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MEASUREMENTS OF THE CESIUM FLOW FROM A SURFACE-PLASMA H^- ION SOURCE*

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Abstract

We have constructed a surface ionization gauge (SIG) and have used it to measure the Cs^0 flow rate through the emission slit of a surface-plasma source (SPS) of H^- ions with Penning geometry. The equivalent cesium density in the SPS discharge is deduced from these flow measurements. For dc operation the optimum H^- current occurs at an equivalent cesium density of $\sim 7 \times 10^{12}$ cm^{-3} (corresponding to an average cesium consumption rate of 0.5 mg/h). For pulsed operation the optimum H^- current occurs at an equivalent cesium density of $\sim 2 \times 10^{13}$ cm^{-3} (1-mg/h average cesium consumption rate). We observe cesium trapping by the SPS discharge for both dc and pulsed operation. A cesium energy of ~ 0.1 eV is deduced from the observed time of flight to the SIG. In addition to providing information on the physics of the source, the SIG is a useful diagnostic tool for source start-up and operation.

Introduction

Surface-plasma sources produce intense H^- beams for both the magnetron[1] and the Penning[2] configurations. In a SPS the addition of cesium to the hydrogen discharge leads to nearly an order of magnitude enhancement of the H^- current.[1] Despite the importance of understanding the role of cesium in the production of H^-,[3,4] there has been only one experimental study of the cesium flow from a SPS.[5] Of equal practical importance to the experimenter is the availability of a device to monitor the cesium flow during SPS start-up and operation. A cesium surface-ionization gauge, which is similar to that of Marino et al.,[6] was built and was used to measure the cesium flow from a Penning SPS source.[7]

Description of Apparatus

The SIG (shown in Fig. 1) consists of a tungsten ribbon filament surrounded by a copper cylindrical collector with end caps. The filament operates above the critical temperature T_c necessary for the impinging cesium atoms to be surface ionized.[8] The collector is freon cooled to dissipate the 50 W of filament heating power. The SIG is completely enclosed in a ground shield to minimize the background of atoms and ions from the source. Further shielding against background ions is accomplished with a bias ring located between the ground shield and the collector.

To measure the Cs^0 emission from the source[7] the SIG is located as shown in Fig. 1. A 1-mm x 25-mm hole machined in the SIG ground shield serves as the entrance slit to the SIG. The SIG is located on the axis defined by the 0.5-mm x 10-mm source emission slit and the 1-mm x 19-mm extraction electrode slit. Neutral cesium atoms effusing through the source emission slit have a direct path to the SIG entrance slit. The 0.05-mm-thick tungsten filament is large enough (2.4-mm wide x 34-mm long) to intercept all of the cesium atoms from the source that pass through the SIG entrance slit. The cesium atoms are surface ionized upon striking the tungsten filament and accelerated to the collector with a bias voltage applied between the collector and the filament. In the presence of a Cs^0 flux the current leaving the filament and the current to the collector are equal (opposite in sign) and both are proportional to the Cs^0 flux through the source emission slit.

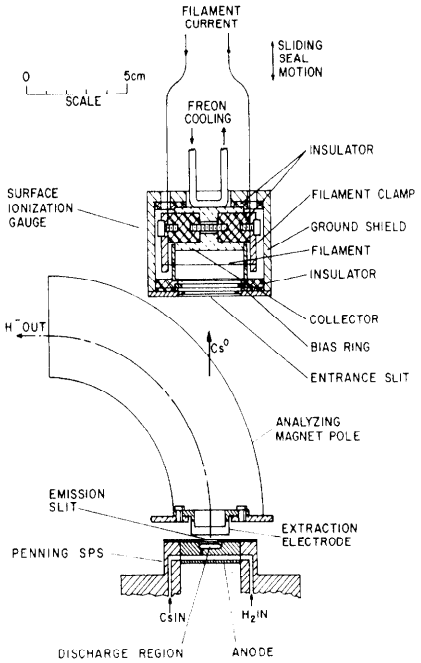

Fig. 1. Schematic of the cesium surface ionization gauge. The position of the SIG during measurement of the cesium flow from the Penning SPS is indicated.

To ensure proper SIG operation the filament heating current is varied to ascertain that the filament operates well above T_c. Also, the collector bias is varied to insure that $\sim 100\%$ of the surface-ionized Cs^+ ions are collected. Typical values for the filament heating current and the collector-filament bias voltage are 10 A and -60 V, respectively.

The ground shield substantially reduces (factor of ~ 100) the SIG background (ion) signal when a H^- beam is extracted from the source. However, a background ($\sim 10\%$ of the SIG current) is observed during beam extraction. We think the background is comprised of heavy negative ions, energetic neutrals (which may induce secondary ion and/or electron emission), and possibly cesium desorbed from the extraction electrode. Therefore, the cesium flow measurements reported are for operation of the source discharge but with no extraction voltage. We emphasize that the cesium density values deduced from the cesium flow measurements are equivalent density values. The actual cesium density in the discharge most likely differs from the equivalent cesium density because of cesium trapping on the electrode surfaces.[5] That is, it is not possible to tell with the SIG whether the cesium is located in the source volume or on the electrode surfaces during the discharge.

Results and Discussion

DC Operation

The measurements of the equivalent cesium density for dc source operation were accomplished by pulsing at 98% duty factor (7.5 Hz). Bel'chenko et al.[5]

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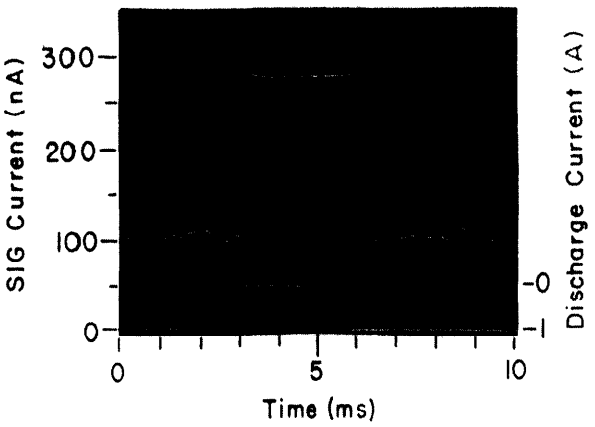

Fig. 2. SIG current (upper trace) induced by Cs^0 flow through the Penning source emission slit during nearly dc (98% duty factor) operation. The discharge voltage (not shown) and current (lower trace) are pulsed off for 3 ms at a 7.5-Hz repetition rate. The SIG current decreases when the discharge is on because the discharge traps cesium.

have reported that cesium is trapped by the discharge for pulsed operation of a magnetron SPS. We observe this effect for both dc and pulsed operation of the Penning SPS. A typical measurement of the cesium flow during dc source operation is shown in Fig. 2. The discharge voltage (57 V) and current (1 A) are driven to zero in <10 μs for 3 ms before being restored to their original values. The equivalent cesium density in the discharge chamber is proportional to the cesium flow through the emission slit during the 3-ms discharge-off pulse. The equivalent cesium density N (cm^{-3}) is calculated from

$$N = 6.8 \times 10^6 \, i/Af\Omega \qquad (1)$$

where i(nA) is the SIG current, Ω(sr) is the solid angle subtended by the SIG entrance slit, A(cm^2) is the area of the source emission slit, and f (=2.4) is the correction factor for nonisotropic effusion of the cesium atoms through the emission slit (Fig. 2.1 of Ref. 9). We estimate that the cesium density absolute scale is accurate to no better than ±50% because the errors in f, in the average source temperature, and in the emission slit conductance are large. The latter two quantities are used to calculate the coefficient 6.8×10^6 in Eq. (1). For the measurement in Fig. 2, $N = 5 \times 10^{12}$ cm^{-3}, about three times the cesium density that would be obtained from the Cs^0 flux while the discharge is on. The average cesium consumption, however, is determined by the Cs^0 flux while the discharge is on, and this rate is 0.4 mg/h for Fig. 2. We estimate that the cesium flow measurements are accurate to no better than ±25% because the uncertainty in f is large. If the filament temperature is lowered below T_c, there is negligible SIG current while the discharge is either off or on. We conclude that the SIG current shown in Fig. 2 is mostly caused by surface-ionized Cs^+ ions.

The discharge voltage and the magnetically analyzed H^- current were measured as a function of the equivalent cesium density (Fig. 3) for constant discharge current (1 A) and constant hydrogen flow rate (16 atm cm^3/min). The discharge voltage drops monotonically with cesium density until a minimum of ∿50 V is attained. Further increase in the cesium density results in a small rise in discharge voltage. The analyzed H^- current maximum (0.8 mA) occurs at

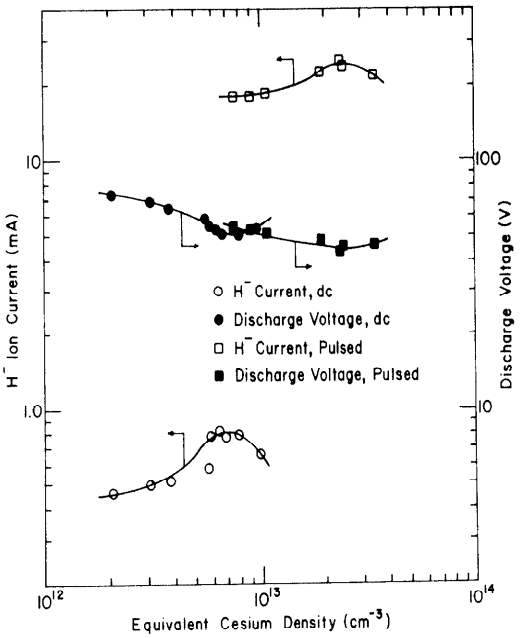

Fig. 3. H^- ion current and discharge voltage as a function of equivalent cesium density in the source for dc (circles) and pulsed (squares) operation. The equivalent cesium density is obtained as described in the text. The curves serve only to guide the eye.

an equivalent cesium density of ∿7×10^{12} cm^{-3}. Only a 40% variation in H^- current occurs for a factor of 5 variation in the cesium density. The H^- current maximum occurs near the minimum in the discharge voltage and at an average cesium flow of 0.5 mg/h. The measurements for dc source operation were obtained by feeding cesium into the discharge with an independently controlled oven containing ∿1/2 g of 2Ti + $Cs_2Cr_2O_7$ mixture.

Pulsed Operation

The discharge voltage, discharge current, and the SIG current for pulsed source operation with the 2Ti + $Cs_2Cr_2O_7$ mixture in a cavity in the anode are shown in Fig. 4. The pulse repetition rate was 15 Hz; the duty factor, 1.5%. The Novosibirsk group uses a mass spectrometer to select only Cs^+ ions from their filament[5] while our SIG filament is directly exposed to the discharge with no mass selection. Nevertheless, the cesium current shown in Fig. 4 and the cesium pulse shown in Fig. 1 of Ref. 5 are remarkably similar. By observing the SIG current when the filament is hot and when the filament is cold, we find that the SIG current from ∿100 μs after the discharge is off until the next discharge pulse is probably caused solely by Cs^0 detection. However, a portion (∿30%) of the SIG current from the beginning of the discharge pulse until ∿100 μs after the pulse is over appears to the caused by background particles from the discharge and/or photoelectrons (light from the discharge can enter the SIG). Electronic noise pickup is not thought to be a problem because the SIG current scales properly with varying distance of the SIG from the emission slit.

The Cs^0 evolution through the emission slit increases slowly during the discharge pulse followed by a dramatic increase in the cesium flow ∿200 μs after the discharge ends. The Cs^0 emission then decays to the steady-state flow before the next pulse. The dis-

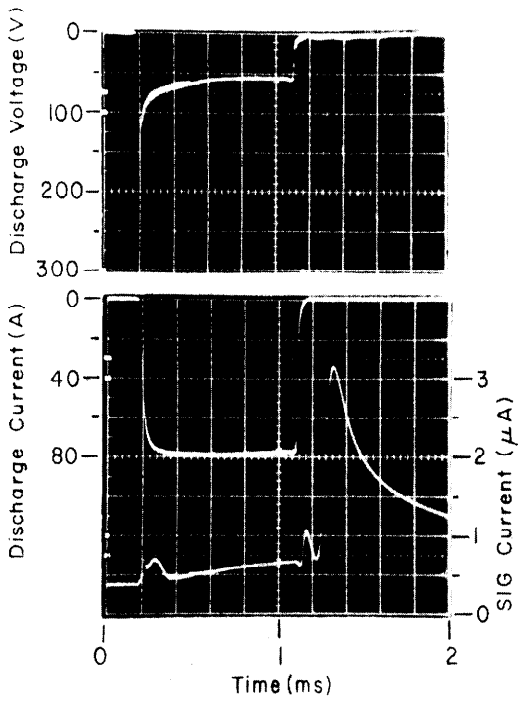

Fig. 4. Discharge voltage (upper trace), discharge current (middle trace), and SIG current (lower trace) for pulsed operation of the Penning source. The pulse length is 1 ms; the pulse rate, 15 Hz. A large cesium pulse occurs ∿200 μs after the discharge is shut off. Approximately 30% of the SIG current during the discharge pulse is caused by background particles from the discharge and/or photo-electrons (see text), as is the small peak ∿50 μs after the discharge pulse.

charge traps cesium during the pulse[5] but we cannot tell with the SIG whether the trapped cesium is in the volume or on the electrode surfaces.

The discharge voltage and the magnetically-analyzed, pulsed H^- yield were measured as a function of equivalent cesium density at the end of the pulse (Fig. 3) for constant discharge current (85 A) and hydrogen gas flow rate (40 atm cm^3/min). The equivalent cesium density is calculated from Eq. (1) using the height of the cesium burst ∿ 200 μs after the discharge pulse for i(nA). The cesium density was varied by using the same independently controlled cesium feed used for the dc measurements. As in the case for dc operation, the discharge voltage drops and the H^- current increases with increasing cesium density until a minimum in voltage and a maximum in H^- current is reached. Further increase in the cesium density results in a slight rise in voltage and a drop in H^- current. The maximum end-of-pulse H^- current occurs for an end-of-pulse equivalent cesium density of $\sim 2 \times 10^{13}$ cm^{-3}. The average cesium consumption rate at the optimum H^- current is 1 mg/h.

By changing the distance of the SIG from the emission slit we change the time of arrival of the cesium burst at the SIG (time measured with respect to the end of the discharge pulse). We calculate an energy of ∿0.1 eV for the cesium atoms by assuming that this change in pulse arrival time is caused by the change in Cs^0 time of flight. The time of flight is also observed in the dc measurements, with the Cs^0 energy consistent with the pulsed measurements.

Other Comments

The cesium flow waveforms are different in the dc and the pulsed cases. In the pulsed case we estimate that the cathode temperature rises by ∿ 100°C during the 1 ms pulse, leading to rapid desorption of cesium atoms at the end of the pulse. The electrodes cool in a time consistent with the cesium flow decay time (∿500 μs). Only $\sim 2 \times 10^{12}$ cesium atoms are contained in each end-of-pulse burst, corresponding to ∿1% of the optimum cesium coverage on the exposed cathode area. The end-of-pulse burst contains only 1% of the total Cs^0 flow from the source during a complete discharge cycle. In the dc case the electrode temperatures are nearly constant. After the discharge is extinguished the cesium flow rate first rises to a high value and then decays with a time constant of ∿10 s to the average value. About 10^{16} cesium atoms effuse through the emission slit in the cesium burst, corresponding to the desorption of ∿ 1 cesium monolayer from the source interior. We have not determined if the observed dc time constant arises from the thermal time constant of the source or from the variation in desorption rate with cesium coverage.

The SIG has proven to be a practical device for monitoring the cesium addition to the source for daily start-up and operation. Thus, the SIG helps to prevent excessive cesium buildup in the source and on the extraction electrode structure when using the independent oven for the cesium supply. In addition, the SIG provides diagnostic information on the operation of the cesium feed mechanism.

Conclusions

Measurement of the cesium flow from the Penning SPS reveals that for the optimum H^- current the equivalent cesium density in the discharge should be $\sim 7 \times 10^{12}$ cm^{-3} and $\sim 2 \times 10^{13}$ cm^{-3} for dc and pulsed operation, respectively. When the cesium density is adjusted to give the maximum H^- current, the discharge voltage is at a minimum. The average cesium consumption rate for optimum H^- current is lower for dc (0.5 mg/h) than for pulsed (1 mg/h) operation, but the discharge intensity is much higher for pulsed (85 A) than for dc (1 A) operation. For both discharge modes the discharge traps the cesium and partially prevents it from effusing through the source emission slit. Time-of-flight measurements imply that the average Cs^0 energy is ∿0.1 eV. The SIG is a useful diagnostic tool for daily start-up and operation of the Penning source.

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