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Title
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ABSTRACT

A novel design for a electron beam focusing column has been developed at LBNL. The design is based on a low–energy spread multicusp plasma source which is used as a cathode for electron beam production. The focusing column is 10 mm in length. The electron beam is focused by means of electrostatic fields. The column is designed for a maximum voltage of 50 kV. Simulations of the electron trajectories have been performed by using the 2–D simulation code **IGUN** and **EGUN**. The electron temperature has also been incorporated into the simulations. The electron beam simulations, column design and fabrication will be discussed in this presentation.

Keywords: electron beam, electrostatic column, IGUN

1. INTRODUCTION

Field emission and thermionic sources are the most common way to produce an electron beam. In this paper we will discuss the possibility of using a plasma source as an electron source. One can achieve high current densities and low spread in axial beam energy with plasma sources.[1] Therefore this design should be suitable for applications such as electron beam lithography (EBL). To demonstrate these features, a plasma source with a compact focusing column was built. The design was optimized by using computer simulations which will be presented in this paper. Furthermore the same design can be used to produce focused ion beams. Since the plasma source can produce different ion species, one can easily form a focused ion beam (FIB) with different elements. At the moment measurements are made with a focused ion beam, but experiments for the electron beam are planed in the near future.

The paper contains the following: first the design of the focusing column is introduced. Then in section 3, the computer simulations for the electron beam are discussed, followed by the experimental setup and the initial experimental results.

2. COLUMN DESIGN

The column consists of three parts. The first part is the plasma source and the extraction electrode, followed by a collimator which is used as a temperature filter for the electron beam by having a large aspect ratio and a rather small diameter. The last part of the system consists of a three lens-system which is used to focus the beam. The whole length of the system (extraction aperture to last lens) is less than 10 mm.

3. SIMULATION

3.1. Software

The design of the whole column was made by using the computer code **IGUN**[2] and **EGUN**.[3]

At the beginning the **EGUN** code was used to simulate the focusing of the electron beam. Later we switched to a newer version of **IGUN**, mainly because **IGUN** has a simpler user interface. The following results are produced using **IGUN**.

Both programs were used because they can simulate space charge effects which play a crucial role during the forming of the beam as well as for the behavior of the beam at the focal point where the current density is very high.

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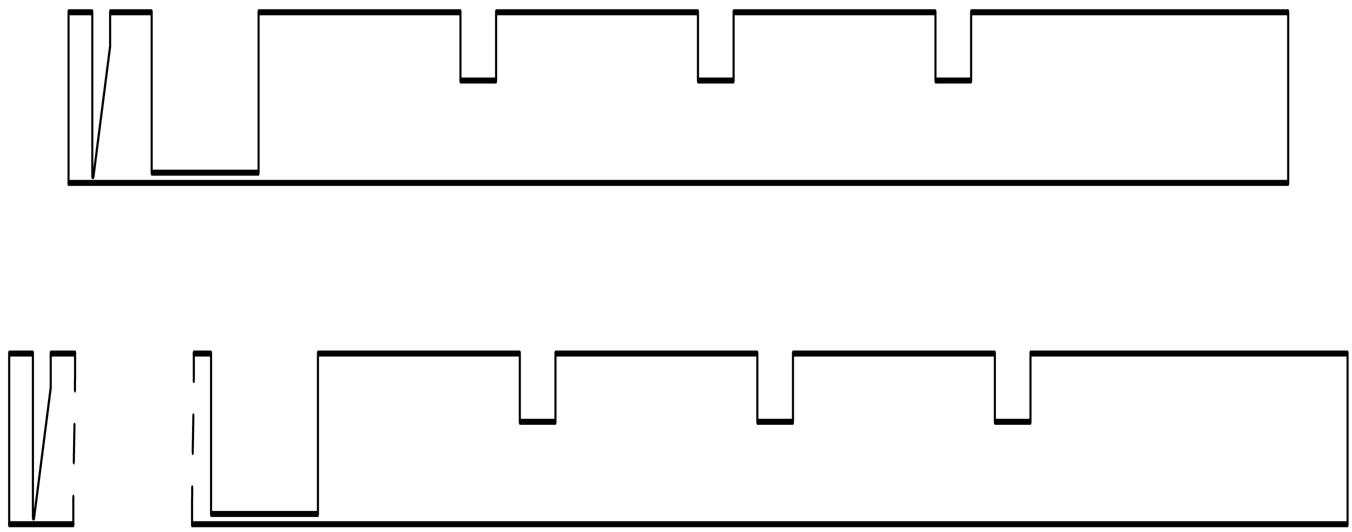

Figure 1. Splitting of the geometry.

3.2. Mesh Geometry

Since **IGUN** can only handle meshes with a constant spacing, the input file was split up in two parts to obtain a higher resolution in the extraction region. For this, an equipotential line between the extraction electrode and the temperature filter was calculated and the geometry was split at this equipotential line (see fig.1). Now the extraction region can be simulated using a higher resolution compared to the rest of the geometry. In this region the **IGUN** code computes the plasma meniscus.

3.3. Simulating the Electron Temperature

The electron temperature is being simulated by adding a transverse velocity to each trajectory after the meniscus is calculated by **IGUN**. This is very easy to do since we already split the geometry at the right spot. **IGUN** produces the trajectories information in a separate file which is then modified and used as an input file for the rest of the geometry.[4] **IGUN** saves the transverse velocity as the angle of the velocity of the particle in respect to the beam axis. The new angle is calculated as

$$\alpha_{\text{new}} = \alpha_{\text{old}} \pm \sqrt{\frac{E_{\text{Temp.}}}{E_{\text{Beam}}}}. \tag{1}$$

The way the temperature is added to the trajectories is shown in fig. 2. Starting by the outermost trajectory the following scheme is applied: a positive angle is added to the trajectory, the next trajectory stays unchanged and to the third trajectory the angle corresponding to the electron temperature is subtracted.

3.4. Results without Temperature

In fig. 3 and 4 the result of a typical simulation run is shown.

3.4.1. The Beam spot at the focal point

In fig. 5 the beam profile for the following voltages is shown: extraction aperture at 0 V, temperature filter at 500 V, first lens at 3 kV, second lens at 15 kV and the third lens at 30 kV. The focal point is at 11.3 mm (3.7 mm behind the third lens). In this plot, a fit for a Gaussian beam profile is also shown. The FWHM value of the Gaussian beam is 180 nm. The total width of the beam corresponding to the outermost trajectory of the beam is 350 nm.

3.4.2. Beam Emittance

The same voltages as in section 3.4.1 are used for estimating the beam emittance. The plot in fig. 6 shows the emittance at the focal point. For a better representation, the data points have been mirrored to include negative r–values. Furthermore the emittance is calculated and shown as the ellipse in the plot. The r–r' rms–emittance is $7.8 \cdot 10^{-5}\pi$ mm mRad, the normalized emittance is $2.7 \cdot 10^{-5}\ \pi$ mm mRad.

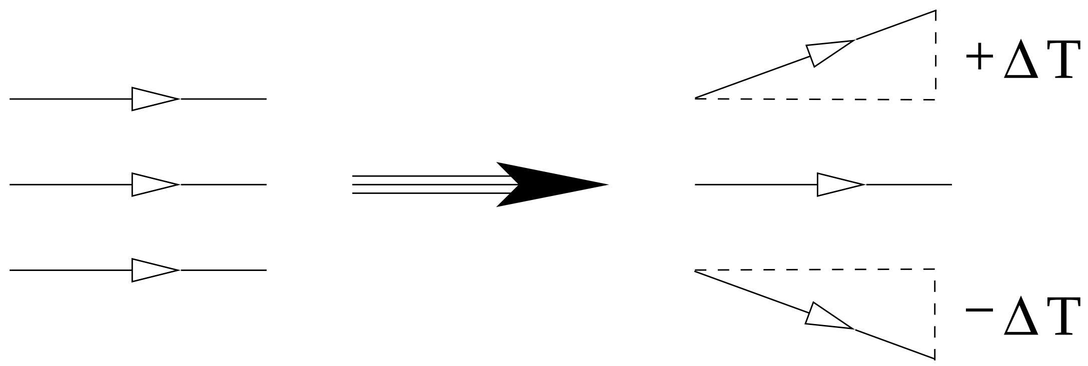

Figure 2. Adding an electron temperature.

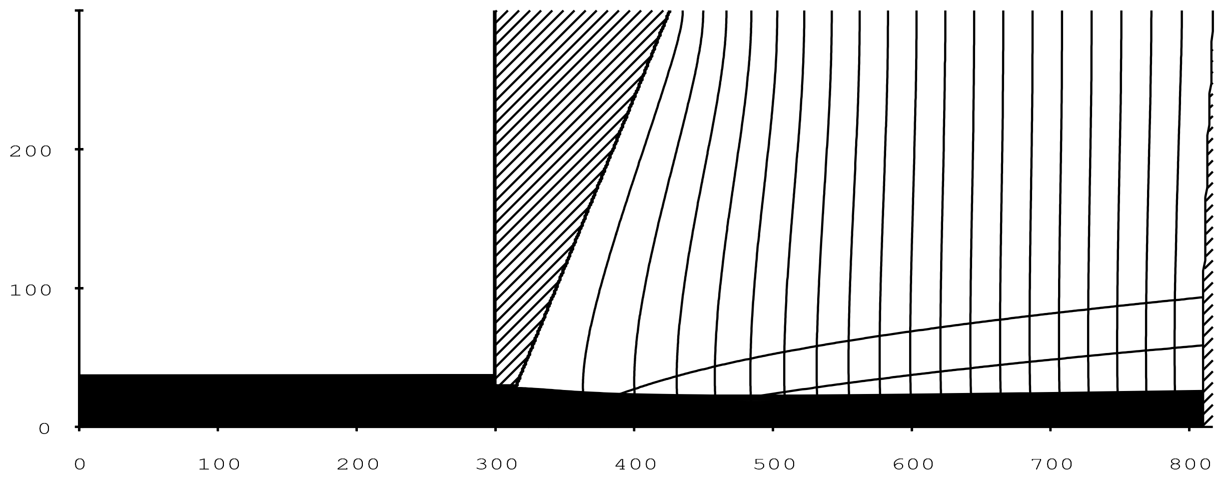

Figure 3. Extraction without Temperature.

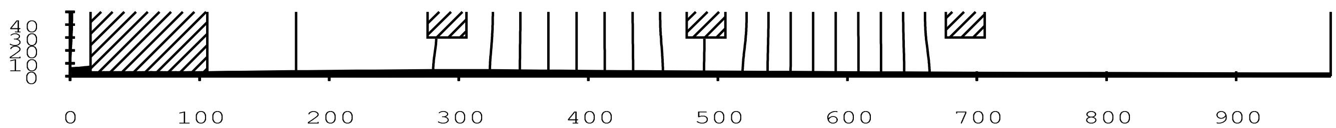

Figure 4. Temperature filter and focusing lenses.

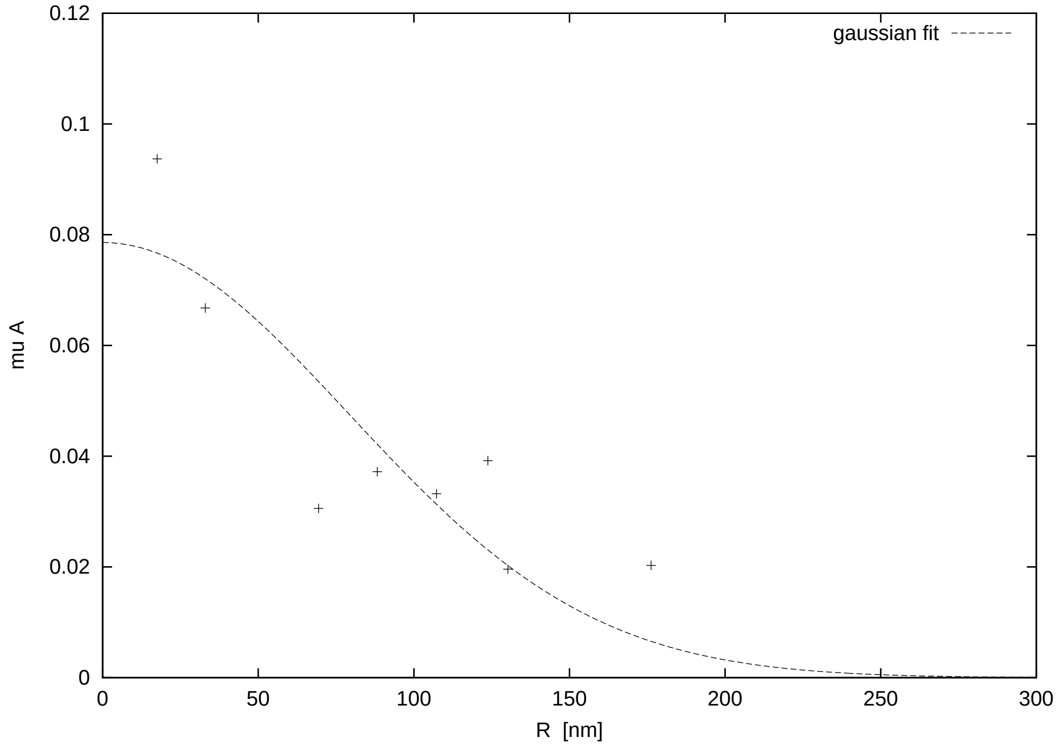

Figure 5. The beam profile.

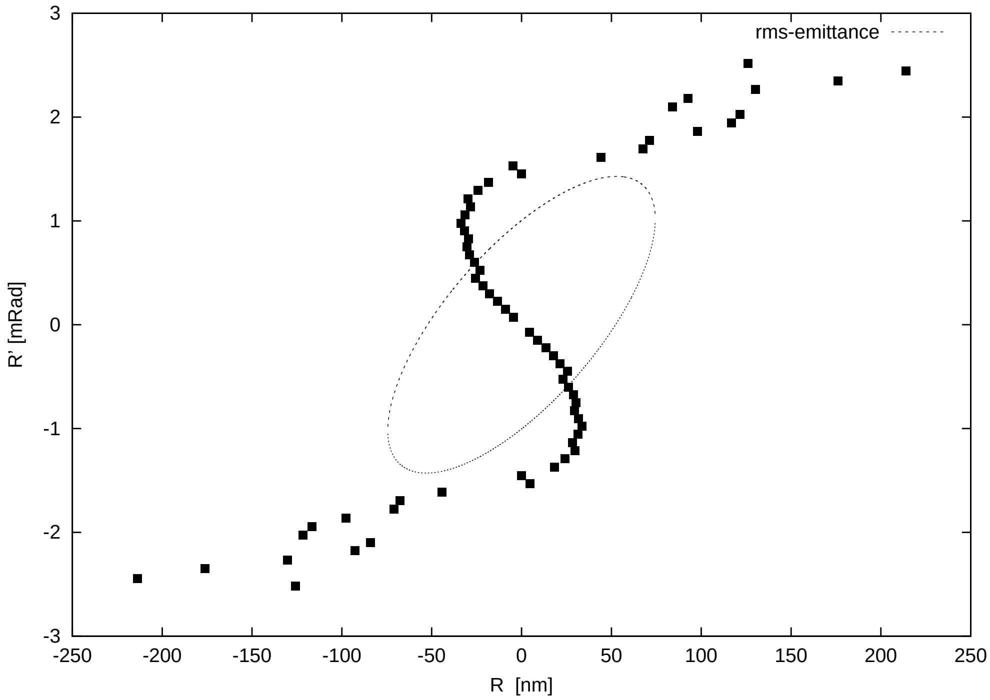

Figure 6. Emittance plot.

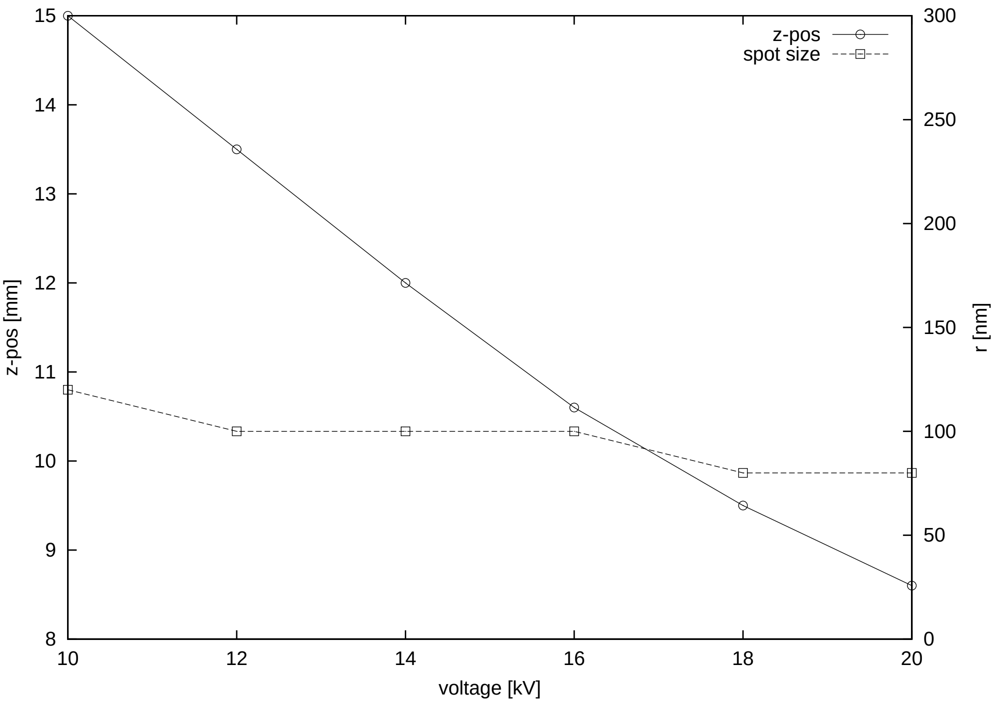

Figure 7. Focal spot size and position vs. voltage at second lens.

3.5. Shifting of the focal point

By varying the voltage at the second lens the focal point can be shifted to different z–positions along the beam axis as shown in fig. 7. Here the solid line represents the position of the focal point and the dashed line shows the radius of the beam spot at the focal point. One can see that the focal point can be moved several millimeters along the beam axis without any significant change in the beam spot size.

3.6. Current

In fig. 8, the dependence of the focal point on the total current is shown. The major effect is a shifting of the focal point along the beam axis. The applied voltages for the simulations are the same as in section 3.4.1.

3.7. Results including Temperature

In fig. 9, the change of the beam spot size at the focal point is shown if different transverse energies are included in the calculation. Furthermore the dependence of the beam spot size to the maximum applied voltage (at the third lens) is shown. The beam spot size decreases from 110 nm to 60 nm at 0 eV transverse energy by increasing the maximum voltage from 20 kV to 50 kV. As a side effect, the focal point is also shifted along the beam axis which is shown in fig. 10, but this behavior can be compensated by changing the voltage applied to the second lens as shown in fig. 7. In addition, the beam spot size increases up to 4-7 μm when a transverse energy is included in the computation.

4. EXPERIMENTAL SETUP

4.1. Plasma Source

For the current setup, a 12.7 cm (5 in.) multicusp plasma source is being used. The plasma is being generated by a quartz–antenna operated at 13.56 MHz RF in C.W.–mode. Normal operating conditions for the source are: gas pressure of 0.13-0.65 Pa (1-5 mTorr) and a RF–power of 500-1500 kW.

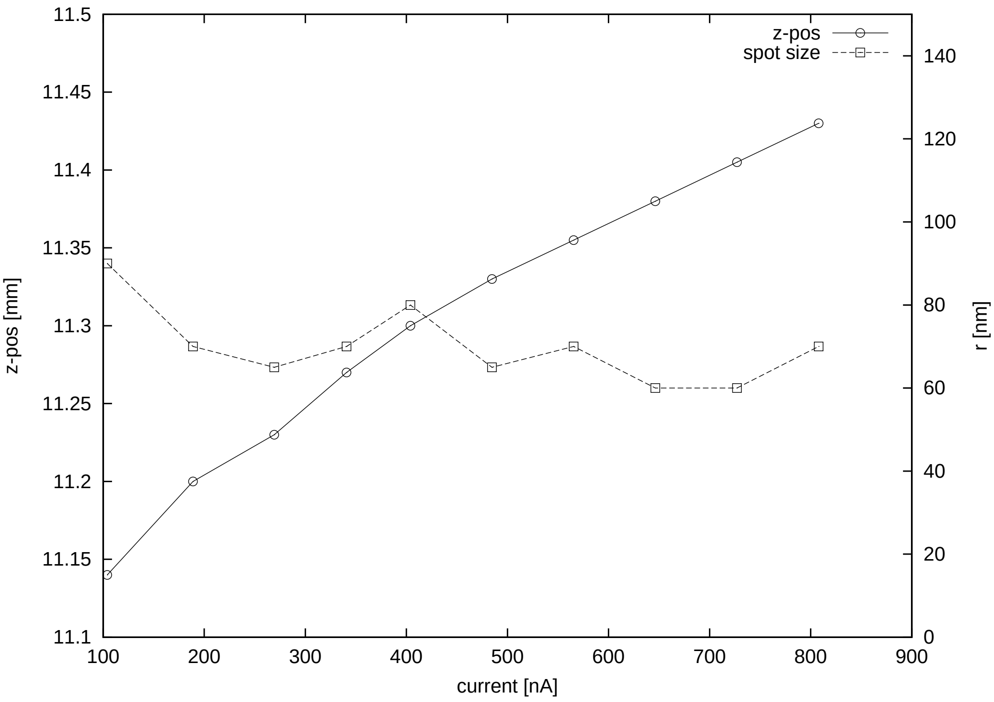

Figure 8. Focal spot size and position vs. beam current

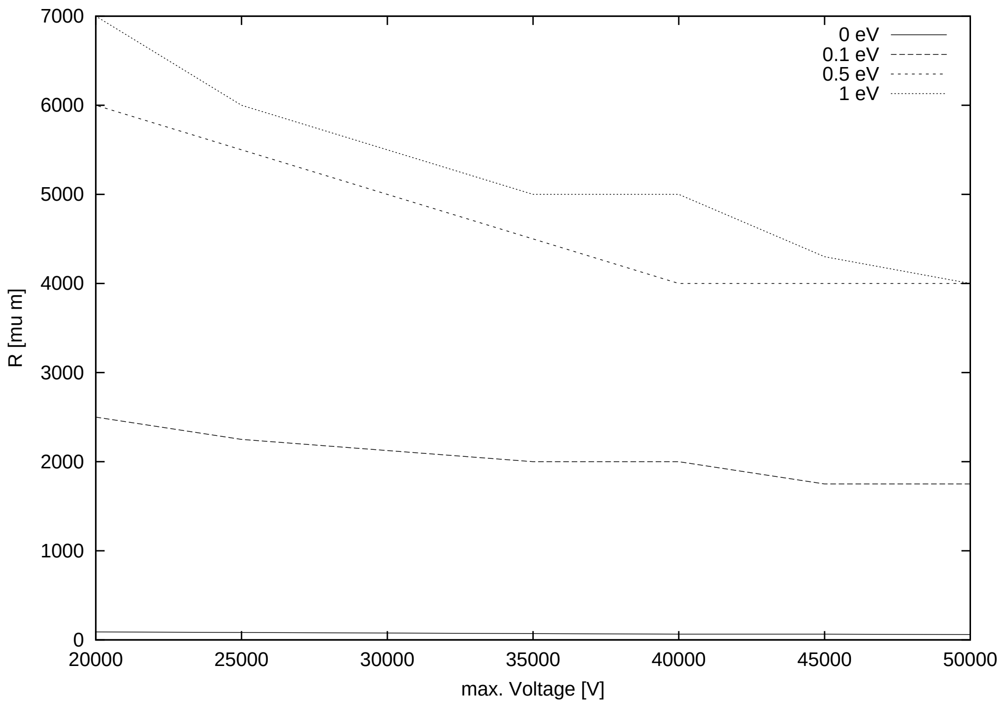

Figure 9. Beam spot size vs. voltage at different transversal temperatures.

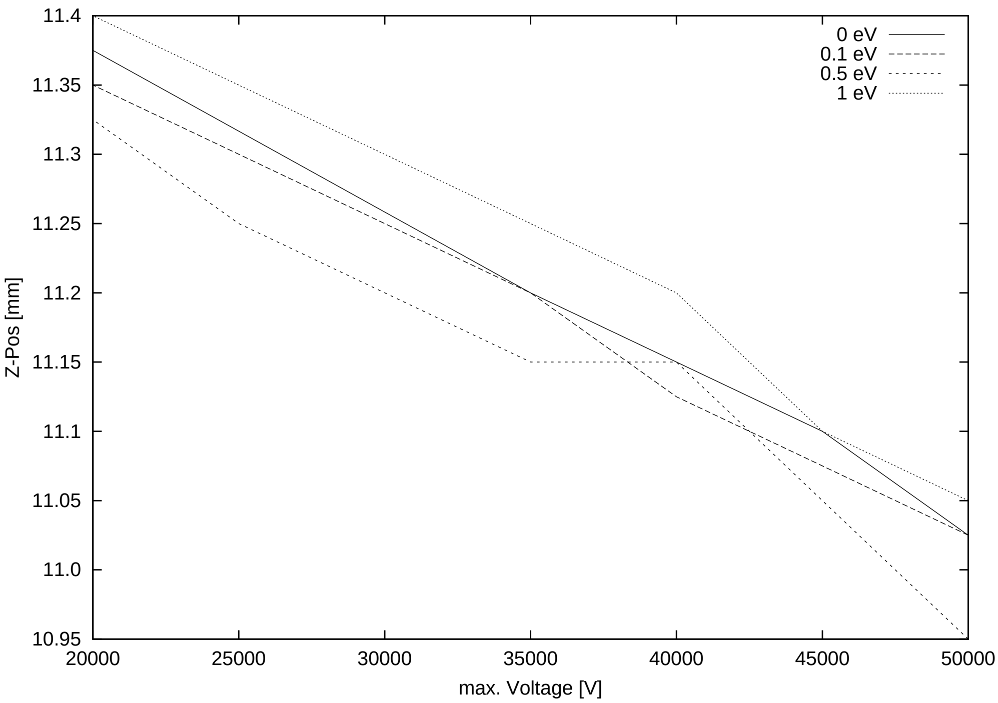

Figure 10. Shifting of the focal point due to the max. voltage at different transversal temperatures.

4.2. The Accelerator Column

The electrostatic column is made out of stainless–steel. The holes in the electrodes are laser drilled and the column is assembled using a optical comparator to ensure the alignment of the setup.

5. EXPERIMENTAL RESULTS AND FUTURE EXPERIMENTS

At present, the setup is used to produce focused ion beams. We plan to make some experiments with the focusing column for an electron beam starting with some current measurements using a Faraday cup and some beam profile measurements using a knife-edge in combination with a Faraday cup. These measurements are going to be made for different maximum voltages and plasma densities.

At this moment the first result for the focused electron beam is that a maximum voltage of 35 kV with and without a plasma can be achieved.

6. SUMMARY AND CONCLUSIONS

In this paper computer simulations for a focused electron beam using a plasma source for electron production are presented. The simulations show promising results especially if a transverse energy less than 1 eV can be achieved. With this a beam spot size of about 1 μm would be possible. In section 3.7 it is shown that the electron temperature has the strongest influence on the beam spot size. It is also shown that the position of the focal point can easily be shifted by just changing one voltage applied to the focusing column.

Further improvements could be made by changing the design of the filter and the lenses so that a even smaller spot size should be possible.

ACKNOWLEDGMENTS

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