APPLICATION OF HOLLOW ANODE ION-ELECTRON SOURCES IN PLASMA CHEMISTRY

Vujo I. Miljević

Atomic Physics Laboratory,
The Institute of Nuclear Sciences "Vinča",
P. O. Box 522, 11001 Belgrade, Yugoslavia

A new type of ion-electron sources based on hollow anode discharge are presented. In these sources an inhomogeneous and high density plasma near the beam extraction aperture is produced, from which both ion and electron currents could be drawn into the extraction and particle optic system.

Introduction

At present, the hollow cathode discharge (HCD) is a well-known inhomogeneous discharge. A very important property of for all types of HCD is that a very bright plasma, with high electron and ion density, is formed in the hollow cathode. However, due to the increased ion bombardment, the density of cathode material atoms is also increased in the hollow cathode plasma. Consequently, the HCD spectrum consists of both carrier gas and cathode material lines. The intensity of carrier gas spectrum is proportional to the discharge current I, and the intensity of the cathode-material spectra varies as I^n, where $n \approx 2$ and depends on the combination carrier gas-cathode material [1]. However, in some applications it is of interest to obtain inhomogeneous discharge with high electron and ion density in operating gas without cathode-material atoms.

In a new type of discharge which is called the hollow anode discharge (HAD) [2], electron and ion densities are increased in a hollow anode but without anode or cathode material spectral lines.

Hollow Anode Discharge (HAD)

A hollow anode discharge is realized in the diode schematically shown in Fig. 1. It consists of the concave cathode (CC) and a hollow anode (HA). The hollow anode is represented by a disk (made of aluminum alloy) with the aperture in the center, for example 1 mm in diameter. The upper side of the disk, facing the cathode, is insulated by a thin ceramic layer (dashed line on Fig. 1) deposited by a plasma arc, thus making only the inner surface of the anode aperture conductive. Teflon insulator (TI) enables the hollow anode to be in the center of the concave cathode curve and knife-edge seal. The operating gas, controlled by a needle valve, enters from the cathode side and is pumped away through the hollow anode aperture by a standard vacuum system.

When the electrical discharge is established in the hollow-anode concave-cathode diode, a very bright plasma is formed within the anode aperture. This discharge is called the hollow anode discharge. The brightness of the plasma depends on the hollow anode diameter, discharge current, and pressure. By decreasing the diameter the brightness of the plasma is increased. HAD plasma flows strongly through the hollow anode into the vacuum chamber. The discharge is stable and transition into an arc was not observed.

The optical spectrum of the argon HAD in the spectral range from 400 to 600 nm consists only of ion lines. Neutral argon lines are not recorded. The ArII 476.5 nm spectral line is more intense than the ArII 488 nm line. The 476.5-nm transition shows linear dependence, while 488-nm has complex dependence on the current. Since the dependence of the intensity on discharge current is linear, it may be supposed that for the upper energy level of the 476.5-nm transition the dominant population mechanism is the result of single-step electron-impact excitation from the neutral ground state directly to the excited ion state. i.e., $Ar + e \rightarrow (Ar^+)^* + 2e$. The theoretical explanation of this type of excitation is given by Bennett et al [3]. The absence of neutral argon lines and very intense argon-ion lines in the spectrum points to a high degree of argon ionization in the HAD. In nitrogen HAD the optical spectrum consists of the first negative band of N_2^+.

Hollow Anode Ion Source (HAIS)

One way to increase ion source efficiency is to form an inhomogeneous plasma with the maximum ion density near the exit aperture. Such a plasma is achieved in several type of ion sources, for example in duoplasmatron source [4]. In the hollow cathode magnetron ion source [5] the maximum ion density is obtained in the cylindrical mesh cathode [6].

In a new type of ion source, based on a hollow anode discharge, the inhomogeneous plasma with the maximum ion density and electron temperature in the exit aperture is obtained by special electrode geometry.

The hollow anode ion-electron source is presented in Fig. 2. It consists of a concave cathode (CC) with a curvature radius R=30 mm and a hollow anode (HA) 1 mm in diameter. Both CC and HA were made of aluminum alloy. The lower side of the hollow anode is the exit aperture of the source and together with the extraction electrode (EE) represents a modified Pierce's system [9]. When the HAD is established and the extraction voltage equals zero, an intensive outflow of the plasma through the hollow anode-source aperture is observed. Then, the ion current is obtained even at low acceleration voltage. Plasma flows through exit aperture and the ion beam is obtained from the plasma boundary which is outside the ion source. Constant hydrogen ion current in excess of 1 mA have been obtained. It depends on the discharge current, source aperture and extraction potential, and can reach several mA. Dependence of ion currents on extraction is shown in Fig. 3.

The characteristics of the source, such as efficiency can be further increased by applying an axial magnetic field. Typical ion source with axial magnetic field is shown in Fig. 4, and dependence of the Ar^+ current on magnetic field for constant discharge current is shown in Fig. 5 [10]. By changing magnetic field from 3 mT to 25 mT (magnetic current from 0.6 to 4.2 A) for other constant conditions, the ion current changes from 15 to 145 μA, i.e. it is increased by about 10 times, and passes through two local maxima. On the other hand, it is possible to change considerably the ion current by a slight change of the magnetic field in the region between the first minimum and the first maximum.

Hollow Anode Electron Source (HAES)

As argon (inert gas) has a small electron affinity, an argon plasma is used to obtain an electron beam from the

HAD. Argon pressure in the discharge is of the order of 0.1 mbar (typically 0.3÷0.5 mbar). For example, the extracted electron current is approximately 300 mA and practically equals the discharge current at the discharge voltage of about 400 V and axial magnetic field of 0.01 T [11].

Large area 4-cm hollow anode ion source [12] is presented in Fig. 6. The ion source is essentially a tandem discharge consisting of a HAD, as the source of both the high energy electrons and atomic hydrogen (predissociation method), and a standard reflex or PIG discharge as a plasma source, supplying ions to the extraction electrodes. They are separated by a hollow anode.

Hollow Anode Radiation Source (HARS)

The main characteristic of HARS is that the special lines of the operating gas, without anode or cathode material, can be obtained in wide spectral range, from UV through visible to IR. HARS represents very bright source owing to small surface of (circular or rectangular) hollow anode aperture. Characteristics of the source, such as efficiency, can be further increased by applying an axial magnetic field. The discharge tube of the source can be filled by a gas in static or dynamic vacuum conditions at a determined pressure. Other characteristics of the HARS are similar to the characteristics of HAIS and HAES.

Conclusions

The hollow anode sources have certain advantages over sources of previous art of the same power dissipation, such as: small dimensions, no heated cathode, high ionization efficiency with low gas flow rates and good power efficiency, absence of ions of cathode or anode materials, instant beam upon switching on (no warm-up period). All these advantages secure the application of hollow anode discharge in effective long lived above mentioned sources.

The life of the source is extremely long. Any change in application, such as a change in exit aperture or swithover to operation with corrosive gases is simple and fast, due to modular construction of the source. The source flange may be either a standard 2 3/4" or larger diameter conflat flange. The source can be mounted in any position. No maintenance whatsoever is required.

The sources with small aperture require only a gas supply and a simple power supply capable of delivering 10 to 50 mA at 1000 V, which could be regulated, if necessary. Breakdown voltage is up to 1000 V, and operating voltage is 400 to 500 V.

The sources are connected to the vacuum chamber through the hollow anode aperture which is, for example, typically 0.3 to 0.5 mm in diameter and 0.5 mm long. With the pumping speeds normally used in such systems and the relatively low pressure within the source, ions and electrons are obtained in high vacuum applications without the need for differential pumping.

Small volume of the source and consequently small electrode areas enable easy outgasing. Absence of ions of the cathode or anode materials, ensures high purity of the ion beam.

References

[1] H. M. Crosswhite, G. H. Dieke, and C. S. Legagneur, J. Opt. Soc. Am. 45, 270 (1955).

[2] V. I. Miljević, Appl. Opt. **23**, 1598 (1984).

[3] W. R. Bennett, Jr., J. W. Knutson, Jr., G. N. Mercer, and J. L. Detch, Appl. Phys. Lett. 4, 180 (1964).

[4] M. von Ardenne, *Tabelen der Elektronenphysik Ionenphysik und Ubermikroskopie* (Deutscher Verlag der Wissenschaften, Berlin, 1956).

[5] V. Miljević, Rev. Sci. Instrum. 55, 121 (1984).

[6] V. Miljević, Phys. Lett. A 92, 439 (1982).

[7] V. I. Miljević, Rev. Sci. Instrum. 55, 931 (1984).

[8] V. I. Miljević, IEEE Trans. Nucl. Sci. NS-32, 1755 (1985).

[9] J. R. Pierce, *Theory and Design of Electron Beam* (Van Nostrand, New York, 1954).

[10] V. Miljević, Rev. Sci. Instrum. 61, 312 (1990).

[11] V. Miljević, Rad. Phys. Chem. 35, 667 (1990).

[12] V. Miljević, Proc. 15th Europ. Conf. Contr. Fus. Plasma Heat., Cavtat, Yugoslavia (1985), p. 1085.

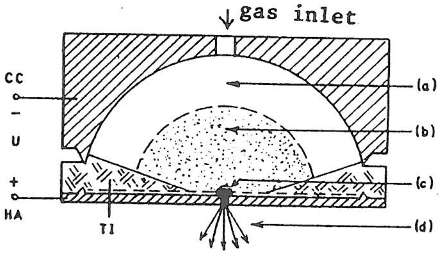

Fig. 1. Schematic diagram the hollow anode discharge.

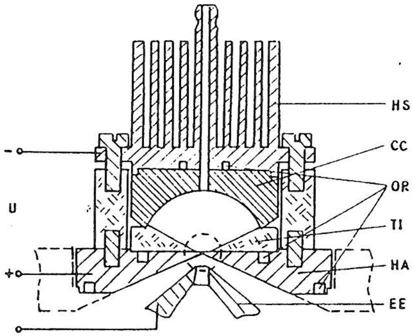

Fig. 2. Cross-sectional view of the hollow anode ion-electron source.

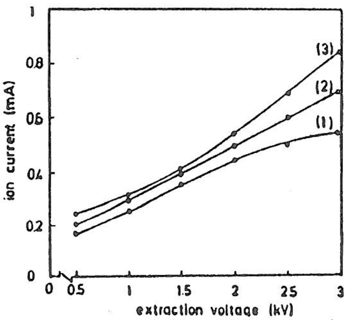

Fig. 3. Dependence of ion currents on the extraction voltage.

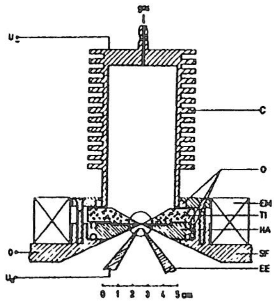

Fig. 4. Cross-sectional view of the HAIS with magnetic field.

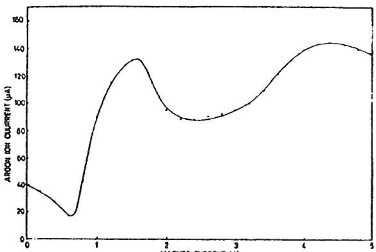

Fig. 5. Dependence of the extracted argon ion current on the magnetic field.

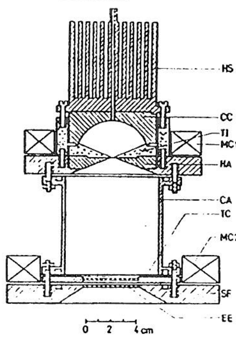

Fig. 6. The 4-cm hollow anode ion source.