A prototype Gabor lens has successfully been tested at the GSI High Current Test Injector (HOSTI) [1]. The experiments comprised the investigation of an emittance dominated and a space-charge dominated beam transport. In particular, the high-current measurements represent a necessary step towards evaluating the focusing performance of the lens and to gain experience in a real accelerator environment.

Besides the evaluation of the technical feasibility, the behavior of the electron cloud was characterized by the parameter analysis of the confined non-neutral plasma during beam transport measurements as well as subsequently performed diagnostic experiments.

This contribution will present experimental results as well as numerical studies on an improved Gabor lens design for the possible application at the GSI High Current Injector (HSI) in the context of an upgrade program for FAIR [2].

In mid-2012 beam transport experiments at HOSTI using a prototype Gabor lens were performed (see Fig. 1).

Figure 1: Scheme and photograph of the experimental setup for the beam transport measurements at GSI.

In both experiments – the emittance dominated as well as the space charge dominated beam transport – a good focusing performance close to the lens’ operation point was demonstrated [3].

In particular, the transport of an 3.1 keV/u Ar$^+$ beam with a maximum intensity of $I_B=35$ mA looked very promising in order to use this kind of focusing device for intense uranium beams in the context of the HSI Frontend Upgrade for FAIR.

A parallel Ar$^+$-beam was achieved for a lens parameter setup of $\Phi_A=9.8$ kV and $B_z=10.8$ mT at an increase in the normalized rms-emittance of only a factor of 1.38 (see Fig. 2).

Figure 2: Measured phase-space distribution of the Ar$^+$-beam without focusing (left) and the beam focused by the Gabor lens (right). Both emittances were measured at the same position behind the lens.

Before the lens was put into operation, high-voltage conditioning was necessary to remove contamination such as dust and moisture, as well as other imperfections.

Figure 3: Example of high-voltage conditioning procedure for the prototype Gabor lens. $I_{Ps}$ denotes the power supply current.

During the applied conditioning procedure, loss electrons originating from the plasma cloud remove deposits from the electrode surface. Electron losses were experimentally investigated by detection of the emitted x-ray spectrum by a gamma-spectrometer [4].

An example of the high-voltage conditioning procedure is depicted in Fig. 3. The increasing current of the voltage power supply can be explained by a growth of the production...
rate in the plasma: in case of the prototype lens CO is leaking from the Vinidur insulator and additionally, the electrodes contribute as a result of the electron bombardment.

However, during the measurement campaign, an increased incidence of high-voltage sparks caused by the damage of the insulator between ground electrode and anode was observed. Figure 4 shows a picture of the lens’ inside that was taken during a technical assessment, indicating metallic spots on the insulator and also a metallic splint, which lowered the distance between anode and ground electrode.

![Figure 4: Technical assessment of the prototype Gabor lens during the measurement campaign.](image)

In order to protect the insulator from further damage from the beam and to prevent sparking, the measurements of the space-charge dominated beam transport were performed using an iris of d=50mm mounted at the entrance of the lens.

With respect to a possible future application at the HSI, the design of the Gabor lens has to be improved technically concerning the high-voltage strength of the electrode system.

**IMPROVED GABOR LENS DESIGN**

As previously mentioned, one major technical concern is the protection of the insulator. For this reason, the influence of shielding electrode rings installed at the inner anode surface on the electron confinement has been investigated.

In Fig. 5 the electron density distribution longitudinally (top) and the radial electric space-charge field (bottom) for a cylindrical anode of $r_A=85$ mm with and without the shielding electrode ring is presented.

Due to the shape of the electric field, the electron column in case of an anode with shielding electrode has a wider spread in z while the extension in its radial dimension becomes smaller.

Beside necessary technical improvements that ensure the reliable operation, another important design issue is the dimension of the Gabor lens and the system length in particular. Therefore, simulations have been performed to investigate the electron confinement and the related focusing strength as a function of the anode length. The results are presented in Fig. 6.

The simulation results show a linear correlation between anode length and longitudinal extension of the plasma column, i.e., with increasing anode length also the confined electron column becomes larger in its longitudinal dimension. Therefore, the effective action of the generated space-charge field on the beam and – assuming the validity of the
thin-lens approximation – the focal strength of the Gabor lens also increases.

For the possible application at the new straight-line branch of the HSI a compact design of the Gabor lens is favored. In order to transport a 35 mA $^{238}\text{U}^{14+}$ beam with an expected maximum radius of $r_B = 30$ mm a lens aperture of 150 mm is proposed. Since the expected, necessary magnetic field strength is limited to $B_z = 50$ mT the overall diameter of the device might not exceed $d_{gl} = 320$ mm, while the overall length might reach $l_{gl} = 436$ mm.

A ceramic insulator and an electrode system with a shielding electrode ring that creates a confining potential of maximum $\Phi_A = 35$ kV is also planned.

As shown in Fig. 9 a first Gabor lens immediately after the extraction is needed and a second one in order to match the beam through the switching dipole into the quadrupol quartet.

As all three injection lines meet at the switching dipole, the small transverse dimension of the Gabor lens might be an important feature.

In this first evaluation of the beam dynamics using the code tralitra [5], a KV distribution of $\varepsilon_{rms,n} = 0.246 \pi$ mmrad derived from the emittance measurements behind the north-terminal of the HSI is transported through the alternative LEBT. The parameters in the presented case are $\Phi_A = 4.8$ kV, $B_z = 5.5$ mT for the first and $\Phi_A = 5.7$ kV, $B_z = 6$ mT for the second lens, while a space-charge compensation degree of 100% was assumed.

SUMMARY AND OUTLOOK

In this contribution a possible layout of an improved Gabor lens designed for the application at the HSI and a proposal for an alternative LEBT consisting of two of these lenses has been presented. A non-interceptive, transverse diagnostic to determine the confined electron density during operation as well as a controlling system for a simplified operation of the lens is currently under preparation.

REFERENCES


