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D.C. GLOW DISCHARGE CLEANING FOR ACCELERATOR*

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ABSTRACT

Average pressure of 1 x 10^{-11} Torr and vacuum stability are necessary for the successful operation of the proton storage rings such as ISABELLE.[1] Vacuum degassing at high temperature and in situ bake-out will reduce the thermooutgassing rate of the beam tubes to $\sim 10^{-13}$ Tℓ/cm^2 sec, therefore achieving the required static pressure. The vacuum instability caused by beam-induced ion desorption can be solved by D.C. glow discharge cleaning. With evidence from this study, the present understanding of glow discharge in a cylindrically symmetric geometry is reviewed. Argon and argon/oxygen mixture serve as plasmas in the glow. The role of oxygen in cleaning the beam tubes during the glow discharge is demonstrated experimentally. Glow discharge cleaning with and without bake-out is also studied.

INTRODUCTION

The beam vacuum system of ISABELLE (Intersecting Storage Accelerator), currently under construction at Brookhaven National Laboratory, is essentially an eight kilometer, 88 millimeter diameter stainless steel (s.s.) tube. All the s.s. tubes have been vacuum degassed at high temperature to obtain a low outgassing rate of 10^{-13} Torr-liter/cm^2 sec. The designed static pressure of ≤ 1 x 10^{-11} Torr has been routinely obtained in an engineering model 40 meters long.[2] This low average pressure is the result of high pumping speed together with low outgassing rate of strongly bonded adsorbates at the surface. When the ISR, a European intersecting ring, is in operation the interior wall of the vacuum chamber is subjected to ion bombardment, which desorbes the strongly bonded adsorbates. This vacuum instability called pressure bump caused by this ion desorption determines the maximum current that can be stored.

D.C. glow discharge cleaning has been employed successfully in the CERN[3,4] ISR as an economical solution to these beam induced pressure bumps. This final surface treatment has been adopted for the beam vacuum system of ISABELLE. With experimental evidence, this paper will review the present understanding of glow discharge in a cylindrically symmetric geometry. Argon, oxygen and their mixture serve as a plasma in the glow. The role of O_2 in cleaning the s.s. tube during the glow discharge of Ar (10% O_2) will be emphasized. The relations among glow discharge voltage, current and plasma pressure are reported. Most of the experimental data presented in this paper are based on a prototype laboratory setup which has an exact dimension as final setup for cleaning ISABELLE's beam tubes. Discussion about a bake-out system using radiation heat from center tungsten wire as a hot filament will also be given.

THEORY

Although the glow discharge has not been completely understood, the fundamental theoretical backbone has graduately evolved during the last century. The basic characteristics of glow discharge is illustrated in Fig. 1 which is taken directly from Papoular's classical book.[5] A self-sustaining electric discharge is the major ingredient of its theoretical framework. For glow to be self-sustained, the production of electrons must be equal to or larger than the consumption of electrons. A lot of experimental evidence has been accumulated to support the various mechanism

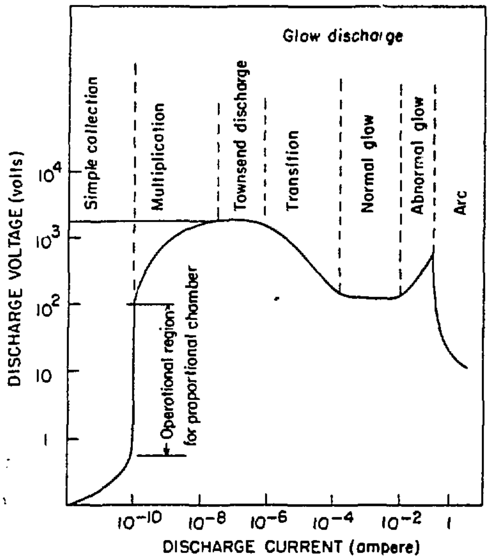

Figure 1. Schematic characteristics for a gaseous discharge.

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for electron production such as α, β, γ, δ, ε effects.[5,6] But the transition from Townsend discharge[5] to glow discharge is still lack of sound physical explanation and it is generally true for other critical phenomena.

In this paper we are concentrated on the cleaning aspect of the glow discharge. The idea of using glow discharge for cleaning the surface to obtain ultrahigh vacuum conditions or to provide a clean surface for surface study has prevailed for sometime even at the early developing stage of surface science. Cleaning is achieved by bombarding the surface with energetic heavy ion projectiles. These high energy particles impact on the surface and transfer its momentum to shake loose the unwanted absorbates. By choosing the right plasma, one can preferentially etch out some elements and leave the others unscratched. This technique has become extremely popular in semiconductor industry under the name of sputter etching. CERN, was the first to use glow discharge cleaning to resolve the ion desorption problem from beam induced pressure bumps in ISR.[3,4] The glow discharge process cleans the beam tubes to such an extent that the ion desorption yield[7] is generally smaller than 1 or ion desorption energy of unit yield is larger than the energy of incoming ions. Glow discharge cleaning at 300°C using ∼10μ Ar/10% O_2 as plasma has been succesfully employed by CERN-ISR to reduce the ion desorption yields and the beam induced pressure bumps. The detail investigation on this proven method is carried out in this laboratory in the light of hoping to understand the mechanism of its success.

EXPERIMENT

The glow discharge setup used in our studies is shown schematically in Fig. 2, which will also be used to clean ISABELLE's 1100 17' long beam tubes. It consists of three parts; the center beam tube; the cold bore (will be at 4°K when the beam tube is inserted in the superconducting magnet) used as an outer vacuum jacket; and glow discharge fixtures. The beam tube is 3.5" O.D. 17' long 304 LN stainless steel (s.s.) tube with Cu plated on the outer surface. The cold bore tube is 4.65" O.D s.s tube with end fixtures to accommodate the glow discharge fixtures which have high voltage feedthroughs, insulation, tungstun wire and springs. The 18' long tungsten wire is used as heating filament during bake-out and as anode during glow discharge; and is suspended between two heavy duty springs to take up the ∼2" thermal expansion of tungstun wire as 200 watts of power passes through it. Thirty-six layers of superinsulation are wrapped between cold bore and beam tube. It takes 6 hrs. for 200 watts (5A) input to reach 300°C in our present configuration. Time required to reach 300°C can be shorted by raising the input power with a risk of embrittling the tungsten wire.

Power supply used for bake-out system is manufactured by STACO model EJ901V isolation power supply. This is a safety precaution in the case of the wire sag and touching to the tube which is grounded to the outside world. Ultac ion pump power supply Model 60-160 controlled by an 8 kW variac was used to supply the D.C. power required for glow discharge cleaning.

The Ar or Ar/10% O_2 mixture is introduced into the system at a controlled leak rate, the the D.C. voltage is applied to initiate glow discharge after the selected bake-out temperature is established. The characteristics of the glow is determined by varying the glow voltage, current and plasma pressure. Varian mass spectrometer (VGA-100) is used to monitor the gas components before, during and after the glow discharge.

RESULTS AND DISCUSSION

The characteristics of the glow in our cylindrical geometry is studied by following the glow voltage vs. current at selected plasma pressure. Figure 3 shows the V vs. I curve at Ar/10% O_2 plasma pressure of ∼5μ. The transition zone from Townsend discharge to glow discharge, as shown here, is rapid and uncontrollable. Glow at ∼10 mA range probably belongs to normal glow while at >100 mA range the abnormal glow. Little

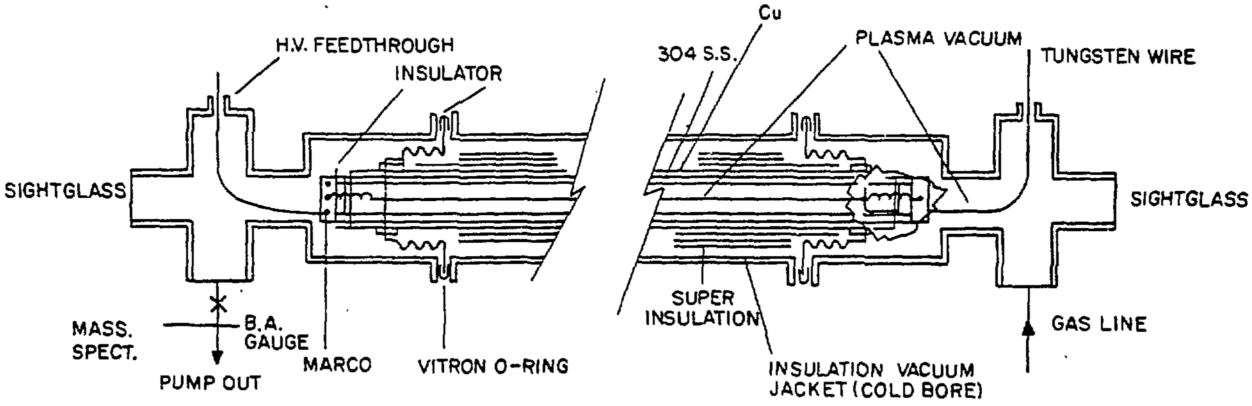

Figure 2. Experimental setup for glow discharge cleaning of ISABELLE beam tubes.

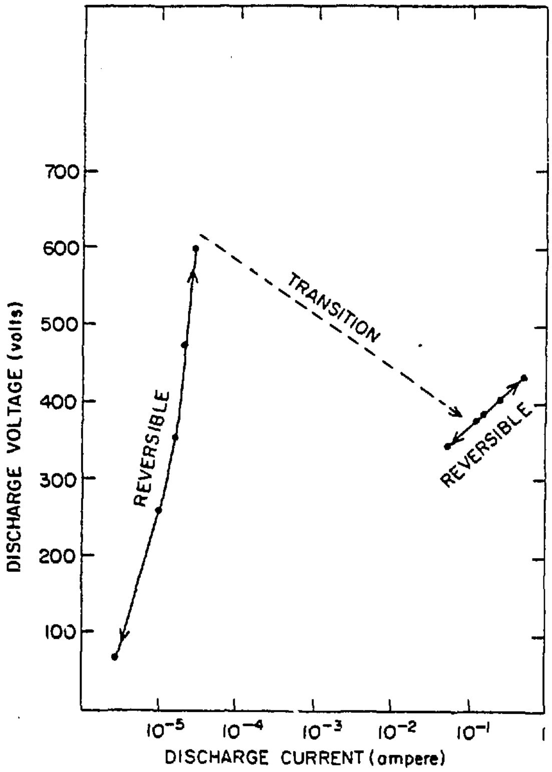

Figure 3. The discharge voltage versus current at Ar/10% O_2 plasma pressure of ~5μ.

difference in V vs. I is seen between pure Ar or Ar/O_2 mixture as plasma. No self-sustained glow is observed for plasma pressure less than 2μ. At higher pressure the Townsend discharge voltage becomes smaller, and the transition zone between Townsend discharge and glow discharge becomes narrower. The transition zone becomes unnoticeable at plasma pressure (Ar or Ar/O_2) of ~30μ.

The main theme of this work is to establish the optimum glow discharge condition (such as the temperature, pressure and current) for successful cleaning of accelerator beam tubes. Fig. 4 shows the thermal characteristics of the glow discharge setup. At the beginning of the bake-out cycle, both pressure and temperature rise steeply. This shows the effectiveness of 200 watts input power to outgas the beam tube and the merit of 36 layers of superinsulation for thermal insulation. This follows by a less steep rise in temperature and graduate drop in pressure. In this region, the pressure ranges from few microns to tens of microns, the gas convection leads the small heat loss. Finally, the pumping speed takes over the outgassing, and gas convection ceases to be a problem, but the heat loss due to the not well-insulated ends takes over. The flatness of the temperature curve at the end of 24 hour bake-out indicates this symptom.

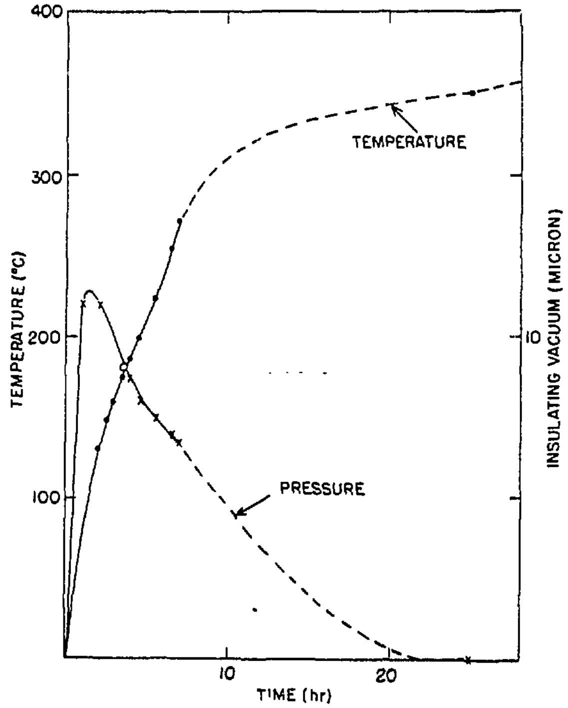

Figure 4. Pressure and temperature versus time during bake-out with 200 watt input power.

The interesting feature of Ar/O_2 mixtures as a plasma for glow discharge cleaning is the disappearance of O_2. This is explained by the dissociation of O_2^+ into oxygen atom which reacts with C on the surface of the s.s. beam tube to produce CO. Of course, the active oxygen atom will also react with the metallic atom at the surface to form oxide. In vacuum term, this means the O_2 will be effectively pumped to the wall in glow discharge condition. To maintain sufficiency of oxygen to effectively remove the carbon (organic contamination), the throughput of the incoming gas must be larger or equal to the output of the glow discharge current. Fig. 5 illustrates this point. At 100 mA glow discharge current, the input gas throughput is slightly smaller than output glow discharge current. The mass spectrum shows the slight decrease of O_2 peak. While at 500 mA, the disappearance of O_2 peak tells us one should increase the gas throughput to ensure sufficient O_2 supply. The increase in CO peak in Fig. 5 gives the solid evidence of chemical reaction between surface carbon and atomic oxygen. Although small amounts of Ar^+ ion do implant into the wall, the intensity of Ar in mass spectra remains fairly constant at different glow current.

The glow discharge in a closed system with some initial fix pressure at different temperatures indicates strong temperature dependent of the diffusion rate of the implanted Ar. But the

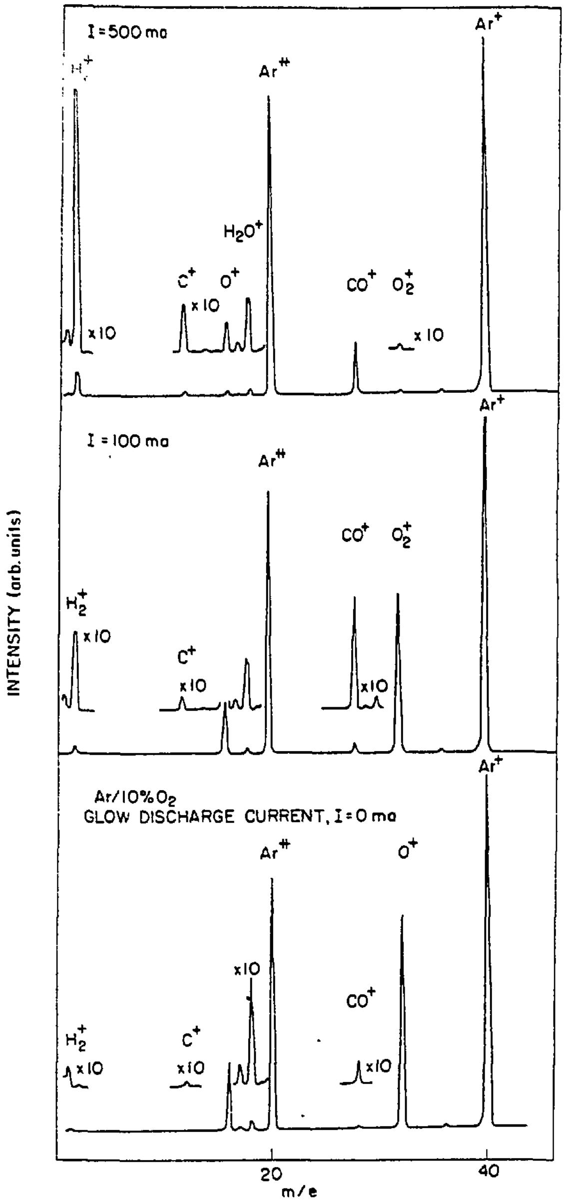

Figure 5. Mass spectra of plasma at different glow discharge current. The Ar/10% O_2 plasma pressure is ∿4.5μ with a throughput of ∿1×10^{-2} T·ℓ/s.

difficulty of controlling the constant temperature during glow discharge makes the evaluation of diffusion rate impossible at this time.

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