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VOLUME H^- GENERATION WITH THE SITEX SOURCE IN THE VITEX REFLEX MODE WITHOUT CESIUM

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ABSTRACT

The ORNL SITEX (Surface Ionization with Transverse Extraction) negative ion source utilizes a reflex discharge operating in a 1300-G magnetic field to generate H^- or D^- ions on a cesiated converter placed directly behind and adjacent to the 100-V/20-A discharge column. We have recently operated a newly assembled source, without cesium, in the VITEX (Volume Ionization with Transverse Extraction) mode to see how many volume H^- ions could be produced. The total gas flow during the test was held constant at $\sim$1.6 torr·L·s^{-1}. This flow would correspond to an arc-chamber pressure of 10 mtorr for a 500°C chamber temperature. In this volume-production mode, the converter was in its usual position; the separation was less than 0.1 mm from arc to converter. Variation of the converter voltage up to -200 V at full output had no appreciable effect on the maximum output current. This is in sharp contrast to the SITEX mode, in which the maximum current increases by a factor of about 5 with converter voltage—the optimum value being dependent upon electrode spacing and magnetic field. H^- beam output of 80 mA, 17.5 keV, and 760 ms has been achieved. This corresponds to 32 mA/cm^2 (2.5-cm^2 extraction aperture) and was extracted with 45 mA of electrons giving an extracted electron to H^- ion ratio of 0.6. All extracted electrons were recovered at 2.5 keV on the source electron recovery system and none were accelerated with the beam. Long-pulse operation of $I_{H^-} = 55$ mA, $I_{\text{electron } R} = 35$ mA, $\tau = 4$ s, $V_{\text{accel}} = 17.5$ kV, and $j_{H^-} =$ 22 mA/cm^2 has also been achieved.

I. INTRODUCTION

Neutral beam injection has proved to be an effective way to heat plasmas in fusion devices.[1-3] To date, this work has been accomplished with positive-ion-based systems.[4] For applications with beam energies in excess of 100 keV/nucleon, the neutralization efficiency[5] of H^-/D^- ions makes negative ions the probable source for energetic neutral beams. Two ways are generally considered to be most successful in producing H^-/D^- ions: surface conversion[6,7] of positive ions, either backscattered or desorbed from a refractory metal properly coated with an alkali such as cesium, or use of a volume-dependent process[8] in which the negative ion is extracted directly from the discharge plasma. The preliminary results reported herein were obtained from our investigation of the SITEX source[9-13] in the VITEX mode (without cesium) to see how many volume H^- ions could be produced. The vacuum liner and all metal source parts were washed to remove cesium accumulated from previous experiments. All graphite parts were new and had been plasma sprayed with molybdenum. The electrode system was optimized[13] for minimum beam divergence perpendicular to the slit, which was the same as that previously used for the surface-converted H^- SITEX mode of operation.

Figure 1 shows a side view of the VITEX plasma generator, while Fig. 2 shows an elevation view with the necessary power supply connections. A reflex discharge is initiated between the hot, directly heated tantalum filament and the electrically floating reflecting electrode in the other end of the anode chamber. A normal discharge is 100 V at 20 A. The converter, which is used in the SITEX mode of operation and covered with cesium, is operated without cesium acting only as an electrically biased wall whose temperature can be varied from about 100° to 700°C.

II. EXPERIMENT

The gas flow during this test was held constant at $\sim$1.6 torr·L·s^{-1}, which is slightly higher than the 1.5 torr·L·s^{-1} typically flowing when operating the source in the surface-converter (SITEX) mode. This flow would correspond to an arc-chamber pressure of 10 mtorr for a 500°C chamber temperature; we have not determined the optimum gas flow. Output current, accelerator voltage, pulse length, extracted H^- current, and

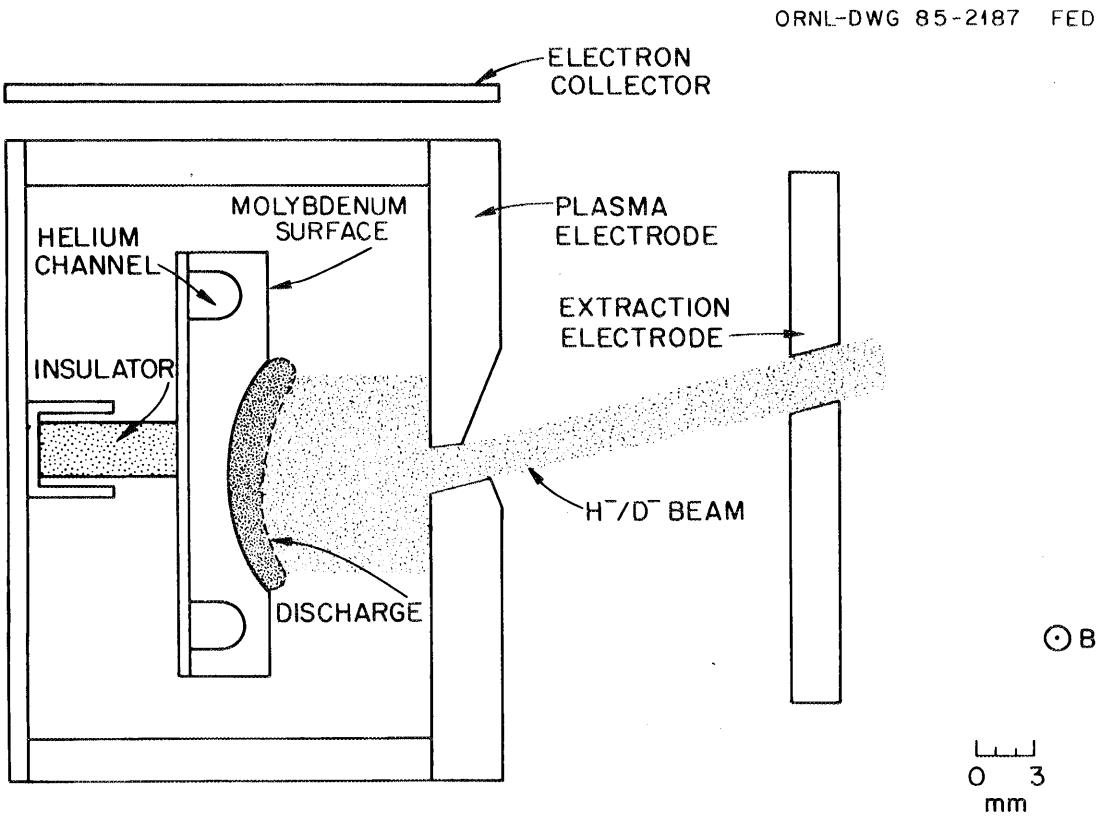

Fig. 1. Side view of VITEX plasma generator.

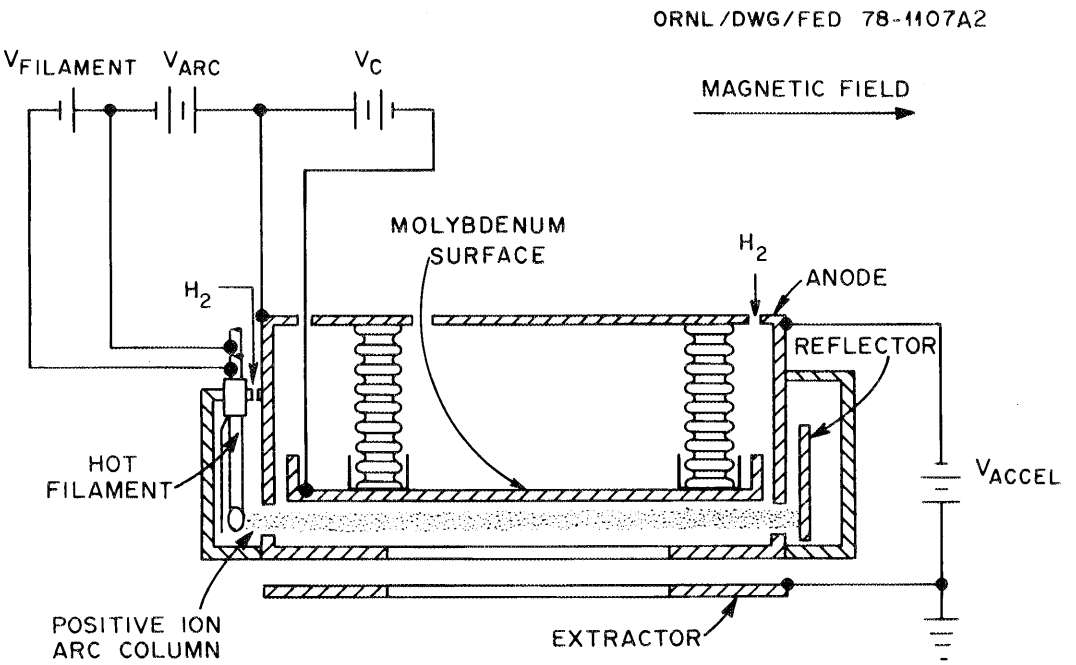

Fig. 2. Elevation view of VITEX with power supply connection.

extracted recovered electron current are shown in Table 1. In the volume-production mode of this experiment (VITEX), the converter wall was very close to the plasma discharge column. The separation was less than 0.1 mm from the arc to the converter. Variation of the converter voltage up to −200 V at full output had no appreciable effect on the maximum negative ion current output. This is in sharp contrast to the SITEX mode, in which the H^- current increases by a factor of about 5 with converter voltage—the optimum value being dependent upon electrode spacing and magnetic field.[9] Also, the VITEX mode is independent of magnetic field from ~1300 to ~2600 G. This result is somewhat surprising since the beam radius must also change with magnetic field and thereby move across the fixed Faraday cup collector. One explanation is that the beam divergence is very large due to the unoptimized accelerator electrode, which was designed for the SITEX operational mode. A more careful beam profile study will be made when all diagnostics are working properly.

Figure 3 shows shot V02717 from Table 1. The accelerator current shown in the Fig. 3(a) ordinate is in milliamperes, while the abscissa is 0 to 12 s. After about 800 ms, the accelerator supply modulator source-protection circuitry detected a momentary overload and shut off the accelerator voltage. Later on in the shot the accelerator voltage was re-established for about 3 s before another overcurrent condition shut it off again. Figure 3(b) shows the accelerator voltage in kilovolt units. Figure 3(c) shows the source-electron recovery current (virtually all extracted electrons are normally recovered) in milliamperes. Notice that the electron current goes down as the H^- current goes down during

Table 1. Selected shot parameters

	Shot number		
	2722	2717	2733
Pulse length (s)	0.060	1	4
I_{H^-} (mA)	130	80	55
j_{H^-} (mA/cm^2)	52	32	22
V_{accel} (kV)	17.5	17.5	17.5
I_{elec} (mA)	80[a]	45[a]	35[a]
I_{elec}/I_{H^-}	0.6	0.6	0.6

[a]Recovered at 2.5 to 2.8 keV.

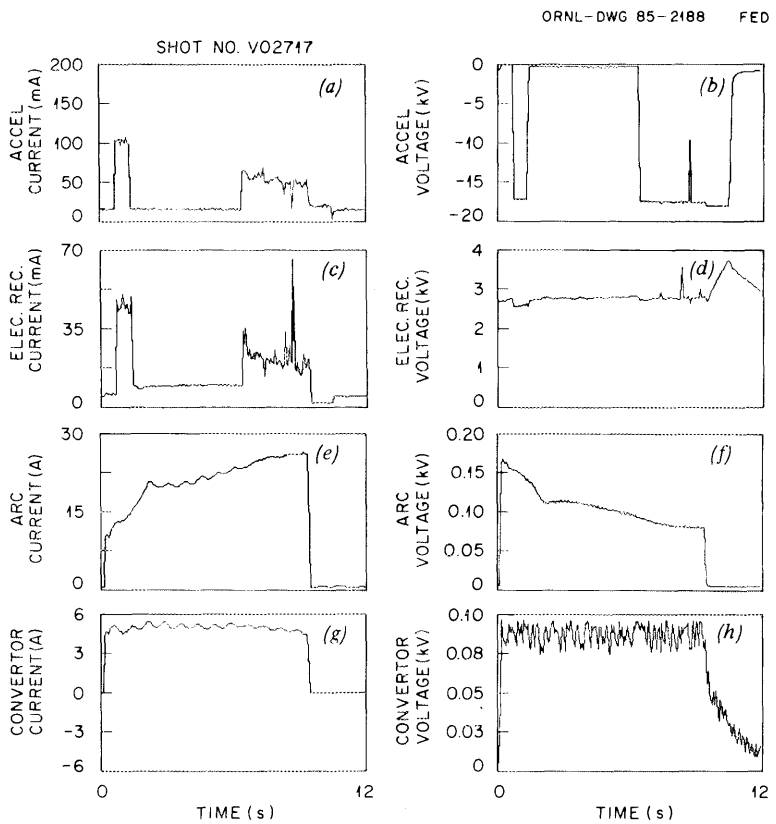

Fig. 3. Shot V02717 parameters.

the 3-s part of the pulse. Figure 3(d) is the voltage at which the electrons of Fig. 3(c) are recovered and has not been minimized. Normally electron recovery is best at ~10% of the extraction gap voltage.[9]

Figures 3(e) and (f) plot the arc amperage and voltage (in kilovolts). We feel that the smaller beam current during the 3-s part of the beam pulse is due to the less efficient H_2 molecular vibrational excitation due to the smaller arc voltage. We think the dissociative attachment mechanism[8] is our dominant volume H^- production mode, and its cross section is greatly enhanced by the higher vibrational states. Figures 3(g) and (h) plot the converter amperage and voltage. The converter has no cesium coverage in the VITEX mode and acts merely as a plasma probe. Notice that the converter current is approximately constant during the pulse, indicating nearly constant plasma density. The arc power efficiency for this shot is 20 to 35 kW of source power per ampere of H^- current extracted. In this study we have equated the accelerator current to the H^- current. This has been shown to be true calorimetrically for the VITEX mode operation.

III. DISCUSSION OF RESULTS

The VITEX operational modes are interesting from several viewpoints. First, we get rid of cesium and the problem of controlling cesium coverage on the converter. Second, the ion temperature may be lower than that obtained in the SITEX mode, which would be of interest to directed energy applications. Probably the most significant variables to study are the arc parameters. There are two processes[14] believed to be responsible for volume-produced negative ions: dissociative attachment and polar dissociation. Dissociative attachment may be written as

$$H_2 + e \rightarrow H_2^- \rightarrow H^- + H \ . \tag{1}$$

In this process, the electron energy must lie in a narrow range of a few electron volts. The H_2^- is a short-lived molecular ion that dissociates. The cross section for this reaction is very low but increases many orders of magnitude if the H_2 molecule can be raised to higher vibrational states. This can be achieved with electrons of tens of electron-volt energies. The trick is to produce the ions in an energetic electron environment and then quickly remove the ions to a region of lower electron energy, where they are dissociated and extracted. Polar dissociation may be written as

$$H_2 + e \rightarrow H^+ + H^- + e \tag{2}$$

and takes place through an ionic state of the molecule formed by a positive and negative ion. The probability of dissociation has a threshold electron energy that must be sufficient to raise the H_2 molecule to an excited state in which a transition can be made from the neutral to the ionic state. The cross section has a very broad maximum with electron impact energy. The integrated cross section for this process is much larger than the integrated cross section for dissociative attachment. Thus, a range of electron energies from ~10 to 100 eV is desired. Our electron energy in the VITEX would seem to lie in this range, especially in the main discharge column. In the region between the discharge column and the extraction exit, however, the electron energy is probably very low. Thus,

we may have either one or both processes occurring to produce our negative ions. We are studying H^- output as a function of wall geometry, wall temperature, and types of material.

Finally, we can test for polar dissociation by using other molecular gases. The molecule CH_4 is reported to have a cross-section maximum that is a factor of 10 higher than H_2 (Ref. 15). We may already have some CH_4 present due to our graphite arc chamber.

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