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Determination of Ion Beam Properties In Nitrogen and Helium Using Mather Type Plasma Focus Device

Someraa Saleh Shakonah, Jalil Ali* ,Natashah Abd. Rashid,Kashif Chaudhary

Institute of Advanced Photonic Science, Nanotechnology Research Alliance, Department of Physics, Faculty of Science, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor Malaysia

*Corresponding author: jalilali@utm.my

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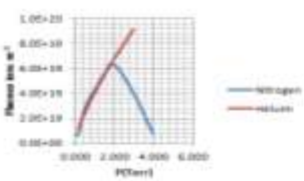
Graphical abstract



Abstract

Some of ion beam properties have been investigated by using Lee model code on plasma focus devices which is operated with nitrogen and helium gases. The operation of plasma focus in different pressure regime gives a consistent ion beam properties which can make the plasma focus a reliable ion beam source .These ion beam properties such as ion beam flux, ion beam fluence, ion beam energy, ion beam current, and beam ion number corresponding to gas pressure have been studied for Mather type plasma focus device. The result shows the differences between helium as lighter gas and nitrogen as heavier gas in term of ion beam properties. The fluence and flux are decrease for nitrogen while increase for helium.

Keywords: Ion beam flux and fluence; Lee model; Nitrogen and Helium gases; Plasma focus

Abstrak

Sifat-sifat alur ion dikaji dengan menggunakan kod model Lee pada peranti plasma fokus yang dikendalikan dengan Gas nitrogen dan helium. Operasi plasma fokus dalam rejim tekanan berbeza menunjukkan sifat alur ion yang konsisten seterusnya menjadikan plasma focus sumber alur ion sumber yang boleh dipercayai. Sifat alur ion seperti fluks alur ion, fluens akur ion, tenaga alur ion, arus alur ion, dan jumlah pancaran ion sepadan dengan tekanan gas telah dikaji untuk peranti plasma fokus jenis Mather. Hasil kajian menunjukkan perbezaan antara helium sebagai gas ringan dan nitrogen sebagai gas yang lebih berat dari segi sifat-sifat alur ion. Fluens dan fluks menunjukkan penurunan bagi nitrogen manakala meningkat bagi helium.

Katakunci : Fluks dan fluens alur ion; model lee; gas nitrogen dan helium; plasma fokus

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1.0 INTRODUCTION

Plasma focus device (PFD) is known for its ability to produce wide range of radiation such as ion beam, X-ray, electron, neutron and particles when it operated with all gases. There are variety of numerical models have been developed to simulate the plasma dynamics in plasma focus device. Results from the simulation complement data are collected from physical experiments. They are beneficial for helping to obtain greater insight and fostering deeper understanding of fundamental physical processes in PFD. Theoretical model gives valuable information like emission yield of particles and radiation that can be reasonably predicted.[1- 2-3-4] Lee Model is theoretical model in PFD, in which it couples the electrical circuit with plasma focus dynamics, thermodynamics and radiation and allowed a realistic simulation of all gross plasma focus properties.[5]

Lee Model is used to obtain emission of soft X-ray and compute focus pinch current from measured discharge current wave form. It is also used to determine ion beam properties by deriving flux and fluence equation of ion beam for any gases. [6-7]

For this study plasma focus is operated with helium and nitrogen filling gases in Lee code by applying the configuration of UNU/ICTP PFF machine. It is found that for a given PF, the energy beam increase from the lightest gas which is nitrogen to the heaviest gas which is helium. Fluence and flux decrease for nitrogen gas and increase for helium gas which mean the properties of ion beam are affected by the working gas being used.

2.0 LEE MODEL CODE

The code couples the electrical circuit with PF dynamics, thermodynamics and radiation. It is energy-, charge- and mass-consistent. The Lee Model code is numerical experimental facility that has been developed as a simulation package that applicable to computes dynamics for any Mather-type PF device by using latest code version of Lee Model, RADPFV5.15. An optimum configuration of the electrodes can be verified by using Lee Model Code in numerical experiment of PF system.[8] Which includes radiation, plasma focus dynamics and thermodynamics data that can be operated in hydrogen, H_2, deuterium, D_2, helium, He, neon, Ne, argon Ar, xenon, Xe, nitrogen, N_2, and kripton, Kr gases. In order to make this model available for wider usage, the phase model and configuration of PF has been rewritten in Microsoft Excel Visual Basic. This model has been used extensively from the sub-kJ PF400 (Chile) through the small 3KJ UNU/ICTP (United Nations University/International Centre for Theoretical Physics Plasma Fusion Facility PFF, Network countries), the NX2 3KJ Hi Repetition lithographic focus (Singapore), medium size tens of kJ DPF78 & Poseidon (Germany) to the MJ PF1000.[9] The Model code used for producing numbers for ion beam and energy fluence and flux and scaling trends for these with PF storage energy. The result can be produced based on Lee Model Code for all the electrodynamics processes including axial and radial trajectories, shock wave, total discharge current as well as energy distributions.

■3.0 THE METHOD

3.1 The Ion Beam Flux And Fluence Equations

The information on the ion flux versus pressures is required in order to understand physical process for ion interaction with surface. The flux equation is shown as follows:

Flux (ions $m^{-2}s^{-1}$) =

$J_b=2.75\times10^{15}\ (f_e/[M\ Z_{eff}]^{1/2})\{(\ln[b/r_p])/(r_p^{2})\}(I_{pinch}^{2})/U^{1/2}$ (1)

The fluence is the flux multiplied by pulse duration τ Thus:

Fluence (ions m^{-2}) =

$2.75\times10^{15}\tau\ (f_e/[M\ Z_{eff}]^{1/2})\{(\ln[b/r_p])/(r_p^{2})\}(I_{pinch}^{2})/U^{1/2}$ (2)

Where

f_e :fraction energy , M; mass number of ion, Z_{eff}: effective charge, b: outer electrode

r_p : pinch radius, I_{pinch} :pinch current [5]. By using Equations (1) and (2) ion beam flux and fluence for both gases can be obtaied.

3.2 Procedure Used In The Numerical Experiments

The UNU/ICTP PFF is used for these numerical experiments to study the number and energy flux and fluence in nitrogen and helium gases. The UNU/ICTPPFF is configured as follows:

Capacitor bank parameters: L_0=102 nH; C_0=30 μF, r_0=24 mΩ

Tube parameters: b=3.2 cm; a=0.95 cm, z_0=16 cm.

Operating parameters: V_0=12 kV; P_0= appropriate range of pressures for both gases.

Model parameters: f_m=0.06, f_c=0.7, f_{mr}=0.15, f_{cr}=0.7

C_0=bank capacitance, r_0=short circuited resistance of the discharge circuit; b=cathode radius, a=anode radius, z_0=effective anode length; V_0= charging voltage and P_0=operating pressure. Model parameters such as f_m, f_c, f_{mr} and f_{cr} are mass and current factors of axial and radial phases; and take into account for all mechanisms in the plasma focus which cause the mass distributions and current distributions to deviate from the ideal situation. These model parameters usually adjusted from fitting the computed current traces to the current traces. A range of pressures is chosen so that the PF axial run-down time encompasses from 0.1 to 4 Torr of the short-circuit rise time. For each shot the dynamics is computed and displayed by the code which also calculates and displays the ion beam properties listed in Table 1.

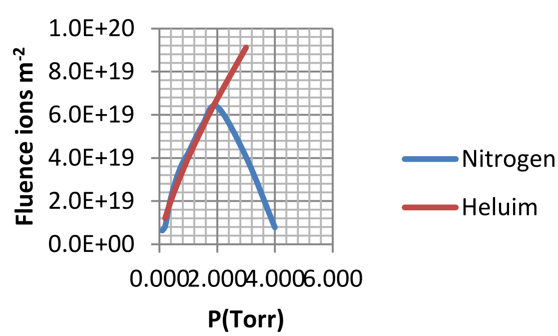
Table 1 Ion beam properties for helium and nitrogen gases using UNU/ICTPPFF device

Device UNU/ICTP	Helium gas(He)	Nitrogen gas(N_2)
Pressure(Torr)	3	2
Z_{eff}	2	4.6
FPS En (%E_0)	7.1	6.4
FPS speed (cm/ms)	37	4
Ion Fluence ($\times10^{20}$ m^{-2})	9.1	6.3
Ion Flux ($\times10^{27} m^{-2}s^{-1}$)	9.6	6.1
E_n Fluence ($\times10^{6} Jm^{-2}$)	22	68
En Flux ($\times10^{13}$ Wm^{-2})	87	36
Ion number/kJ ($\times10^{14}$)	4.9	6.4
FIB Energy (J)	166	138
Ion number/kJ ($\times10^{14}$)	2.3	6.4
Mean ion energy (keV)U*Zeff	84	251

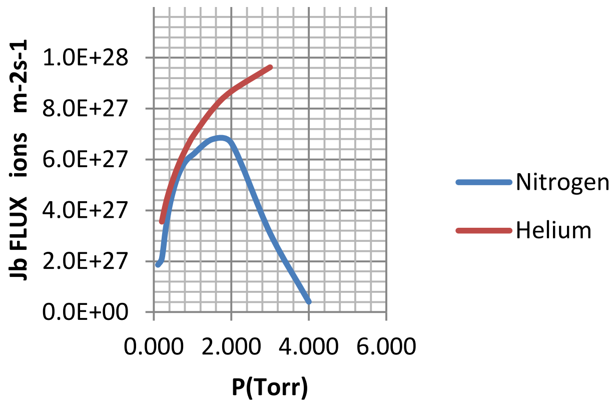
■4.0 MAIN RESULTS

Ion beam properties of plasma focus have been studied by using Lee model with helium and nitrogen filling gases. The ion beams flux and fluence versus pressure for different plasma focus parameters have been studied.

Results show that, the ion beam energy emitted from nitrogen plasma focus has value of 251 keV for ICTP PFF at 2 Torr and for helium gas the ion beam energy emitted has value of 84 keV at 3 Torr.



(a)



(b)

Figure 1 (a,b) Flux and Fluence versus pressure for He and N2 gases

Figure 1(a) and (b) also shown that the ion beam flux and fluence emitted from plasma focus operated with helium are increasing whereas nitrogen are only increases until 2 Torr and gradually decreases as the pressure is increased. As the low pressure is applied the shock waves will move faster and the temperature become high so the plasma is fully ionized. It is notable that the ion flux initially increases with the increase in gas pressure and reaches a maximum values at high pressure at the time of pinch occurred near the maximum of discharge current therefore the maximum energy will transfer into the plasma. By referring to figure 1(a) and (b) in nitrogen gas it shows that when we increase the pressure the pinch no longer ionized so it will drop significantly. Whereas the values of the ion flux and fluence is deduced for nitrogen and helium gases by computing the values of pinch duration τ, effective charge Z_{eff} and pinch current I_{pinch} which calculated from start of pinch. Therefore ion beam flux and fluence strongly depends on the filling gas pressure.

As shown in Table 1 for helium gas, the fluence is $9.1\text{x}10^{19}$ ions m-^{2} and the flux $9.6\text{x}10^{27}$ ions $m^{-2}s^{-1}$ at optimum pressure of 3 Torr. And for nitrogen gas, the fluence is $6.3\text{x}10^{19}$ ions m^{-2} and the flux $6.1\text{x}10^{27}$ ions $m^{-2}s^{-1}$ at optimum pressure of 2 Torr. This means the properties of ion beam are affected by the working gas being used.

■5.0 CONCLUSION

The behaviors and properties of the fluence and flux in ion beam radiation versus gas pressure for helium and nitrogen gases have been studied. The system is tested by using different gases with pressure range 0.1 to 4 Torr. For helium gas gives flux equal to $9.6\text{x}10^{27}$ ions $m^{-2}s^{-1}$ at 3 Torr and nitrogen gas giving flux $6.1\text{x}10^{27}$ ions $m^{-2}s^{-1}$ at 2 Torr.

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