A PLASMA GUN DRIVER FOR THE SNS ION SOURCE

R. F. Welton, M. P. Stockli, S.N. Murray, J. Carr and J.R. Carmichael, SNS*, Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN, 37830-6471

Abstract

The original ion source developed for the Spallation Neutron Source* (SNS) was an RF-driven, multi-cusp source based on an internal antenna (plasma – immersed) and designed to produce ~ 40 mA of H^- with a ~7% duty-factor. To date, the ion source has demonstrated very reliable operation during commissioning of the SNS accelerator and early operations at low duty-factors of ~0.1%. Endurance tests performed at high duty-factors ~7% suggest internal antennas are subject to failure effectively limiting lifetime. We are therefore developing RF sources based on external antennas which have comparatively much longer operational lifetimes. Recently, we found the H^- yield from this type of RF source could be dramatically increased with the introduction of streaming plasma particles injected into the primary RF plasma from a hemispherical glow discharge chamber located in the rear of the source. In some cases, a ~50% increase in the H^- beam current was observed. The system also eliminated the need for other plasma ignition systems like a secondary low-power RF generator. This report details the design and operational characteristics of the plasma gun driver.

INTRODUCTION

The Spallation Neutron Source (SNS) is a large multinational user facility dedicated to the study of the dynamics and structure of materials by neutron scattering and is currently beginning operations at Oak Ridge National Laboratory (ORNL) [1,2]. In order to meet the baseline requirement of 1.4 MW of beam power on target, the ion source must inject ~40 mA of H^- (pulse length = 1 ms, repetition rate = 60 Hz) into the LINAC. The SNS power upgrade project will require the injection of ~60 mA at the same pulse length and repetition rate. Depending on the source emittance and pulse uniformity, this can correspond to an ion source current requirement of ~100 mA with a ~7% duty-factor due to losses of higher-emittance beams through the SNS front end [3].

To date, the ion source has been utilized in commissioning the SNS Front-End (FE) both at LBNL [4] and ORNL [5] and for early operations of the SNS [6]. During these campaigns the ion source availability increased from 86% during FE re-commissioning to better than 99% during early operations. Much of this improvement came as a result of improving Low Energy Beam Transport (LEBT) insulator design [7]. Although commissioning at LBNL and ORNL have briefly demonstrated operation at the design goal of 38 mA at duty-factors approaching 7%, the vast majority of these commissioning periods were spent with the ion source operating at very low beam duty-factors of less than 1%.

Endurance tests performed at high duty-factors show internal antennas are subject to failure, effectively limiting lifetime [8]. We are therefore developing RF sources based on external antennas which have comparatively much longer operational lifetimes. A cross sectional view of one such source, the SNS Prototype external antenna source, is shown in Fig. 1. A detailed description can be found in our accompanying article [9].

For years there has been steady progress made in the field of Electron Resonance Ion Sources (ECRIS) for multiply charged ion production by supplementing the primary microwave driven plasma with sources of free electrons: electron guns, biased disks, ceramic wall coatings, etc. See, for example, Ref. 10. Comparatively little work exists on enhancing the yields of lower-frequency RF ion sources using similar techniques [11]. The DESY group employs an ignition source based on a low-power-pulsed glow discharge in order to facilitate rapid ignition of the primary RF-plasma [12]. In this work we explore the possibility of utilizing a simple plasma gun based on a hollow anode glow discharge, not only for plasma ignition but also for H^- yield enhancement. If successful, this would eliminate the need for the current problematic 13MHz plasma ignition system [13] and boost H^- yields closer to our facility goals.

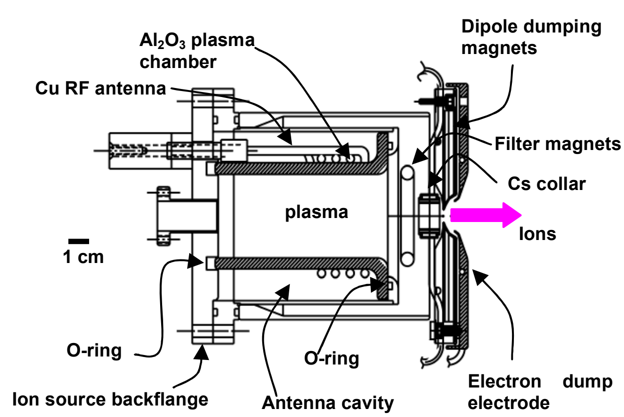

Figure 1: Schematic diagram of the prototype SNS external antenna ion source.

ORNL/SNS is managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract DE-AC05-00OR22725

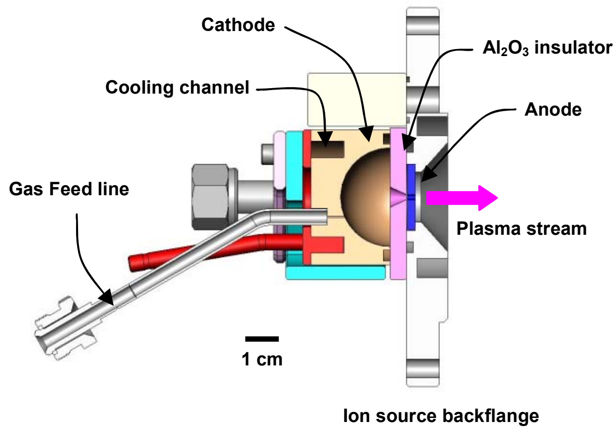

Figure 2: Cross sectional view of the plasma gun.

PLASMA GUN DESIGN AND OPERATING PRINCIPLE

Fig. 2 shows a cross sectional view of the plasma gun. The design is based on a variation of the classical glow-discharge previously referred to as the 'hollow-anode discharge' [14] which later became known as the 'constricted plasma discharge' [15]. Here the emission from a comparatively large cathode surface area is constricted to flow to an anode electrode through a relatively small opening in an insulator or floating electrode. As the discharge current is compressed in the region of the constriction, the anode fall voltage is increased, effectively increasing ionization efficiency leading locally to the formation of relatively dense plasma. Devices operated in this fashion are remarkably efficient at creating small, high-density plasmas ($\sim 10^{11}$ e/cm^3) using very low discharge powers (20-200W) [15]. If the flow constriction is placed near an anode which contains an extraction opening, plasma particles will flow from the discharge chamber. The flow of streaming plasma particles will be enhanced if a pressure gradient is maintained across this extraction opening by gas kinetic expansion of the plasma.

The plasma gun pictured in Fig. 2 employs the above operating principle: A steady-state, DC power supply (1 kV, 1.2 A) is used to supply a negative voltage (0.5-1.0 kV) with respect to ion source potential to the cathode through a 1 kΩ resistor. The anode is maintained at ion source potential. A 45 μF capacitor is connected electrically between the resistor and power supply to shunt RF energy to ion source potential, effectively isolating the plasma gun power supply from RF power. Attaching the capacitor directly to the cathode resulted in unstable operation after ~1 hour of use.

The cathode electrode itself is made of OFHC copper with a direct water cooling channel and large hemispherical emission surface (ϕ = 3.8 cm). High purity H_2 gas is fed from a small opening (ϕ=0.78 mm) in the cathode emission surface. The cathode seats compressively against a high-purity alumina plate (thickness = 6.35 mm) using an o-ring seal. Discharge current is constricted to flow through a conical opening in the alumina (small ϕ=2mm, full angle=50 deg) oriented as shown in the figure. The alumina plate is also compressively affixed to the back flange of the main ion source body by an o-ring seal. Plasma streams into the main ion source chamber through a cylindrical ϕ=2 mm opening in the anode of thickness 3.2 mm.

Fig. 3 shows the Paschen voltage breakdown curve for H_2 gas held at 1 Torr of pressure [16]. Vacuum flow calculations indicate there will be ~1 Torr in the plasma gun discharge chamber and ~ 0.05 Torr in the main ion source plasma chamber during nominal operation with 50 SCCM of H_2 flow. The figure suggests that optimum anode-cathode distance should be ~1-4 cm. We chose a gap of ~3 cm to insure gun operation on the right hand side of the minimum (Stoletow point) of the curve.

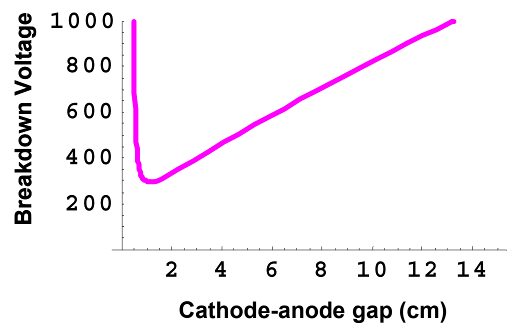

Figure 3: Paschen voltage breakdown curve for a simple glow-discharge calculated for pressures of 1 Torr of H_2.

PLASMA GUN CHARACTERIZATION

The plasma gun shown in Fig. 2 was first characterized on a test chamber operating in the same pressure regime as the ion source: ~1 Torr in the plasma gun and 0.05 Torr in the test chamber when H_2 flow was set to 50 SCCM. The discharge typically ignited with 50-100 SCCM of H_2 flow and discharge voltage of 0.5-1kV. Plasma free streaming from the opening in the anode was collected by a large unbiased plate located 6 cm from this aperture in the test chamber. Fig. 4 shows the characteristic discharge voltage-current curve as well as the extracted current measured on the collector plate. The discharge voltage and current measurement was determined from power supply readings corrected for voltage drop across the 1 kΩ resistor. The current measured on the collector had a net negative charge but is plotted as a positive current for convenient display. These measurements of collected current represent minimum values of the extracted current due to geometrical and collisional transport losses between the anode aperture and collector plate. In addition, the collector plate was unsuppressed against secondary electron emission and therefore likely underestimates the actual extracted current. The plasma gun was then operated continuously for ~500 hours on the test chamber with no observed degradation in performance. The run was then intentionally terminated and a subsequent physical inspection of the gun revealed no visible damage suggesting the actual lifetime is likely much greater than 500 hours.

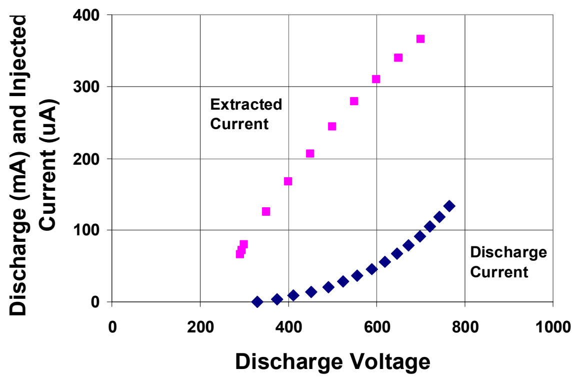

Figure 4: Discharge (anode-cathode) current and extracted current at H_2 flow was 50 SCCM.

Next, the plasma gun was affixed to the rear of the ion source shown in Fig. 1 by replacing the component labeled 'ion source backflange' with the component shown in Fig. 2 with the same name. The construction and operational details of the SNS prototype external antenna source can be found in Ref. 9 in these proceedings. The plasma gun was found to operate in a remarkably stable fashion when used in conjunction with the RF source. During nominal operation the discharge voltage was set to 600 V and both the gun and RF plasmas ignited immediately as soon as RF-power was applied at almost any H_2 flow-rate. Stability and H^- pulse rise times ($\tau < 50\mu s$) were comparable to the original 13 MHz plasma ignition system but free of problematic noise and reliability issues which encumbered that system.

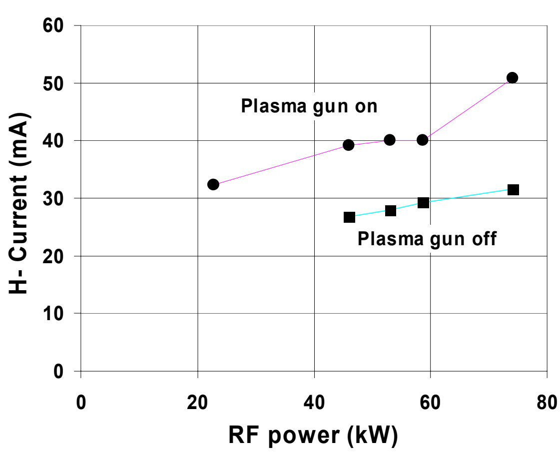

Figure 5: Extracted H^- beam current with and without the plasma gun activated.

Perhaps the most remarkable aspect of this device is the effect on total H^- beam current: Fig. 5 shows H^- current plotted against applied RF power with and without the gun activated. These tests were performed in the air-cooled plasma chamber, limiting the pulse length to ~200 µs, and the plasma gun was operated at 600V and 50 mA of discharge current. The enhancement did not appear to be very sensitive to variations of the discharge voltage of the plasma gun (600-1000V).

DISCUSSION

The observed ~50% increase in H^- beam current could have arisen from several origins. First, the plasma density could have been enhanced by electrons from the plasma gun in the same way ECR sources benefit from low-power electron guns, biased disks, etc. Second, positive ions emitted from the plasma gun have kinetic energies of 5-15 eV and neutrals enter at supersonic velocities, likely in vibrationally excited states [15]. All of these processes are known to enhance H^- production.

REFERENCES

[1] T. Mason, Physics Today, AIP Press, p. 44 May 2006
[2] www.sns.gov
[3] M.P Stockli, "Development of High-Current, High-Duty-Factor H- Injectors", these proceedings
[4] R. Keller, et al., "Commissioning of the SNS Front End Systems at Berkeley Lab", EPAC'02, Paris, France, p. 1025.
[5] S. Henderson, et al, "Status of the SNS Beam Power Upgrade Project", EPAC06, Edinburgh, UK.
[6] A.V. Aleksandrov, "Performance of SNS Front End and Warm Linac", these proceedings.
[7] R.F. Welton et al., "Operation of the SNS Ion Source at High Duty-Factor", EPAC'04, Lucerne, Switzerland.
[8] R.F. Welton, et al., "Advances in the Performance and Understanding of the SNS Ion Source", PAC05
[9] R.F. Welton, et al., "The Development of a High-Power, H^- Ion Source for the SNS based on an External Antenna", these proceedings.
[10] I.G. Brown, "The Physics and Technology of Ion Sources", Wiley-VCH, Weinhiem, Germany 2004
[11] R.F. Welton, et al., "Performance Enhancement of a Compact RF Ion Source by the Injection of Supplemental Electrons", PAC95.
[12] J. Peters, "The Status of the DESY H- Ion Source", LINAC00, Monterey, USA
[13] R.F. Welton, et al., Proceedings of the Tenth International Symposium on the Production and Neutralization of Negative Ions and Beams", AIR Conf. Proc. 763 (2005) p 296.
[14] A. Anders and S. Anders, Plasma Sources Sci. Technol. 4 (1995) 571
[15] A. Anders and M. Kuhn, Rev. Sci. Instrum. 69 (1998) 1340
[16] R. Roth, "Industrial Plasma Engineering", IOP Publishing, London, UK (2001).