OPTICAL DIAGNOSTIC ON GABOR PLASMA LENSES

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Abstract

Gabor Lenses have been built and successfully been used for focussing of particle beams. In the case of a positive ion beam the space charge of the confined electron cloud may cause an over-compensation of the ion beam space charge force and consequently focus the beam. The nonneutral plasma (NNP) is influenced by the external fields and its current state can be determined by the beam emittance growth. Experiments using a high field Gabor Lens have shown a correlation between the thermalisation of the enclosed electron cloud and the focussing quality. Especially a nonuniform energy distribution of the confined electron cloud leads to a Diocotron instability and therefore a change of the radial electron density profile. The resulting nonlinear focussing field forms the observed aberrations.

A three segmented Gabor Lens was constructed recently for a more detailed investigation of the plasma parameters as function of the external fields. The commissioning of the lens has been finished successfully and the light emitted by the interaction between the electron cloud and the residual gas has been observed. In a next step, the experiments will concentrate on the spectral analysis of the emitted light to evaluate the temperature and density distribution of the confined NNP.

INTRODUCTION

The focussing strength of the Gabor Lens depends strongly on the electron trapping efficiency as well as a unifom electron density and hence force linearity [1][2]. In case of similar strengths in longitudinal and radial confinement (purple line, figure 1) the NNP is assumed to be thermalised and its beam focussing quality is free of aberration.

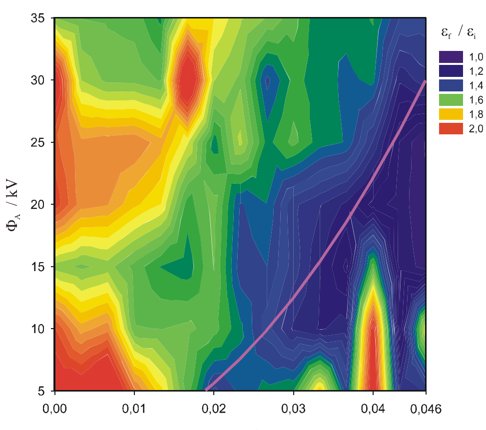

Figure 1: Measured emittance growth as a function of the external fields using a high field Gabor Lens and a 440 keV He^+ beam.

Now the primary concern by using Gabor Lenses is the investigation of the plasma parameters. The electron temperature, density and ion species play an effective role in the extracted beam properties like current, emittance or beam profile. Therefore these are important information on studying different electron traps and concepts like the magnetostatic storage ring [3].

EXPERIMENT

To investigate non-interceptive methods for determining the plasma parameters an experiment including a three segmented Gabor Lens has been established [4].

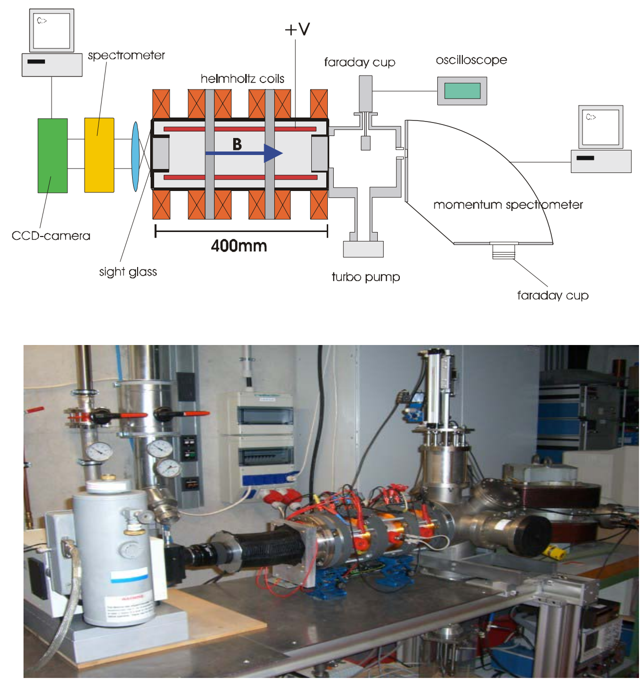

Figure 2: Experimental Setup: Scheme (top) of the plasma lens with diagnostics and photo (bottom).

The emitted ions are detected by a faraday cup and by the momentum spectrometer to determine the ion current and ion energy respectively. Furthermore, the light emitted by residual gas is explored by using a CCD-camera and a monochromator.The Gabor Lens, which was constructed and built at IAP Frankfurt, consists of three anodes and three pairs of Helmholtz coils (Fig. 2).

The total length of this device is about 0.4 m and gives the possibility to confine a plasma column with a length of at most 0.36m. The longitudinal confinement is provided by an electrode system with radius r_A = 0.032m and $\Phi_{A,max}$ = 6.5kV. This provides an opportunity to excite field gradients to also investigate plasma parameter gradients. Additionally, a sight glass attached to the anode of the Gabor Lens enables a transversal diagnositic of the plasma column. Instead of the sight glass, an HF-probe could be installed.

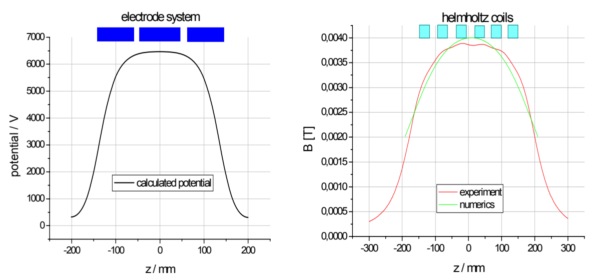

Figure 3: The calculated maximum potential of the Gabor Lens (left) . Measurement of the magnetic on axis field of the Gabor Lens compared to the calculated data for I= 1A (right).

CONFINEMENT

The confinement of the NNP is provided by magnetic and electric fields.

Besides these external fields it has been proved that the residual gas pressure and the involved electron collision frequency is a crucial confinement parameter as well. For each magnetic and electric adjustment it is possible to find a pressure range that improves the trapping efficiency. On the other side far from these parameter ranges a variety of plasma instabilities can be observed [5]. However, a nonuniform density distribution of the trapped electrons leads to a Diocotron instability (Figure 4). This kind of instabilty is also seen in numerical simulations at several magnetic and electric field levels with varying confinement efficiency.

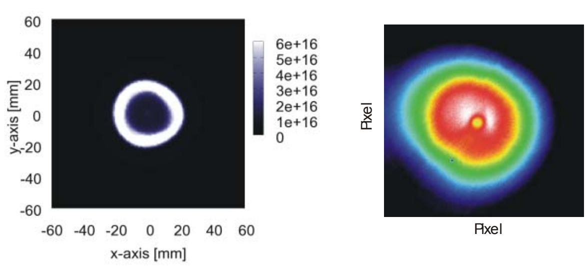

Figure 4: Light density distribution across the Gabor Lens aperture. Measurement (right) and simulation (left) give hints for a diocotron type instability.

TEMPERATURE MEASUREMENT

Because of low electron densities (10^{14} 1/m^3) and by absence of important recombination processes like three body recombination and radiative recombiantion the nonneutral plasma cannot be assumed to be in thermodynamic equilibrium. The plasma column could be described in corona equilibrium because atomic excitation results from collision with electrons while deexcitation results from radiation. Therefore, the requirements for a typical temperature measurement are not fulfilled.

But with similar strengths in longitudinal and radial confinement the NNP performs a transition to a state of thermalisation. In this context thermalisation means a homogenous distribution of electrons in the Gabor Lens and equality of longitudinal and radial average kinetic energies. Then the Boltzmann distribution is valid and the method of temperature measurement by comparison of different intensity levels can be used (Figure 5). This method given by Griem [6] is based on the fact that densities in various excited states are proportional to the products of statistical weights with the exponentials of the negative ratios of excitation energy and the thermal energy kT. The temperature can be estimated using

$$k\mathrm{T_e} = \frac{\Delta E_{12}}{\ln\left(\frac{f_2}{f_1}\frac{\lambda_1}{\lambda_2}\frac{g_2}{g_1}\frac{I_1}{I_2}\right)} \qquad (1)$$

where I, λ, g, and f are total intensity (integrated over the profile), wavelength, statistical weight (of the lower state of the line), and absorption oscillator strength respectively; E its excitation energy.

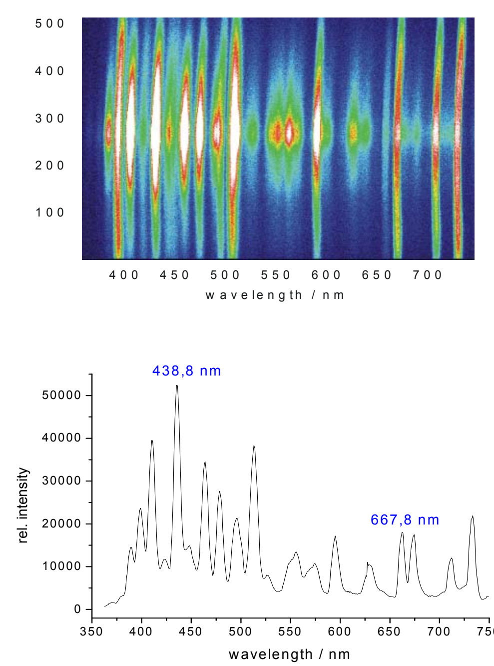

Figure 5: Measured optical spectrum for helium as residual gas (top) and profile of the measured spectrum (bottom).

By several measurements the thermalisation points of the nonneutral plasma could be clearly defined and the measured spectra were analysed (Figure 6).

The preliminary results of the temperature measurement show that the spectral sensitivity has a strong influence on interpretation of data. To reduce the error in measurement the spectral components have to be calibrated.

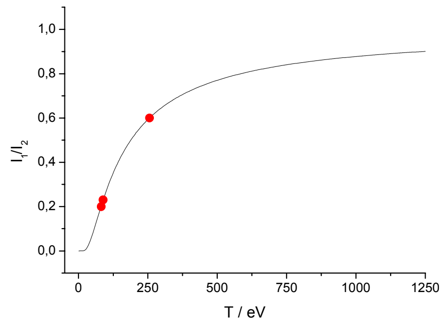

Figure 6: Theoretical progression of electron temperature compared to preliminary results.

DENSITY MEASUREMENT

The trapped electrons reduce the externally set potential and of course influence the electric field (Figure 7). For this reason the energy of the emitted residual gas ions depends on the electron density. Therefore, the ion energy measured by the momentum spectrometer yields information about the average electron density.

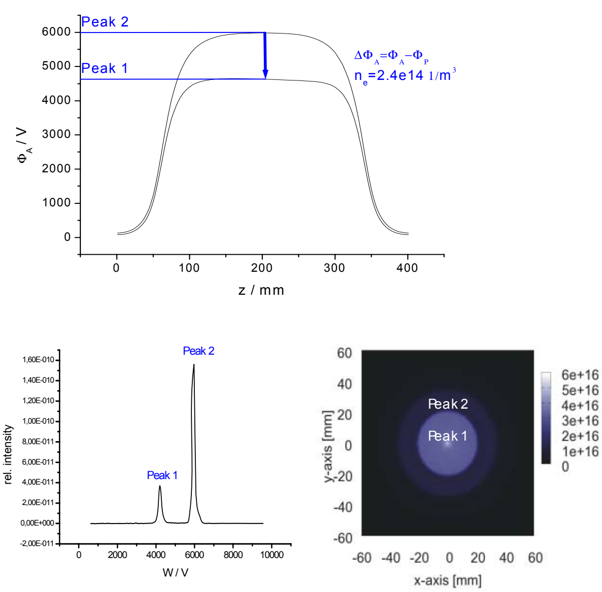

Figure 7: Potential depression by trapped electrons and allocation of the ion energies to different regions within the electron cloud.

Comparing numerical simulations to these measurements it results that there are different regions of ion production within the electron plasma.

The linear dependence between the average electron density and the anode potential is in agreement to the measurement:

$$n_e = \frac{4\varepsilon_0 \Phi_A}{e r^2} \tag{2}$$

where n_e, and Φ_A are electron density and anode potential. This also leads to an increase of the average relative intensity of the light density distribution (Figure 8).

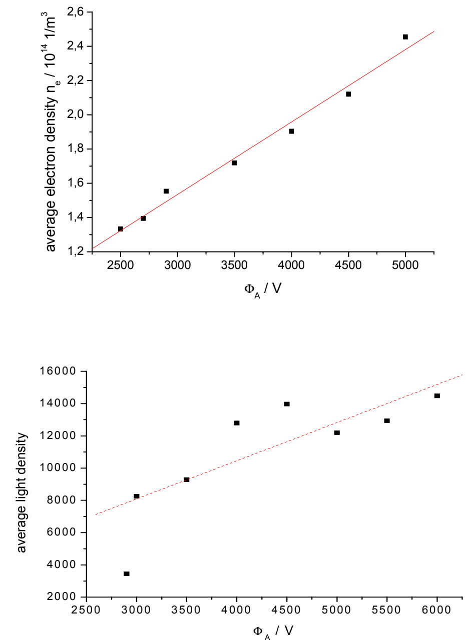

Figure 8: Growth of average electron density in correlation to the light density distribution as a function of the anode potential.

CONCLUSION

Measurments of the emitted light intensity, spectral distribution and energy distribution of emitted residual gas ions were performed in order to improve the focussing conditions provided by the Gabor Plasma Lenses. Further diagnostic techniques were examined for the diagnosis of intense particle beams.

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