Investigation of laser energy absorption by ablation plasmas

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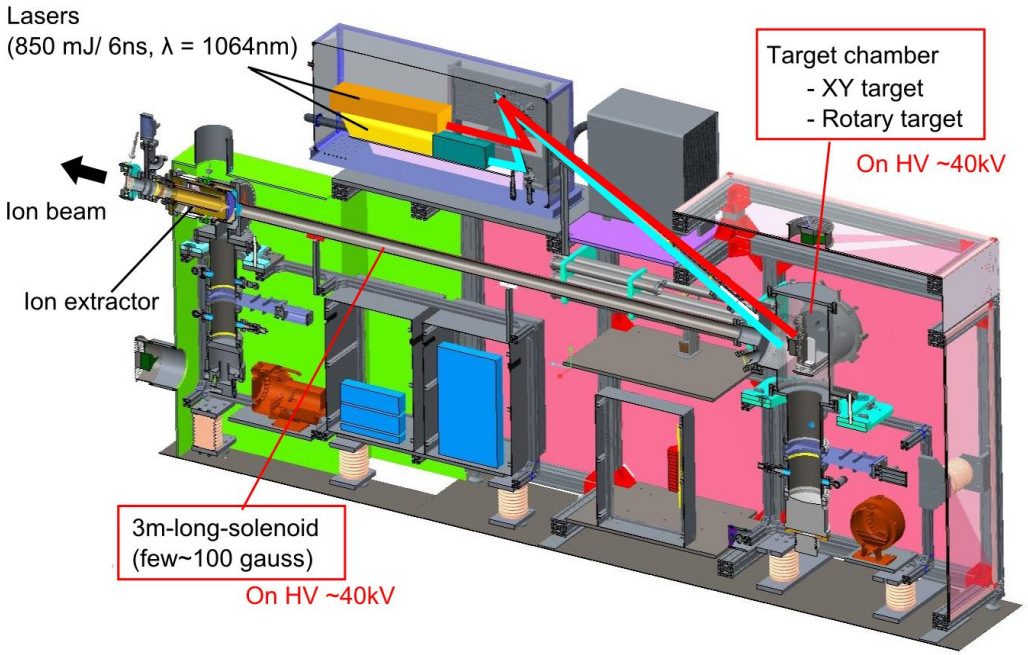
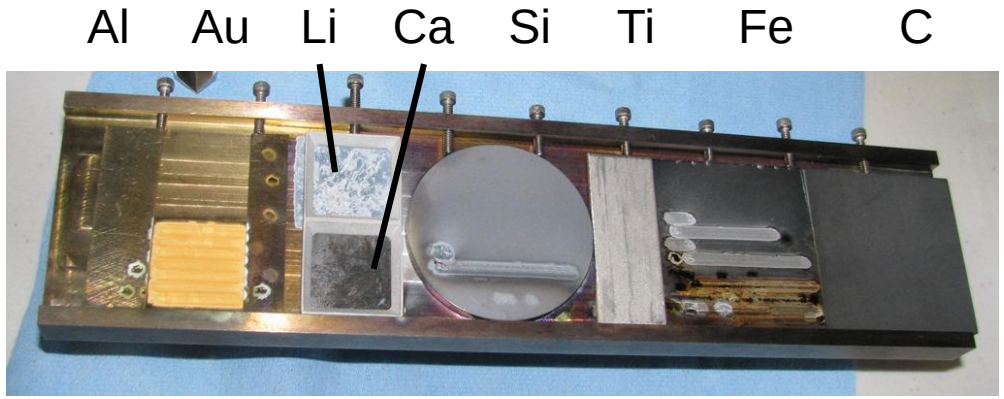
Laser ablation plasma for producing low charge state ion

- Laser ablation plasma is useful for the low charge state ion production.
- The advantage is that the ion source can produce many types of ions from solid targets without breaking vacuum

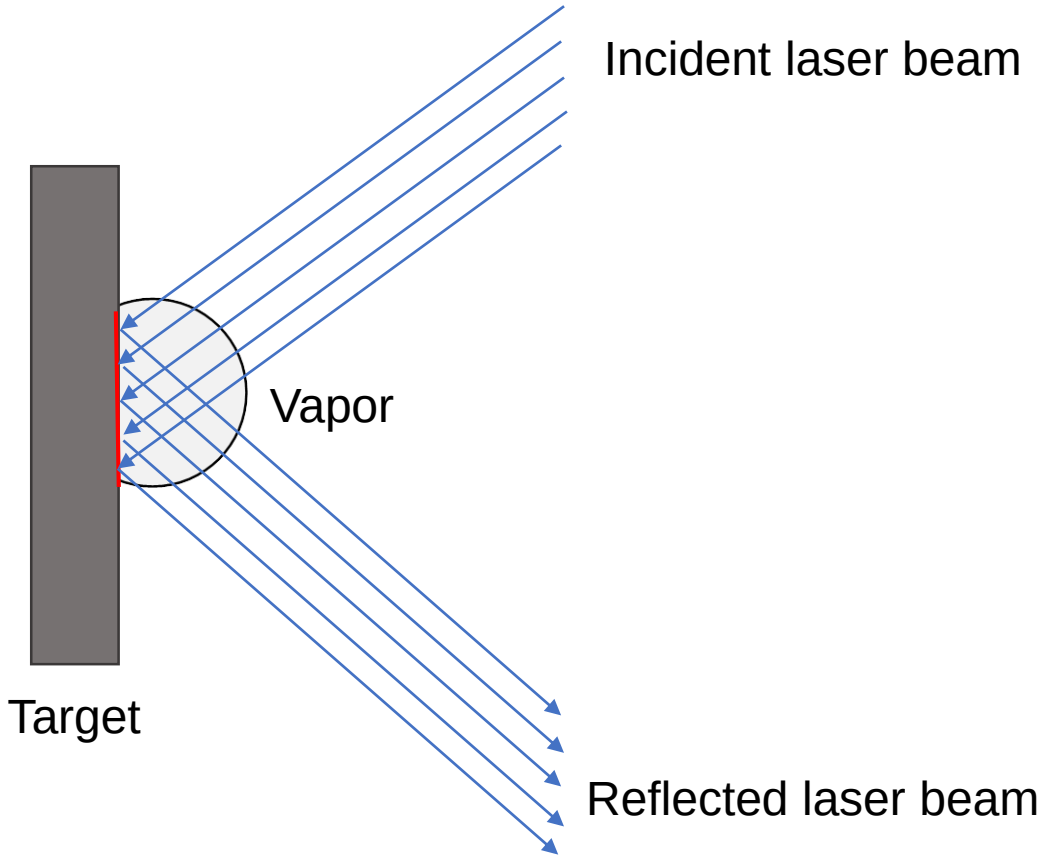


Laser ion source at Brookhaven National Laboratory



Targets materials installed in laser ion source

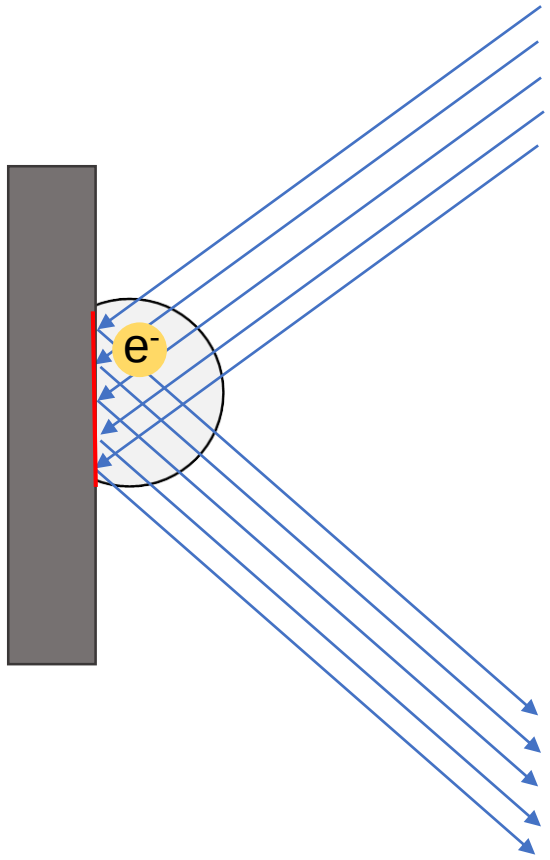
Several stages of plasma production



1. Vaporization

Laser intensity (W/cm^2)

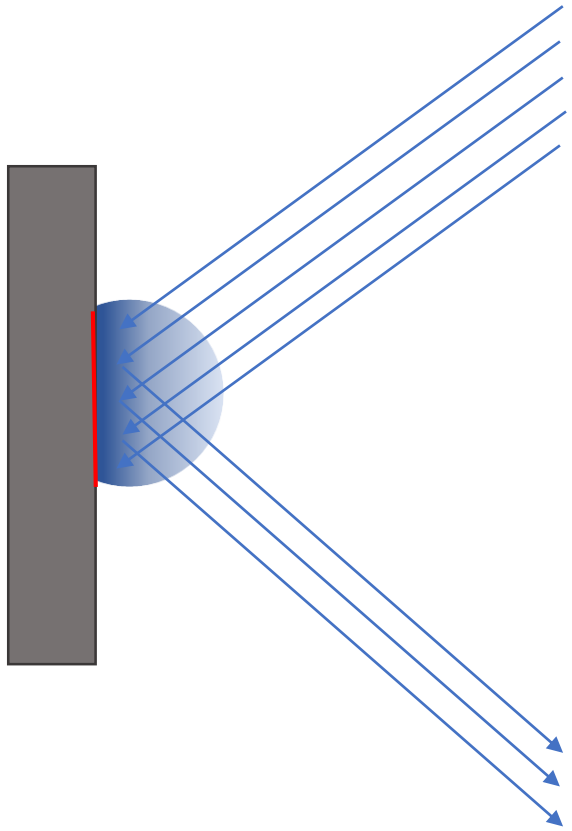
Several stages of plasma production



1. Vaporization
2. Electron production with multi photon process

Laser intensity (W/cm^2)

Several stages of plasma production

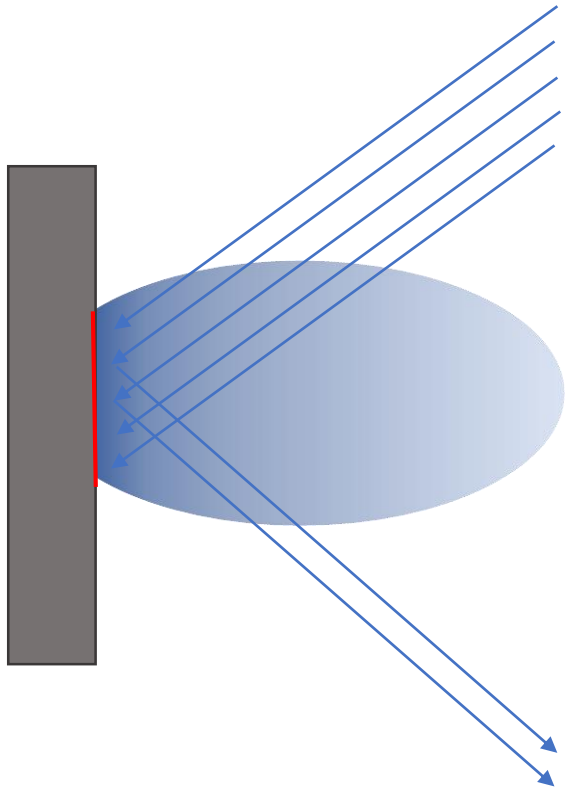


1. Vaporization
2. Electron production with multi photon process
3. Plasma formation with chain reaction of impact ionization

threshold

Laser intensity (W/cm^2)

Several stages of plasma production



1. Vaporization
2. Electron production with multi photon process
3. Plasma formation with chain reaction of impact ionization
4. Heating expanding plasma

threshold

Laser intensity (W/cm^2)

- To produce low charge state ions, laser intensity around ablation threshold is used.
- Energy absorption and the properties of the plasma are sensitive to laser intensity and target materials
- The production process around the threshold is important to design and improve the sources.

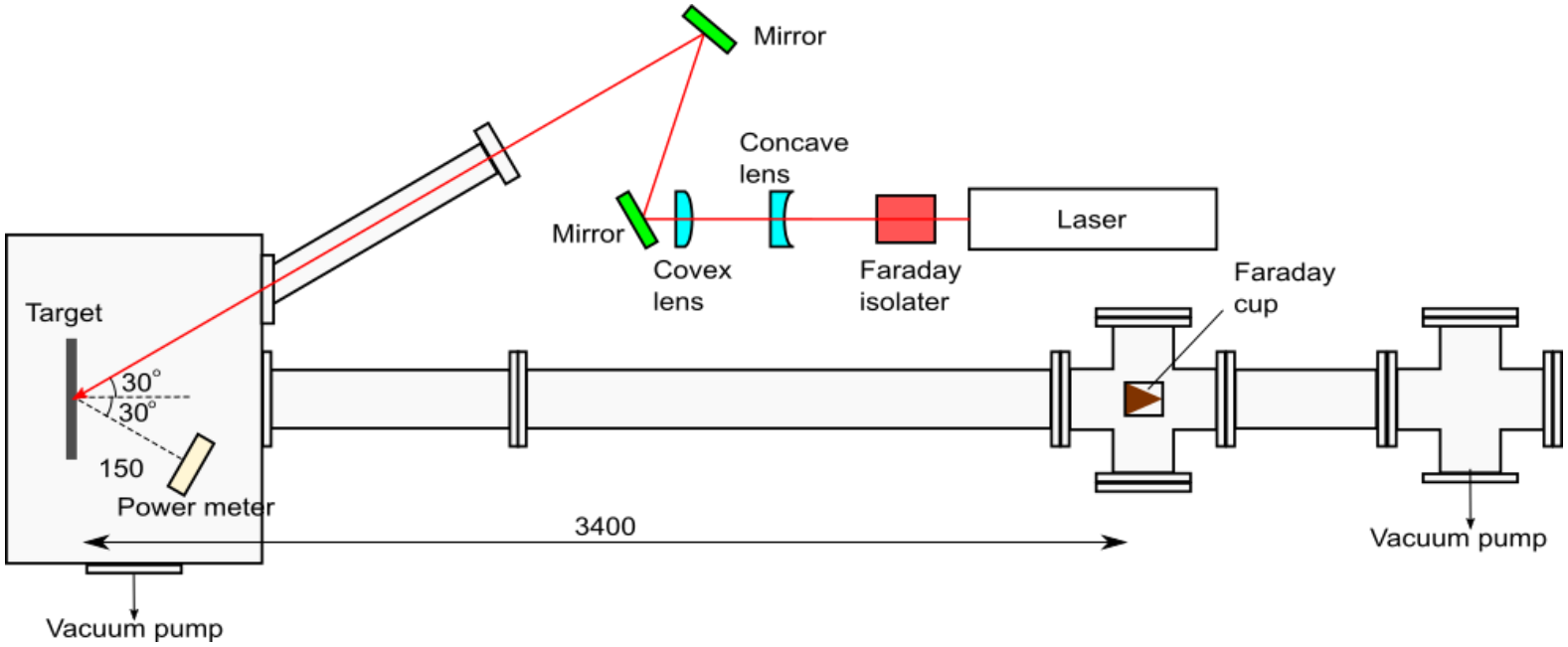
Investigation of plasma production process by measuring laser absorption

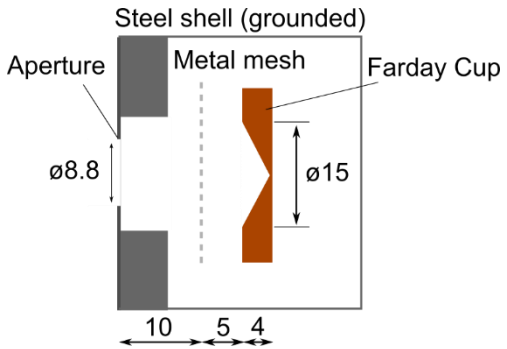
Although the existence of the threshold is known, the detail of the production process and the dependency on target materials are not well understood.

We expected that we can investigate the production process by measuring the laser absorption energy, and the absorption is estimated by measuring the energy of the reflected laser.

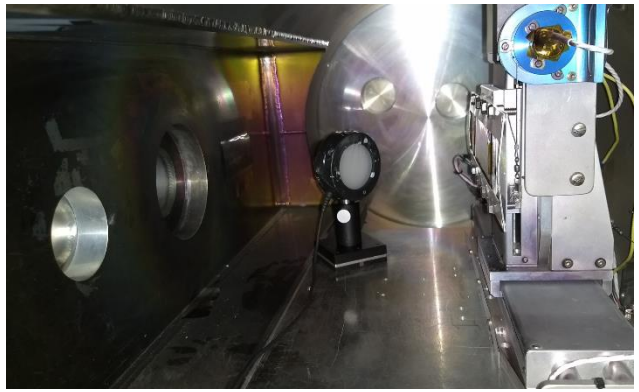
To investigate the plasma production processes near laser ablation threshold for different target materials, we measured laser reflection, and then compared the reflection to the amount and the kinetic energy of the produced ions.

Experimental setup





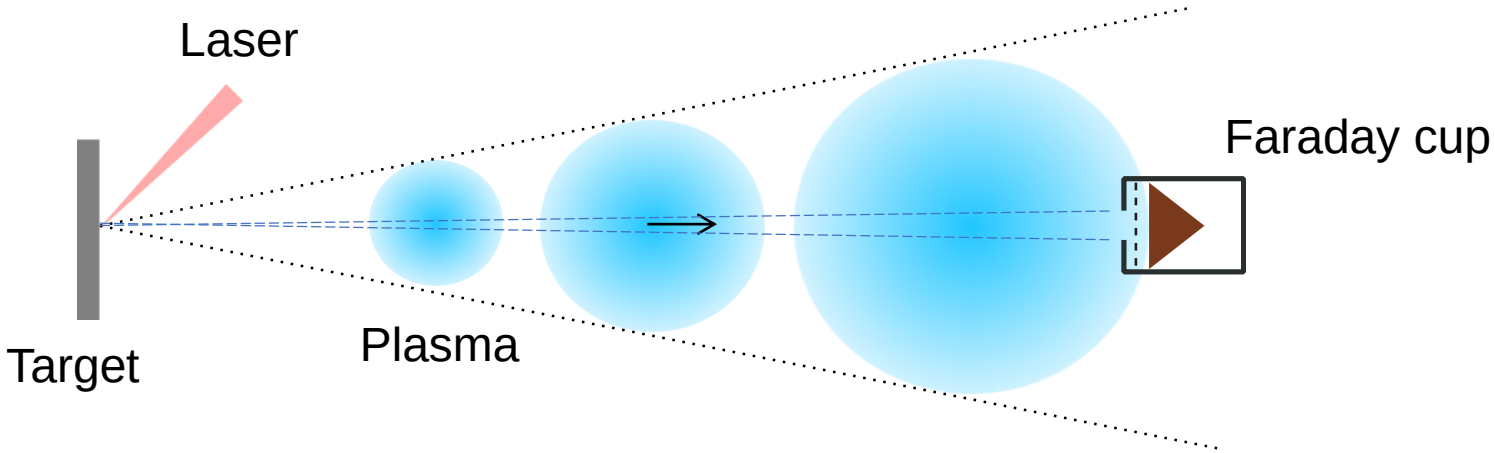
Ion current detector

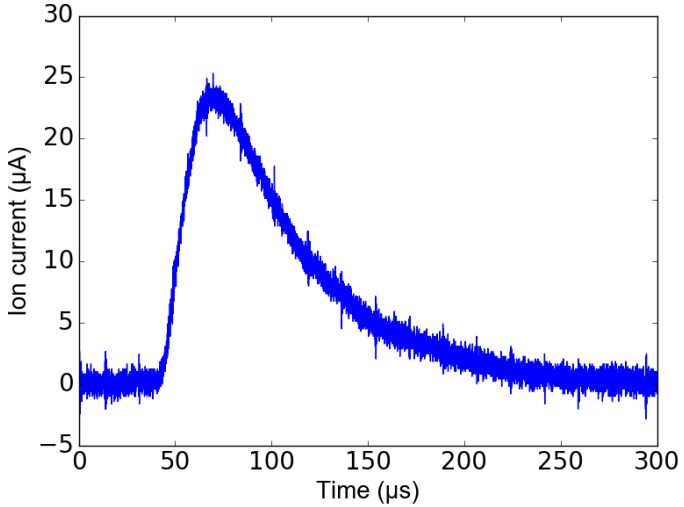


Power meter in chamber

- Nd:Yag laser (1064 nm, 6 ns, 130 mJ)
- Laser spot size = 0.04 cm^2 ~ 3 cm^2
- Laser intensity = $1x10^7$ W/cm^2 ~ $6x10^8$ W/cm^2
- $2x10^{-4}$ Pa
- Targets = Al, Fe, and Ta
- Reflected laser energy was measured with a power meter
- Plasma ion current was measured with a Faraday cup

Plasma properties estimated from ion current waveform

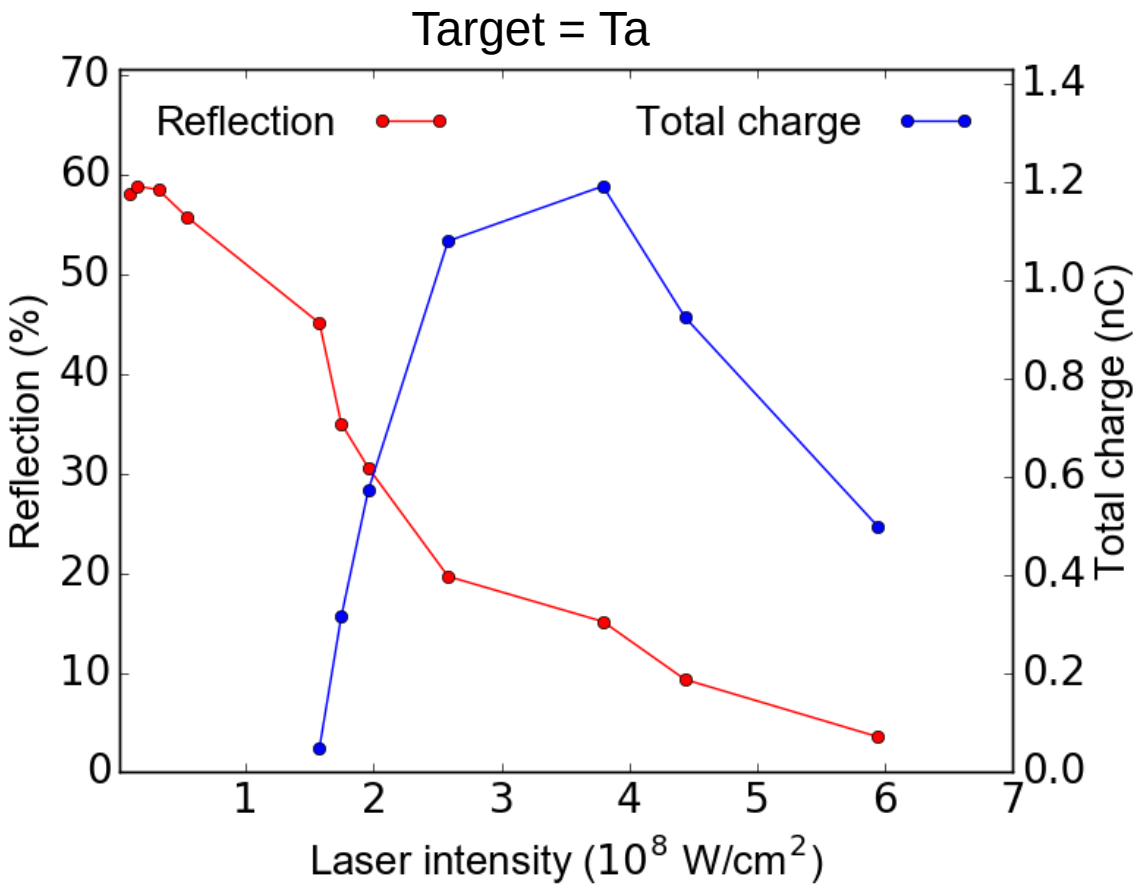




Faraday cup signal

- Total charge within a single beam pulse by integrating the current waveform.
  - This indicates the amount of the produced plasma.
- Kinetic energy of the ions around current peak estimated from time-of-flight.
  - This indicates the total kinetic energy of the ions in the plasma.

Observation of reflection change due to plasma production



As laser intensity I_L increased:

1. for $I_L < 1.5 \times 10^8$ W/cm^2,
   - gradual decrease of reflection
   - no ion produced

-> vaporization

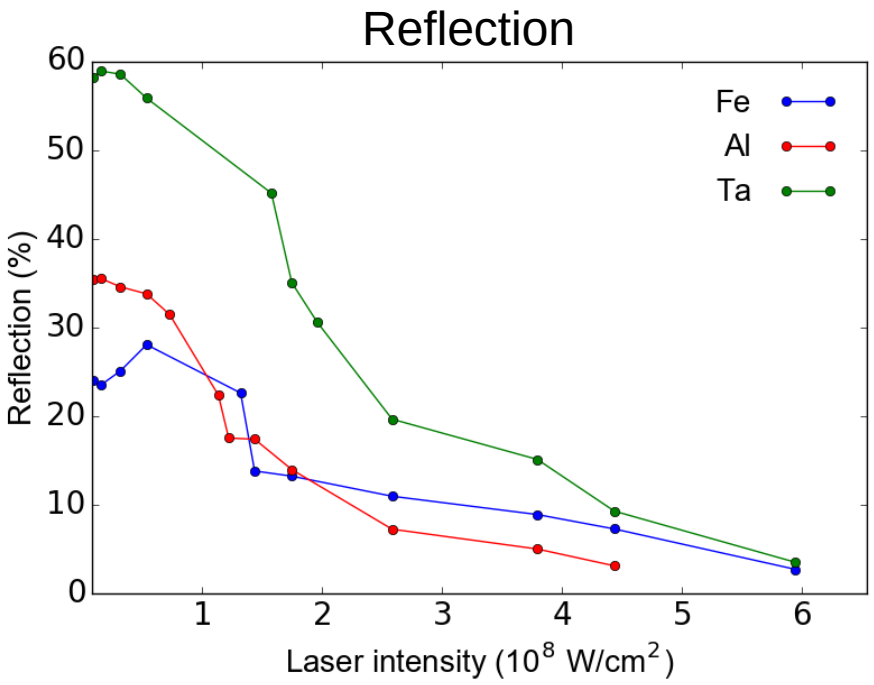
2. for $1.5\times10^8 < I_L < 2.5\times10^8$,
   - Steep decrease of reflection
   - Steep increase of produced ions

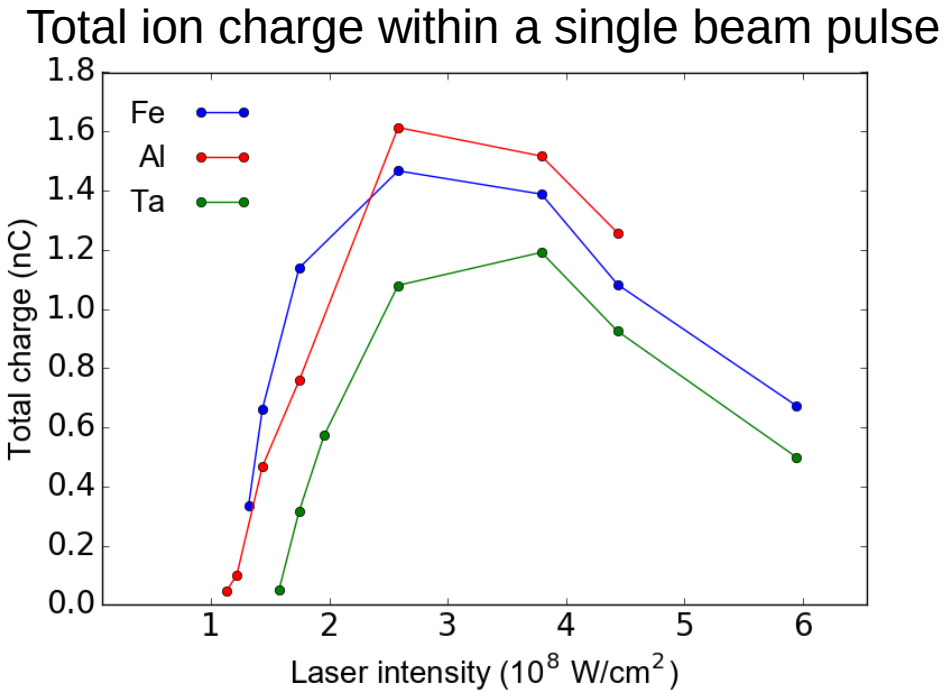
-> plasma production started

3. for $2.5\times10^8 < I_L$,
   - Gradual decrease of reflection
   - Increase and decrease of produced ions

- The change of the reflection shows that the transition from the vaporization stage to the plasma production stage.
- The change of the reflection was consistent with the change of the ion charge.

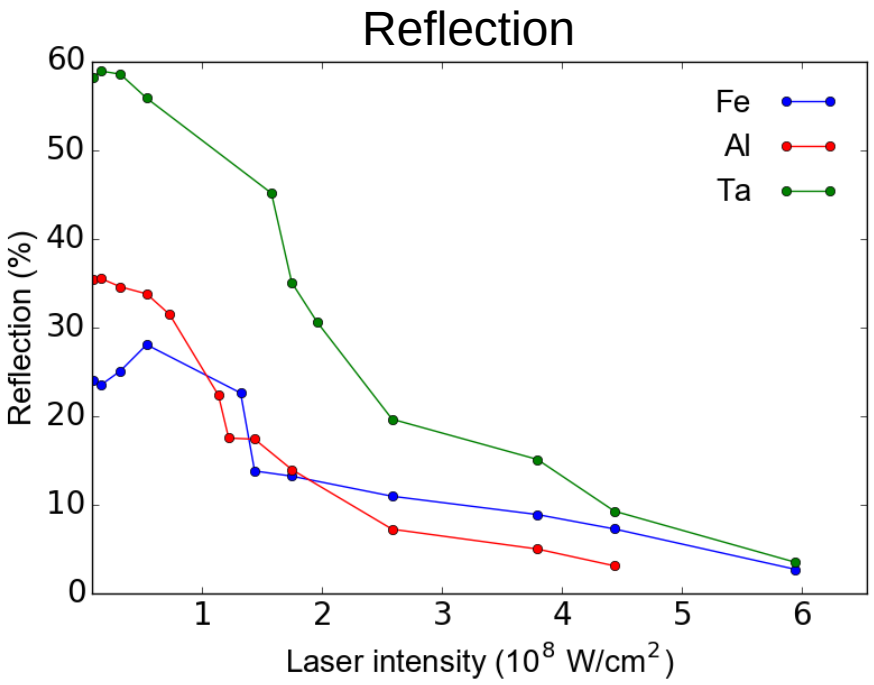
Reflection and amount of ion charge for Al, Fe, and Ta

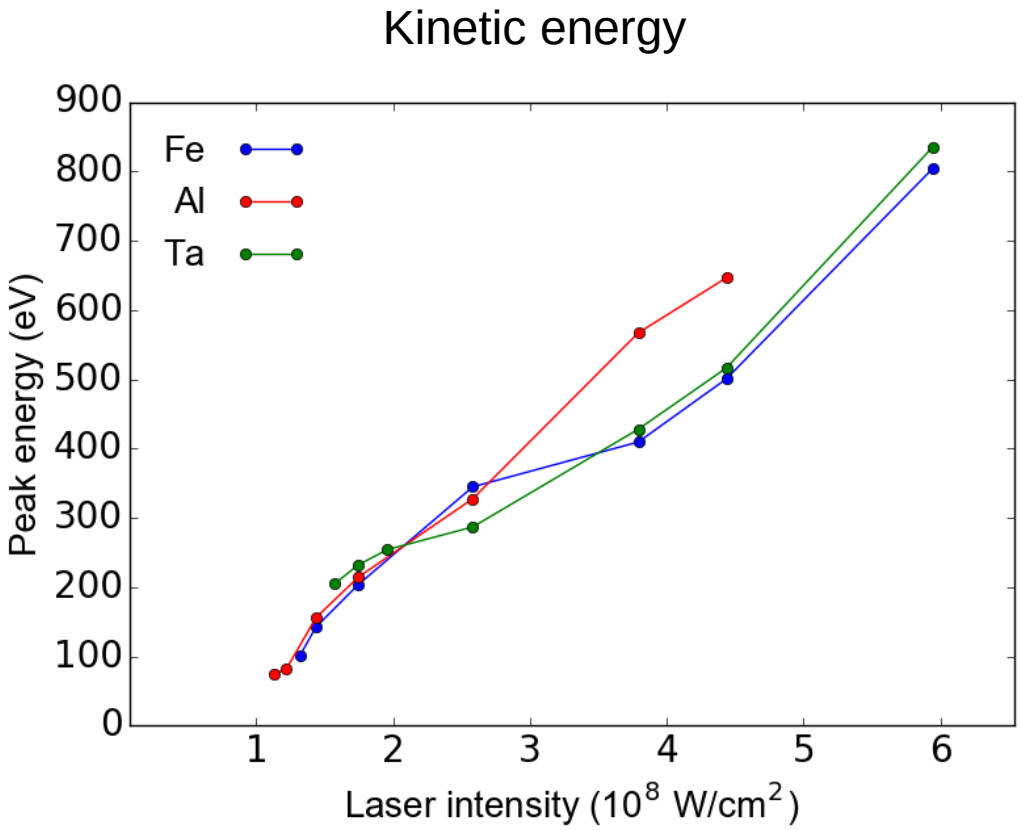




- The laser intensities with which the reflection started to decrease steeply were smaller for Al and Fe (1×10^8 W/cm^2) than for Ta (1.5×10^8 W/cm^2).
- This shows the difference of the ablation threshold between three species.
- Laser intensity thresholds for ion production were also smaller for Al and Fe than for Ta.
- For $I_L > 2.5\times10^8$ W/cm^2, reflections and ion charges became closer.

Kinetic energy of ions for Al, Fe, and Ta





- The kinetic energy increased continuously.
- The kinetic energy did not depend on the target materials.

Influences of ion species on plasma production

The results of the measurements of the reflection, and the amount and the kinetic energy of the ions showed consistently that:

- thresholds for plasma production were smaller for Al and Fe than for Ta,
- reflection, total charge, and kinetic energy did not depend on the species for higher laser intensity.
  - This indicates heating process does not depend.

Other discussions

Further investigation

- We found that the change of the reflection with laser intensity are correlated to plasma production process.
- By measuring temporal or spatial distribution of reflected laser energy, we can investigate more detail of the production process.

Useful information for design of laser ion sources

- Plasma production threshold is 1~2 x 10^8 W/cm^2.
- Kinetic energy of ions around current peak does not depend on ion species.

Summary

To investigate the plasma production processes near laser ablation threshold for different target materials, we measured laser reflection, and then compared the reflection to the amount and the kinetic energy of the produced ions for Al, Fe, and Ta targets.

We found that:

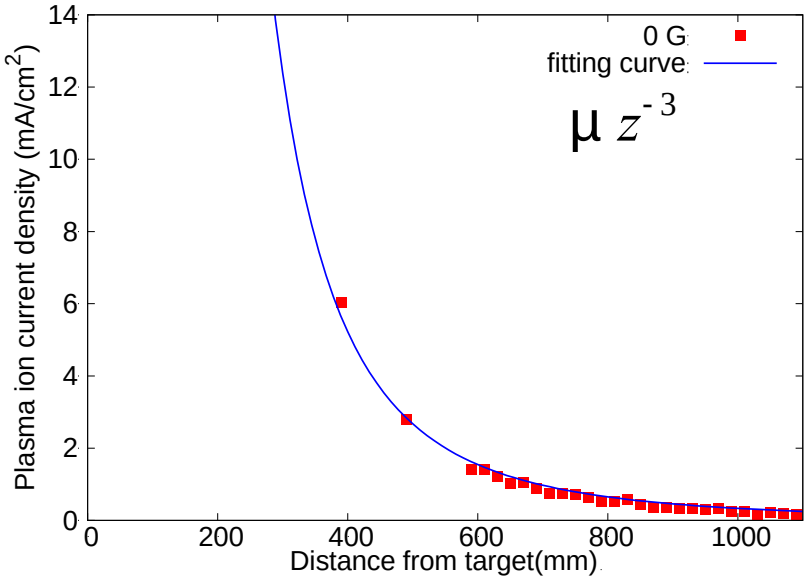
- the reflection was correlated to the the plasma production process,
- the change of the reflection was consistent with that of the ion charge.

The results of the measurements of the reflection, and the amount and the kinetic energy of the ions showed consistently that:

- thresholds for plasma production were smaller for Al and Fe ($1x10^8$ W/cm^2) than for Ta ($1.5x10^8$ W/cm^2),
- reflection, amount, and kinetic energy did not depend on the species for higher laser intensity.

Thank you for your attention

Monotonical decrease without magnetic field



Current density of a slice with 11 mm/μs as a function of *z*

- Current density was proportional to z^{-3}.
- The plasma spreads from the spot three-dimensionally.