Production and Transport of Low Emittance Proton Beam

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1. Introduction

Ion sources are devices which generate ions of atoms of interest which can be extracted as an ion beam by applying suitable extraction method. An ideal ion source shall produce high intensity ions with a minimum emittance for the experimental interest. The development of such low emittance ion sources have a great contemporary significance. They are used for various purposes such as radioactive ion beam production and sophisticated nuclear astrophysics experiments.

Keeping the above facts in view, to produce a low emittance, high intensity ion beam, a low temperature plasma has been generated as shown in FIG 1. Further the ion transport has been verified through simulation studies for understanding the extracted beam properties.

2. Materials and Methods

The constructed ion source, which generates Capacitively Coupled Plasma (CCP)

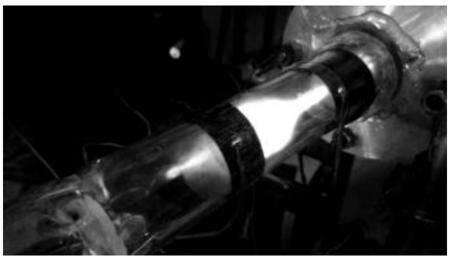

FIG. 1: Capacitively Coupled Plasma (CCP), inside the ion source.

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from which ions are extracted, can be viewed as a hybrid of conventional glow discharge and RF ion sources. The 1.1 MHz, 15KV RF field generated by a SRSSTC circuit is used for plasma generation. Applied linear potential gradient of 3KV/cm produce an intense ionisation. Generated ions gain energy from RF oscillating field and enhance the density of plasma. The plasma generated is shown in FIG 1.

During beam extraction, the ion source is kept at a vacuum level of 4.7×10^{-4} mbar. Temperature of generated plasma is computed by solving Saha ionisation equation, with the help of stringently monitored gas parameters and beam current. The beam emittance is computed as[1],

$$\epsilon_{rms,n} = \frac{1}{2}\sqrt{\frac{kT}{m}}\frac{r}{c} \quad (1)$$

Where T is plasma temperature, c is light velocity, m is proton mass and r, ion extraction bore radius.

A 50 KV potential is used to pre-accelerate the ion beam. The final extracted ions were fired on a photographic paper and the beam parameters were analysed.

Though the ion source work under emission limited mode, as an added precaution for space charge compensation, a special 'fireman's hose' geometry of gas injection is adopted on the extraction electrode.

A sample beam line of length 350 mm is simulated for further beam transport. This is simulated as having two thin lens magnetic focusing elements, keeping the beam envelope intact, with the help of Trace 3D code platform [2]. The transverse transport matrix for each focusing element is computed [3].

3. Result and Discussion

The temperature of generated plasma is computed as 11684 K and electron density, 2.27×10^{19} electrons/m^3. The beam current measured using the Faraday cup arrangement is 178 μA and calculated beam emittance,

$$\epsilon_{rms,n} = 0.057\pi \ mm \ mrad \qquad (2)$$

From the image of the beam obtained from photographic paper, the Gaussian beam profile is plotted for both x and y axes as shown in FIG 2. Using their correlation, a 3D bivariate normal distribution of the ion beam is simulated.

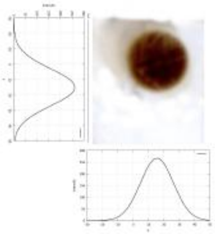

FIG. 2: Transverse Gaussian beam profiles generated from image created at photographic paper (50 kV extraction).

The constructed ion source has a much lower value of emittance achieved due to the space charge compensation by background gas injection. Also the values of plasma temperature and electron density are in good agreement with the other plasma sources of similar gas pressure range [4]. The path of the beam, including magnetic focusing elements, simulated using Trace 3D code is shown in FIG 3. The transport matrices of the magnetic focusing thin lens designed with the help of Trace 3D code are;

$$M(1) = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ -22.2 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 20 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix} \qquad (3)$$

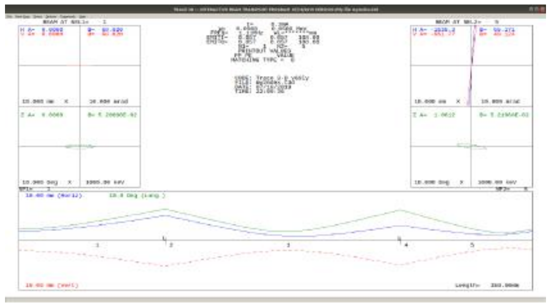

FIG. 3: Trace 3D design of the path of the beam.

$$M(2) = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ -28.5 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 25 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix} \qquad (4)$$

Here the determinants of the matrices are unity as a natural consequence of Liouville's theorem.The lower beam emittance value of the ion source is really promising in the sense that it can be used for various nuclear physics experiments demanding low beam emittance such as nuclear astrophysics experiments and radio active ion beam production.

4. Acknowledgement

Support by Sukesh Dev, Vismay C P, Aswathy Sampanraj and the Physics Department, University of Calicut are acknowledged

5. References

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