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OBSERVATION OF TWO ENERGY REGIMES BY 90° ELECTROSTATIC ENERGY ANALYZER IN REGENERATIVE SOOTING DISCHARGES

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An electrostatic energy analyzer of 90°has been designed to measure the energy spread of argon and carbon ion beam from regenerative sooting discharges. Results of energy analyzed ion beam are presented that have been obtained from graphite hollow cathode duoplasmatron ion source and accelerated upto 27 keV. Two groups of low and high-energy ions are observed which are formed inside the ion source. Energy spread increases with increase in energy. Minimum energy spread is 20 eV whereas Maximum is 1.79 keV.

Keywords: Energy analyzer, Duoplasmatron, Carbon ion beam, Energy spread

1. Introduction

Plasma based ion sources have got inherent energy spread. Energy analyzer is a useful tool to control the spread as well as to filter out unwanted ions. Many researchers have developed various kinds of energy analyzers e.g. application of the analyzer to Auger electron spectroscopy and X-ray photoelectron spectroscopy is demonstrated by Huchital and Rigden [1]. A cylindrical retarding electron energy analyzer was designed with a retarding field on the basis of a calculation of the potential distribution and the electron trajectories [2]. Gaus et al. [3] used parallel plate energy analyzer to measure the energy spreads and resolution for five different types of ion sources and found ECR/magnetron combination source to be the most suitable for high resolution measurements. Valfells et al. [4] performed experiments to investigate the dynamics of space charge dominated low energy (10 keV) ion beam and determined the longitudinal energy of ion beam and also measured energy spread for university of Maryland electron ring. Aidinis et al. [5] studied the temperature dependence of the energy spread of Ge ions beam produced by a liquid metal alloy source. A Toroidal energy analyzer [6] was simulated and the spread function of the limit resolution of deflecting electrostatic energy analyzers calculated. Chi et al. [7] designed a novel cylindrical electrostatic energy analyzer for low energy beams and studied the coherent error taking into account the space charge and emittance effects. High-resolution 90-degree cylindrical electrostatic energy analyzer [8] for 1-MeV (singly ionized) heavy ions for experiments in the heavy ion fusion science virtual national laboratory (HIFS-VNL) has been described. In our experiment graphite hollow cathode duoplasmatron ion source is used in which regenerative sooting discharges generate carbon and support gas ions. The operational and other details of hollow cathode duoplasmatron are given elsewhere [9]. Initial and significant stage for the production of regenerative soot depends on the initiation of the glow discharge of noble gas by two well-defined electron energy regimes; ≥ 10 eV for high-energy electrons near the cathode surface and ≤ 1eV in the positive column for low energy ones [10].

Ions move in specific curved path, inside the energy analyzer, which is provided by applying electric field between two plates. Equating electric and centripetal force leads to the relation $E = E_o \ln\left(\frac{r_1}{r_2}\right)$, Where E_o = energy of incoming ion beam & E = energy of the electric field applied to provide the centripetal force, r_1 and r_2 are the radii of curvature of inner and outer plates of energy analyzer respectively. In our design r_1 = 58.0 mm

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and r_2 = 68.0 mm therefore, $E = 0.158E_0$.

2. Experimental Details

A schematic diagram of experimental set up is shown in Figure 1. Duoplasmatron ion source is operated at a discharge voltage of V_{dis}= 0.8 kV with discharge current of I_{dis}= 100 mA, Ar is used as support gas to initiate the discharge at 1.0 mbar. Ions are extracted by applying voltage V_{ext} = 2 kV. Ion beam is accelerated to higher energies upto 27 keV in various steps. The beam passes through energy analyzer after collimation of full angle divergence of 2.8°. Positive and negative voltages are provided simultaneously to the plates of energy analyzer using high voltage supplies controlled by software developed in LabVIEW by which we can generate a voltage ramp. 90° energy analyzer bends the ions, which are detected by Faraday cup placed at 50 mm from the exit of analyzer. Electrometer reads the current at Faraday cup in pico-ampere (pA) range and signal is finally fed to the data acquisition software, which takes a few minutes for each full energy spectrum in the range of applied electric field.

3. Results and Discussion

Figure 2 shows the energy spectra of ion beam

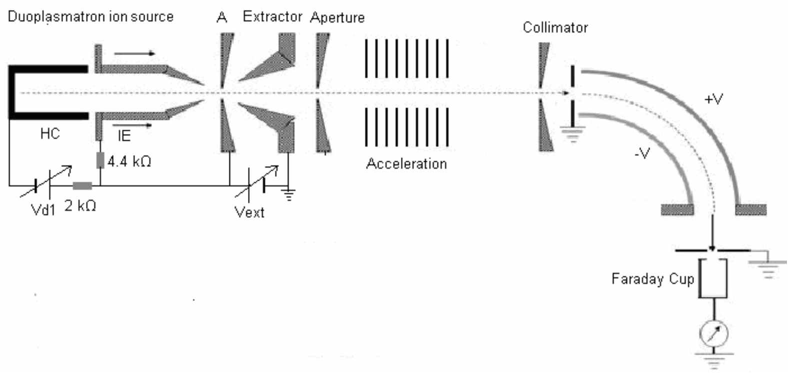

Figure 1. Schematic of experimental setup to analyze the energy of ion beam

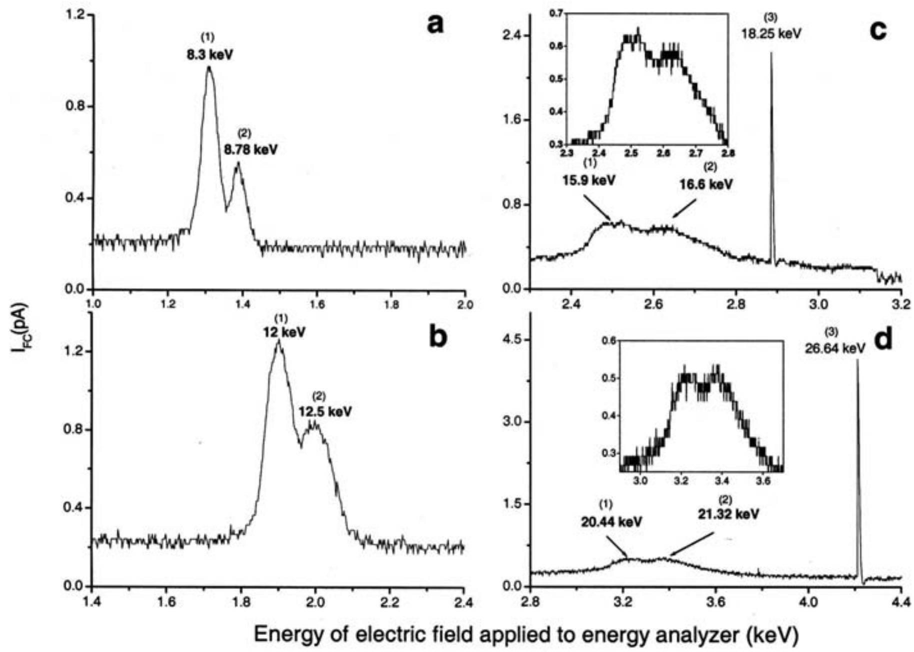

Figure 2. Energy spectra of ion beams at different energies (a) 12 keV (b) 17 keV (c) 22 keV (d) 27 keV.

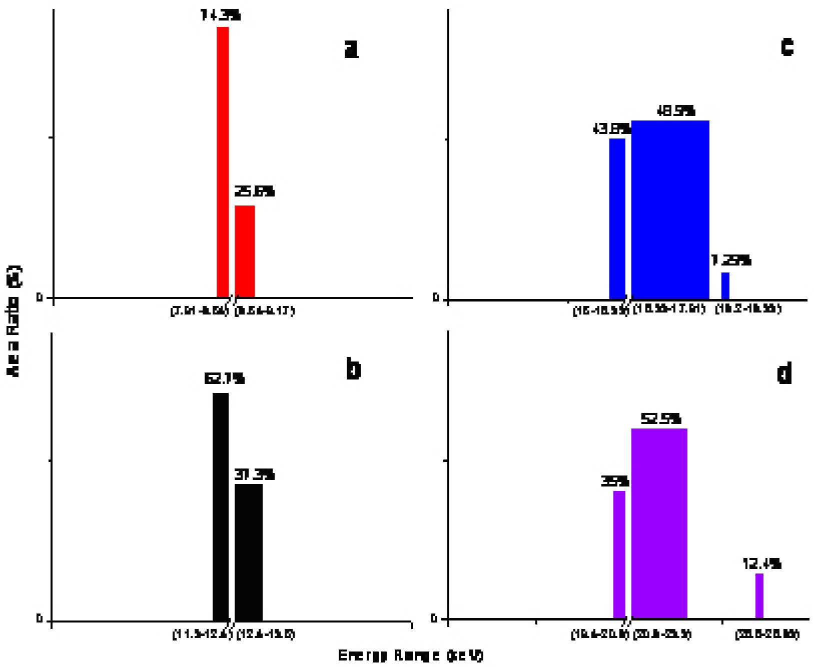

Figure 3. Distribution of ions in different energy ranges taken at applied ion energies (a) 12 keV (b) 17 keV (c) 22 keV (d) 27 keV.

at different energies i.e. (a) 12 keV (b) 17 keV (c) 22 keV (d) 27 keV. Peak energies are calculated by dividing the value of applied energy by 0.158. It is observed that two groups of energies appear, one is low and other is high-energy group. Low energy group consists of two closely lying sub-groups not very distinctly separated and has broad distribution of energies, which is due to the fact that these ions are part of the positive column that follows Boltzmann distribution and is not affected much by the cathode potential rather it is characteristics of thermodynamic temperature. On the other hand high-energy ions form a sharp peak because there are equipotential surfaces near the cathode and ions produced near the cathode is strongly affected by the potential and have higher values of energies and narrow distribution. The inset of the figure 2 is the enlarged part of the low energy group. Figure 3 represents the distribution of ions in different energy ranges taken at applied ion energies (a) 12 keV (b) 17 keV (c) 22 keV (d) 27 keV. Figure 4 demonstrates the trend of ions yield w.r.t ion beam energy. It is clearly observed that for peak 1 yield continuously decreases with increase in ion energy whilst peak 2 shows the opposite trend. Peak 3 doesn’t appear at all upto a certain threshold value, which is around 18 keV, and may be due to ion beam optics of the accelerator; the high-energy peak also has rising trend. The two groups of energy support the existence of two energy regimes in the regenerative sooting discharges.

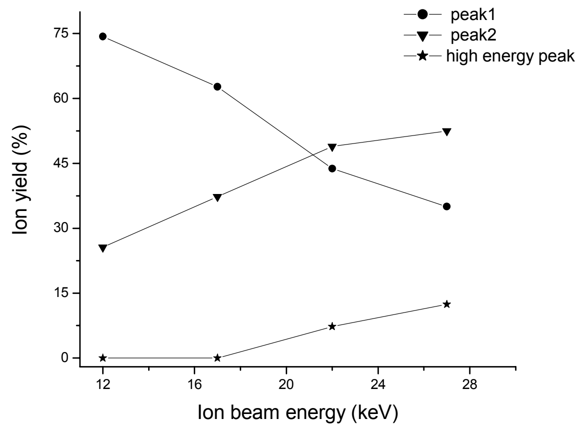

Figure 4. Trend of ion yield w.r.t ion beam energy.

Peak ion energies, spread in peak energies (FWHM) and difference in energies w.r.t applied energy are given in Table 1. Maximum spread observed is 1.79 keV and minimum spread is of 20 eV. Difference between energy of groups and applied energy is calculated, negative sign shows that the corresponding energy is lagging behind the actual applied energy. It can be observed that

Table 1. Peak ion energies, spread in peak energies (FWHM) and difference in peak energy w.r.t applied energy.

No.	Peak. No.	Peak energy in spectrum (keV)	Applied ion beam energy (keV)	Difference in low energy peaks (keV)	Difference in low and high energy peaks (keV)	FWHM (keV)	Difference in Energy (%)
a	1	8.30	12.00	0.48	-	0.32	-28.80
	2	8.78				0.27	
b	1	12.00	17.00	0.60	-	0.57	-27.65
	2	12.60				0.56	
c	1	15.90	22.00	0.70	2.00	1.04	-26.14
	2	16.60				1.38	
	3	18.25		-		0.02	-16.82
d	1	20.44	27.00	0.88	5.76	1.52	-23.76
	2	21.32				1.79	
	3	26.64		-		0.06	-1.33

with increase in ion energy decrease in difference in energy is observed corresponding to higher energy peak whereas the difference remains almost the same for lower energy peaks. Difference between lower energy sub-groups is also calculated and it is found that as we move towards higher energy, difference between sub-group increases from 0.48 keV to 0.88 keV. Similarly difference between average of the lower energy groups and higher energy peak increases with increase in ion energy. Ion beam when extracted contains inherent energy spread common in plasma, in which energy between species follows Boltzmann distribution. Also when ion beam strikes the edges of a) extractor, b) accelerator tube c) apertures of collimator, emit secondary electrons. Sources of generation of electrons are i) secondary electron emission by kinetic process ii) secondary electrons emission due to metastable atoms hitting edges. Secondary electrons can ionize the neutrals and metastables ($C + e^- \rightarrow C^+ + 2e^-$), which are moving alongwith ion beam. The secondary electrons have got their own distribution of energies hence produces further enhancement in the energy spread of ions.

4. Conclusions

Energy spread of Ar and carbon ion beam from regenerative sooting discharges has been measured by 90° electrostatic energy analyzer. Two groups of low and high-energy ions are observed which support the existence of two energy regimes in the regenerative sooting discharges. Energy spread increases with increase in energy. Minimum energy spread is 20 eV whereas Maximum is 1.79 keV.

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