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A PLASMA WINDOW AS A PRESSURE VALVE FOR FAIR

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Abstract

The Facility for Antiproton and Ion Research (FAIR) at *GSI Helmholtzentrum für Schweionenforschung* in Darmstadt is designed to deliver high intensity beams of heavy ions at high energies. The intended intensities render conventional means of beam transport between the vacuum of an accelerator and regions of higher pressure nearly impossible. For efficient high pressure gas strippers or experimental chambers operating close to atmospheric pressure, alternative ways of beam transport need to be evaluated.

A promising approach, the so called plasma window, has been proposed and patented by A. Hershcovitch [1]. His vacuum-atmosphere interface introduces an arc plasma into a differential pumping stage connecting the different pressure regions, significantly improving the pressure ratio achievable. This contribution presents the status and first results of such a plasma window under development at IAP, Frankfurt.

INTRODUCTION

Due to the large intensities encountered at FAIR, metal foil interfaces terminate within short time scales, thus decreasing the operational time of the accelerator or experiment. Differential pumping stages do not suffer from this disadvantage, but for high pressures ($p \approx 1$ bar), they grow infeasible large in length.

In beamline layouts, a large duty cycle combined with reasonable geometric dimensions is required for high pressure gas strippers or high pressure experimental chambers. Thus both established means prove to be insufficient solutions.

Since the volume flow Q of a compressible fluid through a cylindrical pipe is given by [2]:

$$Q = \frac{\pi R^4}{16 \eta l} \bar{p} \Delta p \qquad (1)$$

Where $\bar{p}$ equals the arithmetic mean of the pressures at the pipes ends, Δp equals their difference, R equals the radius of the pipe, l its length and η equals the viscosity of the fluid flowing within the pipe.

With fixed geometric dimensions, the only property open to optimisation in (1) is the viscosity η of the fluid. As Fig. 1 shows, the viscosity of various gases reaches its maximum at temperatures around 10×10^3 K to 20×10^3 K. Bulk temperatures in this range can be achieved by arc discharges which also happen to cover a pressure range from 1 mbar to several bars [3].

For further discussion on the the pressure values, we define

$$\Delta q = \frac{p_H}{p_L} \qquad (2)$$

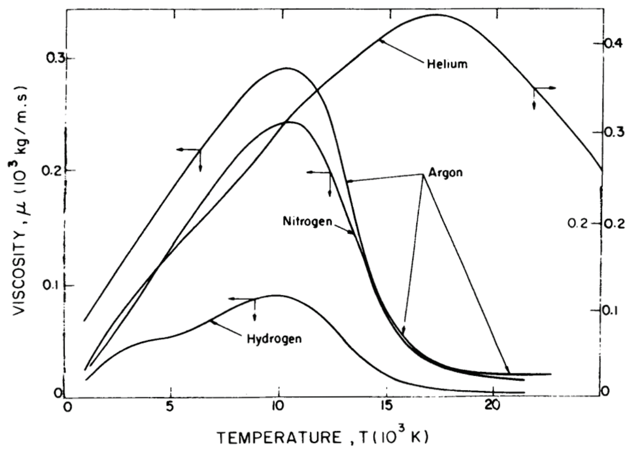

Figure 1: Viscosity of various gases in dependence of the temperature [4].

as the quotient of the pressure at the cathode side of the channel and that at the anode side (see also Fig. 2)

EXPERIMENTAL SETUP

Due to the high power dissipation of arc discharges, $P \approx 500$ W/cm at atmospheric pressure, a water cooling system had to be included. Furthermore the choice of materials from which the electrodes are manufactured proved to be difficult. A first design of cathode tips made from a W-Cu compound showed to be not suited as it just melted away. In contrast to the original and serveral other plasma window designs, the window presented has no need for ceramic isolators between the cooling plates, instead the PEEK-Spacers are protected via a tongue and groove design.

Table 1 lists the setup parameters for the setup shown in Fig. 2. Δq_0 denotes the pressure quotient without the active discharge.

Table 1: Setup Parameters

Parameter	Value
Length over all	390 mm
Channel length	59 mm
Channel diameter	3.3 mm
Current	≤ 60 A
Voltage	≤ 250 V
Gas mixture	Ar + 2% H_2
Δq_0	6 . . . 7
Number of cathodes	1 . . . 4

Fig. 2 shows a cross section of the newest prototype, featuring the external pumping stages. The basic design of the window features 4 cooling plates with spectroscopic ports,

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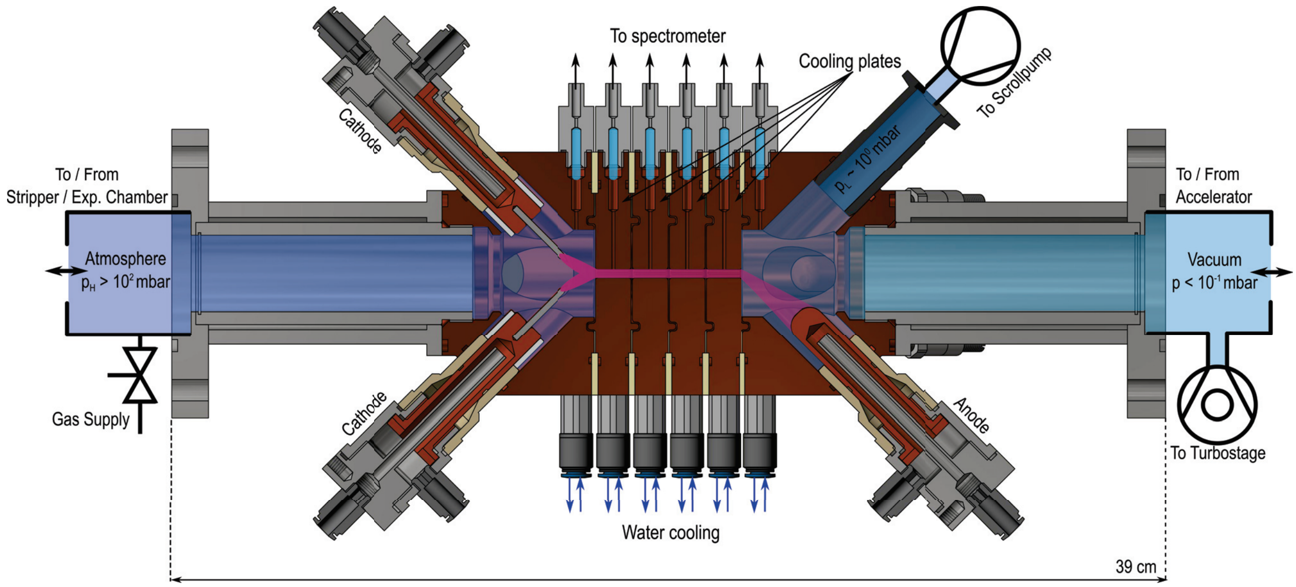

Figure 2: Cross section of the next plasma window prototype. The turbostage has not yet been implemented.

up to 4 cathodes and 3 anodes. Until now, only one cathode and one anode were used simultaneously. An increase in the number of electrodes is suspected to increase the life time significantly while the pressure shielding arises mainly from the plasma within the channel. Therefore the number of electrodes is not suspected to have a significant influence on the pressure shielding. The cathode tips are made from WIG welding needles, which are held in solid copper bodies. To protect the screws holding the tips, a ceramic hood covers it.

The spectroscopic ports are used to gather spectrometric data for the determination of plasma parameters such as temperature and density along the discharge axis. In the long run, these ports are to be used for real-time surveillance of the plasma parameters, enabling the experimentalist to check for the need of maintenance.

As working gas a mixture of 98% Ar and 2% H_2 is used, mainly due to the amount of data available on Argon arc discharges. The hydrogen serves as a diagnostics tool for the density determination.

RESULTS - PLASMA PARAMETERS

The optical diagnostics revealed plasma parameters to be in the anticipated range. The electron density measurement is carried out via measuring the Stark broadening of the H_β-line. It yields densities around $n_e = 1 \times 10^{16}\ \mathrm{cm}^{-3}$, satisfying the assumption of a local thermodynamic equilibrium (LTE) throughout the plasma column.

The presence of a LTE implies that the bulk termperature equals the electron temperature, which is determined via a spectrometric technique called Boltzmann-plot. The temperature obtained in this way is around 13.9×10^3 K for most of the studied parameters. This temperature is close to the temperature of maximum viscosity increase, see Fig. 1. In [4] the authors state that for atmospheric pressure and a bulk temperature around 13.9×10^3 K, the only ionized species in an Argon plasma is Ar^+, thus the electron density n_e equals the ion density n_{ion} inside the plasma.

RESULTS - PRESSURE PARAMETERS

The results presented in this contriubution have been gathered without the turbo stage visible in Fig. 2. The pumping speed of the setup has yet to be determined, it is constant for constant p_L, that is the pressure at the pumping side of the experiment.

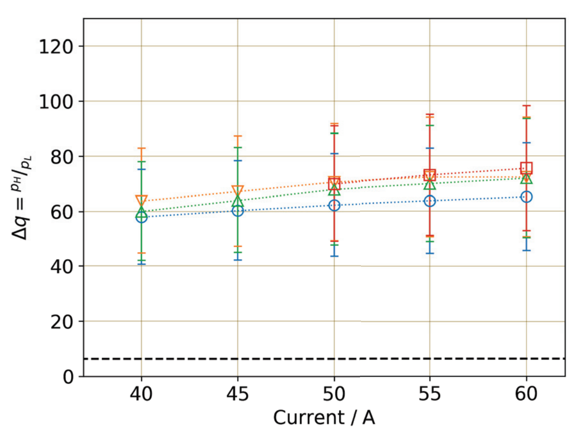

Figure 3: Pressure ratio for various p_L and discharge currents. The dashed line denotes the pressure ratio without a discharge. Higher p_L equals a higher pumping speed. ○: p_L = 7 mbar, ▽: p_L = 6 mbar, △: p_L = 5 mbar, □: p_L = 4 mbar,

At first, the pressure quotient without an active discharge $\Delta q_0 \approx 6 \ldots 7$ has been determined. This quantity is used to measure the improvement of the plasma window over an ordinary differential pumping stage of the same geometry

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and pumping speed. The pressure quotient Δq has been recorded after the discharge has been turned on and the gas flow has stabilized itself. Fig. 3 shows the dependence of Δq to various discharge currents and p_L. Current measurements include p_H up to 450 mbar.

From Fig. 3 it is obvious that the plasma increases the pressure quotient by a factor around 10. Rearranging (1) for two equal volume flows but once without plasma and once with plasma, an *effective viscosity increase ratio*, denoted $\frac{\eta}{\eta_0}$ can be defined, where η_0 is the viscosity without the plasma:

$$\frac{\eta}{\eta_0} = \frac{\bar{p}\ \Delta p}{\bar{p}_0\ \Delta p_0} \tag{3}$$

Using Eq. (3) and the recorded data,

$$\frac{\eta}{\eta_0} \approx 120 \ldots 150 \tag{4}$$

differs plainly from the data displayed for the sole viscosity increase from the heating of the gas in Fig 1, which yields $\frac{\eta}{\eta_0} \leq 4$ for Argon.

Thus additional processes seem to play an important role in the sealing mechanism. Possible explanations include

- plasma ion drift contrary to the gas flow induced by the external electric field
- significant decrease of the density inside the channel due to the high temperature

In order to comprehend which mechanisms are responsible for the behaviour of the pressure ratio, additional measurements are required.

CONCLUSION

As shown above, a fully functional prototype of a plasma window has been built at IAP. This prototype increases the pressure quotient by a factor around 10 in comparison to an ordinary differential pumping system of the same geometrical dimensions. This equals a pressure quotient around 70 using only a single scroll pump. Table 2 summarizes the latest results.

Spectrometric measurements along the discharge axis are to provide real-time surveillance of the plasma parameters in the near future.

Table 2: Measured Parameters

Parameter	**Value**
T_e	$\approx 13.9 \times 10^3$ K
$n_e \approx n_{ion}$	$\approx 1 \times 10^{16}$ cm^{-3}
Δq	$\approx 60 \ldots 70$
Δp	≤ 450 mbar
$\frac{\eta}{\eta_0}$	$\approx 120 \ldots 150$
t	> 5 h
I	$40 \ldots 60$ A
U	$100 \ldots 120$ V

The life time t of a single cathode is currently over 5 h. The limit of t has to be determined, as the tips show only little damage after 5 h of operation.

Measurements including the turbo stage are due this summer. They are suspected to give a further increase in the achievable pressure quotient.

ACKNOWLEDGEMENT

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