Evaluation Method of Plasma Instability in Laser Ion Source using Solenoid

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1. Background
2. Evaluation of plasma instability
3. Plasma instability with solenoid
4. Conclusion
1. Background
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Mechanism of laser ion source

Irradiated laser creates high density plasma.
By using a solenoid, beam current density increases
Ion beam is extracted by electric field from generated plasma.
LION source in Brookhaven National Laboratory

LION is providing stable beams for RHIC (Relativistic Heavy Ion Collider) and NSRL (NASA Space Radiation Laboratory) for many years.

Current density increases by using long solenoid

Effect of solenoid on Au$^{1+}$

High current beam needs solenoid
Examples of Au\textsuperscript{1+} beam waveforms.

The figure below shows that the reproducibility is poor and the waveform is distorted compared with the above figure. When using a solenoid, it is necessary to avoid the range where such a beam becomes unstable.
Understand the mechanism of instability and aim to reduce of instability

Define the instability to quantify the experimental data

Change the solenoid magnetic field and investigate the range where the plasma becomes unstable
1. Background

2. Evaluation of plasma instability

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Examples of instability

Experiment using Au\(^{1+}\) beam
Plasma instability is caused by a magnetic field in a specific range.
In order to evaluate the instability of these plasmas, consider quantifying the instability.
Definition 1:

Peak value

Definition 2:

Total charge
Definition 1: Peak value

Definition 2: Total charge

Calculate standard deviation of peak current from 40 shots of waveform
Definition 1: Peak value

Definition 2: Total charge

Evaluation of plasma instability
Evaluation of plasma instability

Definition 1: Peak value

Definition 2: Total charge

Calculate standard deviation of total charge from 40 shots of waveform
Evaluation of plasma instability

**Definition 1:**
Peak value

**Definition 2:**
Total charge

Indistinguishable →

Same charge
Explanation using four waveforms:
Calculate average waveform from measured waveform
**Definition 3:**

Calculate the total area of the protruding part compared to the average waveform.
Similarly, calculate the total area of the protruding part for other waveforms.
Evaluation of plasma instability

Definition 3:

Calculate the area of the average waveform
Definition 3:

Waveform 1  Waveform 2  Waveform 3  Waveform 4  Average Waveform

$S_1$  $S_2$  $S_3$  $S_4$  $S_{Ave}$
Definition 3:

\[
\begin{pmatrix}
S_1 \\
+S_2 \\
+S_3 \\
+S_4 \\
\end{pmatrix}
\]

\(S_{\text{ave}}\)

Plasma instability
Experiment in order to verify the validity of each definition

Power density: $3.58 \times 10^8 \text{ W/cm}^2$

Laser
Nd:YAG laser (pulse length: 6 ns)

Fe target

Laser

Long solenoid

Faraday cup (Aperture size 11 mm)

31.5 cm

300 cm
Definition 1:
- Peak value

Definition 2:
- Integral value of the protruding part

Definition 3:
- Total charge

Evaluation of plasma instability (Fe example)
Evaluation of plasma instability (Fe example)

**Definition 1:**
- Peak value

**Definition 2:**
- Degree of instability

**Definition 3:**
- Total charge
  - Integral value of the protruding part
Definition 1:

Peak value

Degree of instability

Solenoid magnetic field: 7.8 G

Not good

Small difference between 7.8 G and 52 G
7.8 G should be more unstable

Solenoid magnetic field: 52.0 G
Evaluation of plasma instability (Fe example)

Definition 2:

Degree of instability

Solenoid magnetic filed: 0 G

6.8 G should be more unstable

Solenoid magnetic filed: 6.8 G

Integral value

Not good
Evaluation of plasma instability (Fe example)

**Definition 3:** Integral value of the protruding part

- **Solenoid magnetic field:** 6.8 G
- **Solenoid magnetic field:** 0 G
- **Solenoid magnetic field:** 7.8 G
- **Solenoid magnetic field:** 52.0 G

**Degree of instability**

**Good!**
1. Background

2. Evaluation of plasma instability

3. Measured Plasma Instability Inside the Solenoid

4. Conclusion
The instability was measured by scanning the Faraday cup inside the solenoid.
Plasma Instability Inside the Solenoid

**Graphs:**
- **0 cm**
  - Degree of instability vs. Magnetic field [G]
  - Instability increases sharply at 240 G and decreases at 140 G

- **24.5 cm**
  - Degree of instability vs. Magnetic field [G]
  - Instability peaks sharply at 160 G and drops to nearly zero

- **300 cm**
  - Degree of instability vs. Magnetic field [G]
  - Instability drops significantly at 100 G and remains low
Solenoid magnetic field:

Plasma Instability Inside the Solenoid

Degree of Plasma Instability

Distance from solenoid entrance [cm]
Plasma Instability Inside the Solenoid

Unstable position moves towards the target by increasing the field. We can clearly observe the change by adopting method 3. Karino scheme works great!!
1. Background

2. Evaluation of plasma instability

3. Plasma instability with solenoid

4. Conclusion
Conclusions

Summary

Established evaluation method of plasma instability when using solenoid
Change of instability in the solenoid was investigated

Instability position is shifted when strong magnetic field

Next step

Understand the mechanism causing plasma instability in a solenoid.
Develop to suppress instability of laser ion source.

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Although plasma became unstable, it recovers its stable condition.
Definition 3:

Solenoid magnetic field: 7.8 G

Solenoid magnetic field: 6.8 G

Solenoid magnetic field: 0 G

Solenoid magnetic field: 52.0 G

Solenoid magnetic field: 31.2 G
Evaluation of plasma instability

\( w_n \): Half width

\( I_{p_n} \): Maximum value

\( N \): the number of data (\( N = 40 \))

\( r_n = \frac{w_n}{I_{p_n}} \)

\( \bar{r} = \frac{1}{N} \sum_n r_n \)

\( \sqrt{\frac{1}{N} \sum_n (r_n - \bar{r})^2} \)