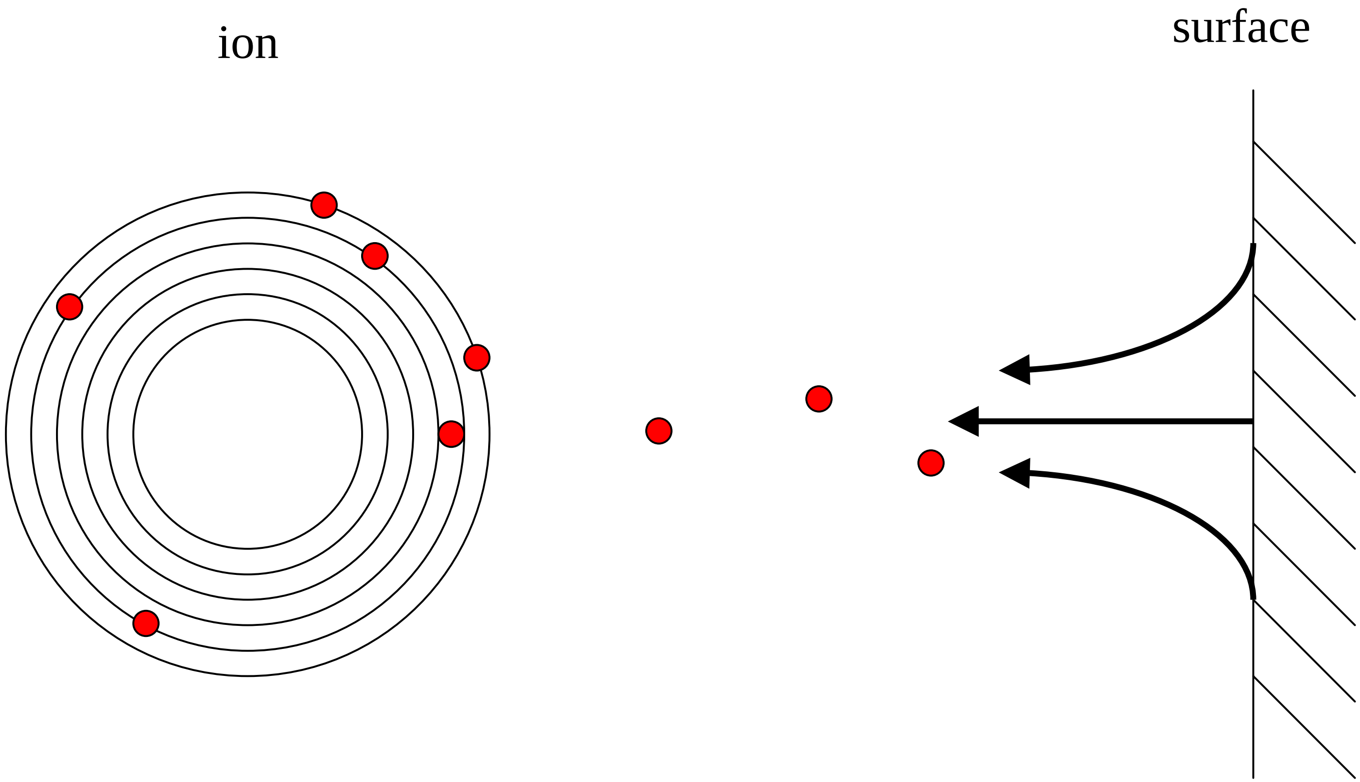
H-like Uranium
E_K = -132 • 10^3 eV
<E>= 1.8 • 10^{16} V/cm

HCIs are very compact, and produce strong electric fields.

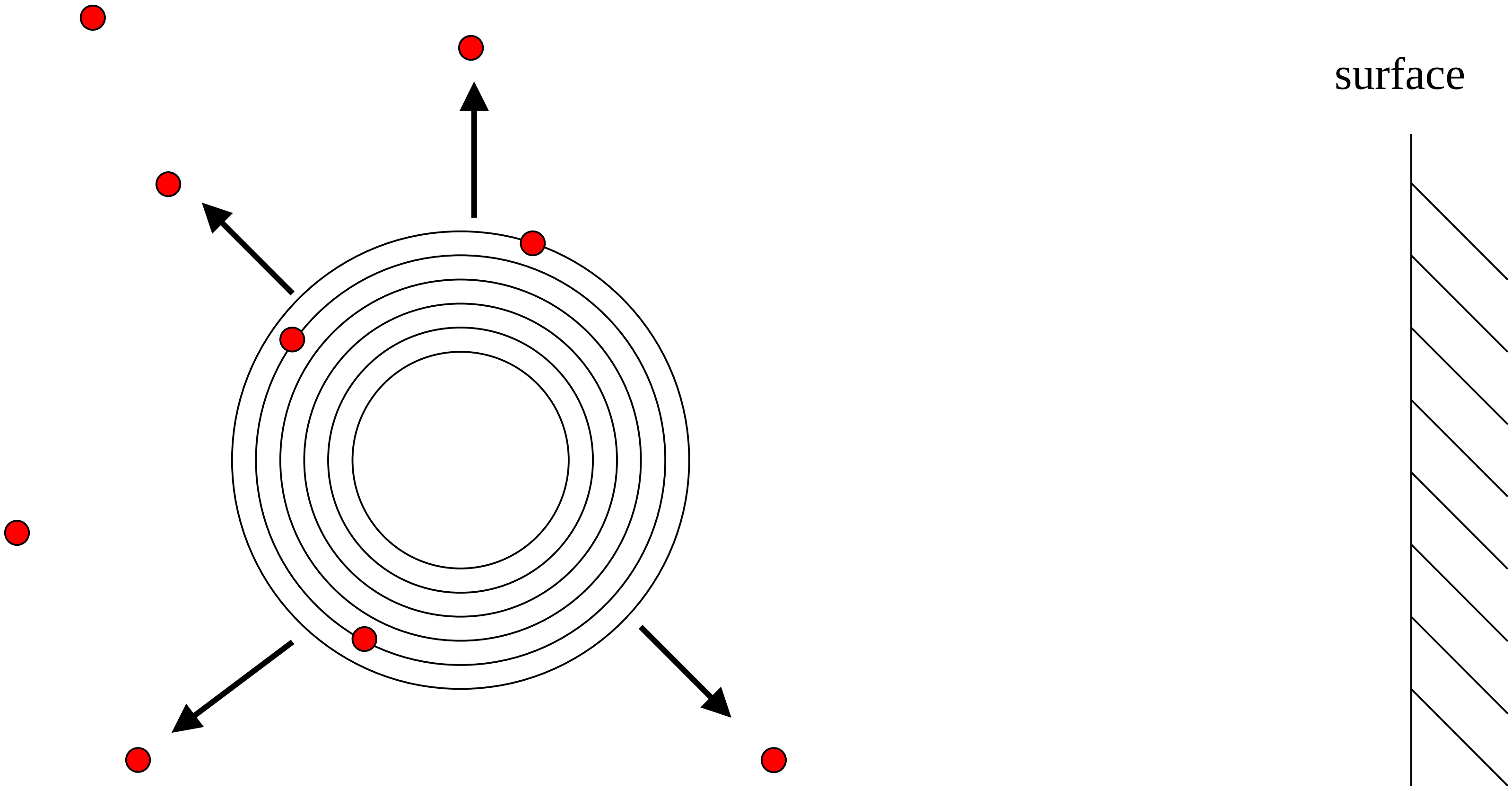
Hydrogen
E_K = -13.6 eV
<E>= 2.8 • 10^{10} V/cm

Plot: T. Stoehlker, GSI

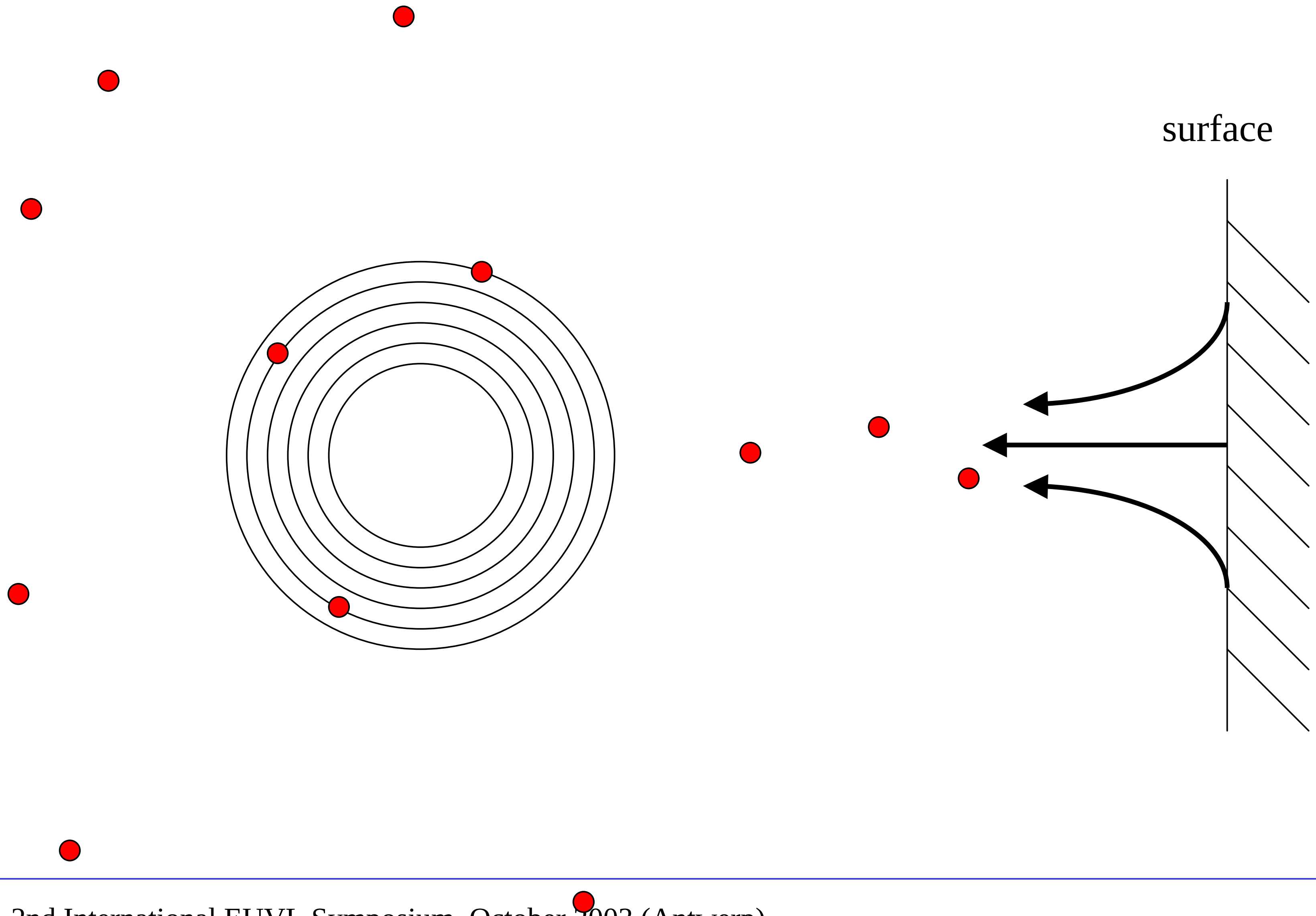
Ion approach to a surface



Auger Decay (electron pump)

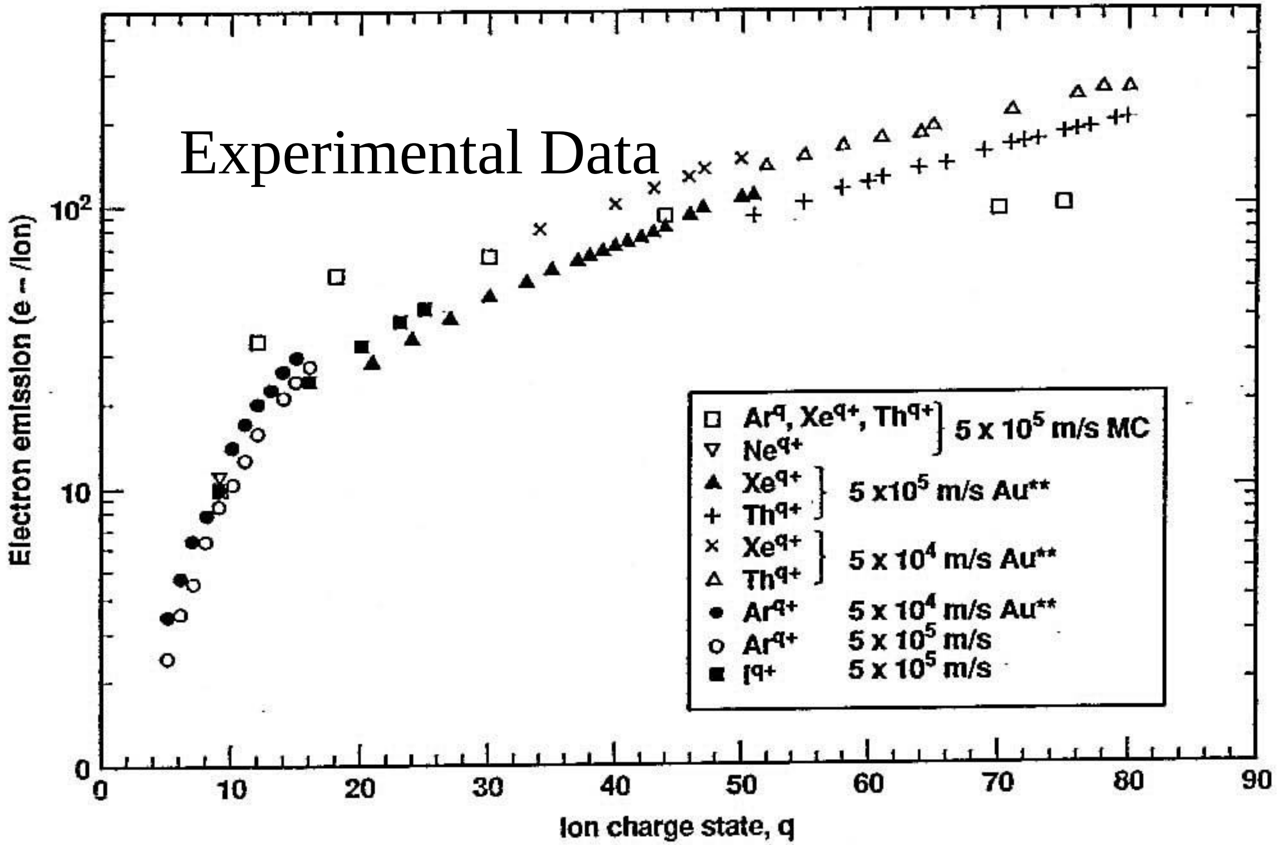


Further Electron Extraction from Surface



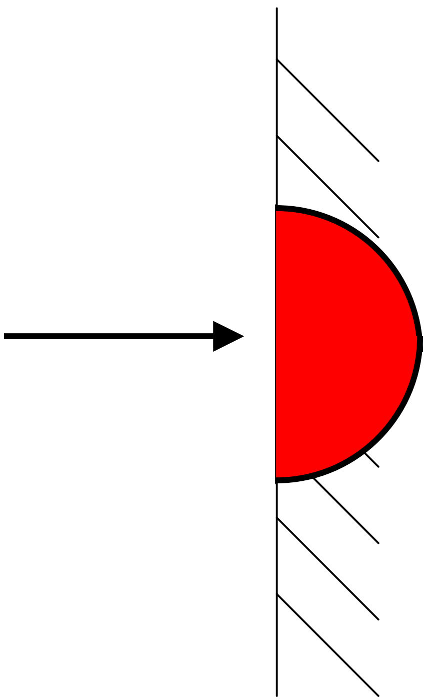
End Result:

Up to 300 electrons/ion ejected



D. H. G. Schneider and M. A. Briere, Physica Scripta, 53, 228 (1996).

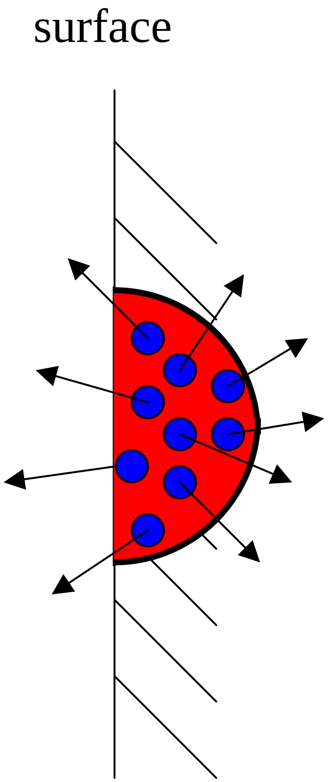
How does the surface respond?



surface

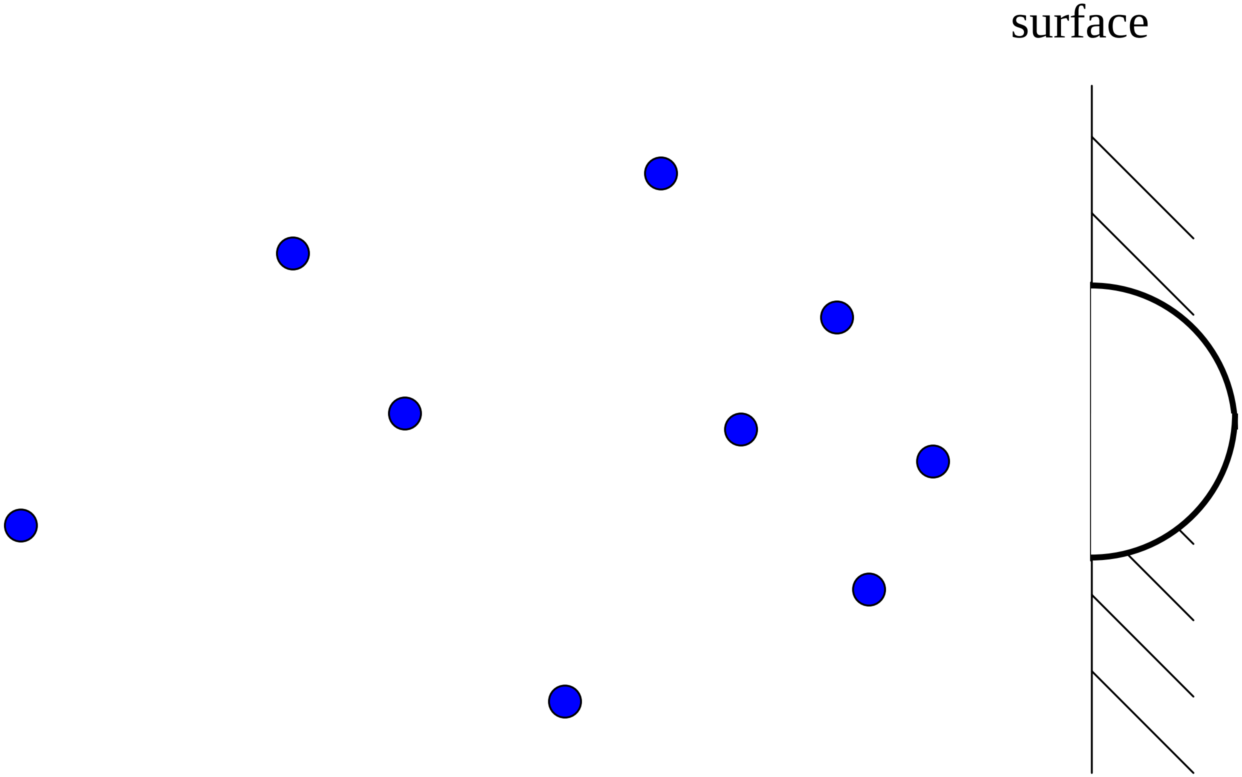
Region of depleted electron charge

This dissolves the “glue” that holds the solid together. . .



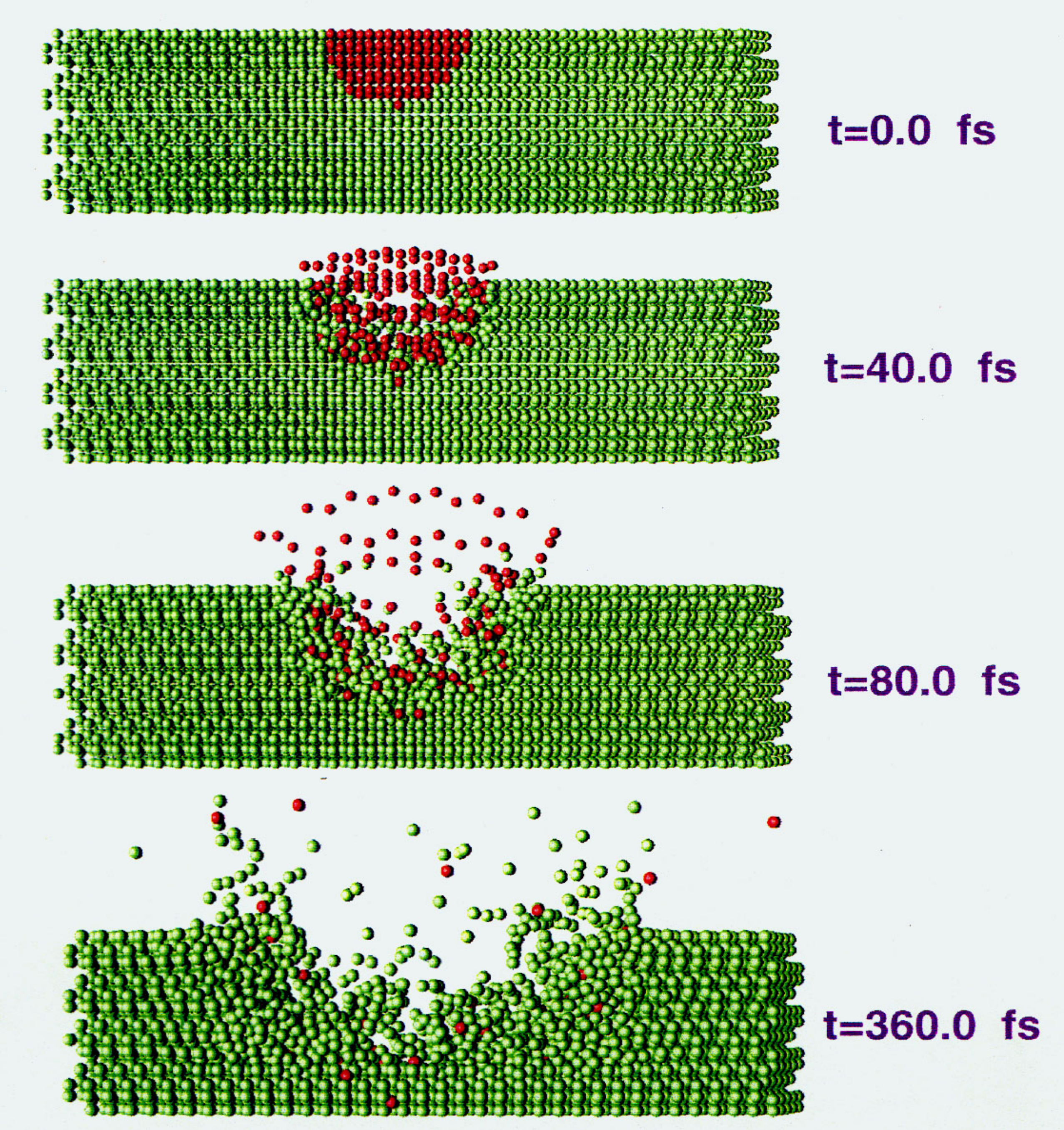
. . . allowing the ionized atoms that make up the solid to blow out . .

Leaving a crater in the surface. . .

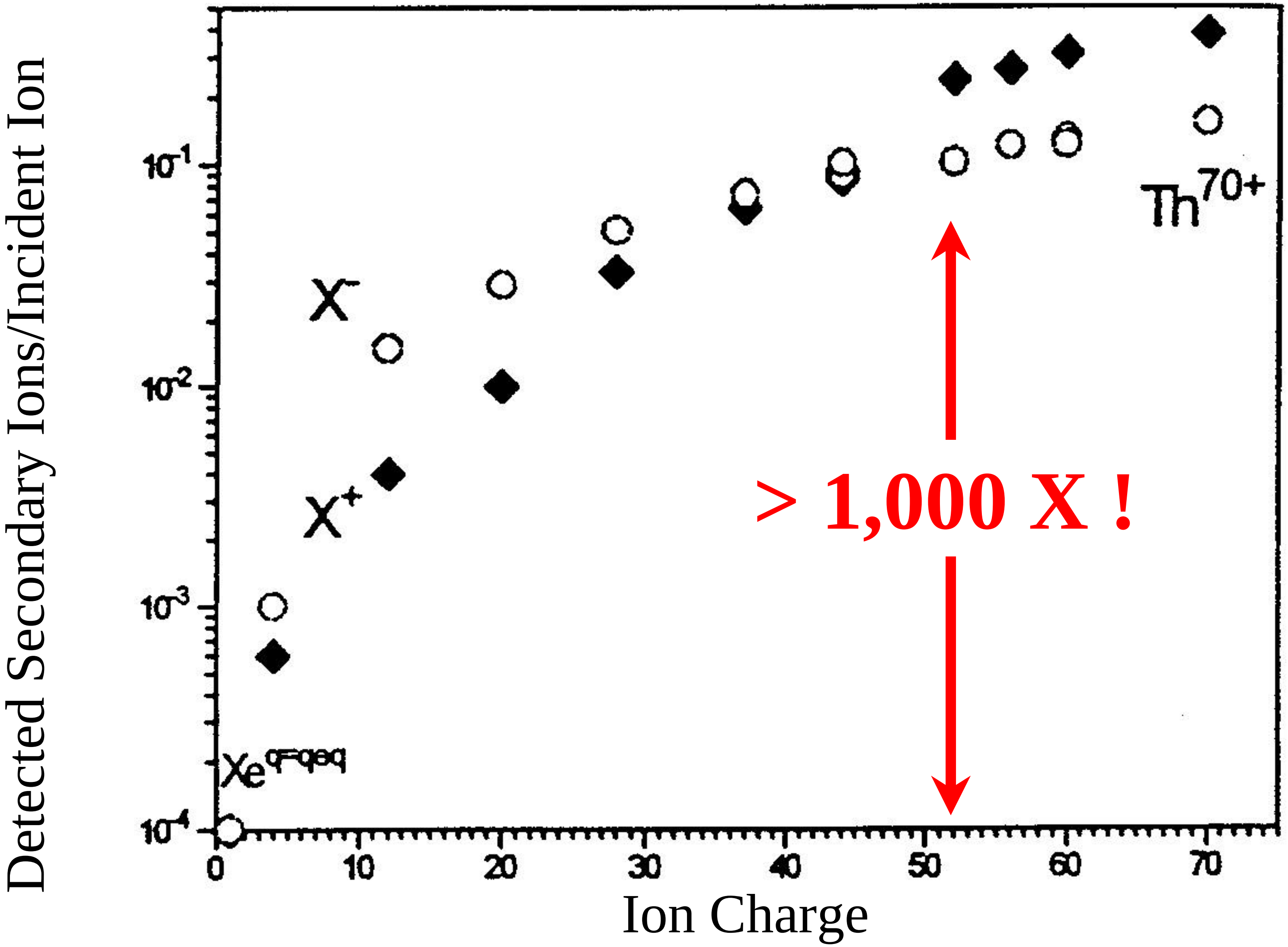


Femtosecond Dynamics

COULOMB EXPLOSION



Enhanced Secondary Ion Yield

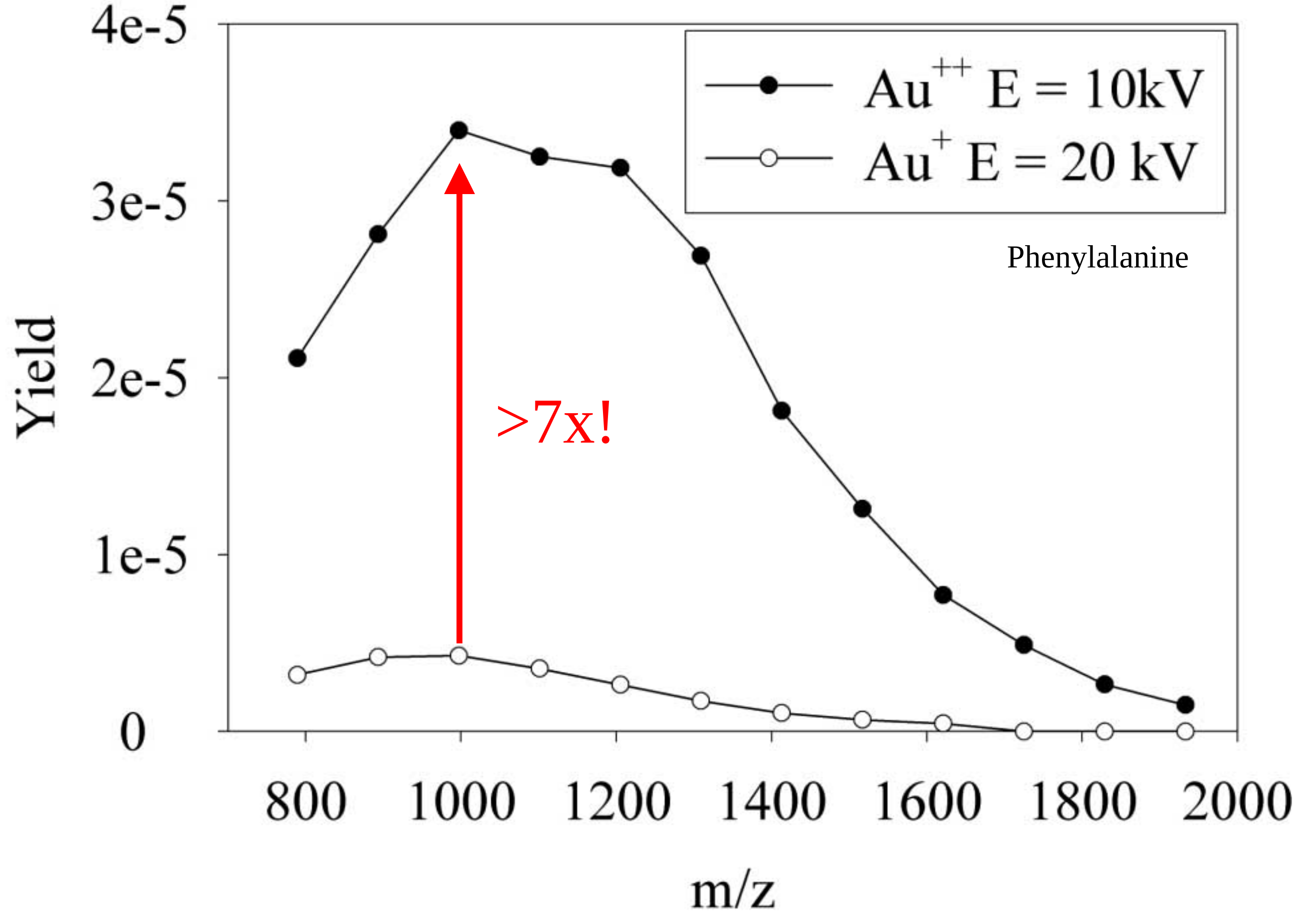


> 1,000 X !

D. H. G. Schneider and M. A. Briere, Physica Scripta, 53, 228 (1996).

An example more relevant to EUVL:

Even changing Q=1 to Q=2, can greatly increase secondary ion yield.



Winograd and Walker, Applied Surface Science vol.203-204 : 198-200, 15 Jan. 2003 (Penn State)

In addition to electron and ion emission, fast neutrals may be emitted (theory predicts even more neutrals are emitted than ions).

Measurements have shown up to 1,000 neutrals/HCI emitted.

All of the enhanced effects (emitted neutrals, electrons, ions, x-rays, surface zones, etc.) depend strongly on material.

No measurements have been done previously on EUVL-relevant materials.

Preliminary reflectivity and SPM studies of HCI bombarded Ru-capped MoSi mirrors (in collaboration with Sasa Bajt).

Small (~1%) <u>increase</u> in reflectivity observed in exposed region, consistent with a 1 nm thinning of Ru+oxide layer.

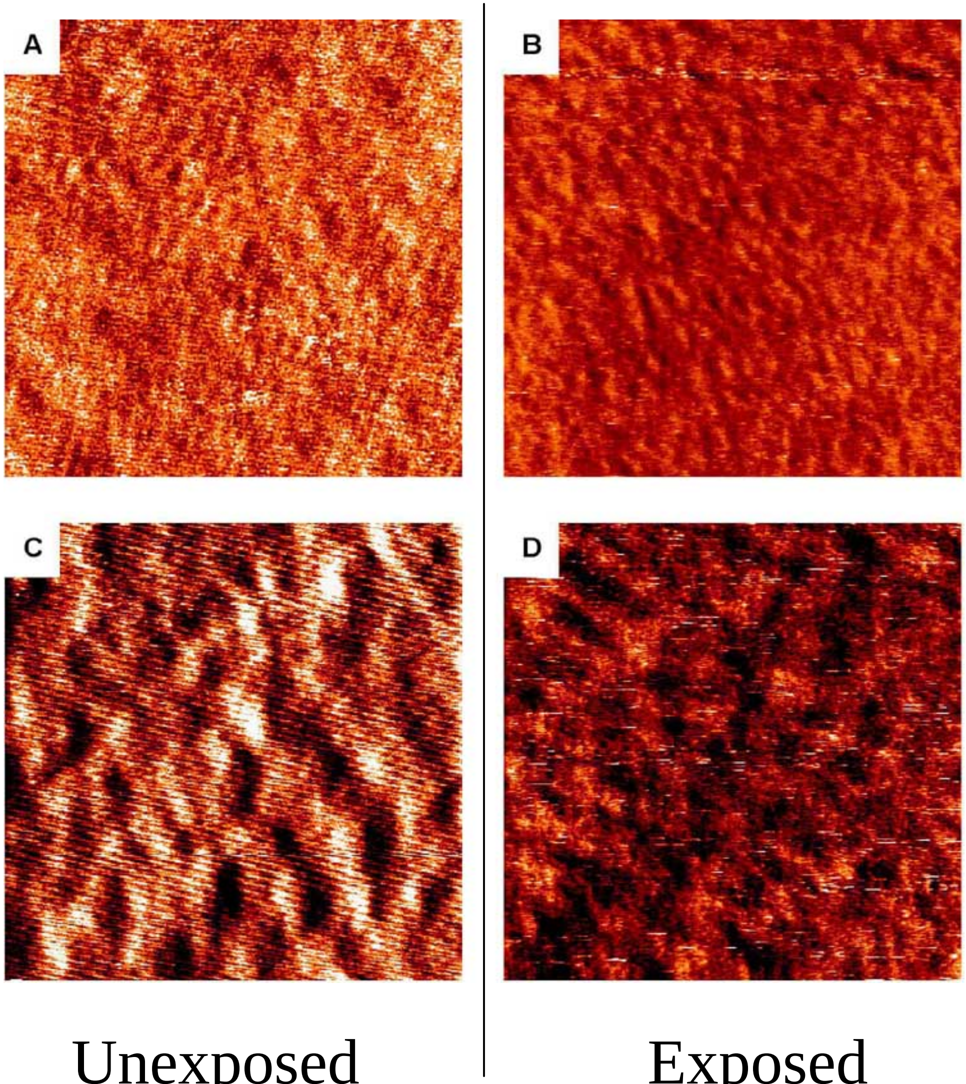
This change took place with an extremely low dose. Even using the maximum theoretical kinetic sputter yield (Y=20, which occurs at the extreme energy of >100,000 eV) one would have expected on the order of a thousand-fold less erosion than what we observed.

All of this is for the extreme case of Xe44+, however.

Extrapolating (linearly with potential energy) to more typical values for EUVL (Q=10, Y=0.2 for K.E.=60 eV), one predicts roughly the same dramatic enhancement:

1000x(800/50,000)*20/0.2=1600.

AFM data shows a 40% reduced roughness in the exposed region, consistent with several HCI ablation models.



375x375x2.5 nm

200x200x1 nm

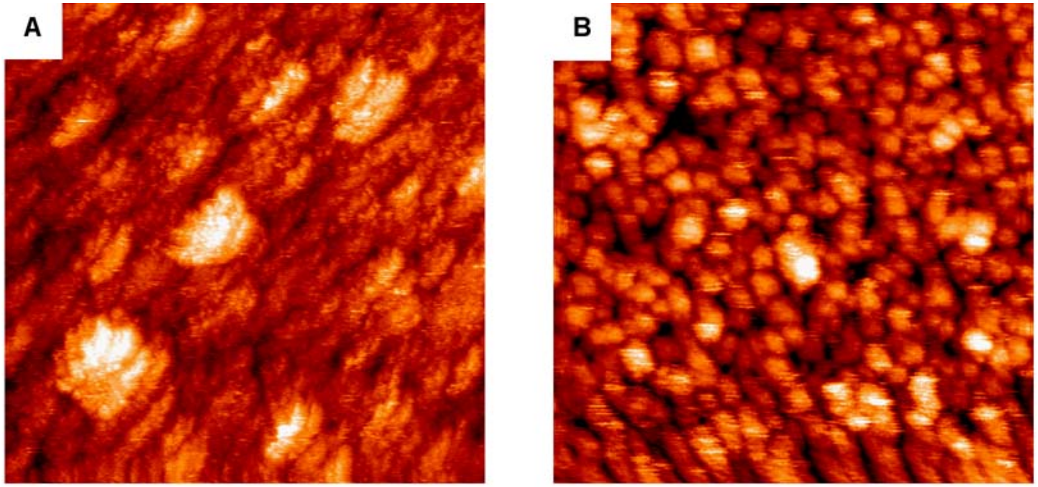
Unexposed

Exposed

W-oxide STM data, exposed with highly charged xenon.

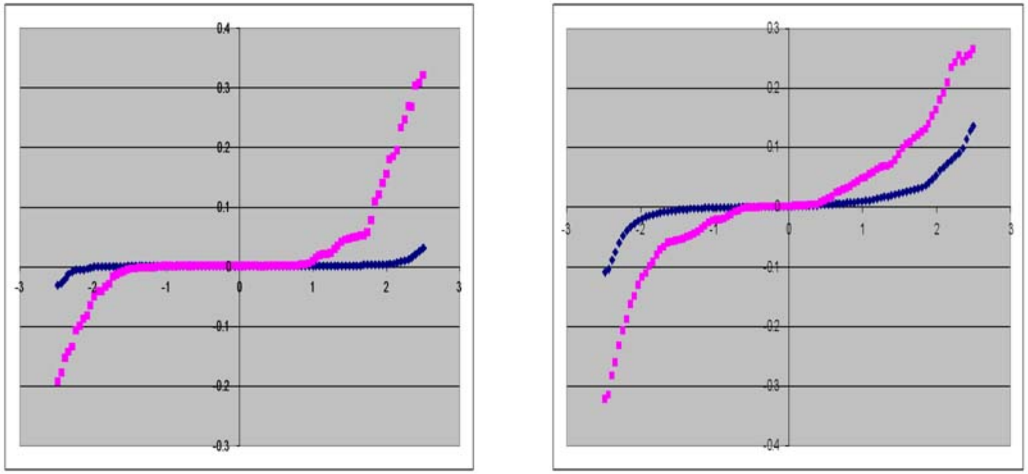
Pre-exposure post-exposure

Topography:



250x250x7 nm

Electrical:



Locally conducting (pink) and insulating (blue) regions. B is <u>consistent with thinner</u> (in some cases absent) <u>oxide</u>.

Summary

EUVL is "extreme" not only in the UV light, but also in the ion internal (potential) energy.

Ion potential energy can be much more important than kinetic energy when considering surface damage.

Ion potential energy can cause huge numbers of secondary electrons, ions, neutrals, and photons to be emitted when a single highly charged ion impacts a surface.

Localized surface charging, and acceleration by electric fields, can be greatly enhanced.