ION ENERGY DISTRIBUTION FUNCTION MEASURED BY RETARDING FIELD ENERGY ANALYZERS

Ane Aanesland
CNRS – Ecole Polytechnique
France
Overview

1. Principle and requirements for correct measurement
   1. Example: LPP design
2. Trouble shooting
3. Plasma physics phenomena understood by RFEA
   1. Diffusion and Boltzmann expansion
   2. Charge exchange collisions
   3. RF oscillating sheaths for IEDF tailoring
   4. Double Layers and beam instabilities
   5. Positive and negative ion beams
RFEA principle

Risk for space charge and secondary electrons adding to the measured current
RFEA principle

Discriminator Voltage (a.u.)

Collector Current (a.u.)

\[ v = \sqrt{\frac{2eV}{m_i}} \]

\[ \frac{dI}{dV} \text{(a.u.)} \]

Discriminator Voltage (a.u.)
Requirements - Size

- **Collisions within the analyzer**
  - 1 mTorr $\lambda_{ex} \approx 3 \text{ cm}$
  - 50 mTorr $\lambda_{ex} \approx 0.6 \text{ mm}$

- **Space charge and ion accumulation**
  - $J_{\text{beam}} \sim J_{\text{CL}}$

- **Ion beam trajectories**
  - sheath “deformation” when $r > 1-3\lambda_D$

- Practical grid distance determines pressure range (differential pumping)

- Limit the current entering the analyzer by the entrance slit

- Grid spacing and wire size
Requirements - Size

- **Collisions within the analyzer**
  - 1 mTorr $\lambda_{ex} \sim 3$ cm
  - 50 mTorr $\lambda_{ex} \sim 0.6$ mm

- **Space charge and ion accumulation**
  - $J_{beam} \sim J_{CL}$

- **Ion beam trajectories**
  - sheath “deformation” when $r > 1-3\lambda_D$

Practical grid distance determines pressure range (differential pumping)

Bohm and Perrin, RSI 1993
Entrance slit
2 mm hole with a mesh grid

Grids
Nickel mesh (60% transparency, 11 µm wires)

Spacing
Kapton rings 250 µm thick

Collector
Steinless steel

Total length 1.02 mm
differentially pumped to increase pressure range
Trouble shooting (Bohm & Perrin, RSI 1993)

Correct IV curve measured by the RFEA

Electrons arriving from the plasma leads to increasing ionization in the RFEA

Secondary electrons from the collector leads to current peak at low energy and a current offset

Plasma physics investigations via RFEA
A few examples
Diffusion with Boltzmann expansion

\[ V_p(x) = V_p(0) + \frac{kT}{e} \ln \left( \frac{n(x)}{n(0)} \right) \]

Local and non-local plasma potential

C. Charles et al., JVST 10, 1992
Charge exchange collisions

\[ V_p(x) = V_p(0) + \frac{kT_e}{e} \ln \left( \frac{n(x)}{n(0)} \right) \]

\[ \lambda_{ex} = \frac{1}{n_g \sigma} = 5.2 \frac{1}{P_{mTorr}} \]

C. Charles et al., JVST 10, 1992
Charge exchange collisions

\[ V_p(x) = V_p(0) + \frac{kT_e}{e} \ln \left( \frac{n(x)}{n(0)} \right) \]

\[ \lambda_{ex} = \frac{1}{n_g \sigma} = \frac{1}{5.2 \frac{1}{p_{mTorr}}} \text{ cm} \]

C. Charles et al., JVST 10, 1992
Charge exchange collisions in beams

IEDFs in RF oscillating sheaths

Low frequency regime – bimodal IEDF
\[ \frac{\Delta \text{ion}}{\Delta \text{rf}} \ll 1 \]

High frequency regime – single peaked IEDF
\[ \frac{\Delta \text{ion}}{\Delta \text{rf}} \gg 1 \]

\( \tau_{\text{rf}} = 74 \text{ ns (13.56 MHz)} \quad \tau_{\text{ion}} = 70 \text{ ns (2x10}^{11} \text{ cm}^{-3}) \)

C. Charles et al., *Phys. Plasmas* 7, 2000
IEDFs in RF oscillating sheaths

IEDF downstream of a Double Layer

C. Charles et al., 1999 - 2011
Instabilities carried by beam ions

A. Aanesland et al., PRL, 2006
RFEA FOR MEASURING POSITIVE AND NEGATIVE IONS
PEGASES
Plasma propulsion with Electronegative Gases

Stage 1
Plasma discharge, power coupling

Stage 2
Electron filtering, ion-ion formation

Stage 3
Acceleration and recombination

\[ \text{RF power} \]
Alternate acceleration concept and requirements

Extraction waveform

Upper limit:
- Ion plasma frequency (10-20 MHz)
- Time of flight through the grids
  \( \approx 50-300 \text{ ns} \) (3-20 MHz)

Lower limit:
- Beam packet blow-up and oscillations (to be determined but expected in the kHz range)

Optimization
- Square wave-forms with variable periods and voltages
RFEA grid bias setup
Alternate acceleration at ±100 V at 1 KHz

Positive ion beam at +114 V,
Negative ion beam at −67 V
Beam energy versus acceleration voltage

Positive ion beam at $+114 \text{ V}$,
Negative ion beam at $-67 \text{ V}$
Alternate acceleration at ±100 V at 1 KHz

Positive and negative ion beam amplitude are similar, constant but noisy
Alternate acceleration in **Argon** at ±150V, 1 KHz

Two positive ion beams at **+155 V** and **+100 V**
Alternate acceleration in **Argon** at ±150V, 1 KHz

Two positive ion beams at **+155 V** and **+100 V**
Summary and Conclusion

1. Pressure and plasma density main parameters for RFEA sizing
2. Potentials on each grid needs to be adapted for the current plasma condition – trouble shooting
3. Provides information on both local and non-local plasma parameters

The RFEA is extremely powerful if used with care
THANK YOU FOR YOUR ATTENTION