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Development of Ion Source with Cold Cathode for Sputtering

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Abstract: Ion sources are of practical importance for scientific research and industrial applications. The developed ion sources are used for evaporation on single crystals. We present in this research the construction and the optimisation of a low-energy ion radiation source. Which supplies a high ion current density using a cold cathode with low power. The physical aspects and the different possibilities for resolution of the problem are discussed with investigations on the parameters of the developed duoplasmatron source. The conception is achieved by experimental investigations on selected construction versions. We show an interesting experimental results concerning the relation between the pressure and volume of the hollow cathode. The results are compared to those obtained by mass spectrometry at Penning and glow cathode ion source.

Key words: Ion source, radiation, mass spectrometry, hollow cathode, physical aspects

INTRODUCTION

There is currently a great deal of interest in ion sources due to their practical importance in research and industrial applications. Ion sources should be as simple as possible and characterized by long lifetime, high current density and low gas consumption.

Some authors have already reported on the construction and the working conditions of different ion sources (Sidenius, 1978; Brown, 1989; Freeman and Sidenius, 1989; Atiken, 1982). Frequently, hot filament ion sources have been employed. Inconveniently, the sputtering and the evaporation limit strongly the lifetime of the filament by corrosion processes.

High frequency ion sources are also used for the generation of multiply charged ions, ion beam etching and ion implantation (Sakudo, 1987).

Penning ion source has been commonly used as other option, however the emitted ion current is low and cannot be increased by higher gas pressure. Another inconvenience of the penning ion source is the damaging of the cathode material by ion sputtering.

Consequently, we propose new concept of effective plasma generation from a cold cathode discharge, which is based on a hollow cathode in combination with special geometry of a magnetic field inside (Kerkow *et al*., 1992). In order to prevent the high discharge pressure and gas consumption, it is necessary to investigate the operation conditions of the hollow cathode at lower discharge pressures.

CONSTRUCTION AND OPTIMIZATION

The most important determining characteristic of a glow discharge is the cathode fall where the avalanche of the charge carriers takes place. Each emitted electron from the cathode must generate enough ions by the cascade process. In a hollow cathode discharge the positive column enters the aperture of the hollow cathode and the cathode fall is extended beyond the volume of the cavity. The minimal working pressure of a hollow cathode discharge depends on the volume of the hollow cathode, as shown in Fig. 1. According to Paschen's law the volume dependence of the gas pressure. Figure 1 shows that for infinite volume a pressure of 0.5 Pa and for e.g., 20 cm^3 about 100 Pa would be required.

A magnetic field crossing the electric field forces the electrons to move on a cycloidal path instead of a straight one. For a given potential difference the effective path length of the electrons increases in relation to the geometrical distances. Three arrangements of the magnetic field in a hollow cathode for low-pressure

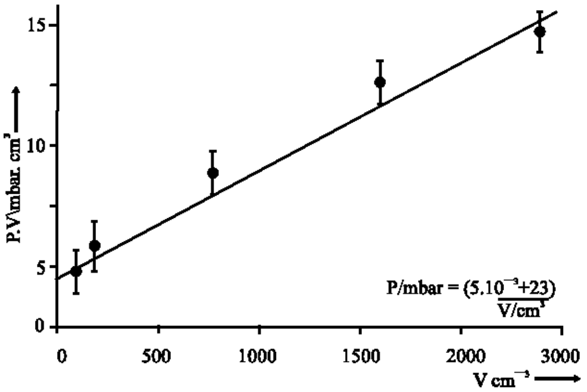

Fig. 1: Minimal gas pressure ($p = p_{min}$) for an Ar discharge in dependance on the volume of a hollow cathode

discharge are represented in Fig.2. In the center of the cavity (Fig. 2a) a permanent magnet produces a radial magnetic field in the hollow cathode. The electric field between the wall and the magnet crosses the magnetic field. In Fig. 2b a permanent magnet creates a magnetic field among two parallel iron plates. The electric field penetrating through the aperture in the upper plate crosses the magnetic field in the cavity. In this region an intense emission was also observed. For a transversal geometry (Fig. 2c) the magnetic field lies either parallel or perpendicular to the bottom of the hollow cathode.

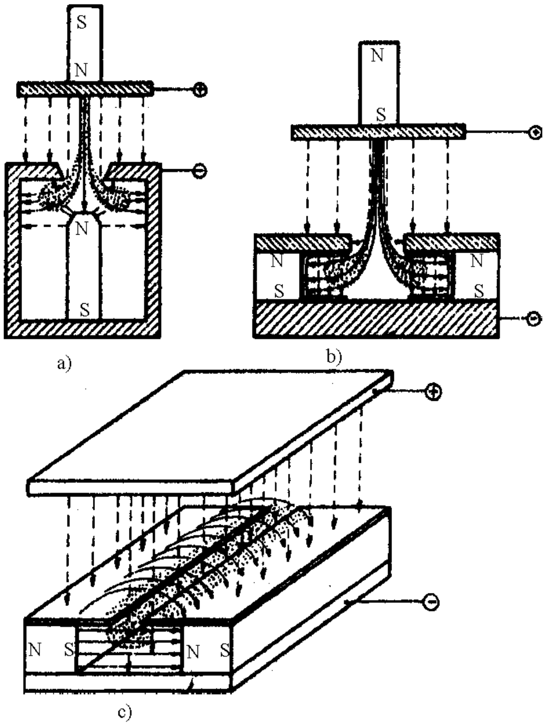

Fig. 2: Possible arrangements of the magnetic field in a hollow cathode for low-pressure discharge: a) radial geometry, b) axial geometry, c) transversal geometry (slit arrangement)

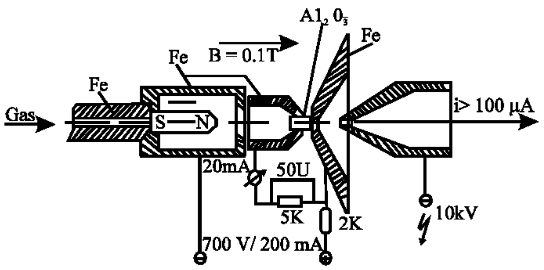

Fig. 3: The magnetic hollow cathode as a module for duoplasmaron source

In principle, inside a cavity the electric field from the anode is crossed by the magnetic field at well-defined positions. In this way the typical working pressure can be significantly reduced.

The magnetic hollow cathode can be used as a module at the same way as a hot filament for the construction of ion sources (Kerkow *et al.*, 1992). A possible arrangement is the duoplasmatron mode (Fig. 3). Between the magnetic hollow cathode and the anode an auxiliary electrode has to be positioned which is electrically connected to the anode over a resistor of about several kilo-ohms. At the beginning of the discharge a small current flows between the hollow cathode and the auxiliary electrode, leading to a potential difference with respect to the anode. Therefore, the discharge is taken over by the anode. The plasma is compressed by a channel in the auxiliary electrode to a Small diameter, which is formed in the space close to the exit aperture. Using this arrangement in an ion source a beam current density of 100 mA cm^{-2} can be achieved.

PHYSICAL ASPECTS

In the duoplasmatron the discharge path consists of 2 zones, the cathode space and the anode space. At the discharge ignition, the current flows firstly between the hollow cathode and the auxiliary electrode. The required preresistance for the restriction of the discharge current

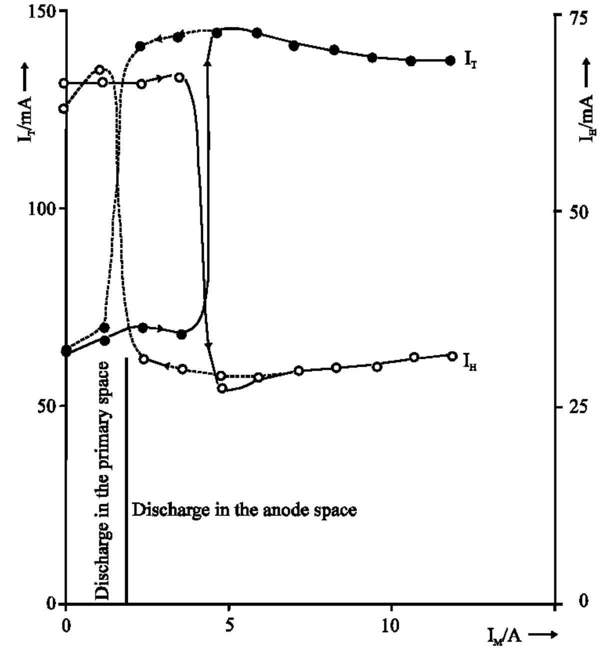

Fig. 4: The dependence of the currents i_T and i_H on the magnetic field force i_M

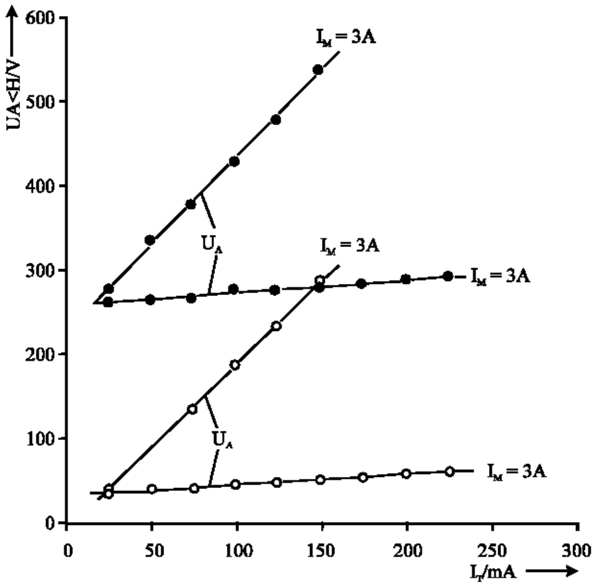

Fig. 5: The voltages dependence on the discharge current for magnetic field force of 3 A and 4 A

between the cathode and the auxiliary anode is greater than for the anode circuit, so that the auxiliary current amounts to approximately 20% from the total current.

The current across the anode depends on the gas pressure and the magnetic field force in the source. Figure 4 shows the dependence of the currents on the magnetic field force. This figure illustrates the behavior of the measured total current I_t and the partial current i_h, which flows across the auxiliary anode (Fig. 4).

At an excitation current of about 4 A increases the total-current approximately 150 mA, whereas the partially current i_h declines in the ignition phase from 5 mA to about 30 mA. In reducing the excitation current in the solenoid, the discharge goes out in the anode space with a smaller value i_B. In this study, a lower magnetic field would be sufficient for the Ion source operation.

The voltage curves at the anode and the auxiliary anode in dependence on the discharge current are represented in Fig. 5 for magnetic field-force of 3 A and 4 A.

As showing in this figure, at low magnetic field-force of 3 A a higher anode-voltage is required. At the same time, the auxiliary anode voltage shows a similar linearity with smaller voltage values.

Finally, the leakage current of a duoplasmatron source with magnetic hollow cathode amounts to about 10^{-5}mbarl/s at an ion current density of 2 mA cm^{-2}. It should be possible to use the source in a sputter mode and the magnetic hollow cathode can be also applied as evaporation source for solid materials as proposed by Menet and Gabrielli (1989) and Boubetra *et al.* (2000).

CONCLUSION

In conclusion, a new concept of effective plasma generation from a cold cathode discharge has been presented. It is based on a magnetic hollow cathode in combination with a special geometry. The arrangement has been used for the construction of the duoplasmatron source. The results show that the source can be applied for sputtering.

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