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Characterization of a Surface-Flashover Ion Source with 10 – 250 ns Pulse Widths

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Abstract. As a step towards developing an ultra compact D-D neutron source for various defense and homeland security applications, a compact ion source is needed. Towards that end, we are testing a pulsed, surface flashover source, with deuterated titanium films deposited on alumina substrates as the electrodes. An electrochemically-etched mask was used to define the electrode areas on the substrate during the sputtered deposition of the titanium films. Deuterium loading of the films was performed in an all metal-sealed vacuum chamber containing a heated stage. Deuterium ion current from the source was determined by measuring the neutrons produced when the ions impacted a deuterium-loaded target held at -90 kV. As the duration of the arc current is varied, it was observed that the integrated deuteron current per pulse initially increases rapidly, then reaches a maximum near a pulse length of 100 ns.

Keywords: deuterium ion source, surface flashover, arc
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INTRODUCTION

At its most basic, the surface flashover ion source consists of two metal contacts on an insulating substrate placed in a vacuum chamber.¹ The distance between the electrodes and the condition of the insulator determines the breakdown voltage, but after the arc initiates, the voltage collapses to a low value based on the electrode material used.² If a reactive metal is used for the electrodes, and they are loaded with deuterium gas, deuterium ions can be produced during the arc without the addition of a background gas. This eliminates the need to regulate the pressure in the neutron source during operation. As a trade-off, parts of the electrodes are eroded by the arc (predominantly the cathode), and as such, the device has a finite lifetime. However, if the pulse length is kept short, this erosion can be slow, and the source can function for many thousands of pulses. To provide a low initiation voltage, we sought to have a small gap between the electrodes. We decided to use magnetron sputtering to deposit the electrodes on to an alumina substrate through an electrochemically-etched shadow mask in order to provide pure titanium electrodes, and to eliminate any post-deposition processing that would have potentially contaminated them. Any oxide or other contamination has been found to interfere with the uptake of deuterium during the loading process.

After deposition, the coated substrates are separated from their masks and loaded into a vacuum system specifically built for loading films with deuterium or hydrogen. The turbo-pumped system employs all metal seals (including the valve seals) and has a base pressure of 2×10^{-9} Torr. A heated stage within the vacuum chamber was used to bring the substrates to the proper loading temperature. Due to the care in processing and handling the coated substrates, we did not require high-temperature vacuum baking of the substrates prior to loading.

SOURCE FABRICATION

The source consists of titanium electrodes deposited on a 2-cm diameter, 1-mm thick, polished alumina substrate. The shadow mask used to produce the desired pattern was photo-chemically etched out of 410 stainless steel stock, 0.076 mm thick (3 mils) and had a separation between electrodes of 0.127 mm (5 mils). This magnetic grade of stainless was chosen to allow the use of a small NdFeB magnet to hold the mask tightly against the alumina substrate during deposition. Since the portion of the mask that forms the gap is relatively long and thin, some method of anchoring the mask is required for a clean, sharp and consistent gap between the 1-cm long electrodes. The distance from the magnetron sputtering source and the substrates is large enough (10 cm) that the field from the magnets behind the substrates does not interfere

with the magnetic field of the deposition source. We coated the substrates to a titanium thickness of 1 μm . Thicker films have been observed to crack and/or delaminate during the deuterium loading process. Fig. 1 shows a patterned disk. The hole in the substrate is used to connect the HV pulser to one electrode; the other is grounded at each end by the holding fixture. A small screw is placed through the hole and connects to HV lead on the backside. The half of the 2-cm disk not shown contains electrodes for a second source.

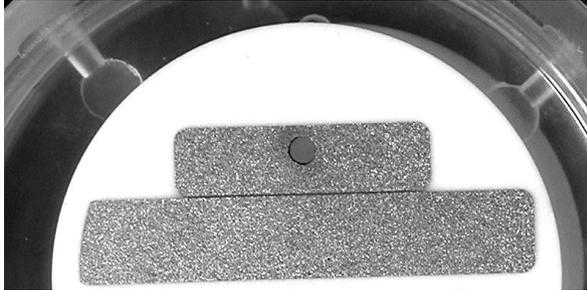


FIGURE 1. Close-up of surface flashover electrodes on the alumina substrate. The smaller electrode is 1 cm long, and the gap between the electrodes is 0.127 mm (5 mils). The geometry is based on the parameters given in Ref. 1.

DEUTERIUM LOADING

Deuterium gas was diffused into the titanium electrodes in a chamber specifically built for this task. The base pressure and leak rate of the chamber was such that we could use a static fill of deuterium gas. After letting the chamber pump for a day or two, we back-filled the chamber to 5 Torr and warmed the substrate heater to 200° C to drive off any water. We then pumped away this gas fill, refilled the chamber to 10 Torr, and raised the substrate temperature to 450° C for approximately an hour. The sources were then left in the deuterium gas as the substrate heater was turned off and the chamber cooled slowly. After they were removed from the loading chamber, they were stored in a dry-nitrogen filled container until needed. We could see only a small change in the appearance of the titanium films, but subsequent neutron measurements proved that we were getting a substantial loading of deuterium. Quantitative measurements of the loading fraction were planned, but not performed.

ION-SOURCE TEST CHAMBER

In order to test the ion source performance, we configured a vacuum chamber with a 100-kV feedthrough on the top, and a mount for the ion source on the bottom of a 4-way cross. We attached a 40-mm

diameter deuterium-loaded disk to the HV terminal to serve as the target for ions generated by the flashover source, located 90-mm away. The HV supply was set to -90 kV for all the data presented in this paper. The solid-state pulser that powered the flashover source was built in-house and could supply pulses up to 10 kV and 1 μsec in duration.³ For this series of experiments, the pulser charge voltage was set to 4 kV and the duration varied between 10 and 250 ns. A series resistor limited the arc current to 45 amps.

D+ CURRENT MEASUREMENT VIA NEUTRON PRODUCTION

We were fortunate to have available for our use (thanks to P. L. Kerr) a sensitive neutron detector that allowed us to measure the integrated deuterium current from the neutrons generated at the target held at high voltage. In this way we were able to measure only the deuterium ion current, as neutral gas, or other evolved species would not be able to produce neutrons and therefore would not be counted. The detector system has built-in x-ray discrimination, so all the recorded counts were from D-D fusion neutrons. A plot of the number of detected neutrons versus the applied pulse width is shown in Fig. 2a. In Figure 2b, the integrated deuterium ion charge from Ref. 1 for pulse lengths of 250, 750 and 2400 ns is plotted. Their data show a similar saturation of the deuterium ion yield, but at longer pulse lengths. This may be due to their higher arc current (100 amps vs. 45 amps for this study). At the higher current, the arc spot can split, and expand the volume of titanium heated.²

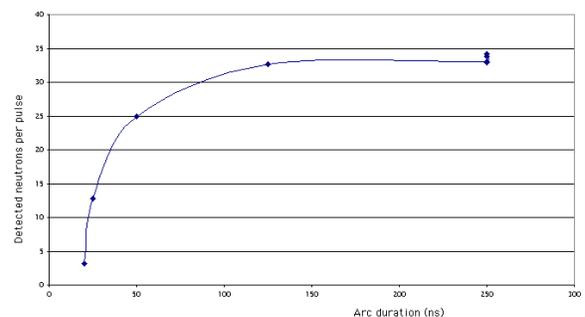


FIGURE 2. The integrated neutron yield is shown to saturate at around 100 ns for an arc current of 45 amps.

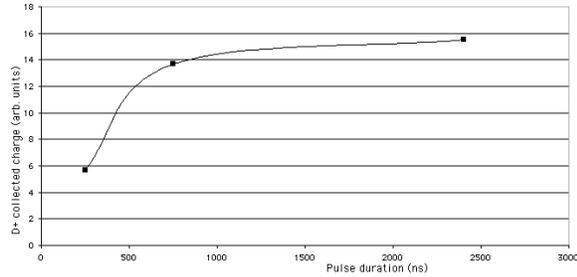


FIGURE 3. Integrated D+ charge collected versus pulse duration data from Ref. 1. The charge was collected using a TOF analyzer to allow counting only D+ ions.

DISCUSSION

To first order, the surface flashover source produces ions by a two-step process. First the arc heats the electrodes and liberates interstitial gas and evaporated metal. The arc electrons then pass through this vapor and ionize it. Since the density near the arc is high, and the electron energy is low, the ionization is quite efficient. At short pulse lengths, the amount of deuterium liberated is approximately proportional to the amount of metal heated above the liberation temperature, so the ion yield increased nearly linearly with arc energy. For longer pulses, the gas near the arc is depleted and much of the arc energy goes into evaporating titanium. Thermal conductivity of the Ti film limits the extent of the arc-heated zone, so the amount of gas liberated saturates. Unfortunately, we were not able to measure the fraction of titanium ions produced to further quantify these phenomena, but it is reported in Ref. 1. However, we did observe that arcs in the 20-30 ns range produced little erosion of the electrodes and would produce ions for over 3000 shots. There was also evidence that the source can recover by the slow diffusion of deuterium from the bulk of the electrode to the gap area if the arc duration is optimized.

Further work planned includes constructing a time-of-flight spectrometer to measure the species mix of ions produced by the source under varying arc duration and current. Initial attempts were hampered by space charge effects at the low accelerating voltages used (~600 volts). At these low voltages, the ion beam would expand and hit the drift tube walls before reaching the detectors. A system that allows higher accelerating voltages, up to 5 kV, has been designed and should mitigate this effect. Also, as time permits, further lifetime studies will be performed.

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REFERENCES

1. E. Cheifetz, U. Adar, and G. Davara, Proc. XVIIth International Symposium on Discharges and Electrical Insulation in Vacuum-Berkeley, p194-198 (1996).
2. R. L. Boxman, D. Sanders, P. J. Martin, (1995). Handbook of Vacuum Arc Science and Technology. William Andrew Publishing/Noyes, p 88 - 92.
3. E. G. Cook, B. S. Lee, S. A. Hawkins, E. M. Anaya, F. V. Allen, B. C. Hickman J. S. Sullivan, C. A. Brooksby, "Solid-state kicker pulser for DARHT-2," Pulsed Power Plasma Science, 2001. PPS-2001. Digest of Technical Papers, vol.1, no., pp. 632-635 vol.1, 2001.