

INVESTIGATION OF ELECTRON BEAM ASSISTED DENSITY BOOSTING IN PLASMA TRAPS USING THE EXAMPLE OF A GABOR PLASMA LENS

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Abstract

Gabor lenses are plasma traps that can be used for focusing an ion beam linearly without aberrations by the electric field of a confined electron cloud. They combine strong electrostatic focusing with the possibility of space charge compensation and provide an attractive alternative to conventional ion beam optics in a LEBT section. The focusing performance strongly depends on the density and distribution of the enclosed electron plasma [1]. As the Gabor lens is usually operated close to the ion source, residual gas ionisation is supposed to be the central electron generation mechanism.

An electron source is introduced in order to investigate the possibility of boosting the electron density in plasma traps using the example of a Gabor lens. This way, a Gabor lens could be operated under XUV conditions, where residual gas ionisation is suppressed.

The particle in cell code bender [2] was used to simulate the injection into the confining fields of the space charge lens in different geometrical configurations and a prototype experiment was constructed consisting of a Gabor lens and an electron source system.

In this contribution, simulations and measurements will be presented.

ELECTRON SOURCE

The electron source used in the measurements was supplied by INFN-Bologna. It consists of a heated filament, a Wehnelt cylinder and an extraction grid, compare Fig. 1. Since no focusing devices after the extraction grid are used, the electron beam is strongly divergent, see Fig. 2. During characterisation, the source supplied 2.5 mA at 170 eV with the pickup direct in front. In the prototype experiment as

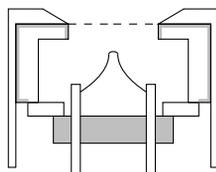


Figure 1: Structure of the electron source.

seen in Fig. 4, 1.35 mA at 170 eV were detected. The anode surface was used as pickup in the prototype experiment, which was polarised to 8 V in order to suppress secondary electrons.

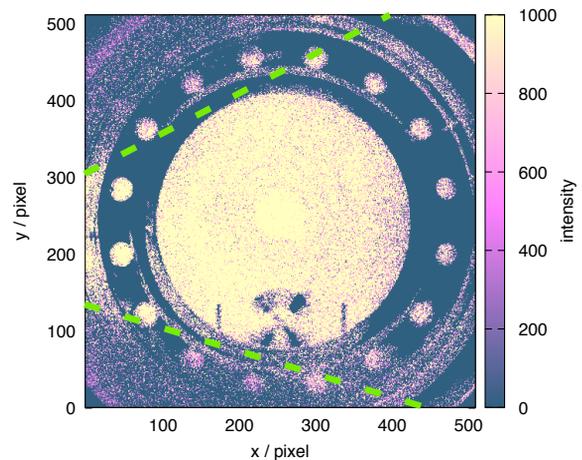


Figure 2: CCD image of the electron beam. The green lines indicate the beam edges. The electron source is positioned to the left.

SIMULATIONS

The particle-in-cell code bender that was developed at IAP [2] was used to simulate the electron density distribution in a Gabor lens with respect to the position of the electron source and various strategies to fill the lens volume despite the magnetic field [3]. Using a movable electron source inserted transversally into the lens volume and utilizing a μ -metal shield in order to attenuate the transversal magnetic field of the Gabor lens is the optimal configuration. Figure 3 shows the simulated density profile in the Gabor lens created by a transversal electron beam. This simulation implements space charge effects, which proved to be crucial in the distribution of the electrons in the confinement. Without these effects in place, a torus-shaped electron density distribution is obtained.

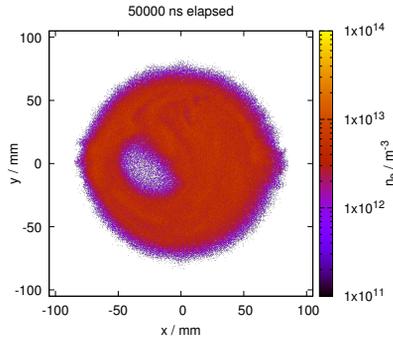


Figure 3: Simulated electron density distribution in a Gabor lens by injecting an electron beam transversally.

EXPERIMENTAL SETUP

The Gabor lens used in the measurements consists of a pair of Helmholtz coils providing the magnetic transversal confinement and an anode with four access ports. The anode is put on up to 8 kV positive potential in order to provide longitudinal confinement of the electrons inside the lens volume. One port is used to mount the electron source, which is adjustable towards the centre of the lens due to a manipulator flange, as shown in Fig. 4.

The confined plasma can be diagnosed using the CCD camera, which observes the light emitted by excited residual gas molecules. Furthermore, a Faraday cup can be used to observe the time structure of the residual gas ion current that is emitted by the lens longitudinally. Lastly, a momentum spectrometer consisting of a 90° dipole magnet and a Faraday cup can be used to measure the mean density in the Gabor lens.

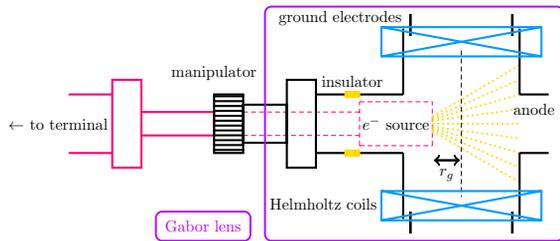


Figure 4: Scheme of the Gabor lens test stand at IAP.

IGNITION BEHAVIOUR

Ignition in the context of Gabor lenses implies the process of electron accumulation due to residual gas ionisation (RGI). Here, a free electron is accelerated by the confinement fields and performs RGI with a residual gas molecule. This leads to an avalanche of RGI electrons that fill the confinement capacity of the Gabor lens. The ignition can be observed by a sudden increase in the current of the anode power supply. Since the plasma improves the conductivity between anode and ground, a larger current is flowing in order to sustain the high voltage.

Ignition is achieved for a given set of potential, magnetic field and pressure if enough residual gas molecules are available in the lens volume and enough energy is present. A sub-critical (not yet ignited) state may be ignited by increasing potential, magnetic field or pressure.

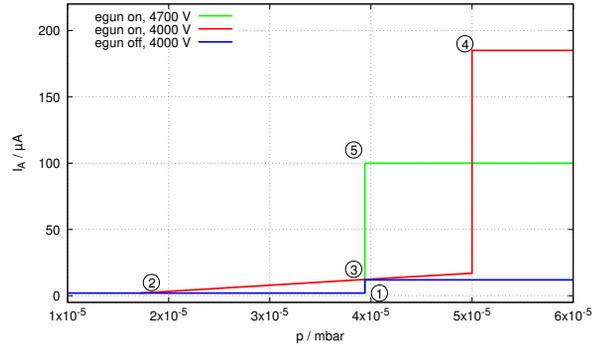


Figure 5: Sketch of the ignition events.

The ignition process is influenced by the transversal electron beam. Figure 5 shows a sketch of the anode current I_A with respect to the residual gas pressure in the Gabor lens. Point 1 on the blue curve describes a classical ignition process without the use of the electron beam. Introducing the transversal electron beam leads to an increase of the anode current at a lower pressure than expected (Point 2) and moves the ignition step to a higher pressure (Point 4). Instead of increasing the pressure after the point of expected ignition (Point 3), the potential and therefore the available energy may be increased (Point 5), until ignition is observed at the same pressure as classical ignition.

Since simulations indicate that the inserted electrons may form a torus distribution [3], the torus may attenuate the potential inside the lens volume and reduce the energy available for ignition. By increasing the potential, the potential depression due to the electron is compensated and ignition is possible at the pressure corresponding to classical ignition.

Furthermore, introducing a metallic object as the electron source into a Gabor lens influences the electric and magnetic field. Hence, the potential was fixed to 4 kV and the magnetic field was adjusted to 5.02 mT. Figure 6 shows the necessary ignition pressure without using the electron beam depending on the distance of the electron source to the centre of the lens, r_g . As the electron source is introduced further into the lens volume, the volume available to sustain an electron plasma decreases.

Considering the ideal gas law and making assumptions that the temperature is constant, a fixed number of residual gas molecules in the available volume is necessary for ignition and that the electron plasma forms a cylinder shaped cloud this leads to:

$$p = \frac{Nk_B T}{l\pi r_g^2} \tag{1}$$

where l is the length of the electron plasma column. This function is fitted to the data behind Fig. 6.

The radius of the anode is 88.5 mm. Due to the impact of the electron source chassis on the potential distribution, the effect of the electron source is visible until $r_g = 110$ mm. For larger values of r_g , the ignition pressure does not depend on the position of the electron source.

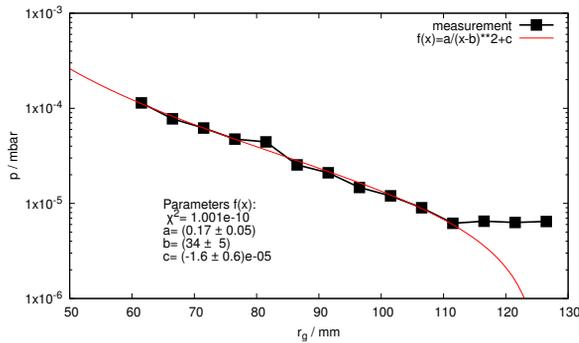


Figure 6: Ignition pressure with respect to the position of the electron source.

ELECTRON BEAM INDUCED IGNITION

Classical ignition relies on the residual gas density and an avalanche RGI reaction that is possible due to the confinement. Instead of increasing the pressure at a sub-critical state in order to reach ignition, the electron beam intensity is increased. The measurements depicted in Fig. 7 show a significant increase of the anode current as a response to the increase in filament heating, while the extraction potential of the electron source was kept constant. During these measurements, the pressure was chosen slightly lower than the ignition pressure measured for the respective positions of the electron source. For instance, concerning the measurement at $r_g = 71.5$ mm, the expected ignition pressure is 6.21×10^{-5} mbar, as in Fig. 6, and the corresponding measurement shown in Fig. 7 was started at a pressure of 5.35×10^{-5} mbar.

Thus, the electron beam is able to compensate for a small deficiency in pressure. The maximum anode current for all positions of the source is roughly 35 μ A, which is limited by the current of the electron source.

DENSITY BOOSTING

Simulations conducted in [3] suggest that creating a potential difference between electron source and anode would improve the density of the confined electrons. In order to evaluate the effect of the electron beam on the density, it is measured with respect to the potential difference and with respect to the presence of the electron beam. The results are shown in Fig. 8. In this measurement, the anode is on 4 kV potential and the electron source is set onto a smaller positive potential. By adding the electron beam to a pre-ignited plasma, the density improves up to 5%. For a potential difference larger than 100 V, activating the electron source does not influence the measured density to a large extent. Nevertheless, increasing the potential difference between

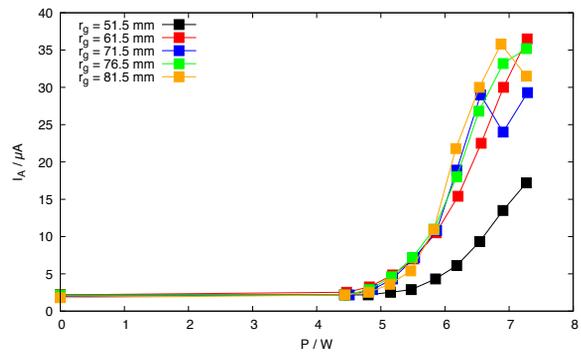


Figure 7: Response of the anode current to the heating power of the electron source. The electron energy for all measurements is 170 eV.

source and anode to 100 V increases the density of the confined electrons by roughly 14% regardless of the presence of the electron beam.

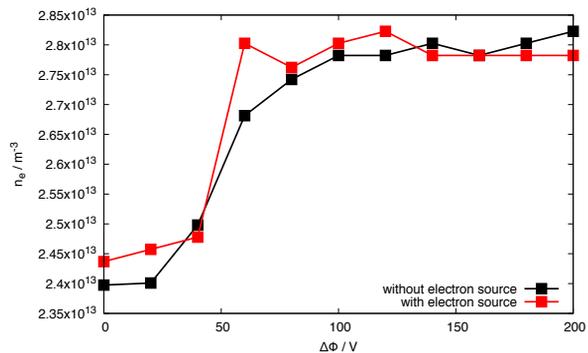


Figure 8: Impact of the electron beam on the density in the Gabor lens.

CONCLUSION

During the measurements, it was shown that a sub-critical Gabor lens is able to be ignited by an external electron beam. As a result, the operation of a Gabor lens under very good vacuum conditions is possible, if the current that is transferred into the lens is sufficiently high. Furthermore, it has been shown that the density in a Gabor lens can be successfully boosted by introducing a transversal electron beam. Interestingly, manipulating the potential distribution in the lens has a larger effect than the electron beam alone. Therefore, the use of an electron source to improve the density of a Gabor lens should be investigated further, especially with a modified electron source that is capable of supplying higher currents and a focusing optic.

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