Elemental Boron Injector for Wall Conditioning on the Alcator C-Mod Tokamak
Abstract

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It has been found on many tokamaks that the deposition of boron on the vessel wall is an essential part of high performance operation. Most techniques use gaseous boron compounds combined with a glow discharge to deposit the boron. A new technique using 50 to 100 µm diameter elemental boron dust injected into the tokamak discharge is being developed. The design of the injector and the instrumentation required to diagnose its operation will be presented. Preliminary results during operation on Alcator C-Mod will also be shown, including effects seen on impurity levels, the H to D ratio, radiation, and general machine operation.
Boronization on Alcator C-Mod

• Typically deposit 5 g of boron during a boronization
  – 10% B<sub>2</sub>D<sub>6</sub> in 90% helium
  – Requires 12 hours using an electron cyclotron discharge technique to breakdown and deposit the diborane
• Boronize again after approximately 200 discharges
  – Moly radiation increases
  – H/(H+D) ratio increases and affects ICRF heating
• Would like to boronize the machine and then maintain an acceptable level of boron on the walls
• An upper limit on the amount of boron required is 25 mg/discharge
  – boron is spread over entire chamber using current technique
Cleanup Discharges

Rf energy (MJ/10)

Boronization

H/(H+D)
Boron Injector

- Solenoid driven piston allows boron particles to fall from hopper into plasma
  - DC solenoid driven at 100 V up to 30 Hz
- Boron particles range in size from 50 to 100 µm
  - Use multiple sieves to determine size
  - Boron is vacuum baked at 1000 C for 48 hours
  - Particles are large enough to penetrate into the C-Mod edge plasma
- Laser scattering system monitors boron injection
- Boron III line monitored to verify injection into plasma
Details of Injector

- Solenoid
- Armature
- Piston
- Fill port
- Hopper
- 2-3/4” flange
Boron Injector Hardware

Boron III detector

Mirror

Boron injector (magnetic shield removed)

150 mW laser

Scattered light detector
Maximum Energy Loss / mg of Boron

- Diameter of pellet: 0.05 mm
- Mass of pellet: 0.000161 mg
- Number of pellets: 6210 / mg
- Number of atoms: 5.560e+19 (C-Mod plasma ~ 2e20)

- Energy to melt: 0.005 kJ
- Energy to vaporize: 0.046 kJ
- Energy to atomize: 0.052 kJ
- Total to gas: 0.100 kJ

- Ionization energies: 0.07 0.22 0.34 2.31 3.04 kJ
- Total all states: 5.98 kJ

- Total energy loss: 6.09 kJ
Initial Injector Test Geometry

- Typical particle fall is 1.8 m
- Fall time of approx 0.6 s
- Particle velocity as it enters plasma is approx 6 m/s
- Particles injected with high transverse velocity and fill injector and gate valve with particles
Valve Closed

- About 0.1 to 0.2 mg/pulse
- Pulse rates of up to 30 Hz
- Boron injected when injector opens and closes
- Scattering signal delay is fall time of boron from injector to scattering region
First Attempt

- No BIII emission
- Nothing seen on TCI, $2\pi$ bolo, VB, or soft X-Ray
- Startup/disruptivity were unaffected
- Did it actually go in?
  - 0.1 mg of boron
    - 1000 40 $\mu$m particles in 30 ms
    - 20 kW (max)
- Most of boron may have been lost before reaching vertical port
New Injector

- Higher through-put of approx 1 mg/pulse
- This system will be tested during current run campaign
- Improved magnetic shielding
New Tubing Geometry

• New injector system includes tubes to direct boron to scattering region and then into gate valve
• Plasma light into scattering system much reduced
• Tube also directs boron through 10” cross and into vertical port (not shown)
Current Injector Geometry

- Typical particle fall is 2.1 m
- Fall time of approx 0.65 s
- Particle velocity as it enters plasma is approx 6.4 m/s
- Particles injected with high transverse velocity will fill vertical port as they fall
- Particles will spread over large plasma surface area
Summary

- A new type of particle injector has been built for the deposition of boron powder into the C-Mod plasma.
- Particle size was chosen to allow some penetration of edge plasma.
- Initial tests indicated that particles were lost before reaching plasma.
- New design restricts transverse movement of particles and directs them into the vertical port.
- We expect to test new design during current C-Mod campaign.