In-situ F cleaning of implanters by remote plasma generation

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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 <100°C
- 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

- \( J_{\text{max}} = 1.72 \frac{(Q / m)^{1/2} V^{3/2} d^{-2}}{b} \) (Child-Langmuir)
  - Where \( J_{\text{max}} \) 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.

- \( \Delta = n \frac{(V_n / V_1)^{3/2} (m_n / m_1)^{-1/2}}{b} \)
  - \( \Delta \) 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^+**

![Graph showing beam current and divergence versus beam extraction voltage for B_{18}H_x^+ ions. The graph includes a functional fit for 500 eV boron, with current and divergence equations given as I = 0.012 V^{1.5} and I = 0.29 V^{0.45}.]

*SemEquip: The Cluster Implant Source*
$B_{18}H_{22}$ 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:

  \[ \text{Etch Rate (microns/min)} = 2.92 \times 10^{-14} T^{1/2} \text{NF exp}(-3900/T), \]

  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\(^\text{®}\) 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

Theoretical Tungsten Etch Rate (um/min) vs Temperature

Etch Rate (um/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

Integrated Vapor, Process gas, and F Distribution system

F Exhaust

F Generator
Before and after F cleans

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

- manual beam shut down, cleaning set up
- specified beam current
- manual beam restart and tuning
- Fluorine clean
- vacuum recovery
- 6.3 pmA Boron
- 7.5 pmA Boron

Time, minutes
0 50
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

![Graph showing ion current vs. time for various species](image)
Cleaning end point detection

$BF_2^+ \text{ ion current}$

$\frac{dBF_2^+}{dt}$

Begin flow of F$	ext{"}{\text{*}}$

End flow of F$	ext{"}{\text{*}}$

$F^\text{"}{\text{*}}$ Cleaning End Point
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.