Secondary electron excitation source for plasma optical emission spectroscopy diagnostics

Frank Mendoza , P.L. Stephan Thamban[2], J. Hosch[1], G. Padron-Wells[2], A. Kueny[1], K. Harvey[1], M. Whelan[1], M.J. Goeckner[2]

[1]Verity Instruments, Inc.
[2]University of Texas at Dallas

Outline

- Motivation/Problem definition

- Current design solutions
  - Secondary plasma sources
  - Issues

- Electron beam exciter
  - Design
  - Merits

- Results in development
  - Energy control
  - Electron density control
  - Long term stability in Fluorocarbon chemistries
  - Sensitivity to detect small changes

- Conclusions

Motivation/Problem definition

Optical emission spectroscopy signals are invaluable in process monitoring

- Some newer processes have weak optical emissions
- An independent excitation source is required
- Source should be compatible with process tool

⇒ A wide variety of secondary plasmas have been tried

Problems with existing plasma solutions

Problems in secondary plasma sources:

- Uncontrollable signal drifts
- Loss of optical signal
- Failure to turn on

Emission Science :

In plasmas, electron impact excitations results in optical emissions

$$I(\lambda) = n_g K_D(\lambda) \int_0^\infty Q\sigma_\lambda(v) v f_e(v) 4\pi v^2 dv$$

$n_g = species\ density$

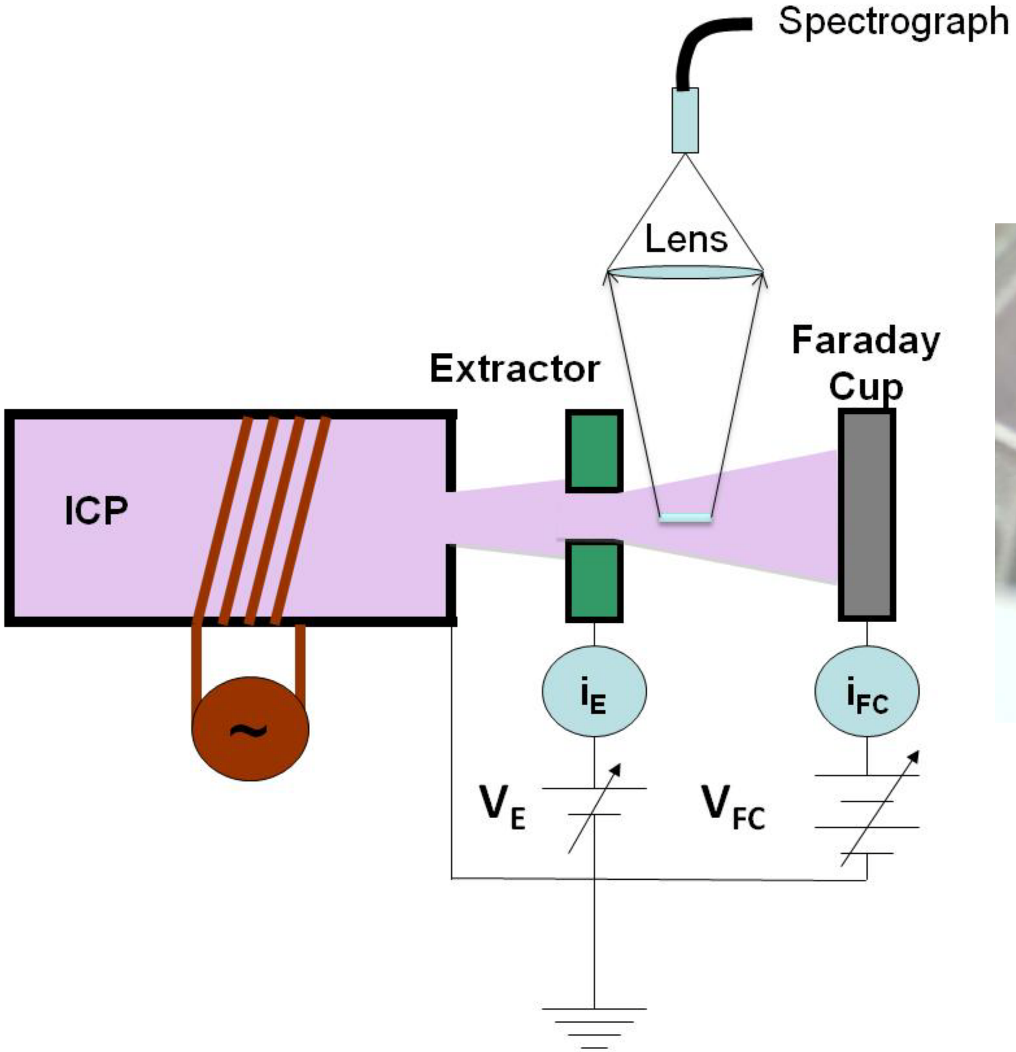
$K_D(\lambda) = detector\ sensitivity$

$Q = quantum\ yield$

$\sigma_\lambda(v) = Cross\ section$

- Electron energy distribution (EEDF) plays an important role
- Fluctuations in high energy section of the EEDF will result in signal instability
- Complex interface chemistry in Fluorocarbon plasmas

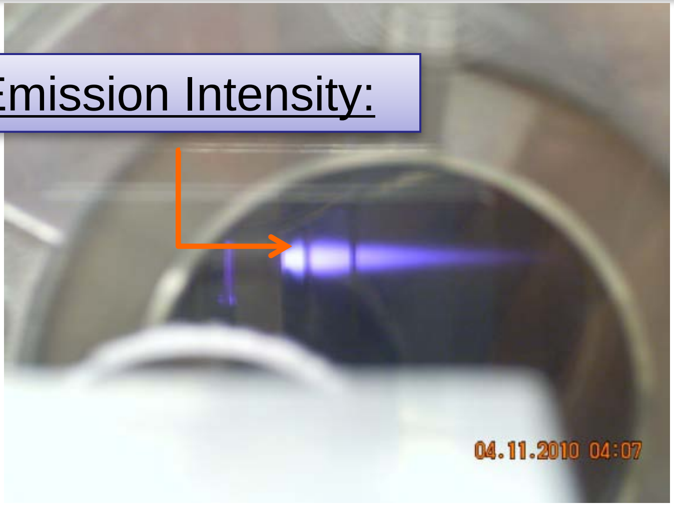
A better solution - Electron Beam Exciters



A better solution - Electron Beam Exciter

Excitation from an electron beam is controlled by :

Electron Density n_e
Electron Velocity v


Emission Intensity:

$$I(\lambda) = n_g K_D(\lambda) Q \sigma_\lambda n_e v = n_g K_D(\lambda) Q \sigma_\lambda \Gamma_e$$

Electron density (n_e) set by ICP power

v set by bias control

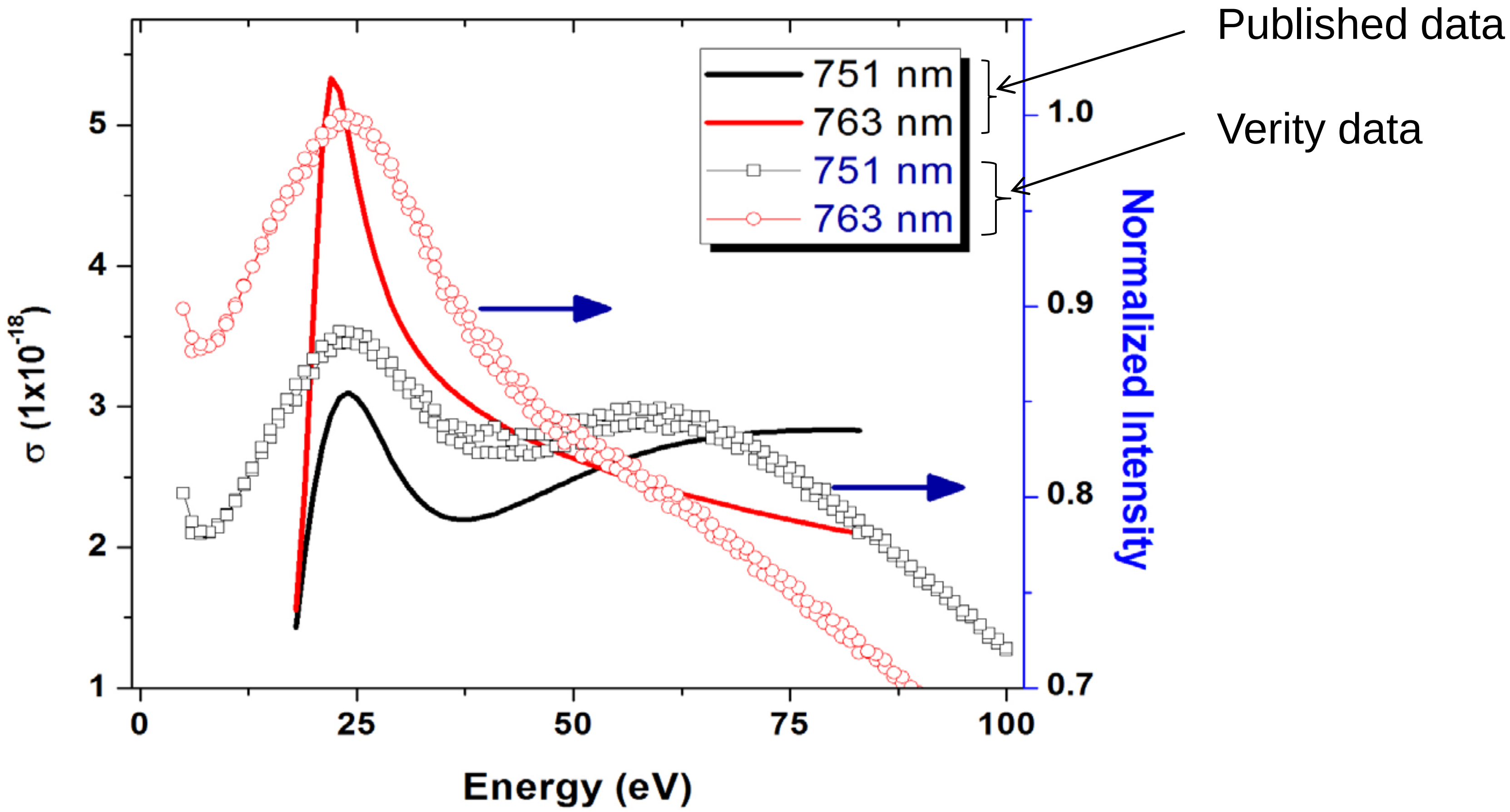
$$eV_E = \frac{1}{2} m_e v^2$$

Electron beam excitation - Merits

- Energy control - cross-sectional response / information: provides means to
    - optimize emission intensity based on cross section maximum
    - isolate specific species emissions from spectral overlap
    - perform multivariate statistical process control (MSPC)
    - measure cross-section of molecular process species

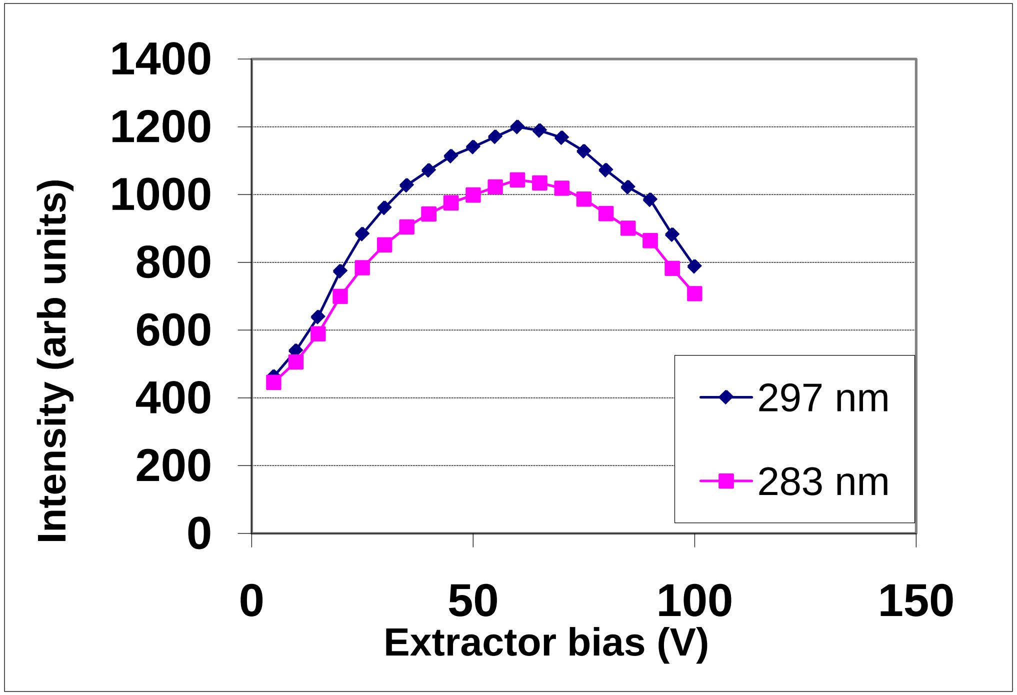
- Density control - signal intensity control
    - Compensate signal drifts during prolonged operation
        - Direct electron flux measurement
          ⇒ **Feedback control on n_e**
          Or can normalize optical signal

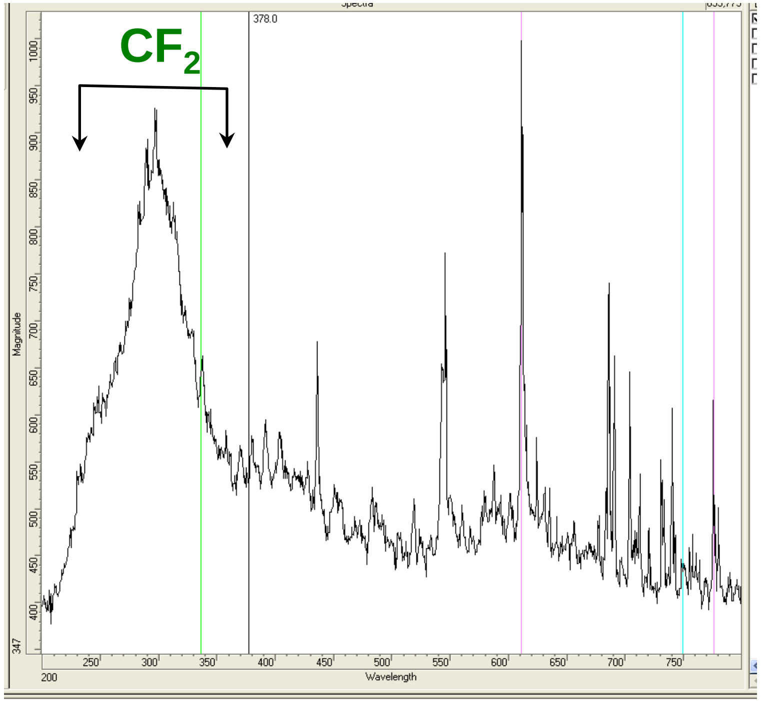
Energy control - Cross section response in Argon



- Ar emission line responses indicate electron impact energy control
- Electron beam energy distribution is representative of ICP electron extraction

Energy control – emission response from CF_2 lines



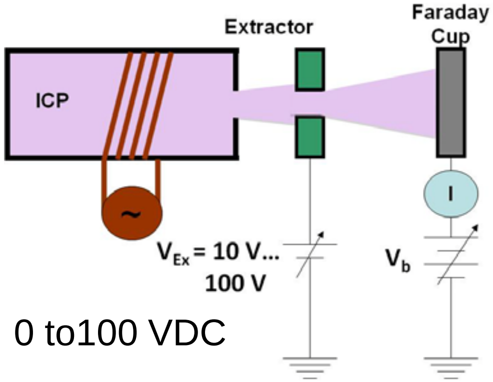


Energy sweep

CF_4 spectra

- Weakly emitting CF_2 system shows intensity increase by a factor of about 2.5
- Cross section information of such molecular systems are yet to be available

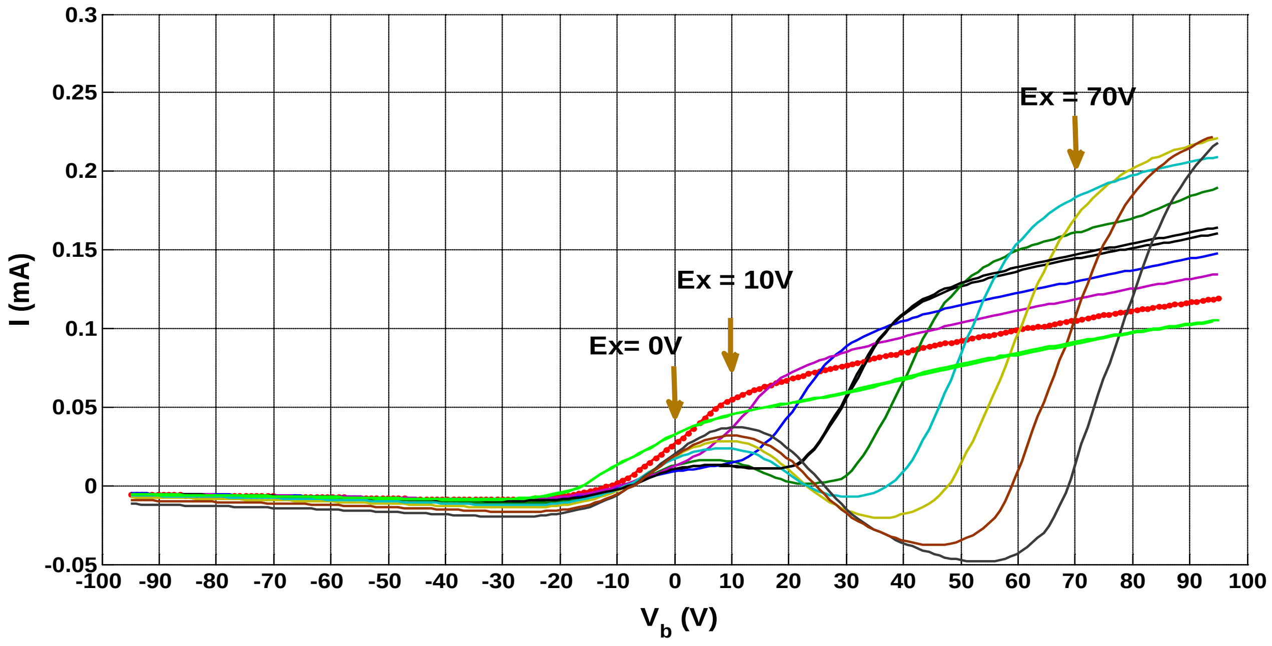
Energy control – Electrical probe measurement



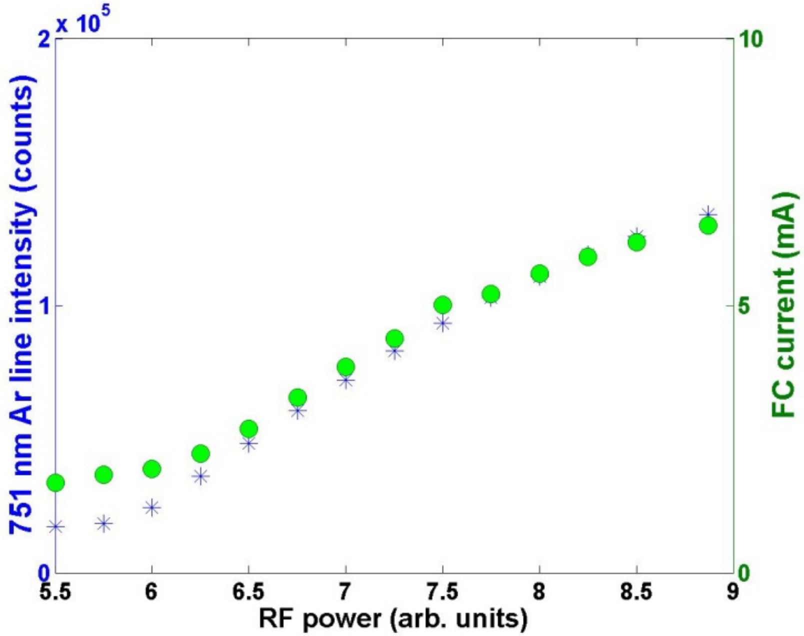
0 to100 VDC

-100 to+100 VDC

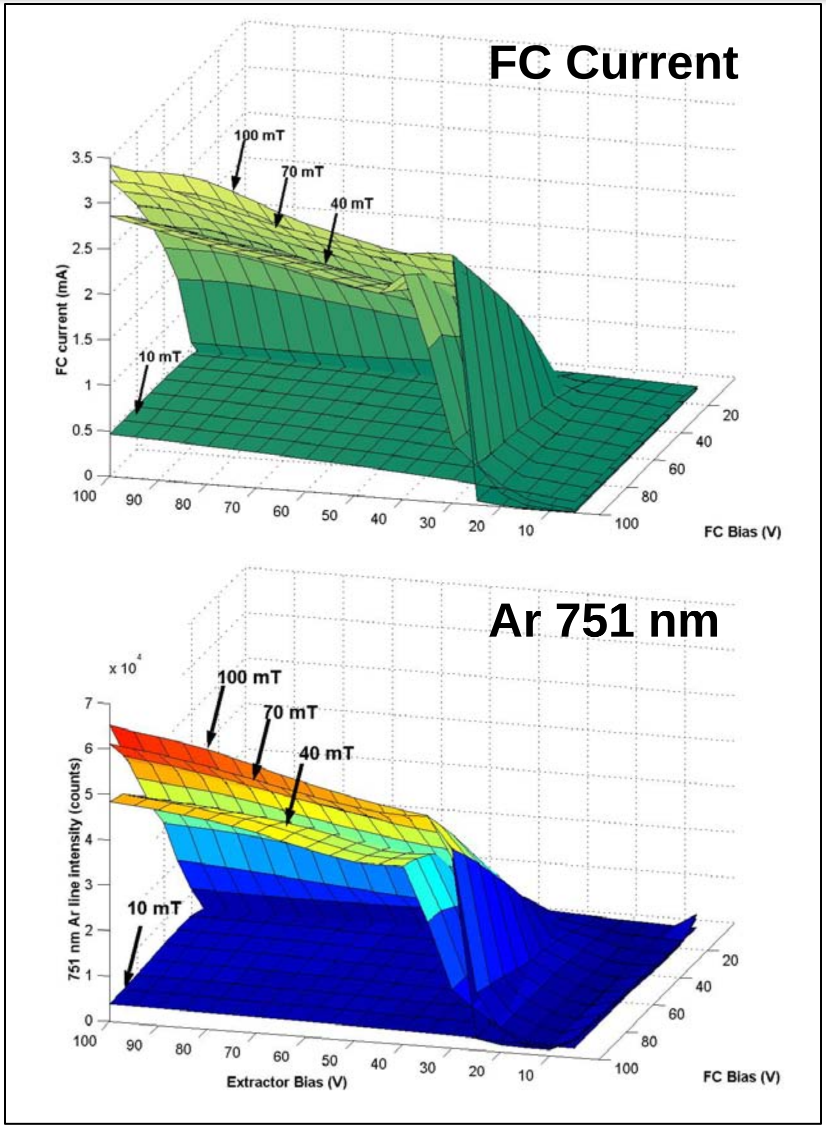
- FC was employed as the electrical probe for energy analysis
- E-beam energy shift is exact
- Distribution function is similar at Ext biases



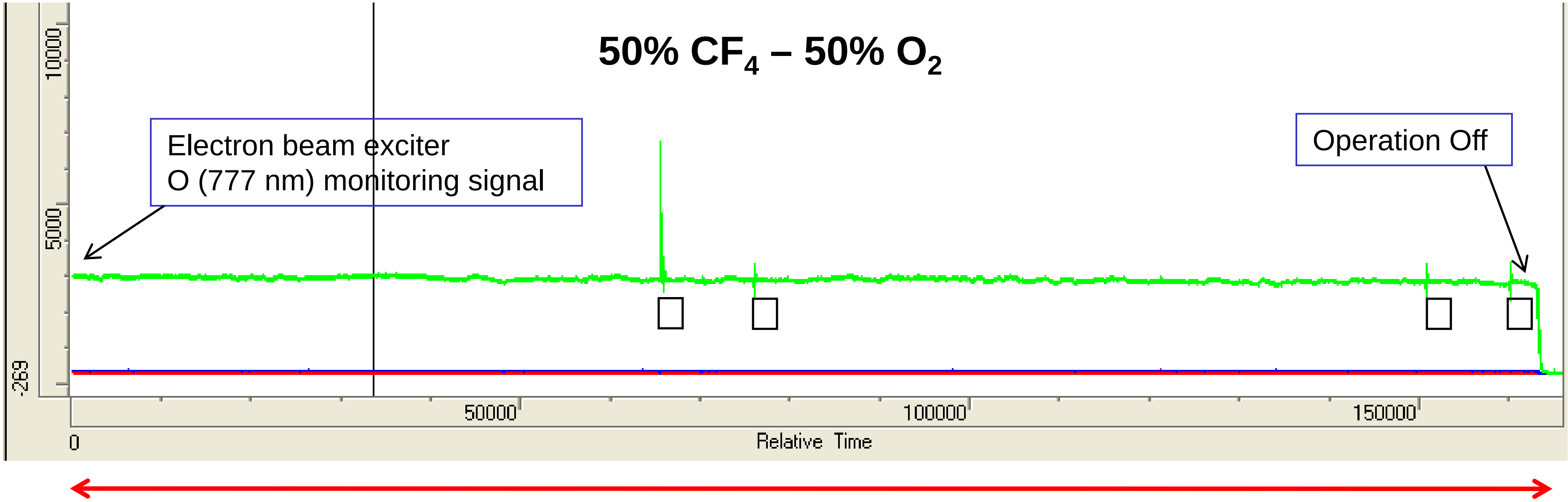
Feedback – Faraday Cup (FC) current - bias and ICP power



- Strong correlation between optical signal intensity and FC current
- Measured FC current provides means to normalize the optical signal and address some of the drift variations



Stability – long/short term



50% CF_4 – 50% O_2

Electron beam exciter
O (777 nm) monitoring signal

Operation Off

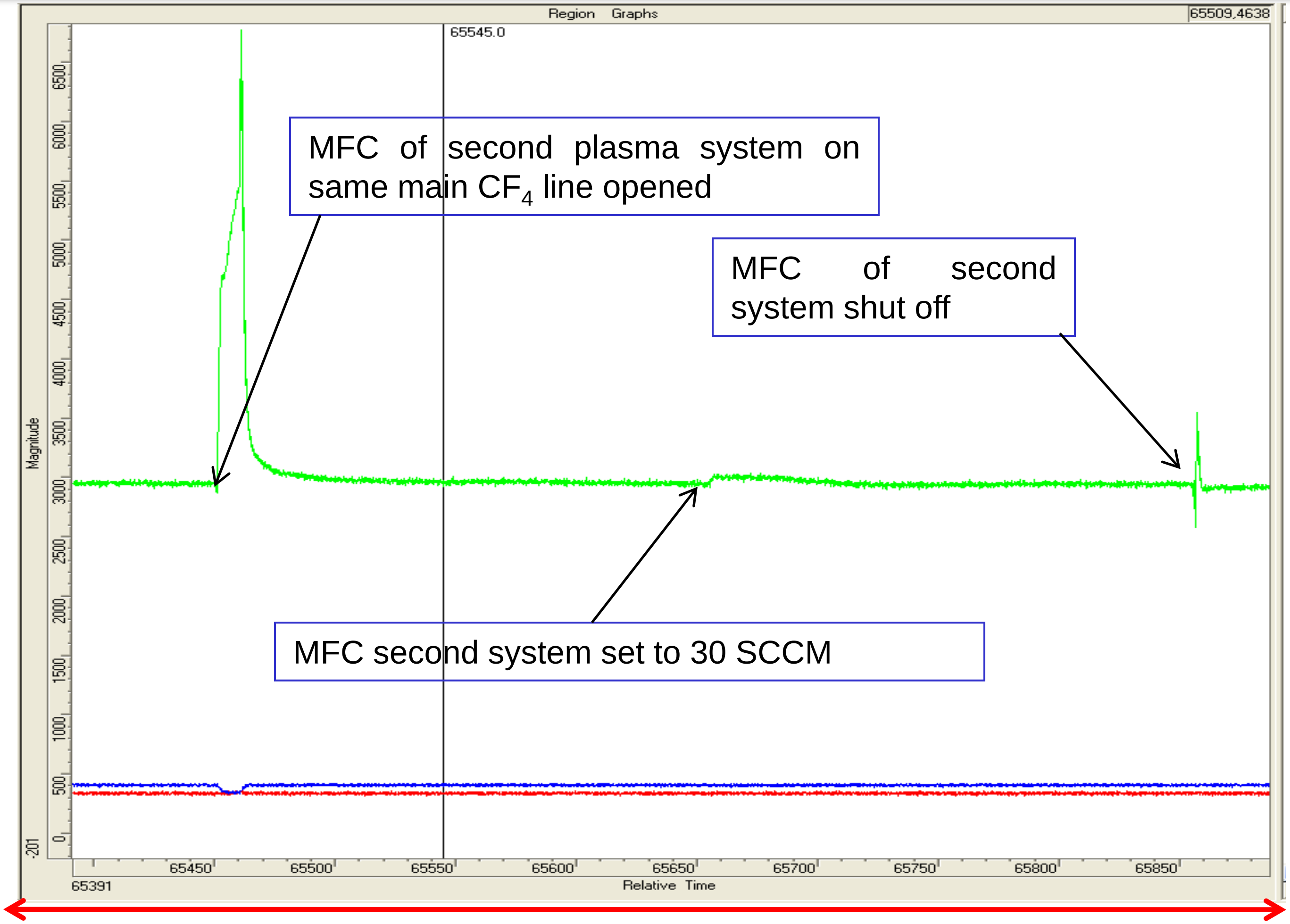
44 Hours

- Achieved Benchmarks:
  - Operability in highly corrosive environments
  - Self sustainable system (stable operation without operator interruption or feedback mechanism control)
  - Minimal signal drift over prolonged operation periods (<1%, can be compensated for in active feedback control mode)
  - High sensitive response to changes in environment chemistry

☐Centralized gas system interference

Short term stability test and sensitivity:

centralized gas system interference



MFC of second plasma system on same main CF_4 line opened

MFC of second system shut off

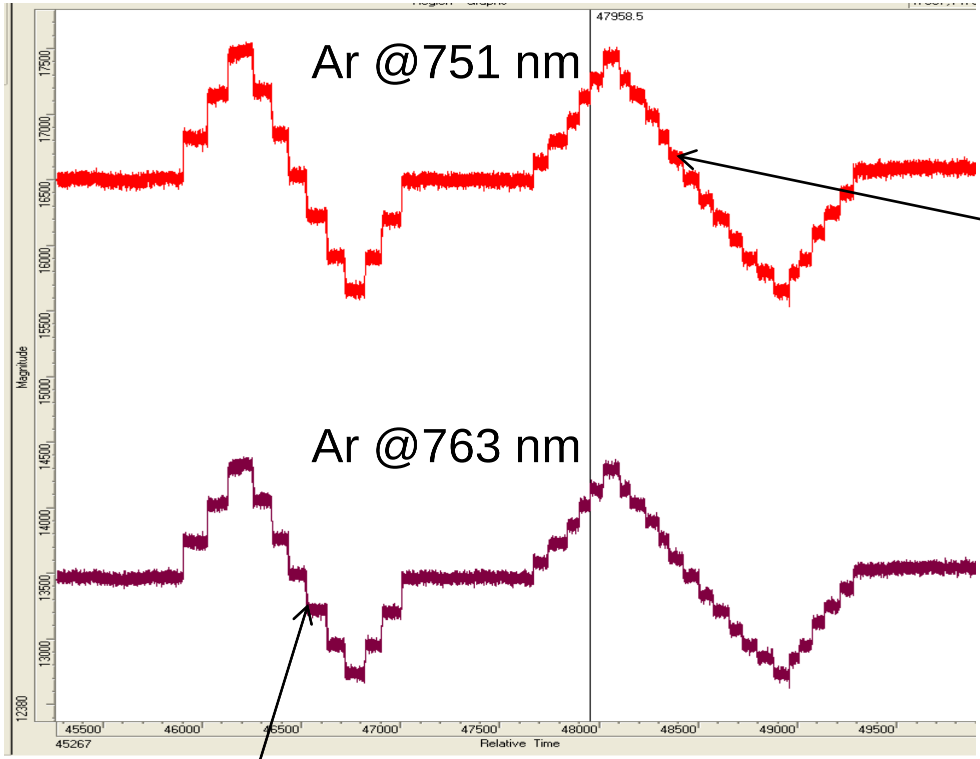
MFC second system set to 30 SCCM

~10 min

- E-beam configuration able to sense subtle pressure changes
- Back end pressure of e-beam MFC affected by laboratory gas centralized system

Stability/Sensitivity control test for e^- beam: 70 mTorr

50% CF_4 – 50% Ar



0.5% changes in gas composition

1% changes in gas composition

- Routine test performed after 13 hours of operation
- CF_4 total percentage changes from 47% to 53% at different interval steps
- Behavior in total chemistry composition observed in Ar emission line intensities

Conclusion

- Developed concepts:
  - Electron Extraction Method – Electron energy/density control
  - Stable performance in Fluorocarbon environments (short and long term)
  - Sensitivity (0.5 % changes or better)

- Further development considerations:
  - Compact Design
  - Efficient thermal integration system
  - Versatile electrode assembly (maintenance and replacement)