Characterization of the neon ion beam emitted from plasma focus device

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Abstract. Ion beam emission from a neon gas filled plasma focus device has been studied by using a fast response Faraday cup. The neon ion beam emission is found to be highly pressure dependant and it is maximum at a pressure of 0.3 Torr. The beam energy is found to be poly energetic ranging from 18 to 1000 keV with higher ion population below 180 keV at optimum operating pressure of 0.3 Torr. The maximum ion density at 0.3 Torr is estimated to be around $5 \times 10^{19}/m^3$. The neon ion beam with this characteristic of energy and density seems to be effective for testing material of interest in tokamak research.

1. Introduction
The plasma surface interaction is an important issue in fusion research. The proper understanding of material properties in fusion environment is quite essential for the better operation, safety and performance of the tokamak fusion reactor. Therefore, the properties of such materials in terms of retention and erosion are needed to be carefully studied. The basic physiochemical processes of plasma material interaction in a small scale experimental facility certainly will give much insight to what is happening inside the huge tokamak reactor. One of such small-scale devices is the plasma focus (PF) device, which can produce high density ($10^{21}$ to $10^{22}/m^3$) and high temperature (1-2 keV) transient pinched plasma by making use of self generated magnetic field. During the pinching, the temperature of the plasma column becomes so hot that the bulk amount of the electromagnetic radiation lies in the X-ray range [1-3] and, after the disruption of pinch column, the energetic electrons and ions are emitted [4, 5]. The direction of acceleration of electrons and ions are opposite to each other and it is away from the anode for ions. The uniqueness of the source is that it produces pulsed ion beams with highly charged states and wide range of energies. Moreover, the PF device is a very compact ion source with low cost and provides excellent performance in terms of ion energy, fluence and exposure time. Due to these exceptional characteristics, PF as ion source is becoming an interesting research topic for basic physical understanding as well as material processing. Nevertheless, the thorough information on ion beam characteristics such as energy spectrum, fluence, distribution and composition are necessary for better applications.

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Number of works have been carried out in different gaseous medium such as hydrogen, deuterium, nitrogen and argon to know the general characteristics of the ion beam emission as well as their correlation with different radiations [4-11]. Generally, the PF device emits pulsed high fluence poly-energetic ion beam ranges from a few keV to MeV. The ion beam energy spectra are found to be continuous, which follow a power law dependence of the type \( (dN/dE)d\Omega \sim E^{-k} \) (where \( N \) is the ion number, \( d\Omega \) is the solid angle measured from the ion source and \( E \) is the ion kinetic energy) from a few keV to few MeV with the exponent \( k \) in between 1.5-4 [10,11]. Due to this uniqueness, the ion beam of PF device has already been successfully utilized for material processing. Feugeas et al. were the first to demonstrate the application of PF as pulse nitrogen ion implanter [12]. On the other hand, the processing of thin PZT film was first carried out by Rawat et al. using argon ions of a PF device [13]. Since then number of works pertaining to material processing and film deposition were reported from different laboratories using PF devices [12-18]. Till now PF researchers have not studied the effect of ion irradiation on the materials that are of typical interest in tokamak reactor. Therefore, lot of scope exists in this perspective so as to simulate expected outcome of ion-material interaction in smaller time and spatial scale.

In the present work, an attempt has been made to characterize the neon ion beam emitted from PF device in order to have information on ion beam energy, distribution and composition so that the device can be utilized for the study of physiochemical changes of some materials, which are of interest in future generation tokamak reactor. The seeding of neon gas in tokamak reactor is a significant feature that reduces the retention and erosion of plasma facing materials [19, 20]. The neon ions used to interact with the materials mainly that are at divertor region. Therefore, we have chosen neon as working gas medium in our device in the present study.

2. Experimental setup
The PF device employed in this work was a Mather type [21] device of 2.2 kJ energy and it was powered by a 7.1 µF high-energy storage capacitor with 25 kV charging voltage. The schematic of the device is shown in figure 1. Further details about our PF device have been published elsewhere [3-5, 14]. The experiment was performed in a neon gas medium. A current derivative probe \((dI/dt)\) was used to know the electrical performance of the PF device. The time resolved study of neon ion beam

![Figure 1. Schematic of PF device with Faraday cup](image-url)
was carried out at different experimental conditions by employing a fast Faraday cup. The Faraday cup [4, 5] was placed inside the PF chamber at a distance of 60 mm from the top of anode as shown in the figure 1 and the output was fed to a digital oscilloscope through an appropriated biasing circuit for monitoring ion beam signal. The biasing voltage of the Faraday cup was kept at -200 Volts throughout the experiments. The information on ion beam energy, flux, energy distribution etc is deduced from the Faraday cup signals.

3. Results and discussion

The figure 2 depicts a typical neon ion beam signal together with dI/dt signal at optimum operating pressure 0.3 Torr. The ion beam signal shows a distinct high amplitude spike of width varying from 60 to 130 ns. This high amplitude spike always follows a smaller spike, which occurs simultaneously with dI/dt signal. This type of ion beam signal was also observed in nitrogen medium in our earlier work [4, 5], where the smaller and the high amplitude spikes are identified as due to EM radiation and ion beam, respectively. Therefore, we assume that the neon ion beam signal bears same time evolution character as nitrogen ion beam and the smaller spike is taken as reference for further time resolved analysis.

To study the dependence of neon ion beam intensity with filling gas pressure, the ion beam signals were recorded by varying the filling gas pressure from 0.1 to 1 Torr. Figure 3 indicates that the ion beam intensity is strongly dependent upon the filling gas pressure. The maximum ion beam intensity is obtained at 0.3 Torr pressure. At this pressure, the device favours a proper discharge dynamics so as to form a strong pinching [22]. Again, at this pressure the pinching time is seen to be occurring near the maximum of discharge current and thereby transferring maximum energy into the plasma. Therefore, the ion beam emission is optimum at this pressure and, hence, maximum beam intensity is obtained. Below 0.3 Torr, the beam intensity decreases and this may be the consequence of weak current sheath dynamics at low filling gas pressures. As the pressure increases beyond the optimum pressure (0.3 Torr), the current sheath velocity decreases due to the increase of sheath mass. Therefore, the focus formation becomes weaker which yields low emission of ion beam. This type of observation on pressure variation on ion beam intensity is also reported by Heo and Park [23].

The neon ion energy emitted from the PF device is estimated from the ion beam signals obtained at different pressure by using Time of Flight technique as reported in [10]. The figure 4 shows the neon ion beam energies as a function of ion flight time, estimated from the ion beam signal.
obtained at optimum operating pressure (0.3 Torr). The curve shows that the PF device emits polyenergetic ion beam ranges from 18 to 1000 keV. The maximum ion energy is calculated for each operating pressure and plotted as a function of pressure as illustrated in figure 5. The plot shows that the maximum ion energy increases as the pressure increases from 0.1 Torr and reaches a maximum at around 0.3 Torr. The further increase in pressure the maximum ion beam energy decreases. The physical phenomenon behind the variation of maximum ion beam energy with pressure may be explained as follows. It is known that the induced accelerating field during the pinching phase is responsible for the acceleration of the ions. Thus, higher is the accelerating field more is the ion beam energy. It is already mentioned that at optimum pressure (0.3 Torr) the PF shows strong pinching and thereby generates strong accelerating field. In case of other pressures, the pinching is weaker than that of optimum pressure and thus inducing a weaker accelerating field.

The neon ion beam energy spectrum at 0.3 Torr is shown in figure 6. The spectrum illustrates that the density of lower energy ions (<180 keV) is more in comparison to high-energy ions. The maximum ion density at 0.3 Torr is found to be around $5 \times 10^{19}$ m$^{-3}$. Similar observations are reported in our earlier work while investigating nitrogen ion emission from our PF device [4,5]. It is noticed that, in case of nitrogen ion, the fluence of ions having energy below 100 keV is more than that of above 100 keV [4, 5]. The emission of less number of high energy ions from the PF device

![Figure 4. Ion beam energy vs ion flight time](image1)

![Figure 5. Variation of maximum ion beam energy with operating pressure](image2)

![Figure 6. Neon ion beam spectrum as a function of ion beam energy](image3)
may be due to following reason. As mentioned earlier, the induced electric field in pinch column accelerates the ions. From X-ray pinhole images, it is commonly observed that the micron size high density zones occur inside the plasma column. These high density zones induce higher local electric field than the rest part. Therefore, fewer numbers of ions accelerate to above 200 keV since their number density is quite small.

It is well known that lower energy ions are more effective for material processing than the higher energy. By varying the experimental conditions of the PF device one can tailor the ion energy regime as well flux. Hence, this device will be an efficient ion source for material testing.

4. Conclusion

In conclusion, we have characterized the neon ion beam emission from PF device by employing a fast response Faraday cup. The ion beam signals are analyzed to deduce beam energy and density. The beam energy is found to be poly energetic ranging from 18 to 1000 keV with higher ion density below 180 keV. The maximum density at 0.3 Torr is found to be around $5 \times 10^{19}/m^3$. The neon ion beam with this characteristic of energy and density seems to be effective for testing material of interest in tokamak.

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