Velocity distribution function of hydrogen atoms in ion source discharges

Tatsuhiro TOKAI[1], Yuji SHIMABUKURO[2], Hidenori TAKAHASHI[3], and Motoi WADA[1]

[1]*Graduate School of Science and Engineering, Doshisha University, Kyotanabe, Kyoto, 610-0321, Japan*
[2]*Naka Fusion Institute, National institute for quantum and radiological science and technology, Naka, Ibaraki, Japan*
[3]*Koichi Tanaka Mass Spectrometry Research Laboratory, Shimadzu Corporation, Kyoto, 604-8436, Japan*

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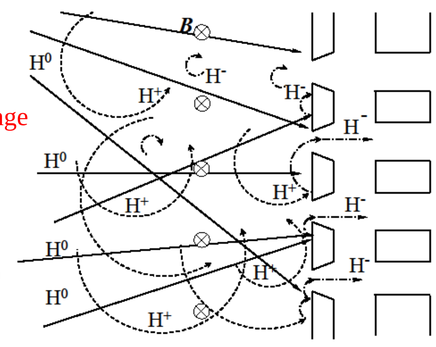
Introduction

Surface production of negative hydrogen (H^-) ions assumed collisions of hydrogen at the surface of the plasma grid of a negative ion source. The production efficiency of the H^- ion component should be highly dependent upon the velocity distribution of atomic hydrogen (H^0) striking the extraction electrode. Our group has designed, build and been improving a system that measures changes in the H^0 velocity distribution function due to the discharge parameters. The system equips a rotating blade neutral beam chopper to modulate the intensity of the neutral flux passing through the skimmer that separates the downstream chamber for time of flight analysis from the ion source discharge. After about 45 cm free flying vacuum space an electron impact type ionizer converts neutral particles to ions. A magnetic deflection type mass separator guides the produced protons to a secondary electron multiplier detector. The system exhibits the existence of a high-speed component in the H^0 velocity distribution when it was tested with an ECR plasma source. We investigated how the fast component of hydrogen atoms changes by changing the input power of the ion source.

Research motivation

Extraction region of H^- source

- Surface collision
  - Reflection
  - Desorption
  - Implantation
- Plasma-wall energy exchange
  - Thermalization
  - Collisions
  - Adsorption
  - Electron injection (Including VUV photons)
- Sheath formation
  - Magnetic field
  - Plasma potential profile



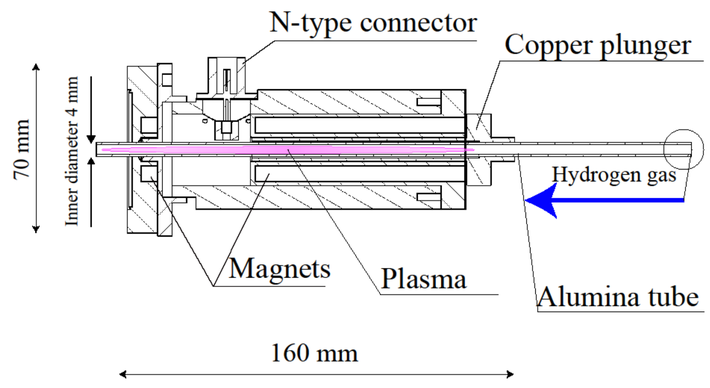
M. Wada, Rev. Sci. instrum.89, 052103 (2018)

☑If the high-speed component of hydrogen atom is too low, it will not produce H^- ions.
☑ If it is too large, the annihilation cross-section becomes large and the surface production efficiency decreases.

It is important to investigate the velocity distribution function of hydrogen atoms.

Atomic source

☑Localized Inductive Coupled Plasma (LICP) source

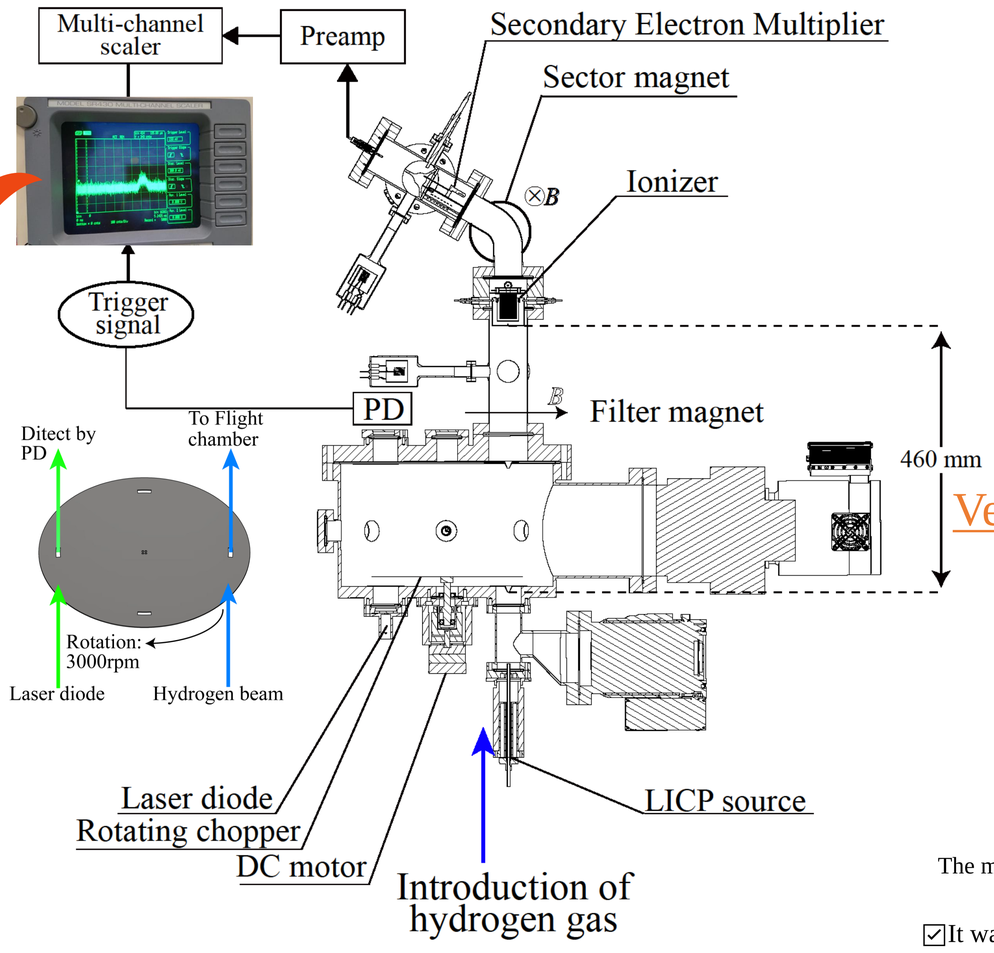


Operating principle

A microwave power of 2.45GHz is supplied to a 0.3 mm thick copper spiral antenna would around a dielectric tube and plasma is generated and maintained by locally induced eddy currents.

Experimental result

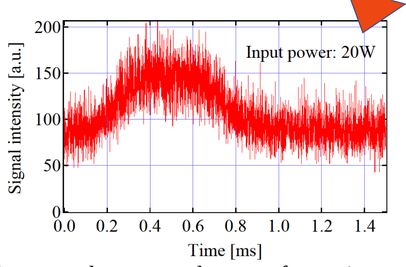
Experimental setup



Velocity distribution function

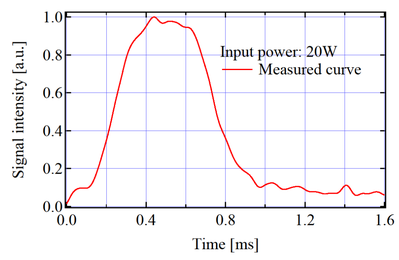
$I(t, T) = \int \eta(v) f(v, T) S\left(t - \frac{L}{v}\right) dv$

$I(t, T)$: Observation signal
$\eta(v)$: Ionization efficiency
$f(v, T)$: Velocity distribution function
$S\left(t - \frac{L}{v}\right)$: Gate function



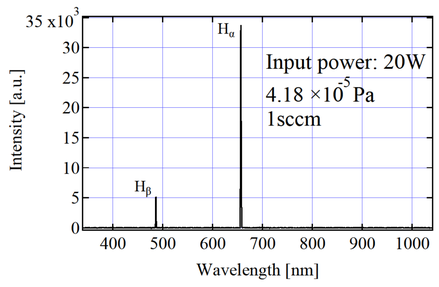
An example measured curve of experimental result of hydrogen molecular velocity distribution integral.

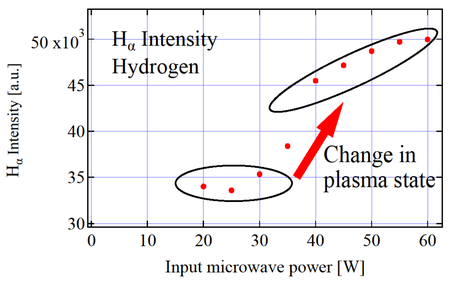
Smoothing



An example of smoothed result of hydrogen molecular velocity distribution.

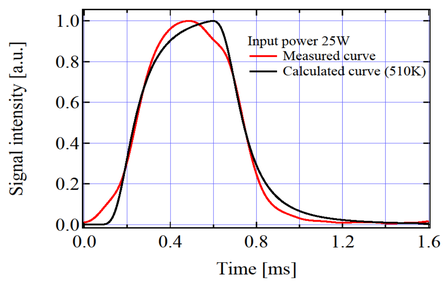
Optical Emission spectroscopy



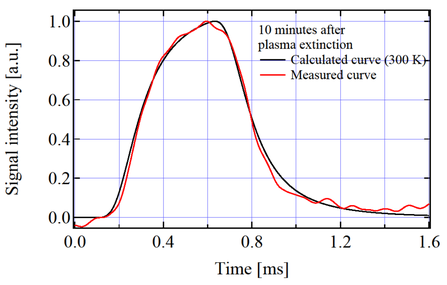


☑There was almost no emission from vibrationally excited molecules (Fulcher series) and emission from hydrogen atoms (Balmer series) was dominant.
⇨The plasma is estimated to have a low temperature.
☑Also, when input microwave power was changed, the mode transition was confirmed because the emission intensity of the plasma changed.

Velocity distribution function of hydrogen molecular ion



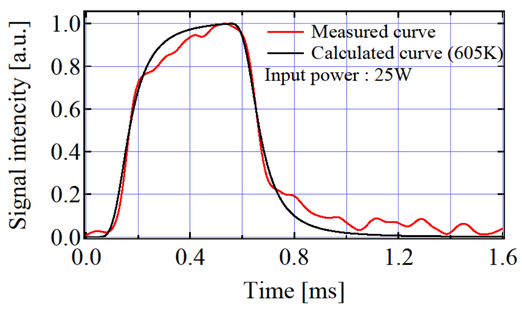
The measured and calculated curves of velocity distribution function for LICP source in 20 W.



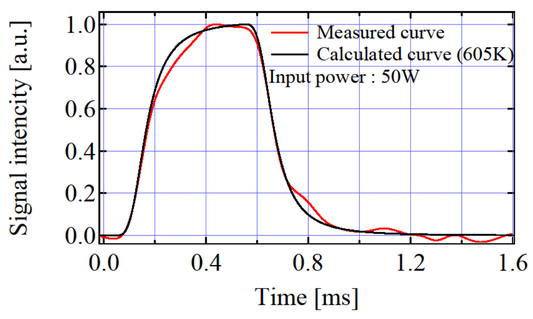
The measured and calculated curves of velocity distribution function for hydrogen gas.

☑It was found that hydrogen molecules were follow the Maxwell distribution of 510K regardless of the input power.
☑After plasma extinction, measurement of velocity distribution function of only hydrogen gas was close to room temperature.⇨Supports the velocity distribution function of hydrogen heated by LICP atomic source.

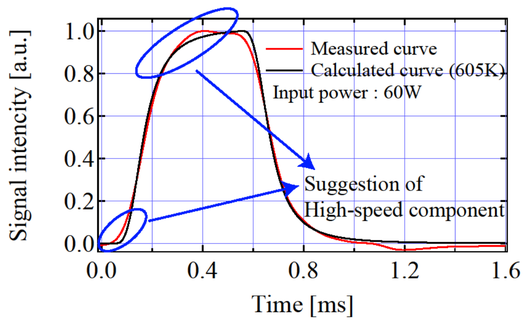
Velocity distribution function of hydrogen atoms



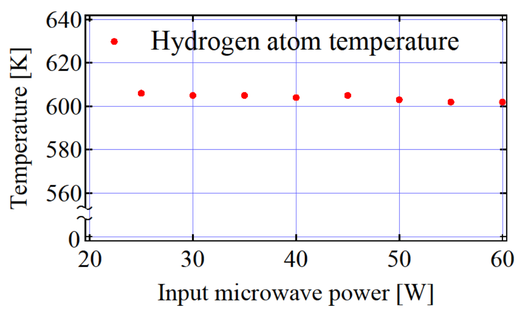
The measured and calculated curves of velocity distribution function of hydrogen atom for LICP source in 25 W.



The measured and calculated curves of velocity distribution function of hydrogen atom for LICP source in 50 W.



The measured and calculated curves of velocity distribution function of hydrogen atom for LICP source in 60 W.



Estimated hydrogen atom temperature when changed input microwave power.

☑High-speed components tend to increase as the input microwave power increase.
☑Hydrogen atom temperature does not depend linearly on input microwave power.

Summary & Future works

■In this study, high-speed component was confirmed in the measured velocity distribution function of hydrogen atoms produced from an ECR plasma source.
◆The temperature of hydrogen molecule and hydrogen atom are about 510 K and about 605 K, which can be due to dielectric tube.
◆High-speed components of velocity distribution function of hydrogen atom tend to increase as the input microwave power increase. On the other hand, hydrogen atom temperature does not depend linearly on microwave power.
⇨ Plasma excitation method suitable for negative ion generation will be studied by producing a high-energy component in the velocity distribution function using a filament plasma source.