The Cluster Implant *Source*

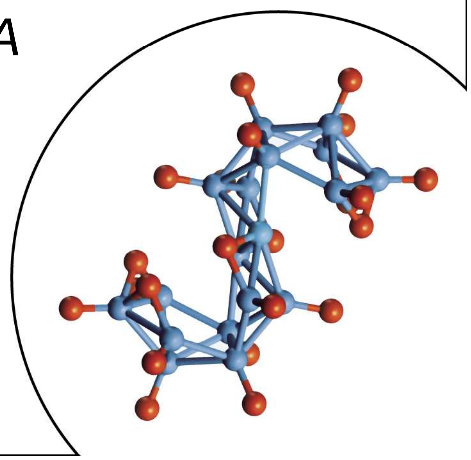
In-situ F cleaning of implanters by remote plasma generation

Thomas N. Horsky

Chief Technology Officer

SemEquip, Inc., N. Billerica, MA 01862 USA

ceradyne,inc. *A Ceradyne Company*



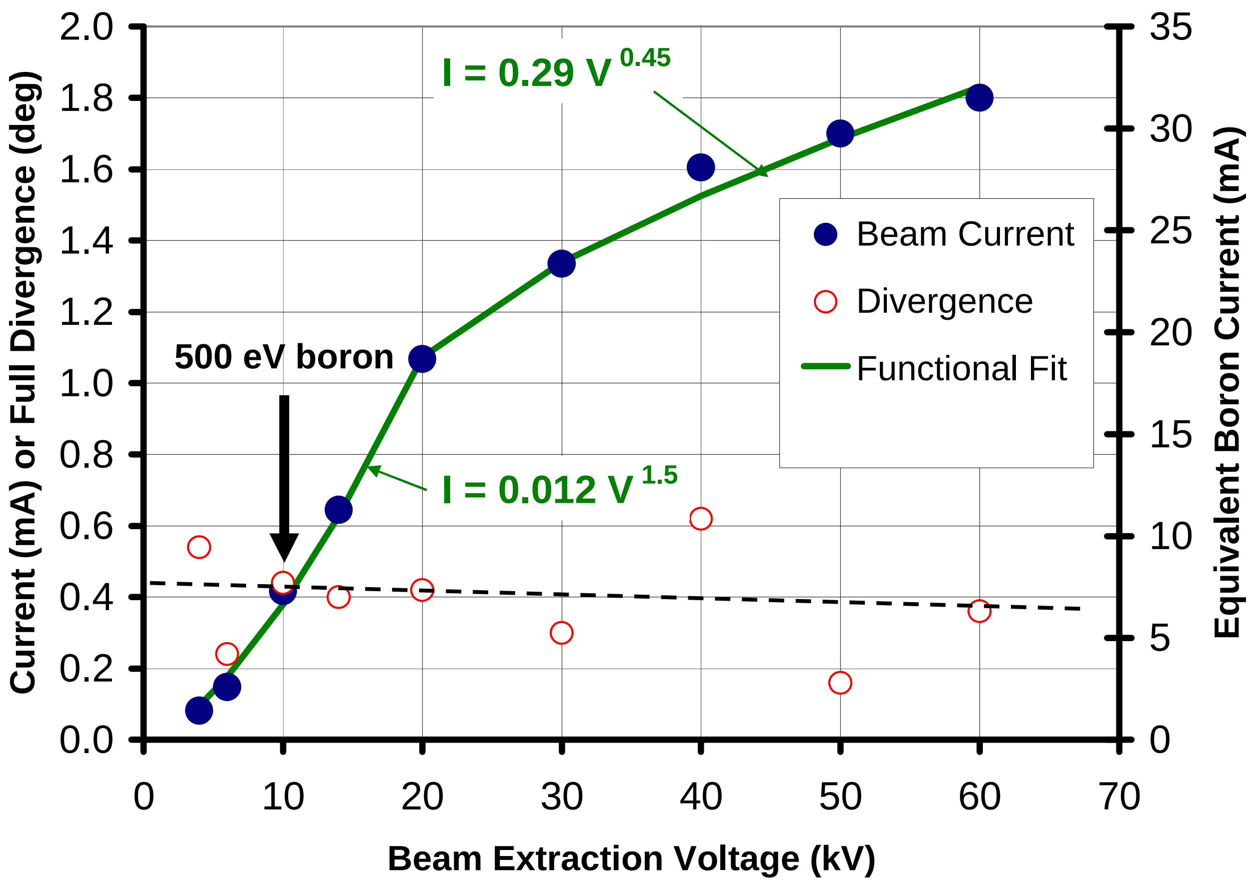
Cluster Implantation

- Implant Species: $B_{10}H_x^+$, $B_{18}H_x^+$, $C_2B_{10}H_x^+$, $C_7H_7^+$, $C_{16}H_x^+$, As_4^+, P_4^+
- Applications: S/D, SDE, Poly Gate, Contact Plug, NMOS Halo, C co-implants for B and P, Si_xC_y formation (NMOS) for strain
- Benefits: High throughput (especially at low energy), self-amorphization, low post-anneal defect density; enables low-leakage devices
- Feed materials are mostly solids vaporized at <100C
- Tend to condense on surfaces
- Ionization by-products from borohydrides form solid B-rich deposits in ion source
- F is effective in removing B-rich deposits by forming volatile BF_3 which is removed by the high-capacity system roughing pump:
  - $B + 3F^* \rightarrow BF_3$

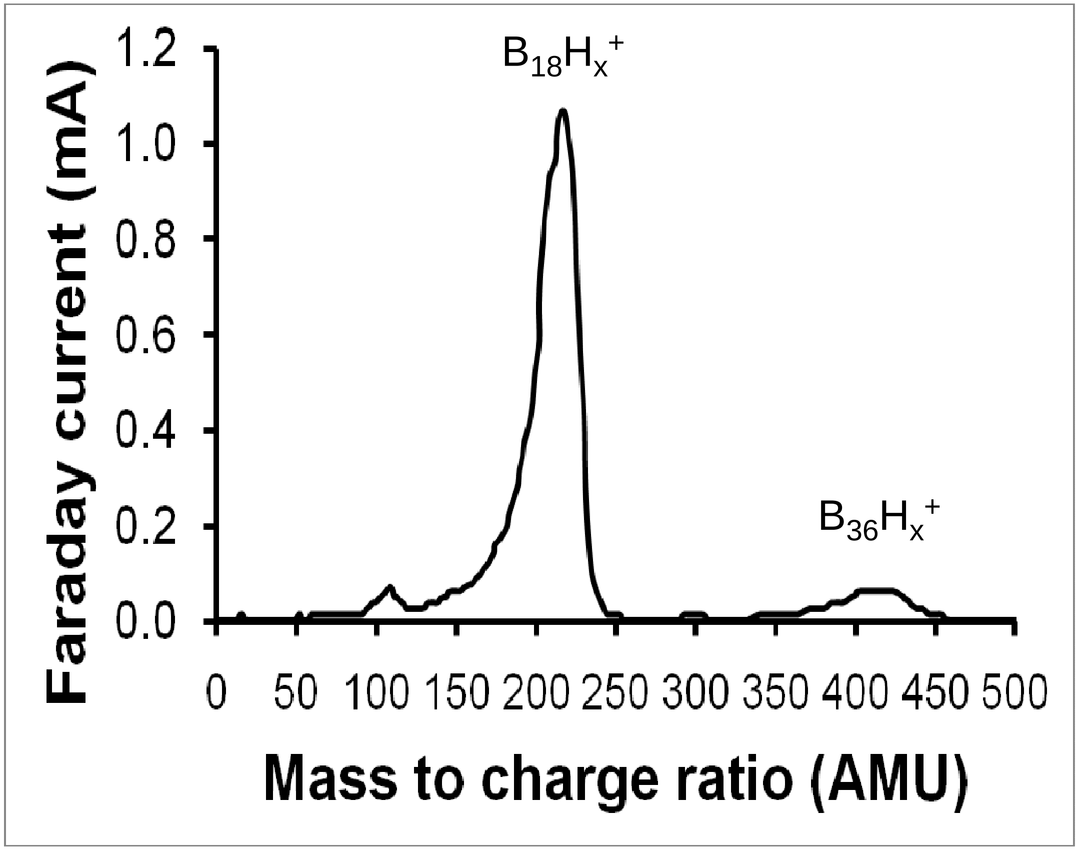
Space Charge Limits on Beam Transport

- $J_{max} = 1.72\ (Q / m)^{1/2}\ V^{3/2}\ d^{-2}$ *(Child-Langmuir)*
  - *Where J_{max} is in mA/cm^2, Q is the ion charge state, m is the ion mass in AMU, V is the extraction voltage in kV, and d is the gap width in cm.*
  - While derived for a planar diode, this relation is also applicable to beam transport, particularly for an uncompensated beam.
- $\Delta = n\ (V_n / V_1)^{3/2}\ (m_n / m_1)^{-1/2}$
  - *Δ is the maximum relative improvement in dose rate (atoms/sec) achieved by implanting a cluster with n atoms of the dopant of interest at an energy eV_n relative to the single atom implant of an atom of mass m_1*
- $\Delta = n^2$
  - *if velocity of cluster is same as monomer (process-equivalent); $V_n = nV_1$*

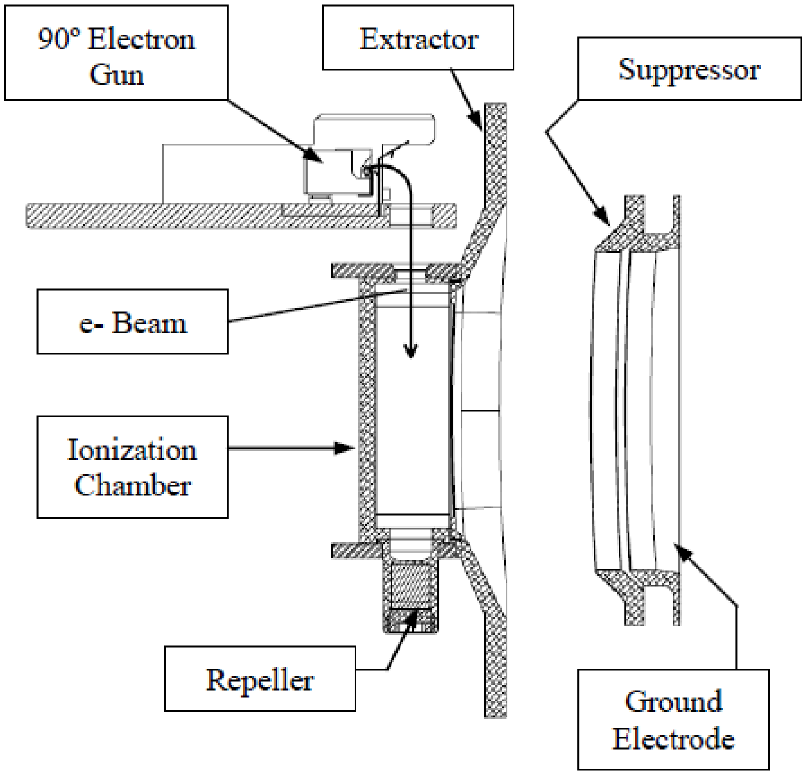
CLARIS™ Beam Current and Divergence: $B_{18}H_x^+$



$B_{18}H_{22}$ Mass Spectrum: CLARIS™ Implanter



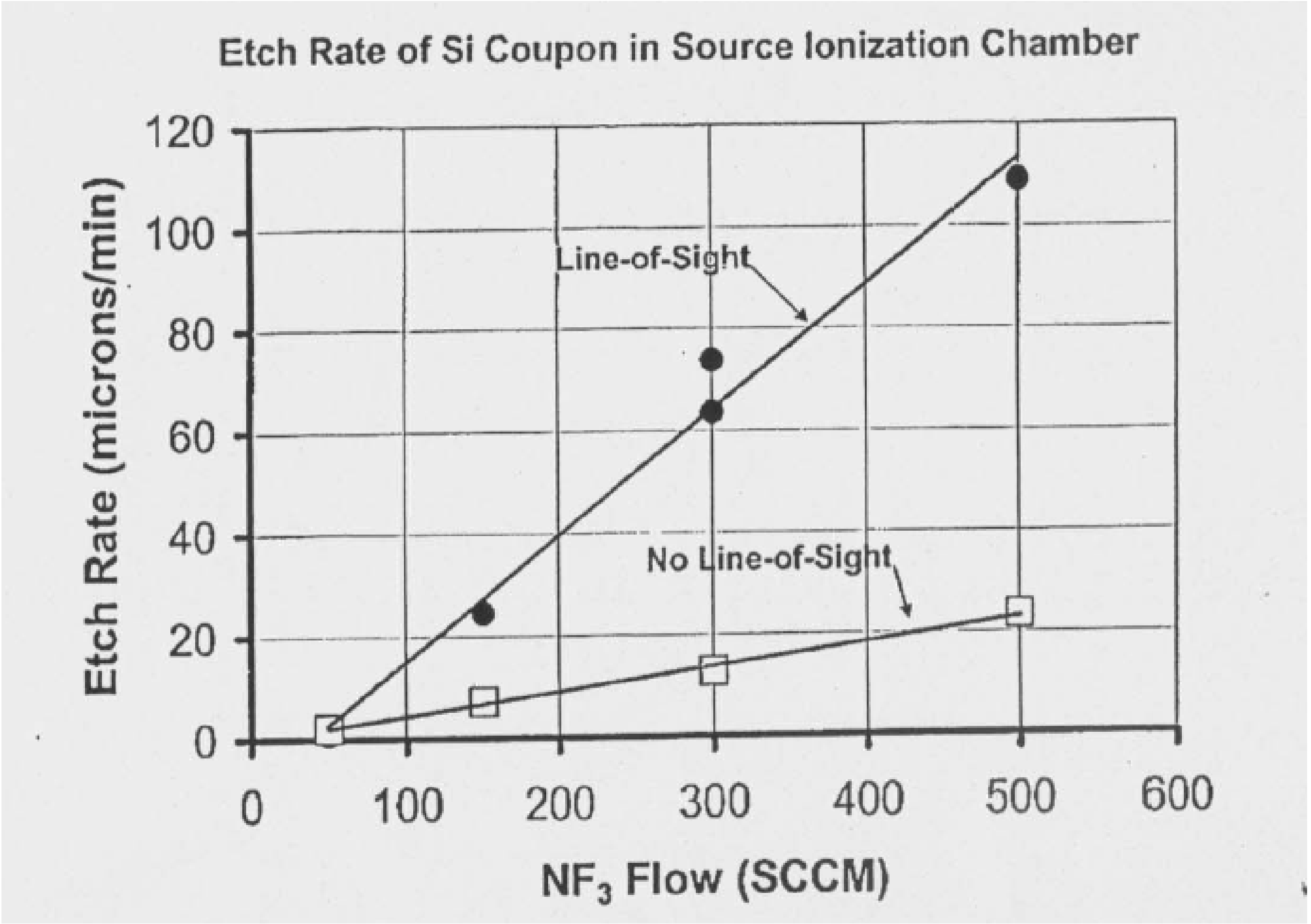
ClusterIon® Source and Extraction Electrode



F* etching of W, Si and B

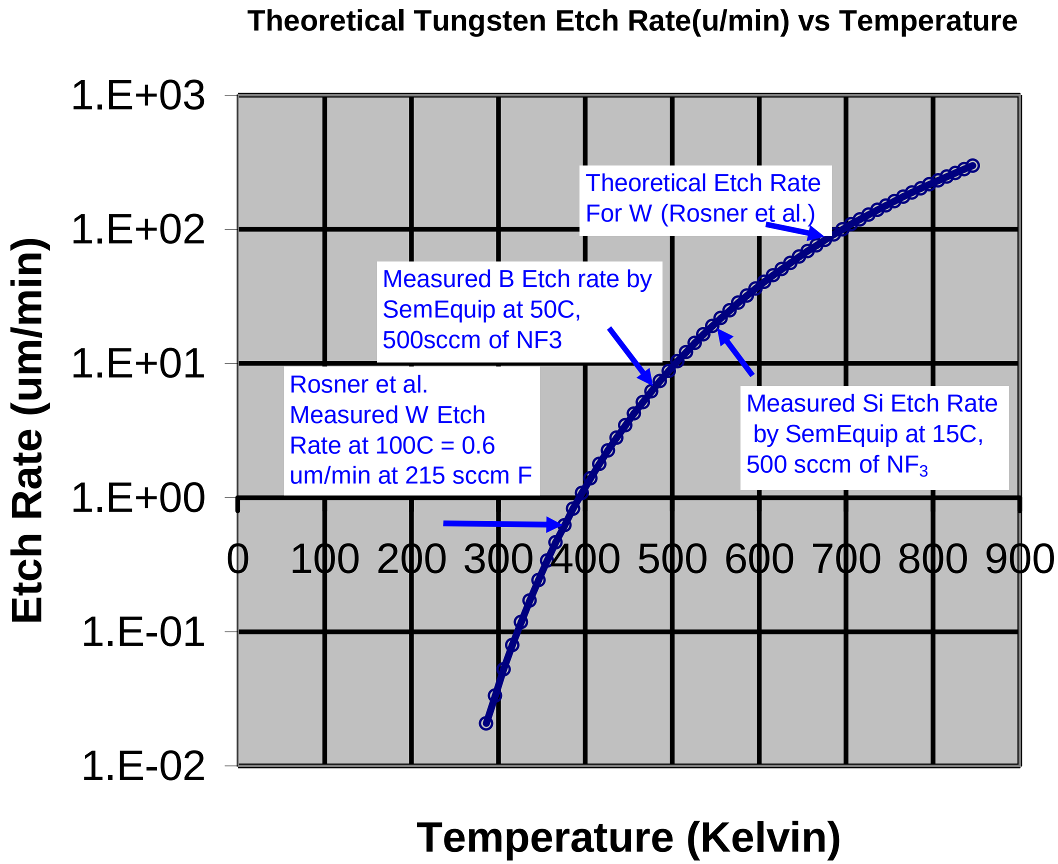
- Halogen gases have been shown to etch refractory metals, Si and other materials at a rate which increases exponentially with temperature.
- Example: Rosner *et al.* propose a model for F etching of a tungsten substrate:
- Etch Rate (microns/min) = $2.92 \times 10^{-14}\, T^{1/2}\, NF \exp(-3900/T)$,
  - Where NF is the concentration of fluorine in atoms per cm^3, and T is the substrate temperature in degrees Kelvin.
- SemEquip has measured the etch rates of Si chips inserted into the ionization chamber of a ClusterIon® source. The results are different for two positions of the Si chip: line-of-sight with the F conduit, and lying on the bottom of the chamber. By precise weighing of components before and after cleans, we measured the etch rate of $B_{10}H_{14}$-deposited boron films. The B etch rates were about 3X less than for Si, or about 7 µm/min for non-line-of-sight F* at a flow of 0.5 SLM of NF3 at about 50C.
- F is benign to Al, forming a surface passivation layer of AlF_3.
- In the SemEquip *in-situ* cleaning system, as embodied in CLARIS (Nissin Ion) and IMAX (Axcelis Technologies) implanters, a remote plasma generator dissociates NF_3 into F* and N by-products. The F* is fed into the ion source and source housing, removing B deposits from source, housing, and extraction electrode.

Etch rate of Si by F* at point of use

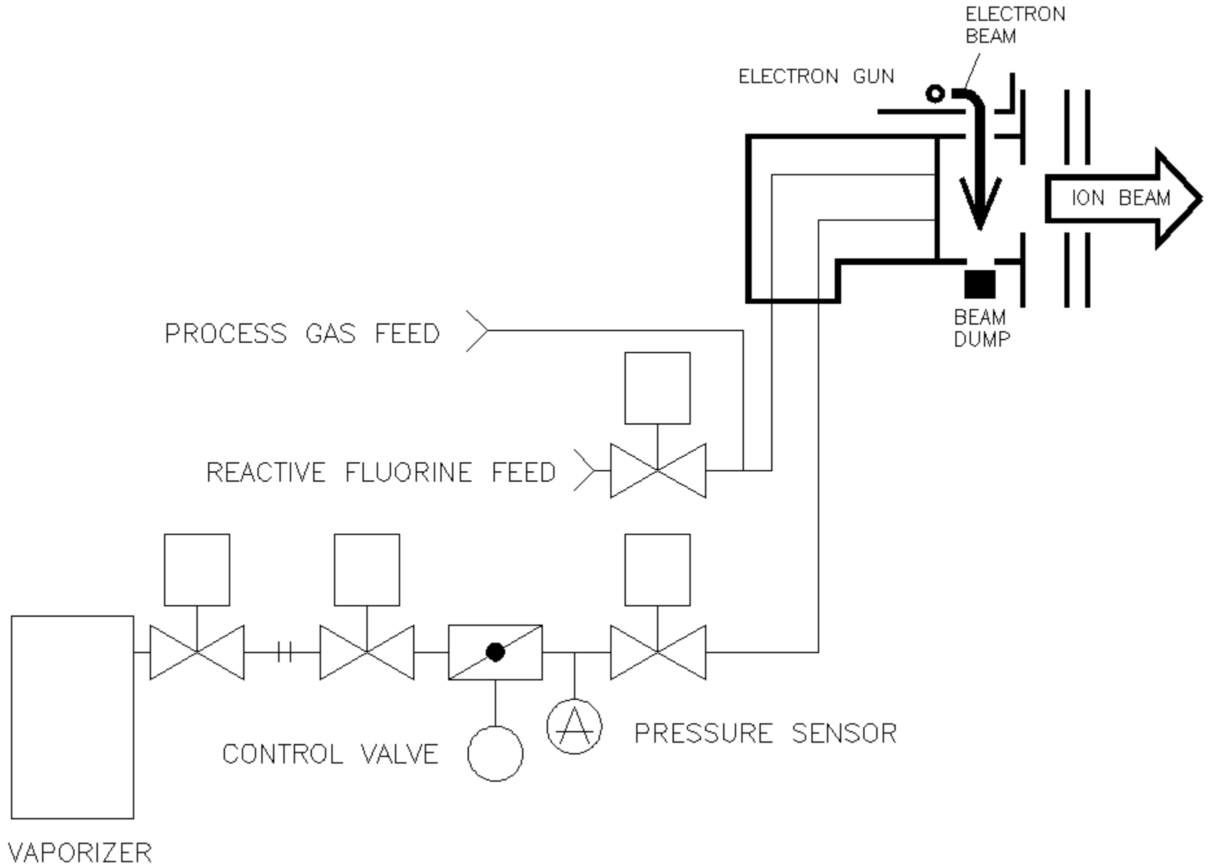


Temperature dependence of etch rate

Etch Rate (microns/min) = $2.92 \times 10^{-14}\ T^{1/2}\ NF\ \exp(-3900/T)$, NF calculated at F pressure of 1 Torr

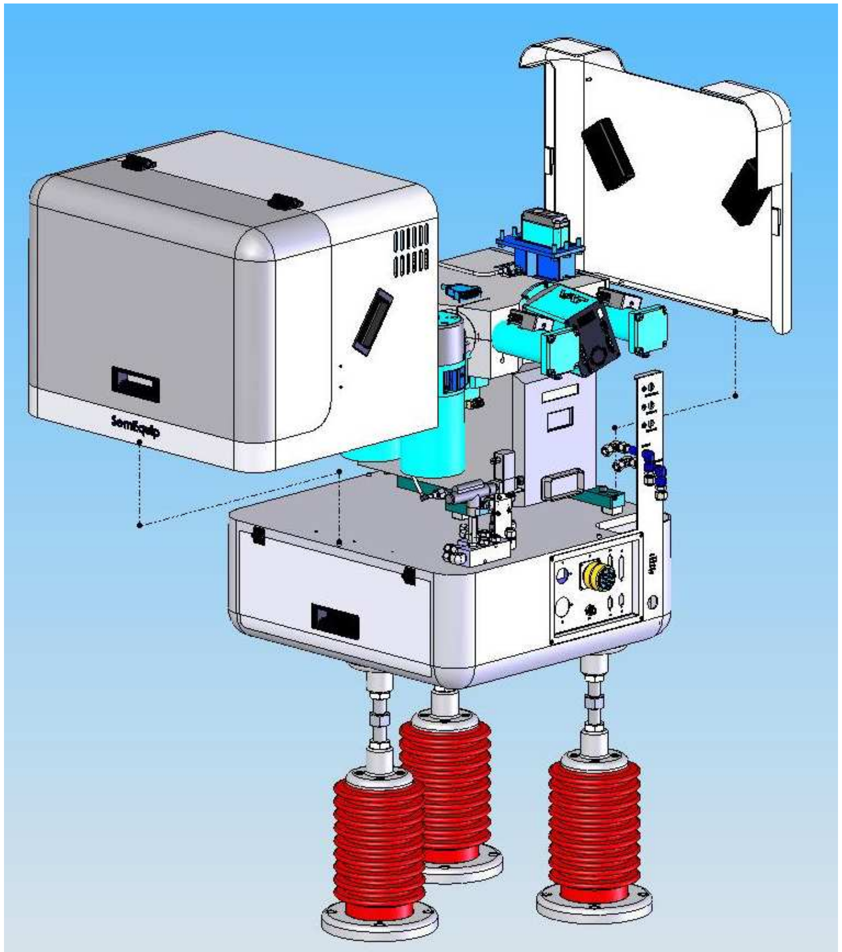


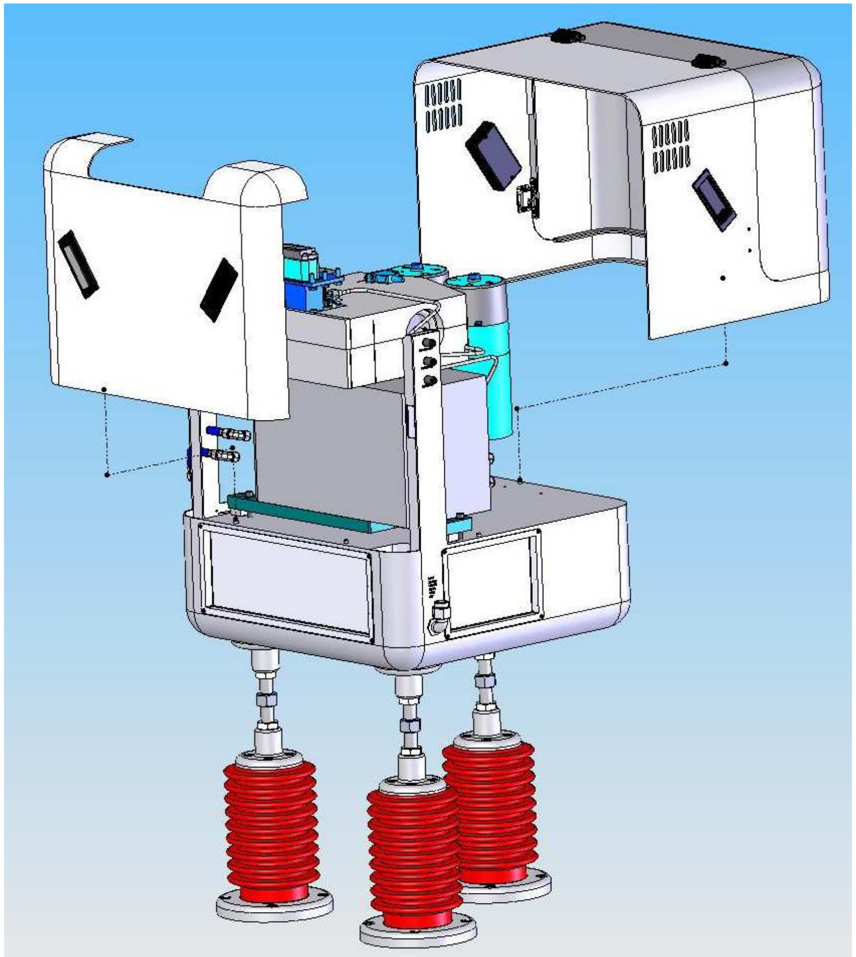
ClusterIon® Ion Source with patented vapor delivery system



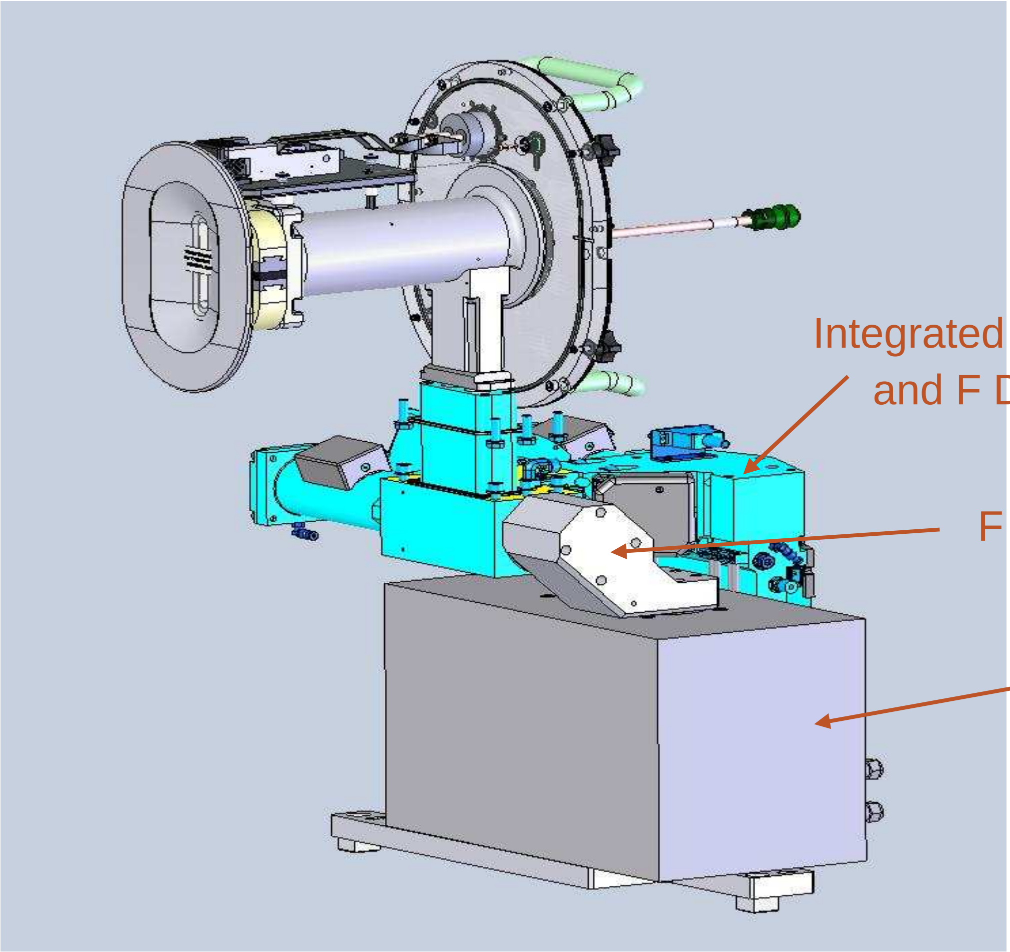
Source, vapor delivery, and F generator

Exploded view of vapor delivery & F generator

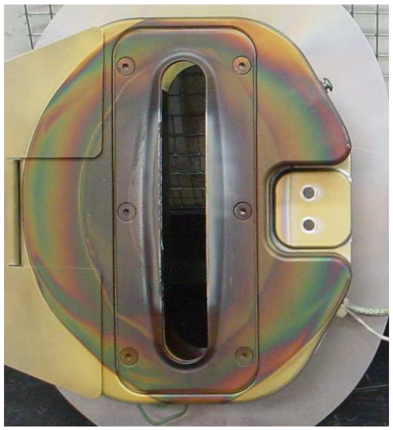
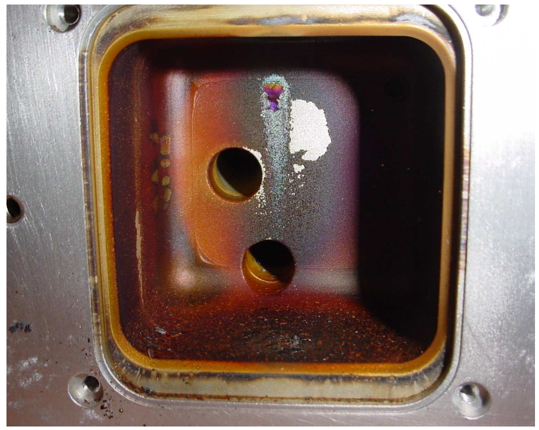
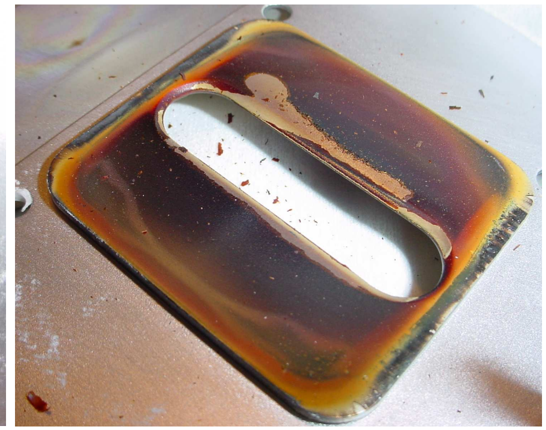
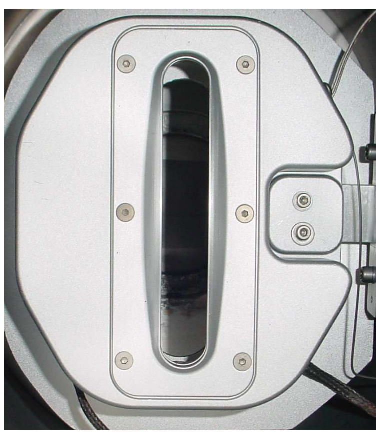




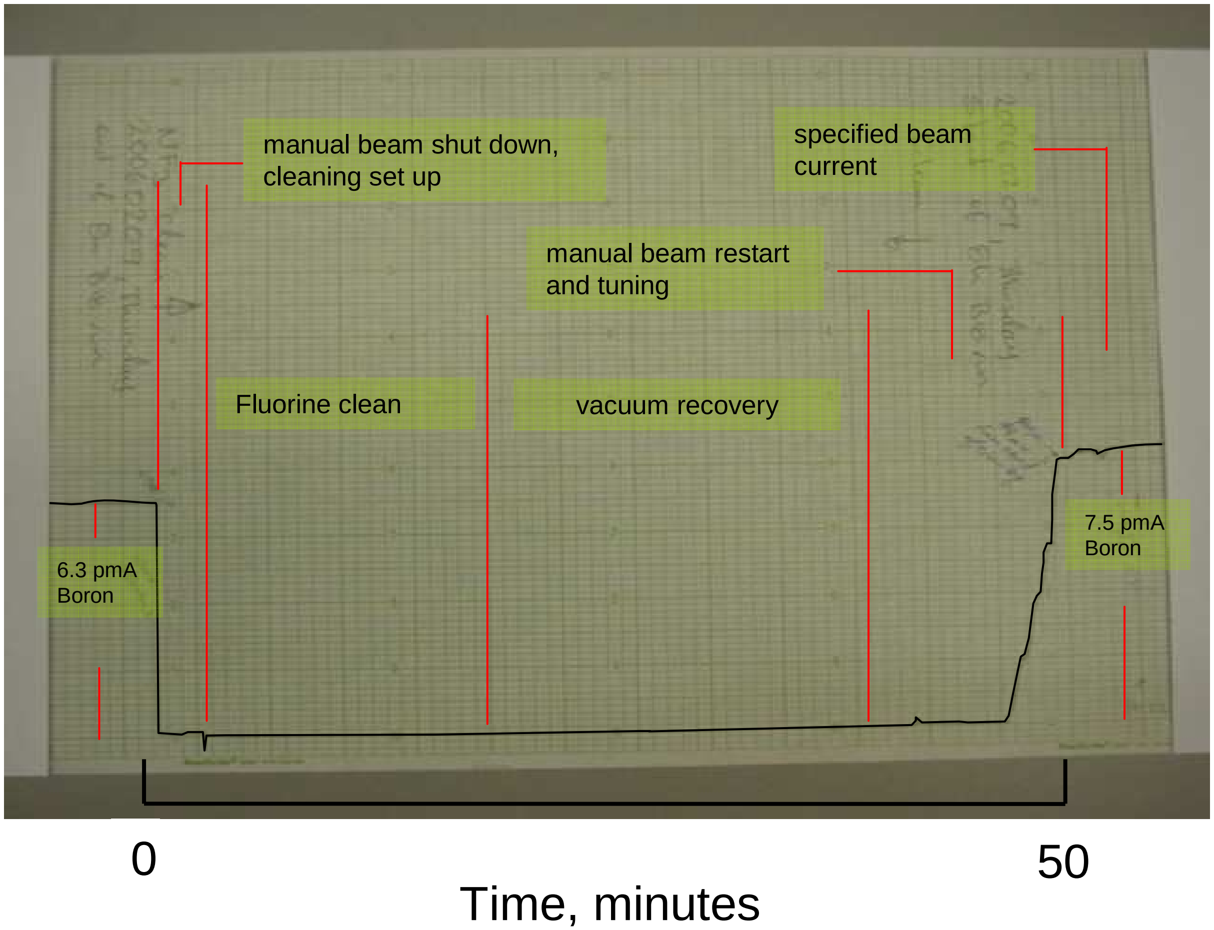
Commercial source system with integrated vapor delivery and in-situ remote plasma clean



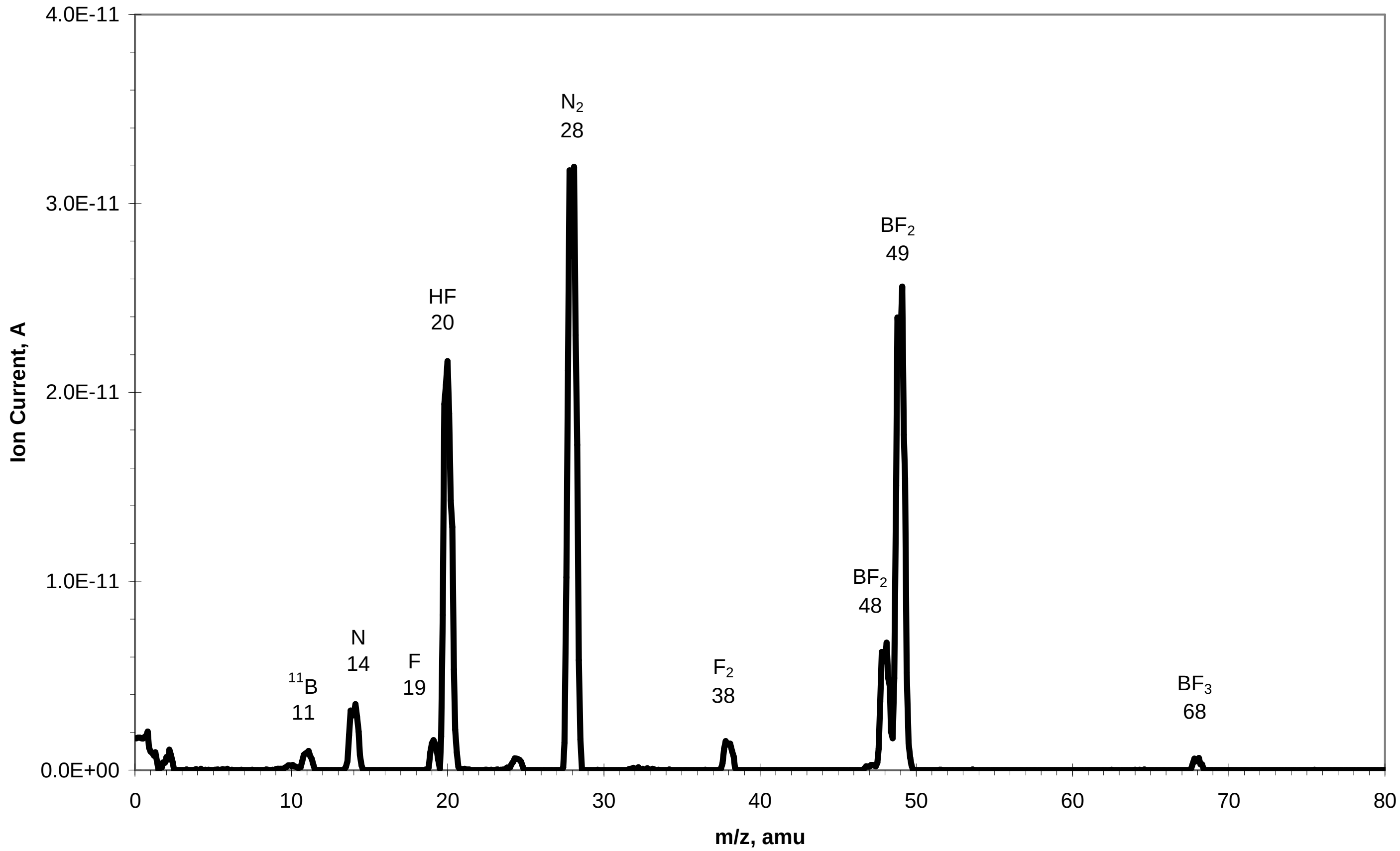
Before and after F cleans

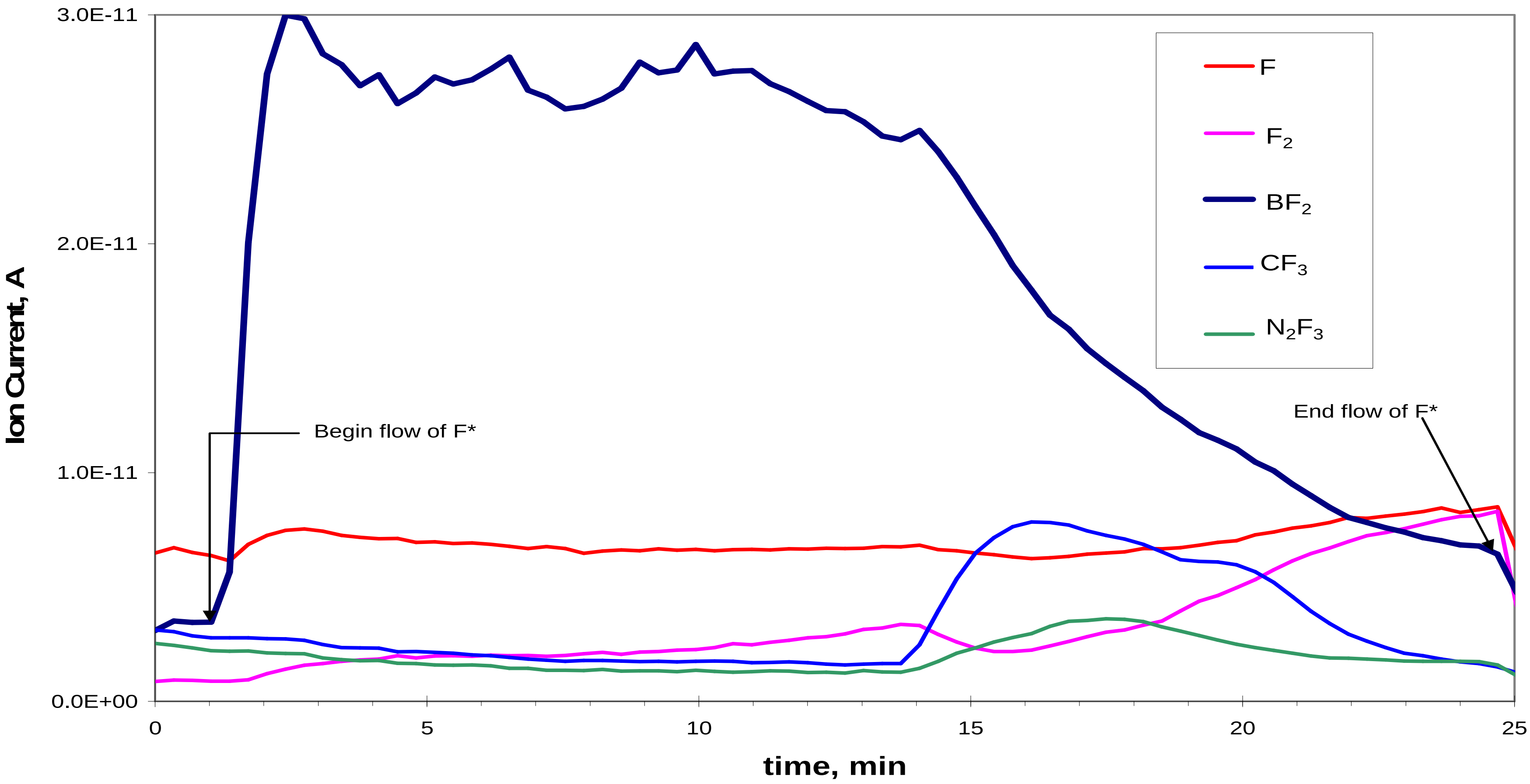
In Situ Reactive Fluorine Cleaning of ClusterIon® source after 8 hours of $B_{18}H_x^+$ operation



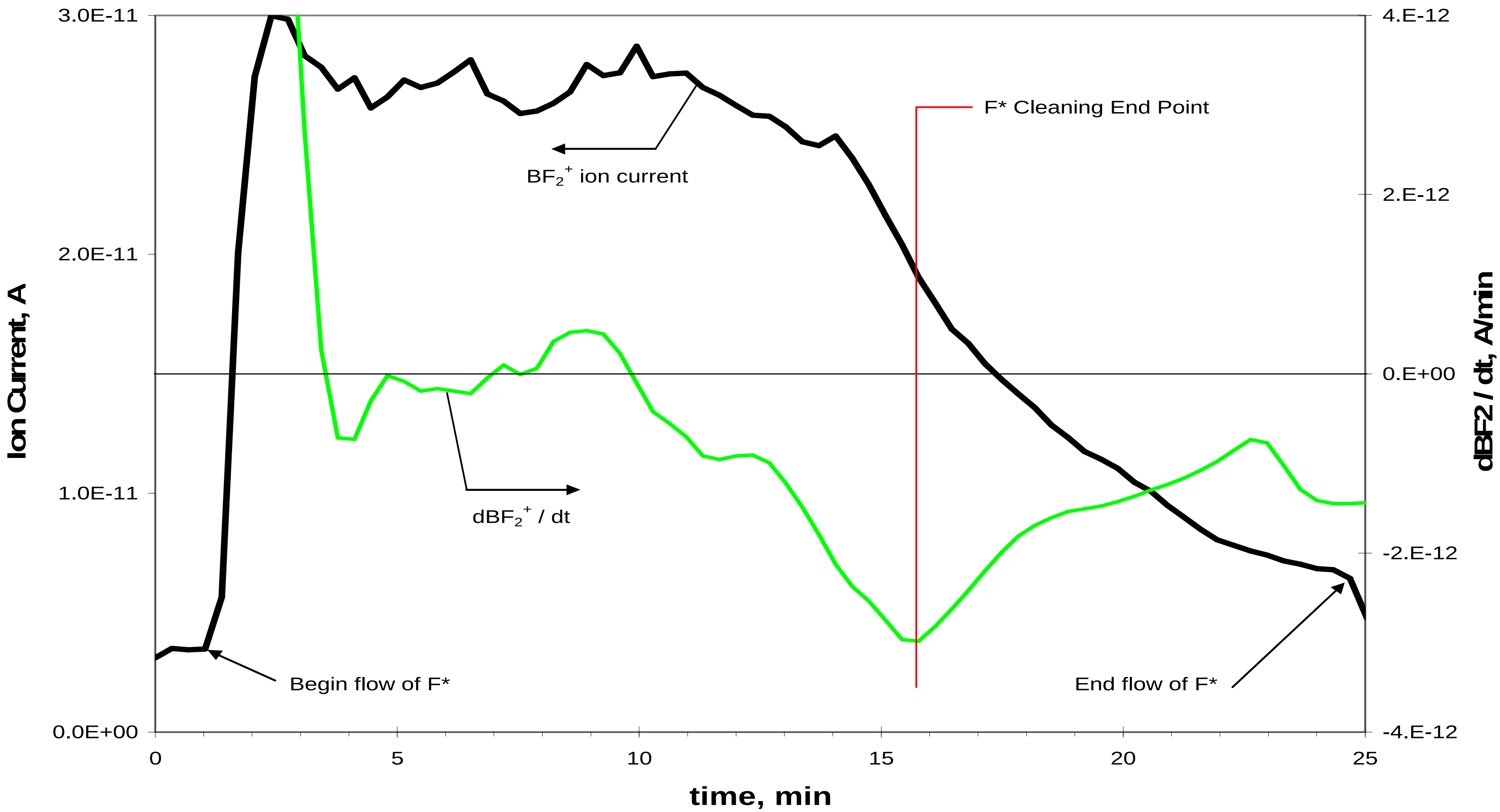
In Situ cleaning of the ClusterIon® source after 8 hours of $B_{18}H_x^+$ operation
Typical RGA spectrum



In Situ cleaning of the ClusterIon® source after 8 hours of $B_{18}H_x^+$ operation
Typical RGA ion current vs. time for ion species of interest



Cleaning end point detection



SemEquip *The* Cluster Implant *Source*

Summary: *In situ* reactive fluorine cleaning

- Addresses the problem of material build-up in the source.
  - Converts condensed and deposited solids to high vapor pressure compounds which are easily pumped from the system.
  - Allows the source to recover beam current typically lost due to material build-up.
- Beam to beam times of less than 1 hour.
- Cleans not only the ionization chamber, but the electrode and source housing as well.
  - Reduces or eliminates the need for mechanical cleaning.
  - When coupled with pump-purge cycling this can reduce the airborne chemistry associated with source maintenance.