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ABSTRACT

A glow discharge technique has been developed and applied to the conditioning of the large (38 m^3) Poloidal Divertor Experiment (PDX) vacuum vessel. The discharge parameters and working gas (H_2) were chosen to maximize C and O removal and minimize metal sputtering. The glow discharge was produced by biasing one or two internal anodes at 400 V to sustain a discharge current of 2-4 A per anode. Purified H_2 at a pressure of 3×10^{-2} torr was flowed through PDX at $\sim 10 \text{ t-l/s}$. The effectiveness of the glow discharge conditioning was monitored by measuring impurity gas (CH_4 , C_2H_4 , and CO) exhaust rates by mass spectrometry and C and O surface removal rates by in-situ AES and XPS. Initial glow discharge operation was accompanied by frequent arcing which subsequently decreased with time. Low Z_{eff} (≈ 2) high power discharges were obtained in PDX after 120 hours of glow discharge treatment, during which more than 100 equivalent monolayers of C and O were removed from the vessel.

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INTRODUCTION

The vacuum vessel for the Poloidal Divertor Experiment (PDX) tokamak is one of the largest and most complex vacuum vessels built for any purpose.¹ The internal volume of the vessel. (38 m³) contains considerable internal structure, such as divertor coils, divertor plates, magnetic loops, cooling tubes, cryo-panels, and liner plates. Much of this structure is not accessible to cleaning by "standard" discharge cleaning procedures which have been developed for tokamaks.² Our earlier studies of discharge cleaning on PLT³ have shown that the most efficient impurity removal from a test probe occurred when the probe intercepted ion flux near or within the radius of the plasma limiter, and the efficiency fell significantly as the probe was retracted to the wall. Thus, if standard discharge cleaning techniques were applied to PDX, then only the relatively small area surrounding the central plasma volume would be cleaned, leaving the majority of the vessel surface area in the divertor and burial chambers unaffected. For this reason we decided to investigate the use of glow discharge conditioning (GDC) which allows for plasma contact in all areas of the PDX vacuum vessel.

The application of glow discharge techniques to reduce hydrocarbon surface contamination and outgassing loads of vacuum vessels is well known.⁴⁻⁶ Generally, in all metal systems, glow discharges are applied with an internal anode, and the vacuum vessel is substituted for the cathode, subjecting the vessel wall to reactive neutral and ion bombardment. For example, ultra-high

vacuum conditions, concomitant with very low electron and ion desorption coefficients, were achieved in the stainless steel vacuum vessel of the CERN Intersecting Storage Ring through the use of argon glow discharge conditioning.^{6,7} Glow discharge techniques have been applied to a number of tokamaks (T-11 and T-12 in the USSR,^{8,9} TFR-600 in France,¹⁰ MACROTOR at U.C.L.A.,¹¹ and ISX-B at O.R.N.L.¹²), but usually in conjunction with other discharge cleaning procedures.

We report on a particular glow discharge procedure which was developed for the initial conditioning of the PDX vacuum vessel.¹³ Our primary purpose was to maximize the removal of carbon and oxygen surface contaminants by the vacuum pumping system while minimizing sputtering of metals because of sensitive internal hardware. The resulting procedure, involving a d.c., dynamically-pumped glow discharge in purified H₂, met this primary aim. In addition, there were secondary benefits to this type of treatment: unipolar arc conditioning of all exposed surfaces¹⁴; near-optimum preparation of the burial chamber surfaces for subsequent adherence of sublimated Ti films¹⁵; and minimization of non-hydrogenic outgassing.⁵

EXPERIMENTAL PROCEDURE

During the initial operating period for PDX (Jan.-April 1979) and for the data presented in this paper, none of the planned Ti liners were installed in the vacuum vessel. Therefore, most of the internal surface area of PDX was the 305L/304L stainless steel of the vacuum vessel, divertor coils, coil supports, and

cryopanel, with an estimated total surface area of 180 m^2 . In addition, 5 m^2 of Al panels were exposed in the upper and lower domes (burial chambers) of the vacuum vessel.

A schematic diagram of the PDX vacuum system and related gas-handling equipment is shown in Fig. 1. The torus vacuum system includes four 1500 l/s turbomolecular pumps which provide a net H_2 pumping speed of 2600 l/s at the torus. Residual gas spectra, outgassing behavior, and the production of residual gases during GDC are monitored by a differentially-pumped RGA which is calibrated against a capacitance manometer for each gas of interest.

A simple electrical arrangement was used to produce the glow discharge. Two stainless steel anodes, each with an area of 300 cm^2 , were fabricated from 0.25 mm sheet stock and inserted within the vacuum vessel at the midplane through a diagnostic port. Cu conductors (6 mm dia.) supporting the anodes were insulated with alumina sleeving to prevent breakdown along the conductor. Each anode was connected to a $0\text{-}500 \text{ V}$, 5 A , d.c. power supply through a 50Ω load resistor. The negative side of the supply and vacuum vessel were grounded.

In addition to the aforementioned RGA, several other diagnostics are available on the torus to monitor the progress of GDC. In-situ surface analysis of stainless steel samples exposed to GDC are obtained using a surface analysis station¹⁶ installed on the torus-midplane 90° toroidally from the primary anode location. The samples are in the form of 1 cm wide, 0.07 cm thick, stainless steel tape. Within the torus, a cylindrical shield with two,

0.35 cm diameter apertures, exposes different areas of the tape parallel or antiparallel to the toroidal magnetic field direction. The radial position of the exposed area could be varied from 38 cm to 90 cm relative to the center of the minor cross section. (The nominal minor radius of the PDX vacuum vessel wall is 74 cm and the inner radius of the Ti limiters is 45 cm.) After exposure to a discharge, the affected sample area can be translated to the analysis chamber for Auger Electron Spectroscopy (AES) and X-ray Photoelectron Spectroscopy (XPS) analysis.

A quartz-crystal thin film monitor was located near the position of the surface analysis station to quantify any deposition of sputtered metal by the glow discharge. Langmuir probes for floating potential, ion saturation, and T_e measurements are located at the torus-midplane and upper burial chamber. Lastly, spectroscopic measurements are available to measure impurity radiation in tokamak discharges that follow the application of GDC.

RESULTS

Discharge Characteristics

Discharge parameters were chosen to minimize sputtering of metal from the PDX vessel by maximizing the gas pressure within the constraint of the choke pressure of the turbopumps. Tests performed in a 100 liter test chamber showed that the equivalent of 50 monolayers of surface material would be removed from stainless steel by exposure to a dose of $\sim 10^{18}$ - 10^{19} ions/cm² from a glow discharge maintained by anode voltage of ~ 300 V at a pressure of 10^{-2} torr. These parameters were the starting conditions for

the first discharges produced in the PDX vessel. Initially, both anodes were used. A discharge could be initiated easily at 10^{-1} torr and maintained as the pressure decreased to $1-5 \times 10^{-3}$ torr, depending on the gas specie. At the chosen operating pressure, 3×10^{-2} torr, 2-4 A were drawn per anode, and the sum of the voltage drop across the discharge and the 50 Ω load resistor was typically 400 V. Under these conditions, floating potentials of 100-200 V were measured on both Langmuir probes and the surface analysis probe when they were introduced into the plasma column. The initial current drain of the discharge was erratic because of frequent arcing noted on all exposed surfaces. Also during this initial period, the spatial distribution of the discharge, as judged by the luminosity of the positive column, was not uniform. However, the frequency of arcing dropped by more than a factor of 100 during the initial 120 hour conditioning period. As the arcing frequency dropped, the discharge became more quiescent and eventually filled the PDX vessel uniformly. Once the quiescent period was attained, only one anode was used for subsequent PDX conditioning.

Residual Gas Analysis

The choice of the discharge gas and operating pressure was based on mass spectrometry of the residual gases produced by the glow discharge. Trial discharges were initiated in PDX with the following gases: N_2 , O_2 , Ne, H_2 , and Ne/ H_2 mixtures. Discharges in H_2 or O_2 produced the most significant reaction products that were considered removable by the (turbomolecular-pump) vacuum

system: CH_4 , CO , and C_2H_4 were produced by the H_2 discharge; and CO and CO_2 were produced by the O_2 discharge.

After determining that the carbon-containing residual gas production was approximately equal for H_2 and O_2 discharges, we decided to optimize the H_2 discharges for PDX conditioning because of several anticipated problems with use of O_2 discharges:

- 1) O_2 GDC would probably aggravate the surface oxygen impurity problem, unless followed by a gas discharge which would reduce oxides.
- 2) O_2 (or any heavy, non-hydrogenic gas) is more likely to cause sputtering of the vacuum vessel metal;
- 3) O_2 (or any non-hydrogenic gas) represents a potential plasma impurity if subsequent outgassing rates following GDC are enhanced.⁵

The optimized H_2 glow discharge, at a torus pressure of 3×10^{-2} torr, was maintained by a 10 torr-liter/sec flow of H_2 exhausting through two of the torus turbomolecular pumps. Even at the relatively high inlet pressure of 3×10^{-2} torr, the loading of H_2 is insufficient to affect the rotor speed, allowing the pumps to be operated unthrottled. However, the measured net H_2 pumping speed per pump does decrease from 650 l/s at pressures $\leq 1 \times 10^{-3}$ torr to 170 l/s at 3×10^{-2} torr. No significant variation was seen in residual gas production as a function of the discharge current for the limited range (2-10 A) that was investigated.

Figure 2 shows the time dependence of the CH_4 (16 amu) and $\text{CO/C}_2\text{H}_4$ (28 amu) residual gas signals during the application of the H_2 glow discharge. The initial partial pressures of CH_4 , CO ,

and C_2H_4 were $>10^{-4}$ torr. For the 120 hours of non-continuous exposure to the discharge, residual gas pressures decreased with a roughly $1/t$ dependence. Using the measured pumping speeds for the heavy gases in the presence of the 3×10^{-2} torr H_2 background flow, the initial impurity exhaust rate was 0.17 torr-liters s^{-1} (6.0×10^{18} molecules s^{-1}), and the time integrated removal of CH_4 was 3500 torr-liters (1.2×10^{23} molecules) and for CO/C_2H_4 , 1300 torr-liters (4.7×10^{22} molecules) for the first 100 hours of GDC exposure. From measurements of CO and C_2H_4 cracking patterns in the RGA ion source, we estimate that $\sim 50\%$ of the 28 amu signal is due to C_2H_4 . Therefore, the total number of carbon atoms removed from the vessel was 1.9×10^{23} , and the number of oxygen atoms removed (by CO only) was 2.4×10^{22} .

The behavior of H_2O during the H_2 glow discharge is not yet understood. Observed increases in H_2O partial pressure in the differentially-pumped RGA were attributed to the reaction of the high background pressure of H_2 ($\sim 1 \times 10^{-4}$ torr) with the RGA ion source.¹⁷ No gaseous H_2O produced by the glow discharge was detected above this increased RGA background level. However, H_2O is removed from the vacuum vessel in some form by the glow discharge process since the measured H_2O outgassing rates for the PDX vessel decreased from 4×10^{-10} torr-liters/cm².s to 2×10^{-12} torr-liters/cm².s during the glow discharge conditioning period.

Base pressures during the conditioning period were within the range $(2-7) \times 10^{-7}$ torr with only turbomolecular pumping and depended on the leak-rate (typically $\sim 2 \times 10^{-4}$ torr-liters/s),

and the H_2 outgassing rate which is enhanced by both glow discharge and high power tokamak discharges.

Surface Analysis

The gas-phase removal rates can be compared to the observed changes in surface composition of stainless steel samples exposed to the glow discharge conditioning. Figure 3 shows the change in elemental composition of stainless steel as function of exposure to the H_2 glow discharge at a radius of 60 cm in PDK. The initial composition is characteristic of stainless steel that has received no specific surface treatments, i.e., the passivation oxide is covered with a hydrocarbon layer.¹⁸ Most of this hydrocarbon layer is removed by the GDC by the time of the first analysis point (≤ 2 hrs) corresponding to an initial surface carbon removal rate of $\geq (8 \pm 3) \times 10^{11} \text{ cm}^2 \cdot \text{s}^{-1}$. For exposures larger than two hours little further change in surface carbon appears, but there is reduction in the oxygen and the minor surface contaminants Cl and S. Somewhat more efficient cleaning is noted for the sample area exposed in the toroidal direction which faces the GDC anode; there is more Fe, less O, and no detectable S or Cl. (≤ 0.5 atomic %).

XPS analysis of the GDC exposed samples confirmed the efficient removal of the C contamination layer (intensities of the C_{1s} transition decreased by a factor of five), and also showed that a partial reduction of the Fe oxide layer occurs via hydrolysis. The oxygen removal from the surface may occur by subsequent decomposition of the iron hydroxides with desorption

of water. No change was observed in the chemical state of the more stable chromium oxide. A more detailed discussion of the surface chemistry of the GDC-exposed samples as deduced from XPS analysis appears in a companion paper.¹⁹

There was no significant transport of metals by the GDC plasma as determined by the following observations:

- 1) after 8 hr exposures to GDC no detectable Ti or Al (from the limiters and shields, respectively) were seen on the surface analysis probe; and
- 2) the thin film monitor at the vessel midplane detected less than the equivalent of $\approx 1 \text{ \AA}$ of total deposition of an Fe-density material.

Measurements with the surface analysis probe show that GDC is able to efficiently clean recessed areas of the vacuum vessel. The radial dependence of cleaning efficiency was not measured during the initial PDX experiments. However, Fig. 4 shows such a measurement, using a stainless steel probe exposed to similar H_2 glow discharge conditions in PLT.²⁰ These results can be compared with previous measurements of the radial dependence of tokamak-type discharge cleaning in PLT (see Fig. 5 of Reference 3) which show a substantial (x30) drop in cleaning efficiency as the surface probe is retracted toward the wall position (50 cm). Also shown in Fig. 4 is the radial dependence of the floating potential and collected ion current for the surface probe. We observed an order of magnitude decrease in cleaning efficiency if the surface probe was introduced into the glow discharge floating, rather than grounded, with respect to the vacuum vessel.

High Power Plasma Conditions After GDC

After 120 hours of GDC the impurity levels of the resulting high power tokamak discharges were quite low.¹³ The effective charge (Z_{eff}) as calculated from the plasma resistivity and temperature profiles was $Z_{\text{eff}} \approx 2.5$. Values of Z_{eff} determined from soft X-ray continua and spectroscopic impurity measurements gave similar values. No specific problems were encountered due to the GDC procedures, such as excessive H_2 outgassing of the vessel or H_2 -loading of the Ti limiters.

DISCUSSION

The H_2 glow discharge process which was developed for the initial conditioning of the PDX vessel met our stipulated goal: the removal of carbon and oxygen (and lesser constituent) surface contaminants from all inner surfaces of the vacuum vessel. After 100 hrs of GDC 1.9×10^{23} carbon atoms and 2.4×10^{22} oxygen atoms (counting CO only) were removed from the vacuum vessel. This represents the removal of the order of 100 monolayers averaged over the surface area of the vessel. In addition, we interpret the observed decrease in the frequency of arcing during GDC exposure as a beneficial effect since the number of sites susceptible to unipolar arcing during high power discharges is probably reduced.¹⁴ (Unipolar arcing is believed to be a major source of metal impurities in tokamak discharges.²¹) There were no deleterious effects of GDC, such as detectable transport of metals around the torus or excessive H_2 loading of the internal structures. The end result of the GDC process was the attainment

of low Z_{eff} , high power discharges in a relatively short time for the initiation of a new fusion device.

Further studies are needed to optimize the GDC process for tokamaks and to understand the mechanisms responsible for the surface cleaning. We expected that because of the relatively high H_2 pressure, that reactive neutral species (H , H_2^*) would play an important role in the observed surface reactions during GDC. However, the substantial difference in cleaning efficiency noted between floating and grounded surface probes (see discussion of Fig. 4) indicates that energetic ions (accelerated by the cathode fall potential) play the dominant role. We note that in Govier's and McCracken's study of rare gas glow discharges⁵ the cleaning effectiveness (as determined by residual gas outgassing rates) was correlated with the energy distribution of the ion flux reaching the wall. More effective cleaning was attained with larger ion fluxes at the cathode fall potential. If one assumes uniform deposition of the discharge current to the wall, then the estimated upper limit for the ion flux in PDX during GDC is $(7 \pm 3) \times 10^{12} \text{ cm}^{-2} \cdot \text{s}^{-1}$. An effective reaction probability with surface carbon atoms of the order of 10^{-1} is required to account for the surface carbon removal rate $(8 \pm 3) \times 10^{11} \text{ cm}^{-2} \cdot \text{s}^{-1}$ entirely by ion bombardment. This rough estimate is not significantly larger than the measured erosion yields for low energy (250-500 eV) H^+ impact on carbon surfaces at 300 K (0.03-0.04 atoms/ion).²²

The $1/t_d$ dependence observed in the residual gas production vs glow discharge time t_d (Fig. 2) can be understood in terms of

the following argument:

If the source of C and O for the surface reactions that produce CH_4 , C_2H_4 , CO, and H_2O were simple bulk diffusion from the oxide layer on the stainless steel surface, then a $t^{-1/2}$ dependence would be observed for times up to $t_m = \frac{\pi}{D} \left(\frac{L}{8}\right)^2$ followed by a dependence proportional to $\exp(-t/2t_m)$ for longer times.²³ (Here D is an average diffusion constant and L is an average oxide thickness.) A similar exponential dependence would be observed if the rate limiting step were desorption from an adsorbed monolayer with a single-valued activation energy for desorption.²⁴ Dayton²⁵ has shown that a $1/t$ dependence applies for the diffusive loss of H_2O from the oxide layer on stainless steel because a distribution of values for the diffusion constant is necessary to account for the variable length and diameter of pores which govern diffusion within the oxide. If such a mechanism is the applicable rate-limiting step during GDC, then a simultaneous mild bakeout of the vacuum vessel wall should improve the efficiency by accelerating the diffusion of contaminants in the oxide layer.

Other mechanisms could account for the observed time dependence, such as non-uniform current density distributions.

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- ¹D. K. Owens, J. Vac. Sci. and Technol. 17, (1980)
- ²L. Oren and R. J. Taylor, Nucl. Fusion 17, 1143 (1977).
- ³H. F. Dylla, K. Bol, S. A. Cohen, R. J. Hawryluk, E. B. Meservey, and S. M. Rosshogel, J. Vac. Sci. and Technol. 16, 752 (1979).
- ⁴L. Holland, Vacuum 26, 97 (1976).
- ⁵R. P. Govier and G. M. McCracken, J. Vac. Sci. and Technol. 7, 552 (1970).
- ⁶A. W. Jones, E. Jones, and E. M. Williams, Vacuum 23, 227 (1973).
- ⁷E. Fischer, Jap. J. Appl. Phys. Suppl. 2, 199 (1974).
- ⁸V. Vlasenkov et al., Proc. Inter. Conf. Plasma Physics and Controlled Nuclear Fusion Research (Innsbruck, 1978) IAEA CN-37-C-5.
- ⁹N. N. Brevnov, R. E. Clausing, A. A. Kazachkov, and N. V. Kuznetsov, IAEA Repr. No. 3100, Moscow (1979).
- ¹⁰TFR Group, J. Nucl. Mater. 76 & 77, 587 (1978).
- ¹¹R. J. Taylor, private communication.
- ¹²R. E. Clausing, private communication.
- ¹³D. M. Meade, Proc. Ninth European Conference on Controlled Fusion and Plasma Physics, Oxford, England (Sept. 1979).
- ¹⁴P. Mioduszewski, R. F. Clausing, and L. Heatherly, Proc. of the DOE Workshop on Arcing Phenomena in Fusion Devices, Knoxville, TN (April, 1979) (unpublished).

¹⁵G. M. Martin, unpublished results; see G. M. Martin in Proc. 6th Symposium of the Engineering Problems of Fusion Research (IEEE, San Diego, 1975) p. 823, for related work.

¹⁶S. M. Rossnagel, S. A. Cohen, H. F. Dylla, and Ph. Staib, (submitted to Rev. Sci. Inst.) see related abstract this issue.

¹⁷E. W. Blauth, and H. E. Meyer, Z. angew. Phys. 19, 549 (1965).

¹⁸The stainless steel sample tape was cleaned ultrasonically in ethanol. The PDX vessel was cleaned by rinsing in hot (80C) Na_3PO_4 solution, followed by a rinse in acetone and a hand-wipe with ethanol. All internal hardware for PDX was cleaned ultrasonically in hot Na_3PO_4 solution, followed by an ultrasonic rinse in deionized water. The effect of all three cleaning procedures as determined by AES analysis was to reduce the hydrocarbon contamination which overlays the passivation oxide of the stainless steel. The first two methods usually do not reduce the relative surface carbon coverage to <50 atomic %, whereas the latter method can reduce the carbon coverage to ≈ 10 atomic %, (unpublished data).

¹⁹Ph. Staib, H. F. Dylla, and S. M. Rossnagel, this issue.

²⁰H. F. Dylla, S. A. Cohen, S. M. Rossnagel, G. M. McCracken, and Ph. Staib, Div. of Plasma Physics, American Physical Society Annual Meeting, Boston, MA, (Nov. 1979); 24, 97(1979).

²¹G. M. McCracken and D. H. J. Goodall, Nucl. Fusion 18, 537 (1978).

²²D. M. Mattox, A. W. Mullendore, H. O. Pierson, and D. J. Sharp, 85 & 86, 1127 (1979).

²³B. B. Dayton, Vacuum Symposium Transactions (1959), Pergamon Press, New York (1960), p. 101.

²⁴P. A. Redhead, J. P. Hopson, and E. V. Kornelsen, The Physical Basis of Ultrahigh Vacuum (Chapman and Hall, London, 1968) p. 78.

²⁵B. B. Dayton, Vacuum Symposium Transactions (1961), Pergamon Press, New York (1962) p. 42.

²⁶H. F. Dylla, J. Vac. Sci. and Technol. 15, 734 (1978).

FIGURE CAPTIONS

Fig. 1. Schematic diagram of the PDX vacuum system. External pumping is provided by four 1500 ℓ/s turbomolecular pumps (TMP). Only one complete pumping line is shown for clarity. (The details of the TMP system are described in Ref. 26.) Pumping within the torus is provided by 80 m^2 of Ti sublimation pumping and 0.6 m^2 of liquid nitrogen-cooled cryopanel (not indicated). Gases are admitted to the torus through piezoelectric leak valves from a stainless steel gas manifold (GM). H_2 and D_2 are purified by diffusion through a hot Pd leak. Torus pressure $\geq 10^{-5}$ torr are measured with a capacitance manometer (CM) and pressures $\leq 10^{-3}$ torr are measured with Bayard-Alpert ion gauges (IG). For partial pressure measurements in the range 10^{-11} torr to 10^{-4} torr, valve V_2 connects a residual gas analyzer (RGA) through a large conductance (150 ℓ/s) line to the 46 cm ID torus pumping duct. For measurements from 10^{-4} torr to 10^{-1} torr, V_2 is closed and valve V_1 in a small conductance (0.1 ℓ/s) line is opened to same pumping duct.

Fig. Partial pressures of the primary residual gases (CH_4 at 16 amu, CO and C_2H_4 at 28 amu) produced within the PDX torus during H_2 glow discharge conditioning. The H_2 pressure was 3×10^{-2} torr, and the net pumping speed for the heavy residual gases at this H_2 pressure was $\approx 280 \ell/s$.

Fig. 3. Observed changes in elemental surface composition of a hydrocarbon-covered 304 stainless steel sample as a function of exposure to H_2 glow discharge conditioning in PDX. The sample was exposed at a minor radius of 60 cm with different areas of the sample facing (right side) or opposing (left side) the anode.

Fig. 4. Radial dependence of H_2 glow discharge conditioning. The cleaning efficiency of a 15 minute exposure, as measured by the appearance of increasing Auger signals from the Fe_xO substrate of a hydrocarbon-covered stainless steel sample, is shown as a function of exposure position in the PLT vacuum vessel. Also plotted is the radial dependence of the floating potential and collected ion current for the surface probe. Discharge parameters for the glow discharge in both PDX and PLT were similar.

Fig. 1. 793343

Fig. 2. 793987

Fig. 3. 793921

Fig. 4. 803269