ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-WEPS03

# HYBRID PLASMA GENERATOR FOR HIGH INTENSITY FAST PULSED ION SOURCES

J. Rausch*, T. Dönges, M. Droba, O. Meusel
Goethe Universität Frankfurt, Frankfurt am Main, Germany

## *Abstract*

The main challenge in the development of high intensity ion sources is, besides the space charge limited extraction, the available plasma density. Conventional plasma generators use e.g. arc-discharge plasmas or RF generated plasmas. Preliminary tests are carried out on both types of plasma generators and plasma parameters are determined to create a basis for evaluation. A concept is being developed that combines the advantages of both types. This hybrid plasma generator will also be investigated in terms of plasma parameters in order to test a possible application for high intensity ion sources. Further the proposed plasma generator has the property that due to a permanently available low-density RF plasma a faster rise of the highly dense arc-discharge plasma may be achieved. The properties of the concept with regard to a fast plasma rise time are being investigated in order to test a possible application for the fast pulsing of high intensity ion sources.

## INTRODUCTION

Huge effort is being put towards the development of high intensity ion sources for the use in high luminosity accelerator facilities and high brilliance particle sources [1]. One limitation of beam intensities is given by the design of extraction systems that inject the highly space-charge dominated ion beam into the LEBT-section while minimizing the emittance growth in this critical region.

Another important issue towards higher intensities is the generation of high density plasma that can sustain stability under the extraction of large ion currents. This is usually achieved by either a high power RF-discharge yielding a dense high temperature plasma or by a arc-discharge using a hot filament. The latter is used to form low temperature plasma.

Many applications as most power limited linear accelerators require a pulsed operation. The problem with pulsing ion sources at very high intensities are: Pulsing of the discharge in the plasma chamber leads to non-uniform bunches both in current and also in the composition of ions.
Pulsing the extraction system, i.e. stopping ions in the extraction gap can lead to secondary electron production and with it to sparks in the extraction gap and erosion of the electrodes.

Therefore other, complex solutions are developed e.g. the use of a fast chopper combined with a beam dump [1, 2]. In an attempt to both provide cold high density plasma and to enable pulsing through a pulsed discharge with short rise times, a plasma generator utilizing a hybrid discharge is built. Instead of a high maintenance heated filament, it uses a low power cw RF-driven pilot-plasma to provide the electron density for the pulsed arc-discharge.

## RF-PLASMA

The pilot-plasma is driven by cw RF-powers of up to 300 W. This power is very low compared to conventional RF-driven ion sources [3]. For the first experiments, a capacitive coupling antenna was used at lower power levels. The plasma is formed inside a vacuum recipient with diagnostic ports on four sides for electrical and optical diagnostics of the plasma and discharge. The conductivity of the pilot-plasma can be measured using the plasma electrode. Additionally the shape of the plasma boundary and the electron density distribution can be investigated with a camera. Also the detuning of the RF-circuit due to the permittivity of the plasma is measured by adjusting the RF-frequency for minimum reflected power.

Figure 1 shows the dependency of the plasma resistance and the tuned RF-frequency on the pressure. Higher pressure leads to a lower frequency because of increased electron densities, while the resistance increases due to lower electron temperatures. In Fig. 2 the decrease of plasma resistance with higher RF-powers indicates higher temperatures. The frequency however stays constant.

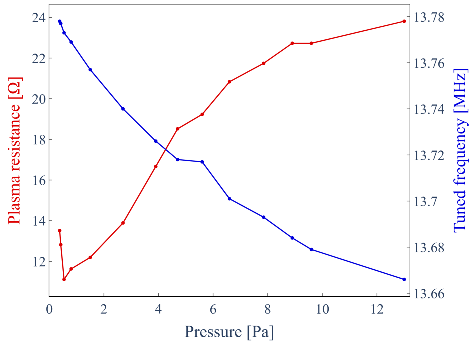

Figure 1: Plot of the resistance of the plasma for a current to the plasma electrode and the RF-frequency, tuned to minimum reflected power, over a variation of pressure.

It was observed that the distribution of plasma inside the chamber was significantly deformed by applying an electron attractive voltage between the plasma and extraction electrode, with the plasma boundary layer detaching from the walls of the chamber. This is shown in the image in Fig. 3. It is also clearly visible, that this forms a local change in the plasma distribution with an increased density in front of the extraction aperture.

---

* rausch@iap.uni-frankfurt.de

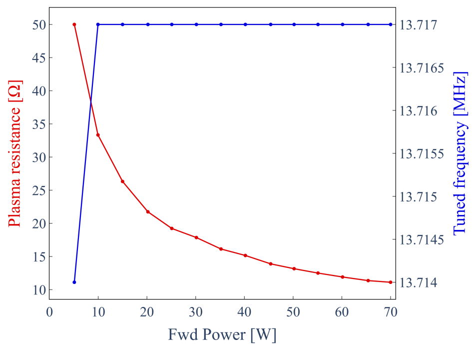

Figure 2: Plot of the plasma resistance and tuned RF-frequency for a variation of the RF-power.

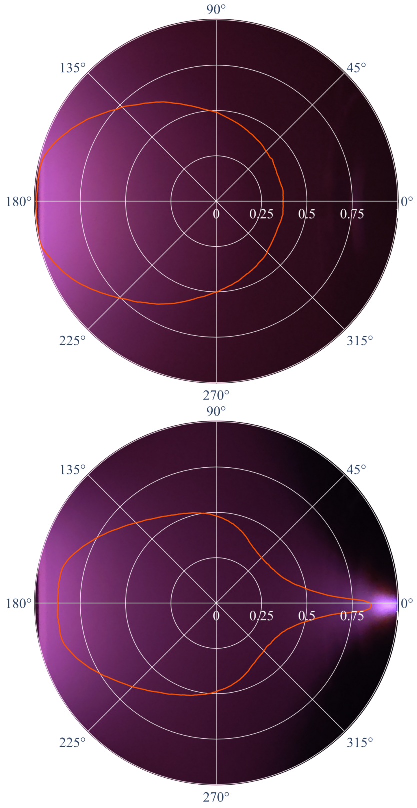

Figure 3: Camera image of the RF-plasma (top) and the RF-Plasma with a HV-discharge inside the extraction gap (bottom). The plot shows the radially integrated intensity normalized to the maximum intensity.

## ARC-DISCHARGE

The initiation of a sustained arc-discharge at the desired pressures requires an initial electron current provided by some source, usually a hot filament. The emitted electron current of a filament depends on its material and temperature (Richardson equation). For the use of a pilot-plasma as a source of primary electrons, the available electron current depends on the temperature and electron density of the plasma.

### *Measurements*

During the first experiments with air as residual gas, the whole plasma volume was used for the discharge, keeping the walls of the chamber at ground potential, while applying a positive potential to the plasma electrode. For high voltage at low currents provided by the power supply, very short sparks with a low average current could be optically observed. With a low voltage, high current power supply, intense discharges, initiated at around 100 V repetitively, reached the current limit (10 A) of the power supply leading to a collapse of the discharge.

Measurements on the discharge current as a function of time were performed with the discharge in series with low-ohm resistor, tracing the voltage drop across the resistor with an oscilloscope. Simultaneously, images of the discharge were taken with a camera at 480 fps and an intensity filter.

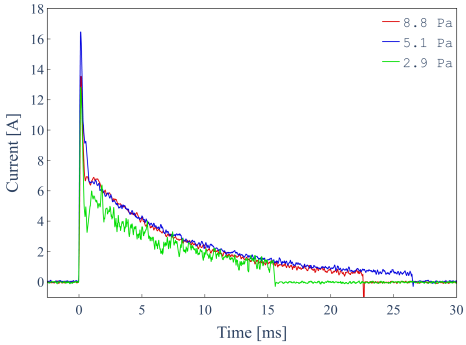

Figure 4: Time profile of the discharge current to the plasma electrode for different pressures.

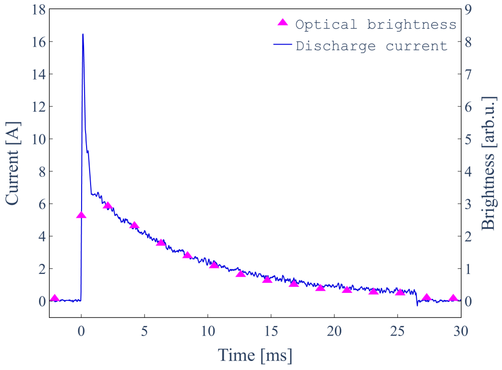

Figure 5: Time profile of the current of one discharge event and optical brightness of the plasma during the discharge.

The current traces of the discharge at different pressures are shown in Fig. 4. They show a sharp rise of current well beyond the rated limit of the power supply, followed by a long decay, usually lasting between 15 ms and 30 ms, and a sudden drop at the end of the discharge. It was possible to verify the duration of the discharge optically within the

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-WEPS03

limitation of $\Delta t < 2.1$ ms for each frame. Also, except from the very quickly occurring rise, the time profile of averaged brightness over the region of the discharge matched very well with the decay in discharge current (see Fig. 5).

The time profile of the current rise at the start of the discharge is shown in Fig. 6 for three different pressures. The rise time to maximum current (in the preliminary phase, using the whole plasma volume) was estimated to be between 50 µs and 150 µs, depending on the residual gas pressure. To study the rise time also optically, the scanning property of the used camera sensor was utilized. With reference images it was determined, that the sensor took 1.85 ms to scan over all 1080 (interpolated) pixel lines. Evaluating the first frame of a discharge event line by line, an estimation of the brightness profile could be made simultaneously to the current measurement. As shown in Fig. 7, the optical brightness increases slower than the current, reaching a maximum at later times and while the current is already decreasing.

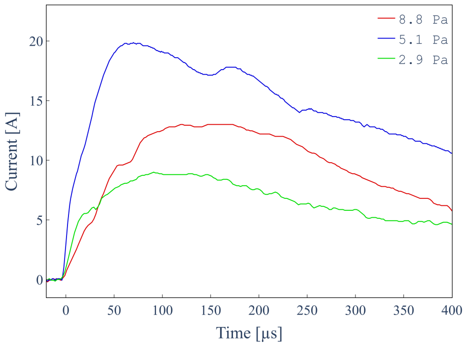

Figure 6: Time profile of the discharge current in the first microseconds of the discharge for different pressures.

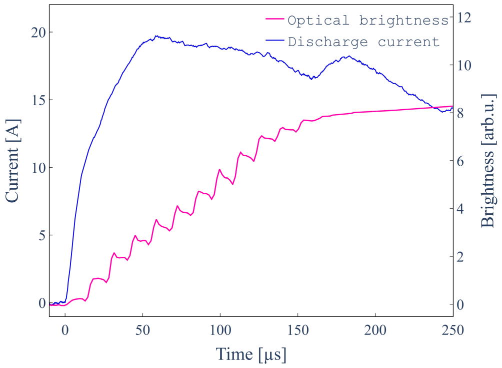

Figure 7: Comparison of current and brightness in the first microseconds of the discharge event.

## EXTRACTION

A simple extraction electrode is placed in a distance of 5 mm downstream of the plasma electrode which has an extraction aperture of 5 mm. For first tests, the plasma generator was kept at ground potential, while a negative potential was applied to the extraction electrode. The current on the extraction electrode is monitored with an oscilloscope.

Figure 8 shows the current on the extraction electrode at a potential of −2 kV during the plasma discharge. The current is positive, indicating positive ions extracted from the plasma volume as well as a backflow of secondary electrons produced on the surface of the extraction electrode. After the rise of the discharge, short sparking events initiated by those electrons inside the extraction gap lead to large current pulses with short decay times, which are observed overlaying the extraction current. After the initiation process of about 250 µs the measured current remained stable in the observed timescale.

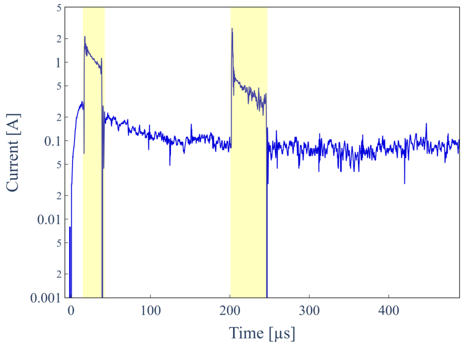

Figure 8: Current on the extraction electrode during one discharge event with the electrode at −2 kV potential. Marked areas indicate the secondary electron discharges inside the extraction gap.

## CONCLUSION

A plasma generator was built which enables several possibilities for plasma diagnostics and for plasma and discharge manipulation. The geometry of the plasma generator was chosen for better control of the Bohm criterion and sheath formation [4].

First tests showed a pulsed arc-discharge initiated after applying a potential to the plasma electrode inside the RF-powered pilot-plasma. The discharge pulses could be measured over time not only electrically but also as optical brightness profiles with good agreement in the total intensities between both in ms-timescales.

A moderate high voltage extraction electrode showed an initial evidence for ions extracted from the dense plasma following the discharge process and sparking effects inside the extraction gap.

This opens up a range of future research in the field of plasma generation and manipulation, studies on the rise and decay of arc-discharges immersed in a plasma, which may also target longer sustained discharges, as well as the formation and disturbance of the plasma sheath at the extraction region of an arc-discharge ion source.

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-WEPS03

## REFERENCES

[1] R. Gebel *et al.*, ”Technical Design Report HBS, Volume 1 – Accelerator”, Forschungszentrums Jülich, Jülich, Germany, 2023, pp. 19-21.

[2] C. Wiesner, ”Chopping and transport of high-intensity ion beams”, Ph.D. thesis, IAP, Goethe Univeristät Frankfurt, Frankfurt am Main, Germany, 2014.

[3] P. Beller *et al.*, ”The Frankfurt RF-driven ion source”, *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 449, iss 1-2, pp. 16-21, July 2000. `doi:10.1016/S0168-9002(99)01455-2`

[4] K -U Riemann, ”The Bohm criterion and sheath formation”, *J. Phys. D: Appl. Phys.*, vol. 24, no. 4, pp. 493-518, Apr. 1991. `doi:10.1088/0022-3727/24/4/001`