A novel gridded retarding field energy analyzer for IEDF measurement

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Abstract

A retarding field energy analyzer (RFEA) has been designed and developed to measure ion energy distribution function (IEDF) in helicon plasma. To design RFEA, determination of shape, size of the analyzer orifice, choice of grid and their separations are discussed. The four grid energy analyzer assembly provides easy access of all internal mechanical components and electrical connections. Fundamental problems regarding acquisition of correct RFEA data and their probable solutions are discussed.

1. Introduction

Conventional Langmuir probe measures electron energy distribution function (EEDF) in plasmas. RFEA is useful diagnostic for both ion energy distribution function (IEDF) and EEDF measurements. RFEA is widely used in expanding plasma systems, particularly where ion beam is generated [1]. RFEA has been used in capacitive and inductive RF plasma to measure IEDF and local plasma potential [2]. In this paper we describe the design of parallel plane four grid retarding field energy analyzer, which has been developed primarily to measure ion beam energy and plasma potential in helicon antenna produce radio frequency (RF) plasma. It is also shown that the design is flexible and provides easy mechanical and electrical access. Entering energetic electrons into the RFEA cavity, bias voltage scheme, offset adjustment, capacitive pick up problems are addressed.

2. RFEA principle and design

Charge particles are transmitted through an aperture, are analysed by the retardation of electric field established through bias potentials applied to the number of grids. The entrance slit must be wide enough to permit adequate flux transmission, yet sufficiently small such that the electrostatic sheath established around the slit edges be large enough to bridge the aperture width and hence shield the aperture from the bulk plasma. After the first entrance grid, second grid repels electrons (in ion mode operation) called repeller. Third grid samples different energetic ions, called discriminator. Forth grid suppresses the secondary electrons coming due to ion bombardment on the collector surface is the suppressor followed by the collector plate. A fraction of incident ion flux is transmitted through the slit. The slit entrance plate can be kept floating or biased negative to repel thermal electrons. The schematic of RFEA bias scheme is shown in figure (1).

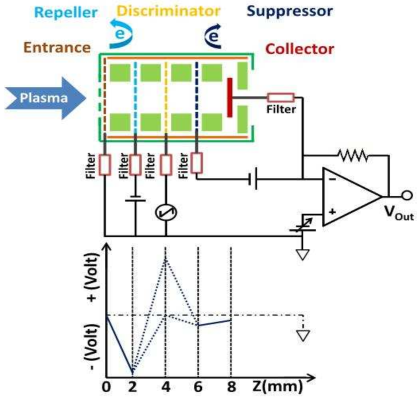

Fig 1. RFEA bias scheme for ion collection mode.

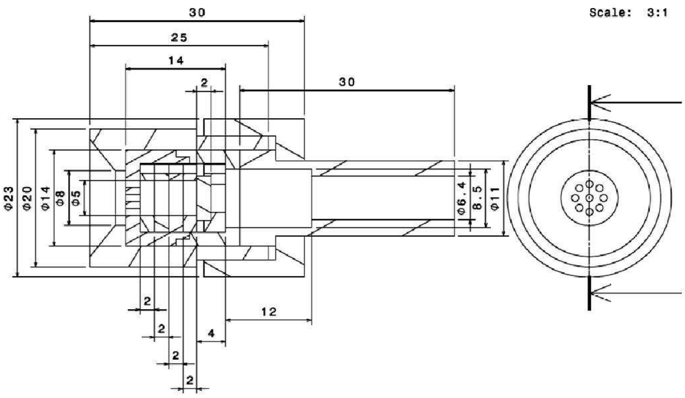

Fig 2. RFEA mechanical design, where all dimensions are in mm.

The ions of charge e, are assumed to enter from the main plasma with kinetic energy $E = eV_0$. They are retarded by the axially directed electrostatic field between the grid electrodes and collected at the collector. If $V_0 > V_d$ they will reach the plate and appear as collector current I_c; and if $V_0 < V_d$ they will be resisted. For discriminator voltage $V_d = 0$ to V_S, I_c remain constant, means all ions gain a parallel energy of eZ_iV_S, where eZ_i is the ion charge and V_S is the sheath voltage, which is the plasma potential (V_P) with respect to the grounded chamber for a collision-less sheath. For $V_d > V_S$, I_c starts to decrease. I_c is expressed in equation (1)

$$I_C = eZ_iA_{eff}T_ET_1^4\int_{v_{min}}^{+\infty} f(v)dv \;\ldots(1); \qquad \frac{\partial I_c}{\partial V_d} = -\frac{e^2A_{eff}T_ET_1^4}{M_i} f\left(\sqrt{\frac{2eV_d}{M_i}}\right) \propto f(v)\ldots(2)$$

Where, A_{eff} is the effective area of entrance apertures, T_E is the transparency of the entrance slit plate, T_1^4 is the transparency of the total four mesh grid, $v_{min}=\sqrt{(2eV_d/M_i)}$, v is the parallel ion velocity and $f(v)$ is the parallel ion velocity distribution. Ion energy distribution function (IEDF) as indicated in equation (2), which is proportional to the derivative of collector current and discriminator voltage. That will be derived from the RFEA (I_c - V_d) characteristics.

Mechanical drawing of RFEA assembly is shown in figure (2). Distance between entrance grid to collector of RFEA is chosen to be less than ion neutral collision mean free path (λ_{i-n}) which is 8mm at 3.75×10^{-3}mbar. The inner diameter (circular plasma facing front side) of the RFEA is optimized to be 5mm, which accommodate array of holes, of diameter 0.9 mm each to make it close to satisfy the condition of electron entering into RFEA ($d \sim 2\lambda_D$) [3]. RFEA energy resolution ($\Delta E/E$) = $D^2/16S^2$ depends on the inter grid separation (S) and grid wire separation (D) [4]. Large (~mm) grid wire separation increases energy resolution. However, this leads to very poor transmission (T) = $(D-2r)^2/D^2$, if the grid wire radius (r) is not very thin (1-10µm). We are using grids having D=110µm and 2r=33µm with grid transparency 0.49.

3. Results and discussion

Experiment is performed in helicon plasma system [5] [6], where plasma is produced by application of 200W RF power at $2x10^{-4}$mbar Argon fill pressure. Initial troubleshooting experiments are carried out by applying bias to all the grids with respect to the entrance grid, which is electrically connected with the Aluminium enclosure. While doing that we have also applied suppressor grid bias with respect to this common reference instead of suppressor grid bias with respect to collector as shown in figure (1). Keeping that bias configuration, the role of repeller bias or retarding potential on the RFEA characteristics is studied.

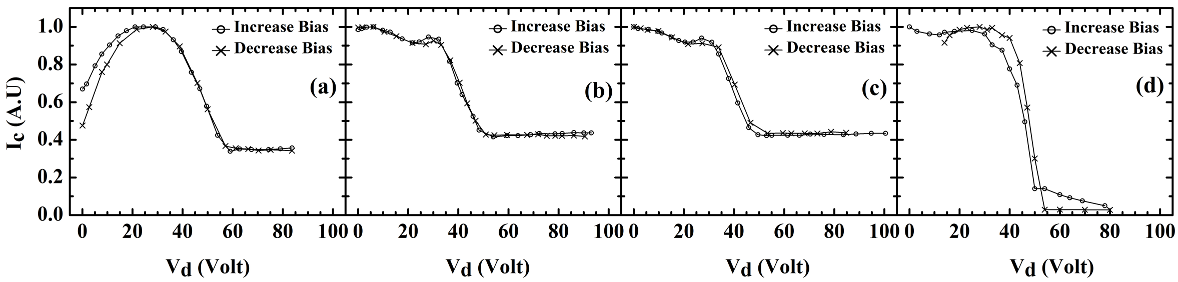

Fig 3. Collector current (I_c) versus discriminator bias (V_d) voltage with (a) Repeller bias (V_R) -60V, Suppressor bias (V_S) 0V, (b) V_R= -120V, and V_S= 0V, (c) V_R=-120V, V_S= -25V with respect to entrance grid and (d) V_R= -120V and V_S= -1.5V with respect to the collector.

Figure 3a shows that for V_R = -60V, I_c increases with V_d from 0 to 15 V. Whereas, for V_R = -120V (figure 3b), I_c remains constant up to the plasma potential. In both the cases, the suppressor grid is kept at same potential. In figure (3c), V_R= -120V and V_S =-25V, no significant change is observed in the characteristics figure (c) compared to figure (b). These results indicate that there is no significant role of V_S for this biasing scheme. However, increased repeller bias significantly improves the characteristics by objecting high energy electrons entering into the RFEA. High energy electrons are restricted by the -120V repeller bias but not for -60V bias. The data presented in figure (3a, b, c), shows a dc off-set in all cases. To adjust this off-set the efficient way of using suppresser grid response for secondary emitted electrons, suppressor bias is applied with respect to collector as shown in figure (1). In that configuration, even a very small suppressor bias (-1.5V) with respect to the collector is sufficient to make the necessary off-set adjustment (figure 3d). In figure (3a, b, c and d), measurement of collector current for both increase and decrease bias voltage are found to be almost identical nature (I_c - V_d) characteristics. This confirms that there is no such space charge accumulation between any grids.

After preliminary dc characterization and testing different measurement circuit schemes, a unipolar transistor amplifier ramp generated bias (0-120V) is applied to the discriminator grid to sample different energetic ions entering into the analyzer. This low frequency (~50mHz) ramp bias application to the discriminator essentially helps to reduce the capacitive pickup from the signal. At 50mHz ramp frequency, signal to capacitive pickup ratio is ~10^3. Therefore, the collector current signal is well resolved. Figure 4 shows the collector current to discriminator bias voltage along with its differentiation, which is then fitted with double Gaussian fit. First peak corresponds to the local plasma potential (V_P) and the second peak representation of ion beam (V_b). The ion beam energy detected by this RFEA is e(V_P-V_b)~13eV, which is generated by the double layer like potential structure formation in this kind of expanding helicon plasma system.

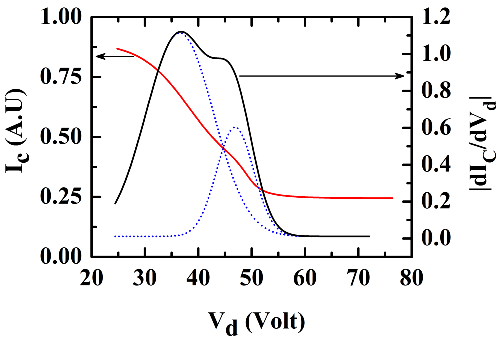

Fig. 4 Collector current (I_c) versus discriminator bias (V_d) with V_R= -100V with respect to the entrance grid and V_S= -5V with respect to the collector. Discriminator ramp bias frequency 50mHz.

4. Summary and conclusion

RFEA diagnostic has been designed and developed for measuring IEDF in helicon antenna produce plasma. The designed gives flexibility to access all the electrical components, grids and electrical connections. Initial dc characterization is carried out to understand suitable repeller bias voltage and bias scheme for ion collection mode operation. A low frequency (~50mHz) transistor amplifier circuit is used for application of bias to the discriminator and collector signal is acquired using an analog (*I to V*) convertor circuit, which detects the ion beam generated from the double layer like potential structure.

References

[1] D. L. Rudakov et. al., *Rev. Sci. Instrum*. **70**, 476 (1999).

[2] K. Denieffe et. al., *J. Phys. D: Appl. Phys.* **44**, 075205 (2011).

[3] R. A. Pitts et. al., *Rev. Sci. Instrum.* **74**, 4644 (2003).

[4] J. Arol Simpson, *Rev. Sci. Instrum.* **32**, 1283 (1961).

[5] S. Ghosh et. al., *Plasma Sources Sci. Technol.* **24** 015017 (2015).

[6] K. K. Barada et. al., *Rev. Sci. Instrum*. **83** 063501(2012).