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Steady-state Plasma Production Device by Direct Current Discharge

By

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Summary: A method of highly-ionized, magnetically constrained steady-state plasma production is described. The device utilizes hot-cathode arc discharge of several amperes in helium, and the plasma produced in it is constrained in a uniform magnetic field. The electron temperature and density are measured by a double probe method for various working conditions of the apparatus. Typical values of them are 10 eV for electron temperature and $1.5 \times 10^{14}\,cm^{-3}$ for electron density, as the discharge current is 8 A and the magnetic field strength is 2550 gauss.

1. INTRODUCTION

This report describes the construction of a high density, steady-state plasma device by a direct current discharge, and also some results of the measurement of fundamental parameters of the plasma.

In general, the objects of such a steady-state plasma production are the investigation of various oscillations and instabilities excited in a plasma, radiations from plasma, and the interaction of a plasma with electron and ion beams, the development for new diagnostic techniques, such as micro-wave, laser, and electric and magnetic probe method, and some experiments for space plasma simulations.

RF discharge and DC current discharge are often used for the production of high-density steady-state plasma and the latter method was adopted here.

The similar plasma production devices already constructed are an energetic arc of Oak Ridge National Laboratory, an arc plasma device of the Institute of Physical and Chemical Research, and a TP-D machine of Institute of Plasma Physics of Nagoya University. Our device is constructed mainly on the base of TP-D.

The advantage of this system is that the plasma production chamber is separated from the plasma drift chamber so that the background neutral density in the drift chamber can be lowered considerably, compared with ordinary high current arc devices such as those in ORNL or the Institute of Physical and Chemical Research. Moreover, the high discharge current for the plasma production flows only in the production chamber, and the plasma in the drift chamber is expected to be quiet and stable.

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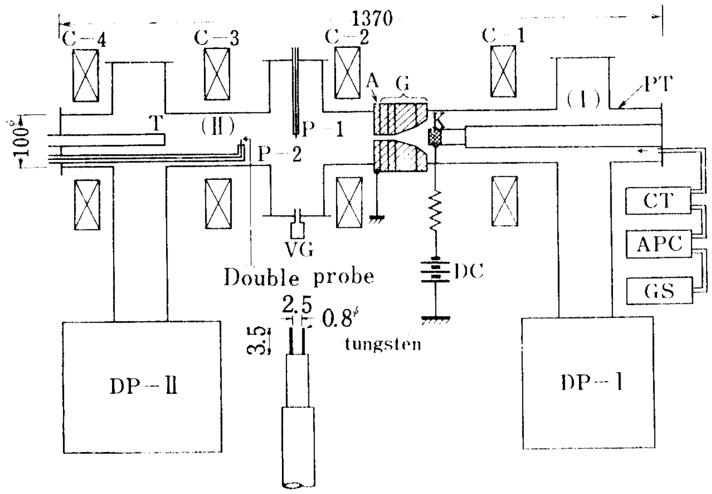
2. Apparatus and Its Performance

A plasma is produced in a gas filled plasma production chamber and it diffuses away into a highly evacuated plasma drift chamber along magnetic field lines of force through a small anode orifice.

The apparatus is composed of following components as shown schematically in Fig. 1; (1) Vacuum pumps, (2) Vacuum chamber including electrodes, (3) Gas introducing system, (4) Air-core coils, and (5) DC power supply.



DP-I, DP-II: 4″-oil diffusion pumps
(I): Discharge chamber
K: Oxide coated cathode
G: Intermediate electrodes (floating)
VG: Ionization vacuum gauge
CT: Liquid nitrogen cold trap
GS: Helium gas surce
DC: DC power supply
PT: Pyrex glass tube
(II): Plasma drift chamber
A: Anode (grounded)
T: Target (floating)
P-1, P-2: Double probes
APC: Automatic pressure controller
C-1~C-4: Air-core coils

Fig. 1. Schematic diagram of DC plasma production device.

The vacuum chamber is composed of pyrex glass tubes, and is divided into two parts, (I) discharge chamber, and (II) plasma chamber, separated at anode and intermediate electrodes. Each part is evacuated independently by a 4-inch oil diffusion pump. The back ground pressure of the discharge chamber is required to be maintained below 5×10^{-6} Torr in order to protect an oxide coated cathode from contamination from impurities.

Tungsten dispenser electrode and ordinary oxide coated electrode were used for the cathode of this device. The former has a very high quality with a large emission current density and a long life-time when operated in a high vacuum, but it is very sensitive to impurities such as H_2O and halogens, and to an abrupt change of the pressure, so that the electron emission current decreases rapidly as helium gas is introduced to the chamber. For this reason, the ordinary oxide coated cathode was mainly used in this apparatus. It has a cylindrical shape, 2 cm in diameter,

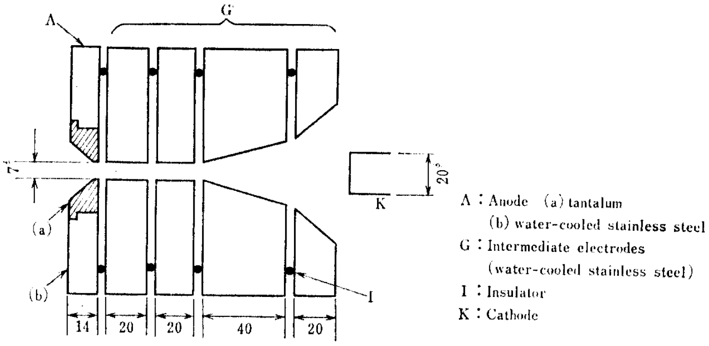


FIG. 2. Details of anode and intermediate electrodes.

and is operated at 900°C~1000°C.

When an arc discharge is maintained, the surface of a cathode suffers the back-bombardment by positive ions and is superheated, which reduced the life-time of an oxide coated cathode. So the cathode was put at the center of a magnetic cusp field in order to turn the positive ions away from the oxide coated surface.

The details of an anode and intermediate electrodes are shown in Fig. 2. The center part of the anode is composed of tantalum to reduce the evaporation caused by intense heating due to a large current discharge. The other part of the anode and the intermediate electrodes are composed of water-cooled stainless-steel.

The intermediate electrodes control the focusing of the electron beam from cathode to anode in order to increase the ionization rate. These are divided into four sections, insulated with each other and set at floating potentials, which results in the reduction of the oscillations excited in a plasma.

The amount of gas flow is controlled by an automatic pressure controller. The gas first passes through the liquid nitrogen cold trap which removes the impurities and then introduced in the discharge chamber. Typical operating pressures are 0.1~1 Torr in the discharge chamber and 10^{-4}~10^{-3} Torr in the plasma drift chamber, respectively.

Four coils are used in the apparatus as shown in Fig. 1. Coil-1 and coil-2 are used for the cusp field formation as described above. Coil-2, -3, -4, are used for the uniform field formation which constrains the plasma diffused out from the discharge chamber.

The uniform magnetic field strength can be varied from 800 gauss to 3000 gauss. The change of the magnetic field strength along the axis of the field is shown in Fig. 3.

A constant current power supply of 400 V, 10 A was used for an arc discharge.

At the operation of this apparatus, helium gas is introduced in the discharge chamber and the pressure is raised to about 0.1 Torr. As the magnetic field and the DC voltage are applied, then the discharge is started.

The discharge voltage is kept almost constant at about 100 V for the discharge current ranges between 0.5 A and 10 A. The most stable discharge conditions are as follows: the pressure of the discharge chamber is above 0.7 Torr and the discharge current is above 2 A. The length of a plasma column is about 50 cm.

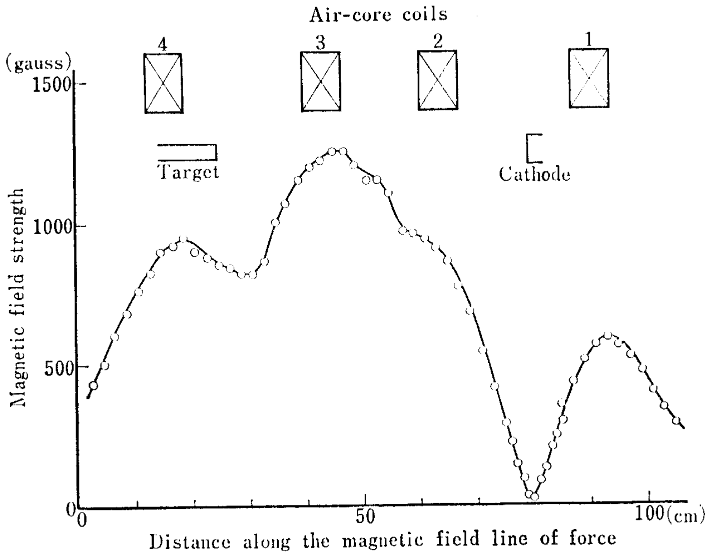


FIG. 3. Spacial distribution of magnetic field strength.

3. MEASUREMENTS OF ELECTRON TEMPERATURE AND DENSITY

Electron temperature and density were obtained by the double probe technique. The position of the probes in the apparatus and the details of them are shown in Fig. 1.

In Fig. 1, probe-1 was set at a distance of 17.5 cm from the anode surface and movable in a radial direction to the plasma column. Probe-2 was set at the center of the column and movable along the column axis. Double probe characteristic

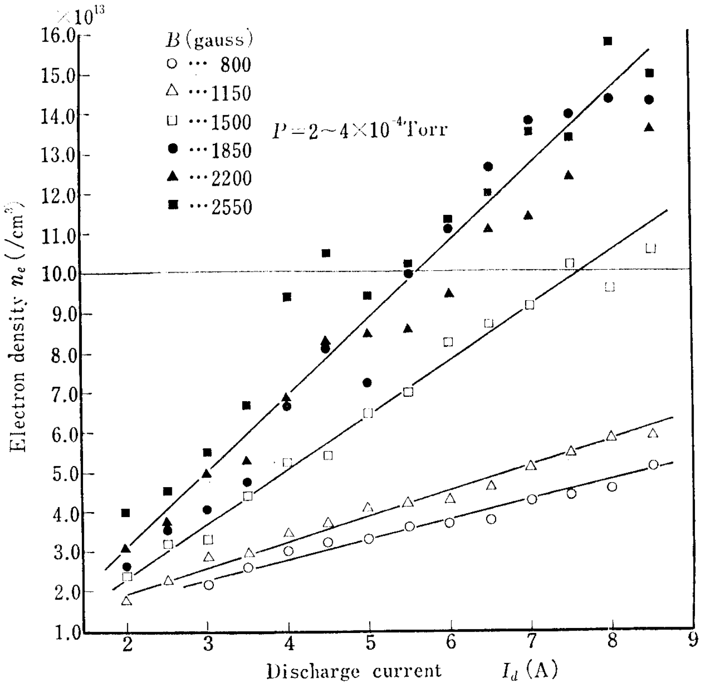


FIG. 4. Change of electron density with dischage current for various values of magnetic field strength.

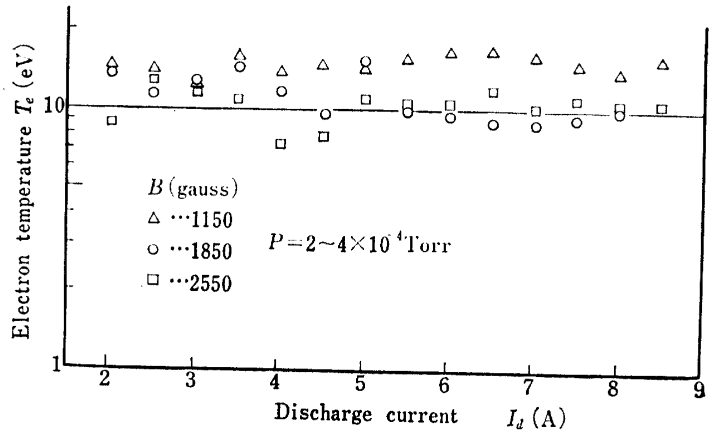


FIG. 5. Change of electron temperature with discharge current for various values of magnetic field strength.

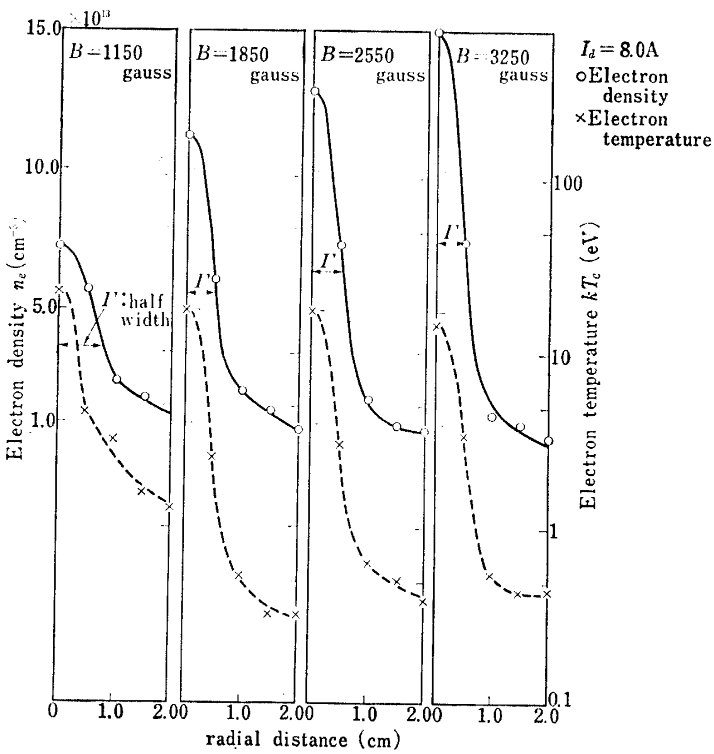


FIG. 6. Radial distribution of electron density and temperature at a constant discharge current 8.0 A for various values of magnetic field strength.

curves of ion current were pictured by an X•Y recorder, and from which electron temperature and density were calculated.

The results are shown in Fig. 4~Fig. 7. The change of electron density and temperature with discharge current are shown in Fig. 4 and Fig. 5 for various values of magnetic field strength. The curve of electron density vs. discharge current shifts upwards gradually for the lower range of magnetic field, and it rises rapidly for the magnetic field between 1150 gauss and 1500 gauss. For the higher values of magnetic field strength above 1850 gauss, these curves almost coincide each other.

Fig. 6 shows the radial distribution of electron density and temperature for various magnetic field strengths at a constant discharge current. The half-width of the density distribution curve, which is considered to be the radius of a plasma column, decreases as the magnetic field increases. This tendency is remarkable especially between 1150 gauss and 1850 gauss. And for the values of magnetic field above 1850 gauss, the half width does not decrease very much. This result corresponds to that of Fig. 4, that is, the constraining effect for the plasma column saturates for the values of magnetic field above 1850 gauss.

Fig. 7 shows the electron density distribution along the magnetic field lines of force. There is not very much change in the electron density along the plasma column.

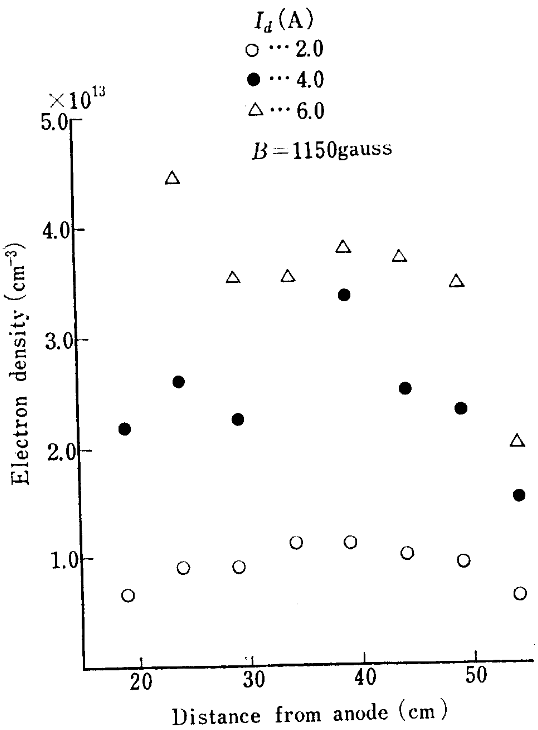


FIG. 7. Electron density distribution along the plasma colume.

4. DISCUSSIONS

A highly ionized steady state plasma was obtained by direct current arc discharge, in which the electron temperature and the electron density were 10 eV and 1.5×10^{14} cm^{-3} respectively for the discharge current of 8.0 A, the magnetic field strength of 2550 gauss, and the pressure in the discharge chamber of 0.8 to 1.0 Torr. The plasma in the drift chamber was sufficiently constrained with a uniform magnetic field above 1850 gauss. Under these conditions, the length of the plasma column was 50 cm and its diameter was 1.2 cm.

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