Development of NSTX particle control techniques

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Abstract

NSTX High Harmonic Fast Wave (HHFW) current drive discharges will require density control for acceptable efficiency. We have compared boronization on hot and cold surfaces, varying helium glow discharge conditioning (HeGDC) durations, and brief morning boronization with between discharge boronization for improving density control. Access to Ohmic H-modes was enabled by boronizationon on hot surfaces, however, the duration of the effectiveness of hot and cold boronization was comparable. A 15 min HeGDC between discharges was needed for reproducible L-H transitions. Brief morning boronization followed by a comparable duration of applied HeGDC restored and enhanced good conditions. Additional short boronizations between discharges did not improve plasma performance (reduced recycling, reduced impurity luminosities, earlier L-H transitions, longer plasma current flattops, higher stored energies) if conditions were already good. Between discharge boronization requires increases in the duty cycle due to the need for additional HeGDC to remove codeposited D_2.

PSI16 Subject Categories: Wall conditioning; Impurity control; Glow discharge cleaning; discharge cleaning.

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1. Introduction

The investigation of non-inductive current drive with the goal of eliminating the central solenoid from future machines is a major focus of international Spherical Torus research and the National Spherical Torus Experiment (NSTX) program [1]. Elements of the NSTX current drive research program include High Harmonic Fast Wave (HHFW) current drive (~100kA achieved) and Coaxial Helicity Injection (CHI) (400 kA achieved). Integrated scenario modeling of NSTX HHFW current drive discharges [2] shows that an average plasma density less than n_e ~$3x10^{19}$ m^{-3} is optimal for acceptable HHFW current drive efficiency. However, during long-pulse NBI-heated H-modes, the density rises continuously, reaching up to n_e ~$7x10^{19}$ m^{-3} in 0.3 s. Analysis of the time dependence of these density rises [3] has found τ_p* ~0.5 s or ~10x τ_E. It has become evident that the existing NSTX particle control techniques [4, 5] of gas puffing, high temperature PFC bakeout, boronization on room temperature substrates, and brief HeGDC wall conditioning between discharges need augmenting to provide plasma density control for longer pulse operation.

We report on a comparison of boronization on hot and cold substrates, brief morning boronization, between discharge boronization, extended HeGDC between discharges, and He discharge conditioning to reduce and control spontaneous density rises, and in particular control τ_p* for improved HHFW current drive efficiency, as well as, for transport studies, and power and particle handling research.

2. Comparison of boronization on hot and cold surfaces

The NTSX plasma facing surface is about 41 m^2, consisting of graphite tiles on power handling surfaces (75.6%), and the 304-SS midplane vessel wall (24.4%). During bakeout following a vent, the graphite is baked to 300-350°C and the vessel walls to 150°C. 25 boronizations have been performed on the room temperature plasma facing surfaces using about 10 g of deuterated trimethyl boron ($B(CD_3)_3$) injected into a HeGDC [6]. Based on machine performance and spectroscopic signals indicative of relatively higher impurity luminosities, these boronizations have been performed in NSTX every 200-400 discharges or about every 2-3 weeks. Although such room temperature boronization has been effective in enabling high performance in NSTX to date [4, 5], a test of boronization on high temperature substrates was made. The goal of testing the effectiveness of hot boronization on graphite surfaces (300-350°C) and the vessel wall (150°C) was to determine if changes in codeposition, deposited film microstructure, and uniformity could reduce impurity traps and recycling. A hot boronization was performed after pump-down, following a short venting of the vessel. The hot and cold (room temperature) boronizations were compared using D lower single null (LSN), 600 kA plasma current (I_p), Ohmic, and LSN, Ip 800 kA, NBI fiducial discharges.

Following hot boronization, a significant improvement in the performance of the initial Ohmic and NBI fiducial discharges was observed relative to those following cold boronization. The Ohmic fiducial discharges exhibited the most favorable Ohmic performance to date. The previously elusive Ohmic H-mode was achieved after the 2nd discharge, and maintained in many discharges thereafter. This relatively facile transitioning to the Ohmic H-mode may be related to the lower D_α luminosity observed after hot boronization, which may in turn be due to less retention of codeposited D_2 during boronization on hot surfaces, and possible reduced porosity and trapping sites in depositions on higher temperature surfaces. Laboratory work has indicated that boron films grown at high temperatures exhibit characteristics that imply a different microstructure [7, 8]. The D LSN NBI fiducial discharges exhibited the most promising first-day-NBI operation to date following a vent. However, although the first NBI fiducial discharges transitioned easily to H-modes, these discharges exhibited a D_α luminosity comparable to NBI discharges following cold boronization. This may have been due to the D_2 wall loading resulting from the 56 Ohmic discharges that preceded the D LSN NBI fiducial discharges. However, while the initial performance of NBI fiducials following hot boronization was significantly improved relative to cold boronization, as the fluence to the wall increased with succeeding NBI discharges, the operating conditions following hot boronization deteriorated (increased recycling, increased impurity luminosities, later L-H transitions, shorter I_p flattops, lower stored energies), and became indistinguishable from those following cold boronization, In addition, the durations of the improved operating conditions following hot and cold boronization were found to be comparable (Fig. 1). These results may indicate that as the fluence to the wall increases, erosion and similar changes to the deposition microstructure eventually dominated over the initial deposition conditions.

3. Comparison of between discharge HeGDC and helium discharge conditioning

The duration of between discharge HeGDC was varied to optimize conditions for density control, boundary physics characterization experiments, and sensitive studies of early H-mode access as a method for limiting rapid penetration of the current density during ramp up to achieve access to q_{min}>>1 at the end of the current ramp up. It was found that a 15 minute HeGDC between discharges was needed for reproducible timing of the L-H transition. Shorter HeGDC applications were found to delay the L-H transition, and may eventually result in a higher L-H power threshold by mid or latter part of run day. Fig. 2 shows the time of the L-H transition moves earlier in the discharge as the duration of the applied GDC is increased.

Fig. 3 compares the density rise for D, LSN, NBI discharges after the application 15 minutes of HeGDC between discharges and a technique with a 5 minute HeGDC preceding and following by a double null diverted (DND), He, I_p 500 kA, Ohmic conditioning discharge. Preceding D discharges with He conditioning discharges provided better density control than only preceding the D discharges with HeGDC. This provides a prescription for slowing the rise in density during ramp up and improving density control.

4. Comparison of short morning boronization and between discharge boronization

The standard NSTX boronizations have applied ~10 g in ~140 minutes, at a rate of one per 2 to 3 weeks (after 300-400 discharges) [6]. Experiments were performed to investigate ways that might stabilize conditions between boronizations, and when conditions are good to determine if they could be improved. These experiments focused on the following questions: "Is a short morning boronization (prior to daily operation) sufficient? If morning boronization is good, is between discharge boronization even better? Does more frequent, shorter boronization improve reproducibility?".

Morning and between discharge boronization were tested about midway between 2 standard boronizations. In order to determine the optimal balance between the duration of boronization, the required HeGDC for desorbing the codeposited deuterium, and the subsequent fiducial performance, 5 short boronizations were performed, ranging in duration from 1 minute to 17 minutes followed by HeGDC applications ranging from 5 to 30 mins.

Fig. 4 shows the relative luminosities following a 17 min morning boronization followed by a 17 min HeGDC and a 15 min boronization followed by a 30 min HeGDC using high performance LSN NBI fiducials. It was found that the luminosity ratios for Da/BII measured at 0.250 sec exhibited the largest fraction change. The BII/CIII luminosity ratio was relatively constant. This may be due to the signals measured both then fresh and residual passivated products (B and C) from previous standard boronizations, and hence, sampled approximately the same deposition stoichiometry. Fig. 5 shows the experimental sequence used for comparing the effect of various short boronizations, different durations of HeGDC, and Helium conditioning discharges using DND NB fiducials. Preceding the D discharges with He discharge conditioning was more effective than HeGDC alone in restoring good conditions. The resultant conditions were later used to produce the LSN discharges with the highest stored energies for a 2 NBI discharges to date (~300 kJ, τ_E ~ 45-50 msec).

5. Conclusions

It was found that boronization on hot surfaces yields a significant improvement in initial operating conditions (lower recycling, lower impurity luminosities, earlier L-H transitions, longer I_p flattops, higher stored energies) relative to boronization on cold surfaces, but that the duration of the improved operating conditions following hot and cold boronization was comparable as fluence to the wall increased with succeeding discharges. A 15 min HeGDC between discharges was needed for reproducible L-H transition timing. Brief morning boronization followed by a comparable duration of applied HeGDC restored and enhanced good operating conditions. Additional short boronization between discharges with relatively good operating conditions produced no improvement. Between discharge boronization increases duty cycle due to the need to apply HeGDC for a sufficient duration to remove codeposited D_2. Remaining questions involve using between discharge sample analysis to measure changes in microstructure as fluence increases, determining the most sensitive fiducial discharges and the optimal figures of merit for determining the frequency of applying morning boronization. In addition, more work is needed to determine the optimal balance between the frequency of applying boronization, the amount of boronization (duration), and the duration of the succeeding HeGDC for reproducible operating conditions and accessing high performance regimes.

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Figure Captions

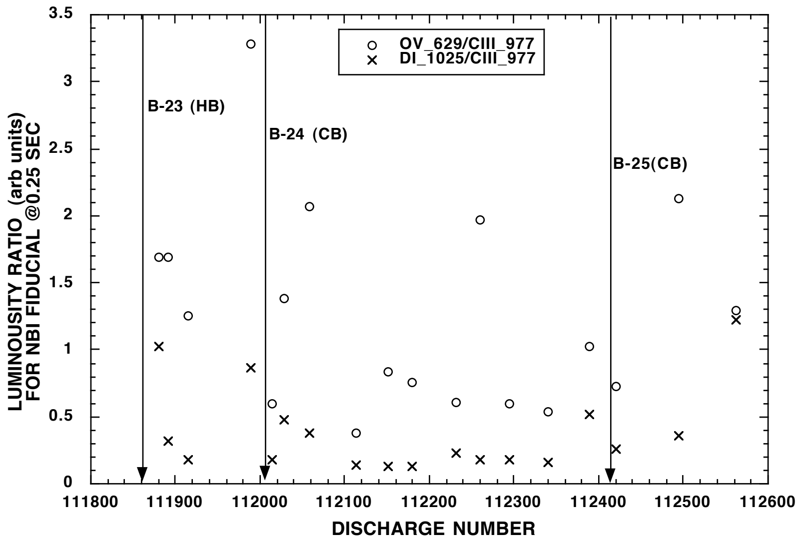
Fig. 1 Core luminosity ratios for LSN NB fiducial discharges after hot (B-23) and cold (B-24, B-25) boronization.

Fig. 2 The change in time (sec) of the L-H transition from the L-H transition in the preceding discharge. The L-H transition moves earlier in the discharge as the duration of the applied HeGDC is increased.

Fig. 3 Comparison of the line integrated density (cm^{-2}) rises for D LSN, fiducial discharges preceded and succeeded by different durations of HeGDC and a He conditioning discharge. Both discharges transitioned to H-mode, but the discharge preceded by the He conditioning discharge had a lower density rise which caused a locked mode (rare in H-modes).

Fig. 4 Relative change in luminosity ratios following short boronizations followed by a comparable duration of HeGDC.

Fig. 5 Conditioning sequence for comparing the effect of various short boronizations, different durations of HeGDC and Helium conditioning discharges using DND NB fiducials.



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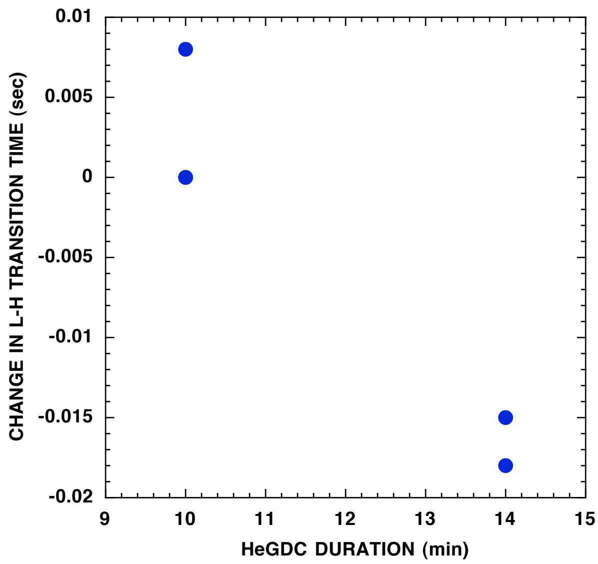

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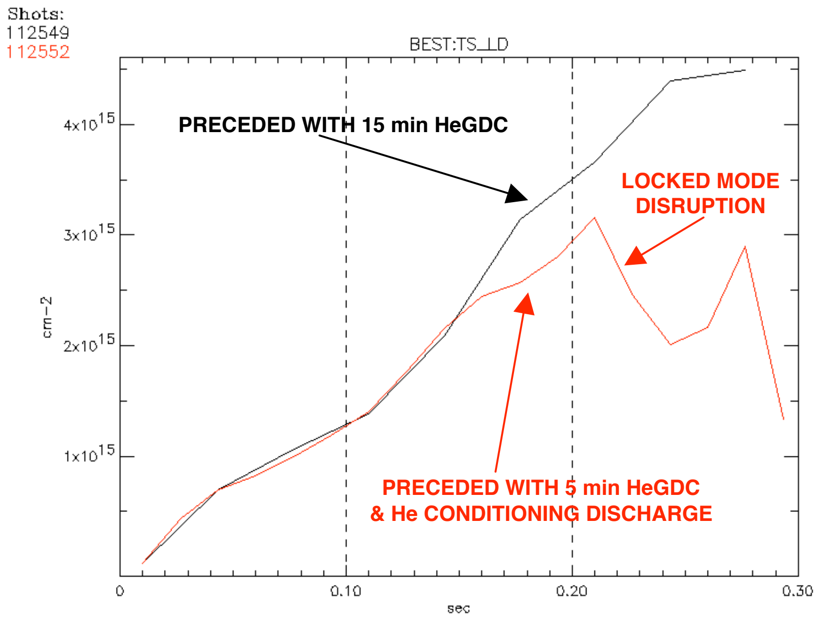

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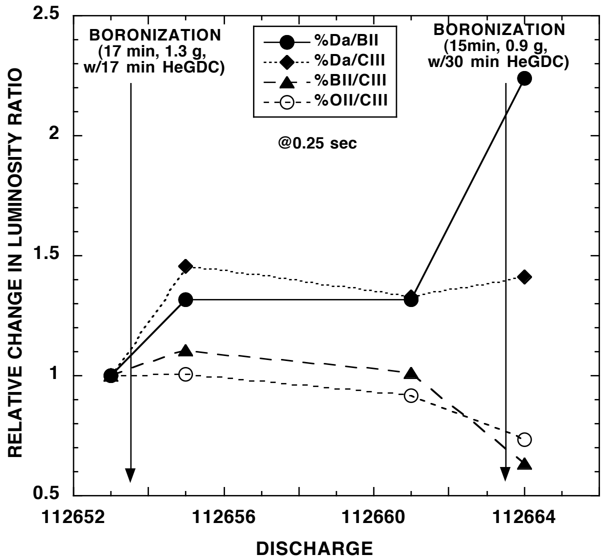
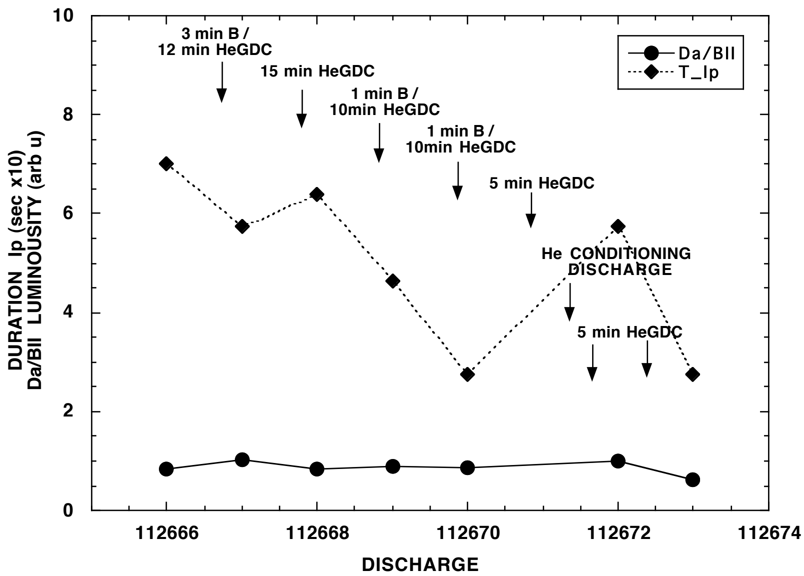


Fig. 4 Relative change in luminosity ratios following short boronizations followed by a comparable duration of HeGDC.



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