Potential Sputtering from Rare Gas Solid Surface by Multiply-Charged Ion impact

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INTRODUCTION

Rare Gas Solid (RGS)

- van der Waals Solid
- Insulator with a large band gap energy (E_g = 21.6 eV for solid Ne)
- Very small cohesive Energy (0.02 eV/atom for solid Ne)
- Excited states (Exciton) can migrate through the solid

Why RGS for sputtering/desorption study?

✓ Atoms in the solid have almost the same electronic state with isolated atoms because of inactivity of rare gas atoms.

➡ Gas phase information can be used to explain the primary excitation/ionization processes

✓ Rare gas solid is very fragile

➡ Excitation/ionization effectively leads to the desorption

Multiply-Charged Ion (MCI)

LARGE Potential Energy

Potential Energy : $\mathrm{PE}(\mathrm{A}^{q+}) = \sum_{n=0}^{q-1} \mathrm{IP}(\mathrm{A}^{n+})$

Ar^{q+} Potential Energy

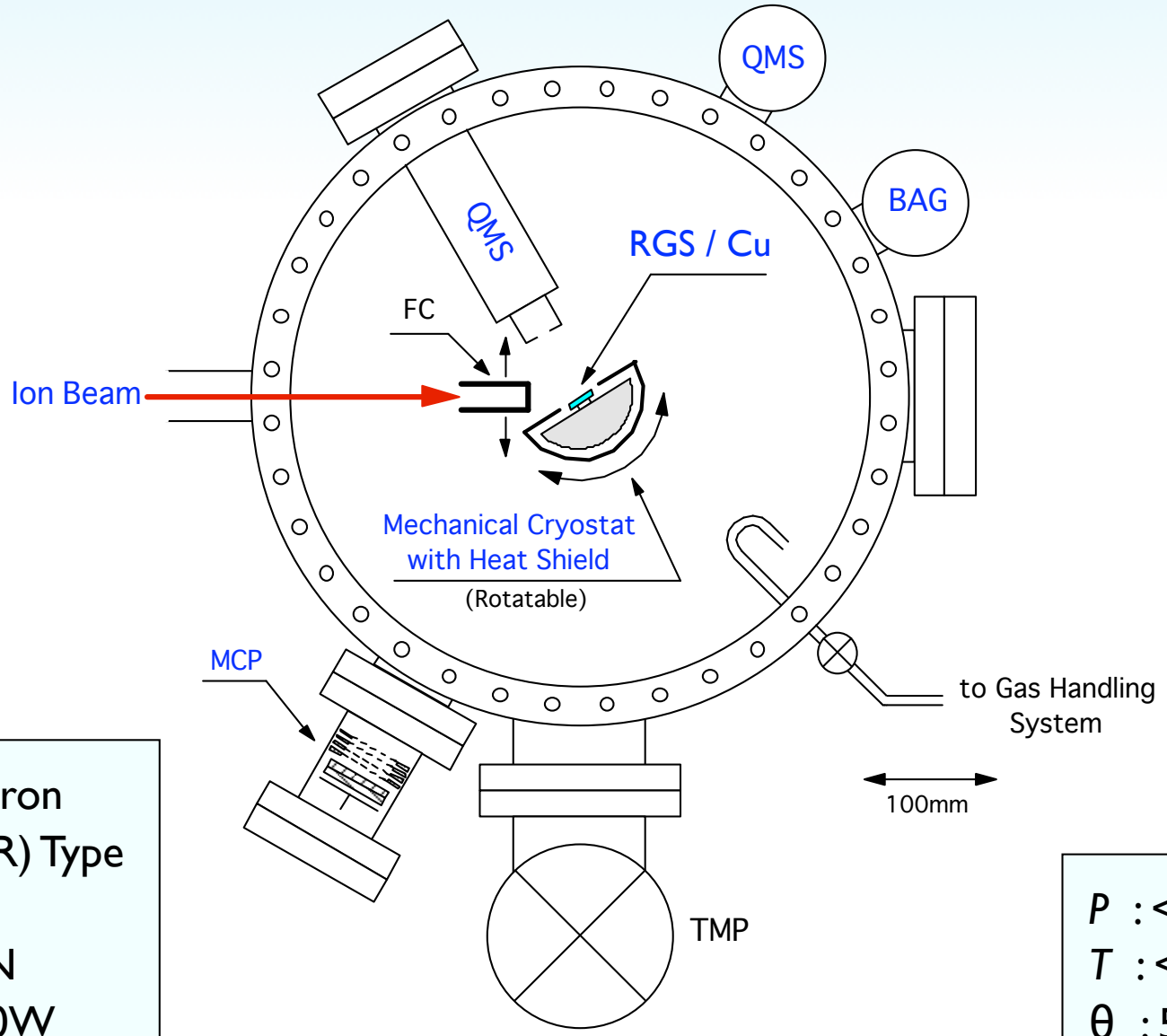
q	1	2	3	4	5	6	7	…	18
PE (eV)	15.8	43.4	84.1	144	219	310	434	…	14k

MCI can ionize (take electrons from) the surface/bulk atoms using its potential energy. → Desorption of Ions

Potential Sputtering (PS)

Kinetic Sputtering (KS)

Experimental Apparatus



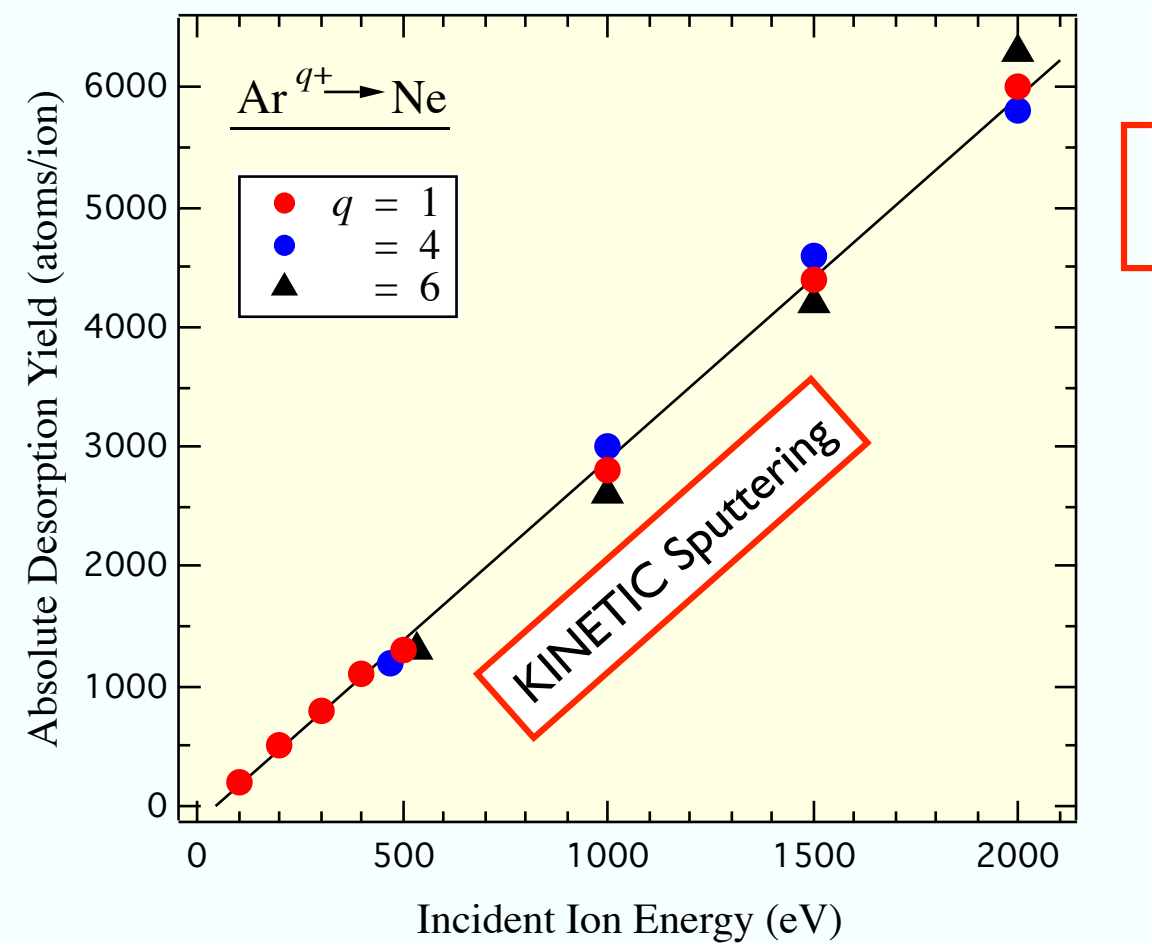
Electron Cyclotron Resonance (ECR) Type Ion Source:
NANOGAN
10 GHz, 100W

P : $<10^{-8}$ Pa
T : < 5K
θ : 500 - 1000 ML

Total Desorption Yield

Total Desorption Yield of Solid Ne by Ar^{q+} Ion Impact

Surprisingly Large Desorption Yield

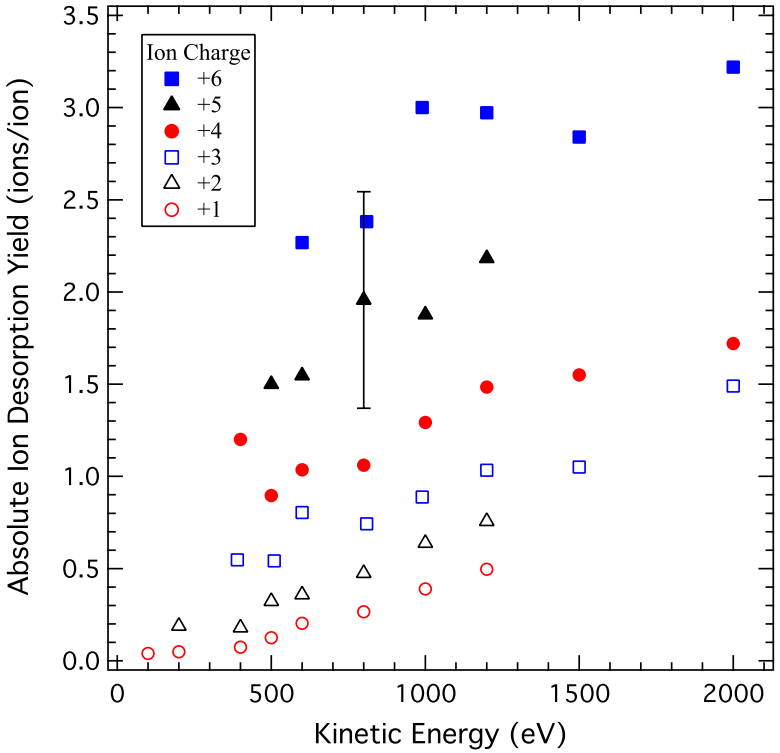


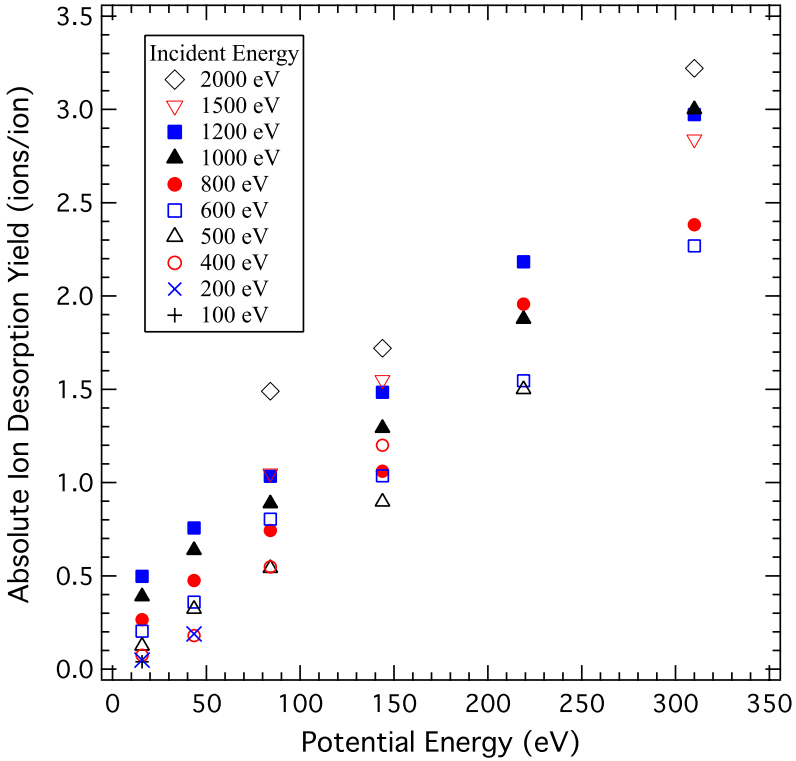
No Dependence on Charge State

Fujita et al., J. Phys. Conf. Ser. **163**, (2009) 012083.

Absolute Ion Desorption Yield

Absolute Ion Desorption Yield of Solid Ne by Ar^{q+} Ion Impact



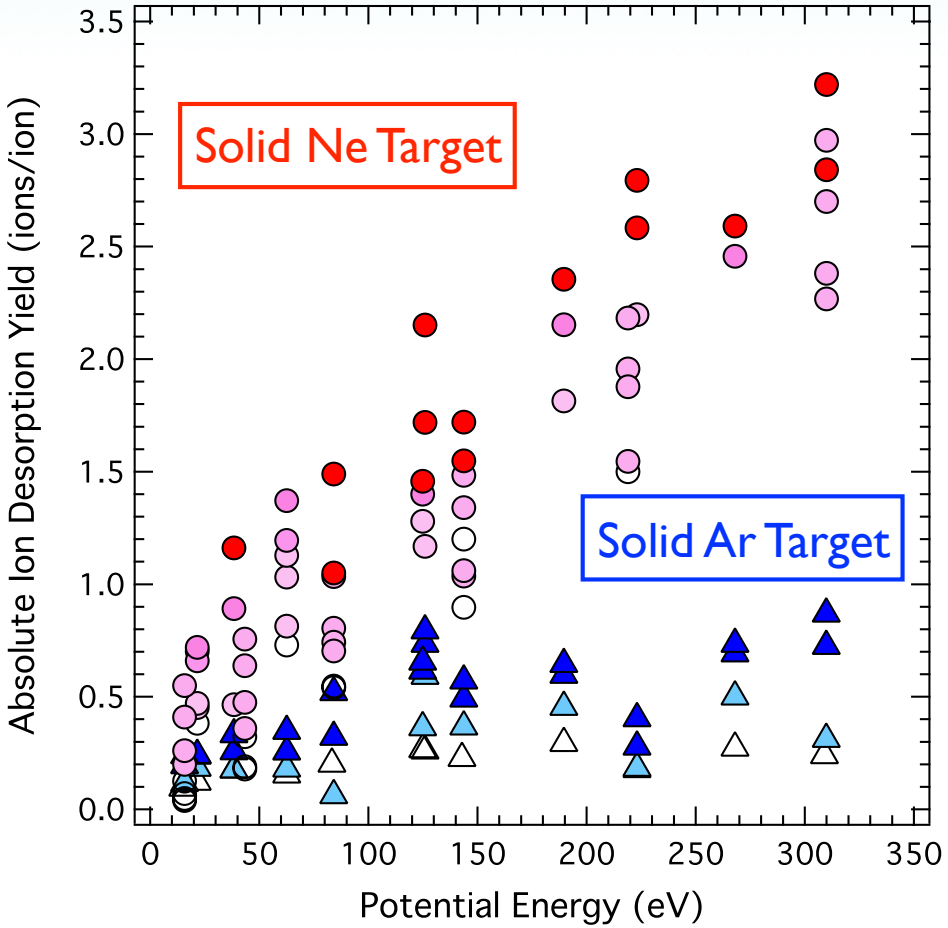


Clear Correlation between Potential Energy and Desorption Yield!

Ban et al., Low Temp. Phys. in press.

Absolute Ion Desorption Yield

Absolute Ion Desorption Yield of Solid Ne and Ar by MCI Impact



Ban et al., Low Temp. Phys. in press.

Incident Ion : Ne^{q+} (q = 1~4)

: Ar^{q+} (q = 1 ~6)

: Kr^{q+} (q = 2~6)

Target Solid : Ar, Ne

Incident Energy : 100 - 2000 eV
(Thicker color : Higher energy)

Y_{ion} ∝ No. of Created Ions ∝ σ_{ion}

Ion Creation: Charge Transfer
(Negligible Contribution of Direct Ionization)

Charge Transfer Cross Section: σ_{CT}

$\sigma_{CT}(Ar) > \sigma_{CT}(Ne)$

Ion Desorption Yield : Y_{ion}

$Y_{ion}(Ar) < Y_{ion}(Ne)$

Ion Desorption Model fro PS

$Y_{ion} \propto$ No. of Created Ions $\propto \sigma_{ion}$

Charge Transfer Cross Section: σ_{CT}

$\sigma_{CT}(Ar) > \sigma_{CT}(Ne)$

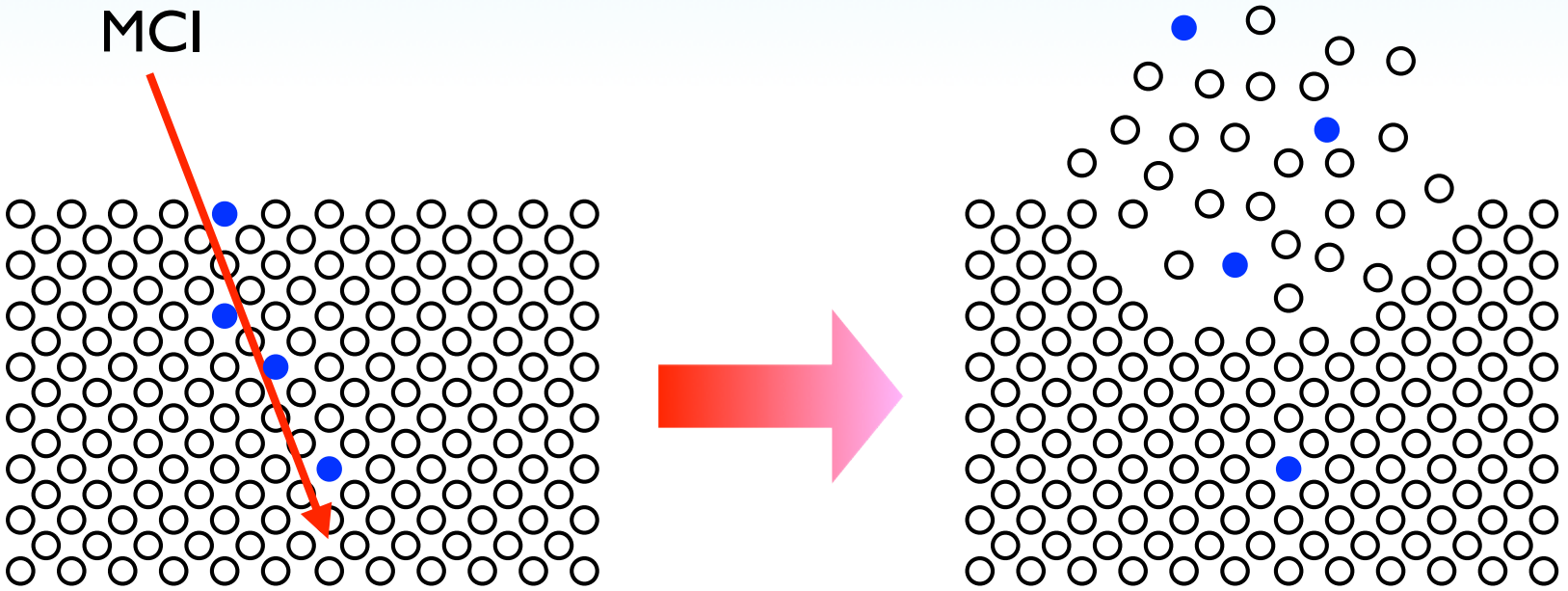
Ion Desorption Yield : Y_{ion}

$Y_{ion}(Ar) < Y_{ion}(Ne)$

- Coulomb Explosion Model (Bitensky and Parilis, 1989)
- Defect-Mediated Sputtering (Neidhart et al., 1995)
- Kinetically Assisted Potential Sputtering (Hayderer et al., 2001)
- Desorption by Charge Accumulation, Defect Accumulation
- Exciton Induced Desorption
- etc...

Desorption Mechanism

New Model



Ion Creation by Incident Ion

Ion Desorption with Very Large Number of Neutral Atoms

Ion Desorption Yield ∝ Number of Created Ions × Total Desorption Yield

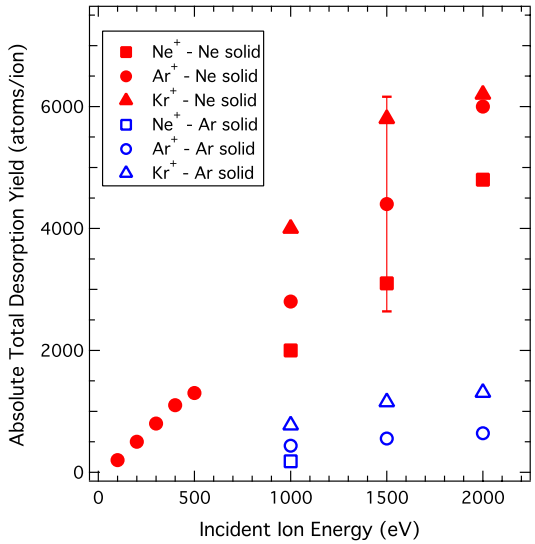
$$Y_{\mathrm{ion}} \propto \sigma_{\mathrm{CT}} \times Y_{\mathrm{total}}$$

Desorption Mechanism

Ion Desorption Yield ∝ Number of Created Ions × Total Desorption Yield

$$Y_{\mathrm{ion}} \propto \sigma_{\mathrm{CT}} \times Y_{\mathrm{total}}$$

Total Desorption Yield : Y_{total}



Ban et al., Low Temp. Phys. in press.

Fujita et al., J. Phys. Conf. Ser. **163**, (2009) 012083.

Charge Transfer Cross Section : σ_{CT}

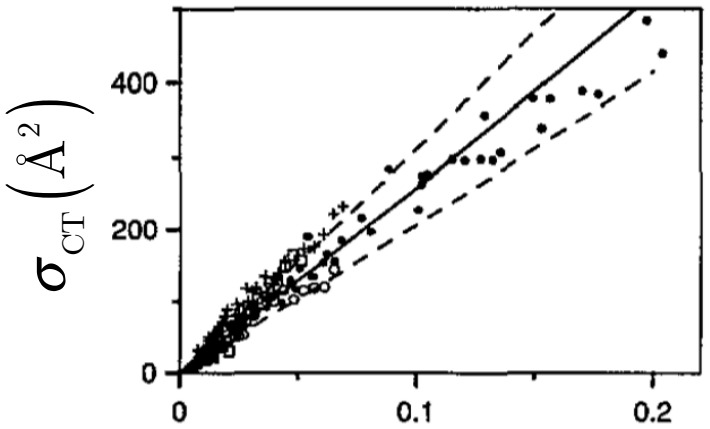
No Available Data for Solid Target

KIMURA Scaling (NICE group in NIFS)

$$\sigma_{\mathrm{CT}} = 4\pi q \,/\, E_{\mathrm{IP}}^2$$

q : Charge State of Incident Ion ($q \geqq 5$)

E_{IP} : Ionization Potential of Target Atom

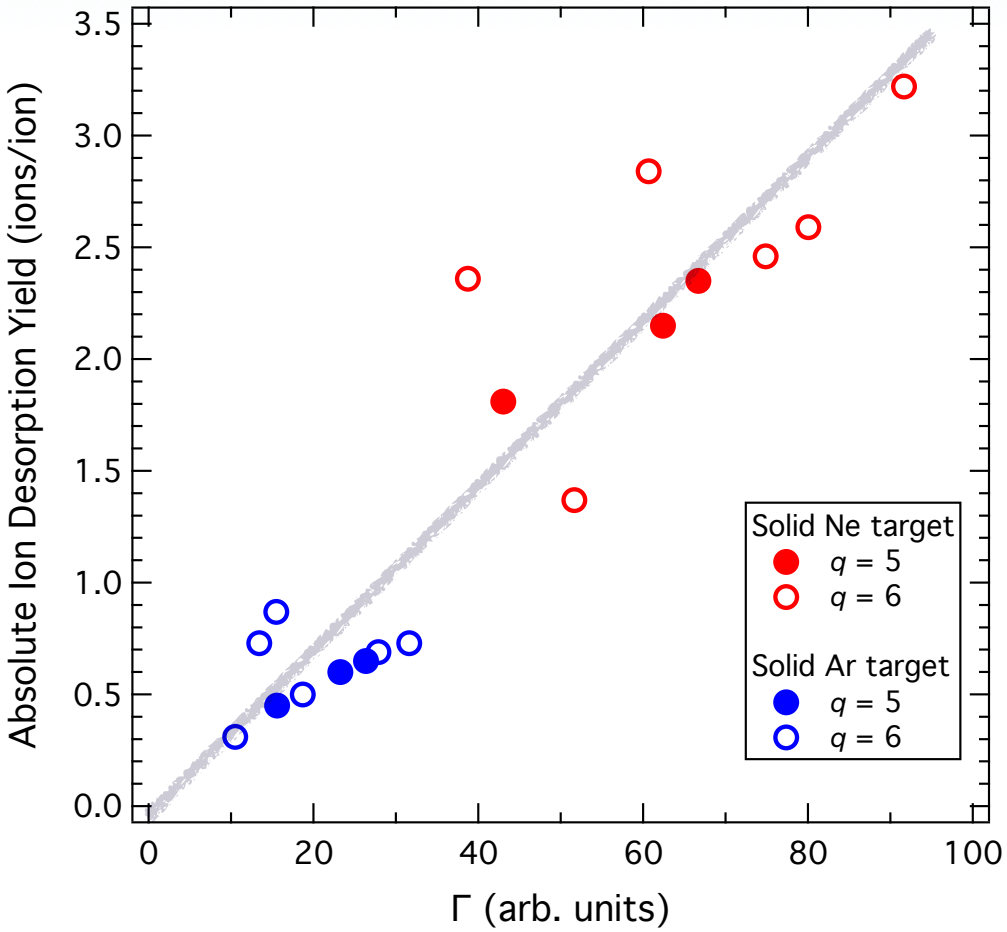


Kimura et al.,
J. Phys. B**28**, L643 (1995)

$$Y_{\mathrm{ion}} \propto \frac{q}{E_{\mathrm{IP}}^2} \times Y_{\mathrm{total}} \equiv \Gamma$$

Desorption Mechanism

New Model



Scaling Parameter

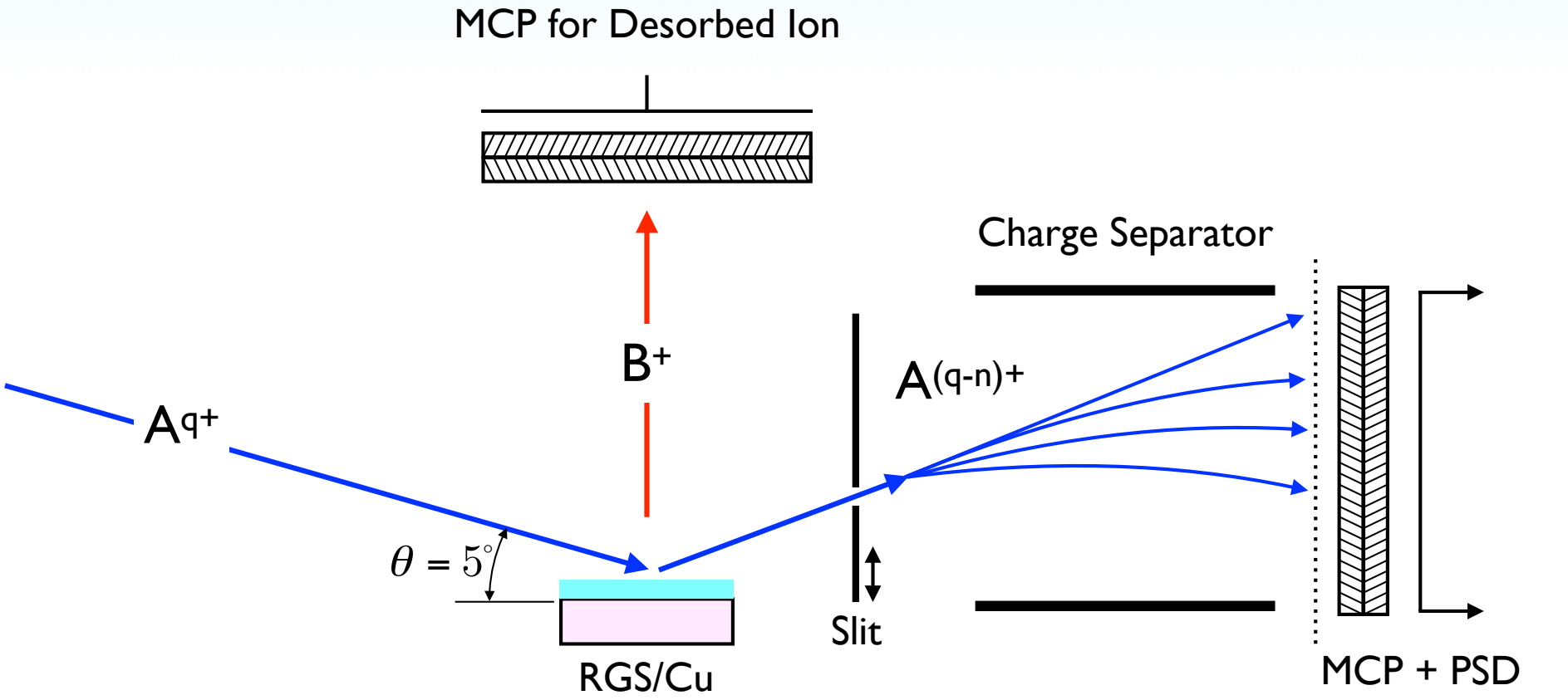
$$\Gamma \equiv \left(q / E_{\mathrm{IP}}^{2} \right) \times Y_{\mathrm{total}}$$

Incident Ion : Ne^{q+}, Ar^{q+}, Kr^{q+} ($q \geqq 5$)

Target Solid : Ar, Ne

Incident Energy : 100 - 2000 eV

Observation of Desorbed Ions in coincidence with Scattered Ions



$A^{q+} + B\ (solid) \rightarrow A^{(q-n)+} + nB^{+}\ (solid)$

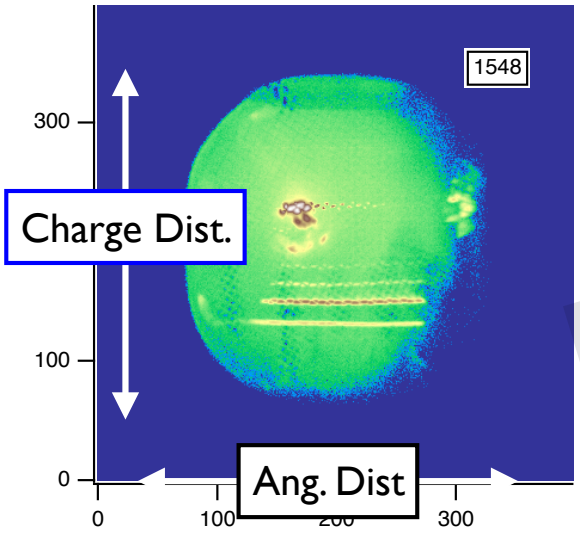
B^{+} (desorption)

Sawa et al., in press

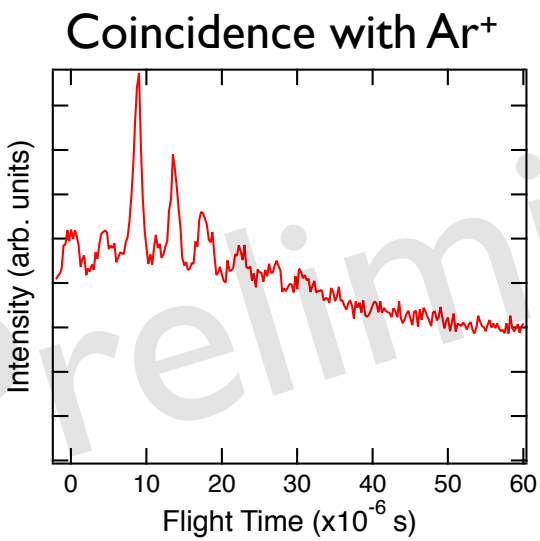
Preliminary Results

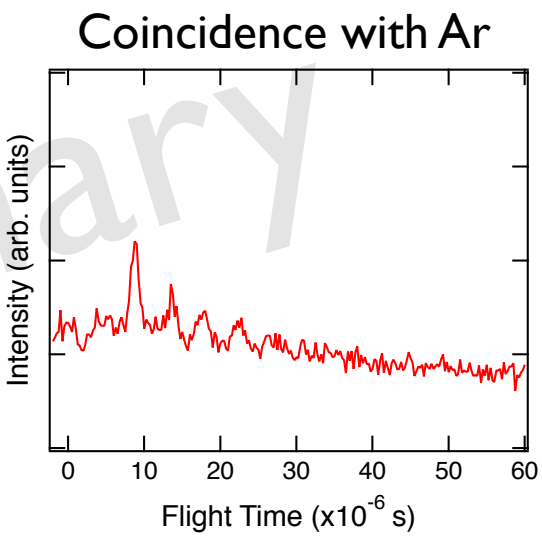
3 keV Ar^{6+} → Solid Ne

Reflected Ar^{q+} Ion



TOF of Desorbed Ne ions in coincidence with Ar ions





- Most of the scattered ions are Ar^{1+}, with weaker signal of Ar^{0}, Ar^{2+}, Ar^{3+}
- Almost no signal of $q > 3$
- Correlation of desorbed ion mass spectra with the charge state of scattered ions

SUMMARY

- We have succeeded in measuring the ABSOLUTE ion desorption yield from solid Ne and Ar by multiply-charged ion impacts.
- New ion desorption model has been proposed :

  Contribution of both Kinetic and Potential energy of incident ions
- Coincidence measurements of desorbed ions with the scattered ion are now in progress.