Practical experience in extending the ion source and injection system H^--ion source duty cycle

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The ion source and injection system H^- Penning surface-plasma source is currently being developed on the ion source development rig at Rutherford Appleton Laboratory in order to meet the requirements for the next generation of high-power proton drivers. Finite element modeling has been used previously to study the effect of increasing the duty cycle. The main requirement to allow increased duty cycles is improved cooling. By simply reducing the thickness of a sheet of mica to improve thermal conductance to the cooling system, duty cycles of 1.5 ms at 50 Hz can be achieved. Slight increase in hydrogen flow rate is required as the duty cycle is increased. As the duty cycle is increased the output current reduces, however, there is no change in beam emittance. The source cooling system is described and the heat flows within the source are discussed. © *2006 American Institute of Physics.* [DOI: 10.1063/1.2166427]

I. INTRODUCTION

The ion source and injection system (ISIS) H^- Penning surface-plasma source (SPS) is currently being developed on the ion source development rig (ISDR) at RAL in order to meet the requirements for the next generation of high-power proton drivers. The source, which currently produces 35 mA of H^- ions during a 200 μs pulse at 50 Hz for uninterrupted periods of up to 50 days, is regarded as one of the leading operational sources in the world. The development goals are to double the output current to 70 mA and lengthen the duty cycle to 1.5 ms at 50 Hz. This work details the success in achieving the long duty cycle.

II. SOURCE CONSTRUCTION

The basic construction of the ion source is shown in Fig. 1. The source is of the Penning SPS type, comprising a molybdenum anode and cathode between which a low-pressure hydrogen arc is struck. Hydrogen and cesium are fed into the discharge via holes in the anode. The anode and cathode are housed in the stainless-steel source body. The anode is thermally and electrically connected to the body, whereas the cathode is isolated from the body by means of a ceramic spacer. The whole assembly is bolted to a flange, separated by a thin layer of mica to provide electrical isolation for the cathode. The ions are extracted through the slit in the aperture plate.

III. COOLING

There is an optimum range (400–600 °C) of electrode surface temperatures for the production of H^- ions; therefore stable electrode temperatures are essential for reliable ion source operation and consistent output currents. Steady-state electrode temperatures are reached when the amount of energy put into the source by the discharge current power supply is in equilibrium with the amount of energy removed by the cooling systems and lost to the surroundings.

Source cooling is provided by two systems as shown in Fig. 2: air cooling via two pipes in the source body nearest the electrodes and water cooling via a channel cut into the ion source flange. Air flows along one pipe and is then returned down the other. Air is used because of the safety hazards involved with having water close to the cesiated ion source. The cathode is primarily cooled via the water in the mounting flange; the anode is primarily cooled via the air cooling; however, both systems are coupled together.

Finite element modeling[1] has been used to understand the thermal properties of the source. Modeling studies[2] have shown that the additional heat loading generated when operating the source at longer duty cycles can only be mitigated by improving the thermal conductance between the mounting flange and the source. The simplest way to achieve this is by reducing the thickness of the mica sheet.

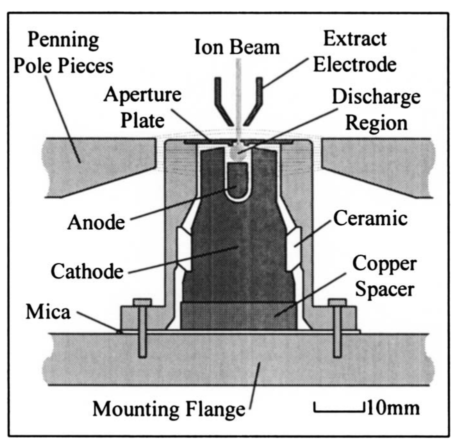

FIG. 1. The ISIS Penning SPS.

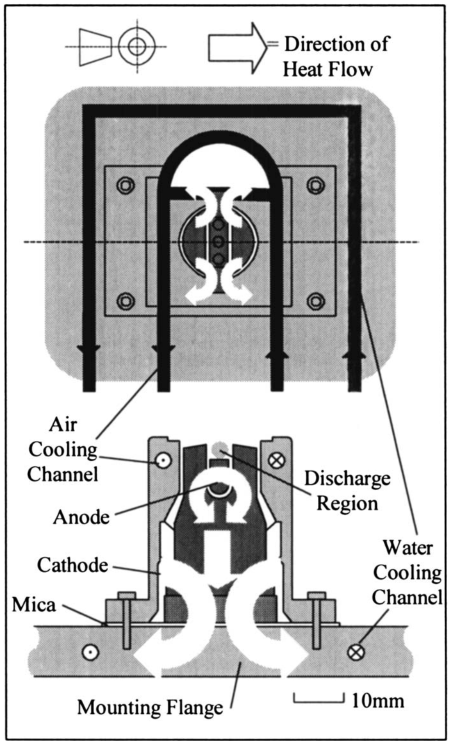

FIG. 2. The ion source cooling systems (aperture plate removed).

IV. REDUCING THE MICA THICKNESS

Mica sheet can easily be cleaved into very thin sheets. The source was assembled with different mica thicknesses and run up to normal operating temperature with the longest discharge length possible without overheating the source. The extraction voltage was kept at 17 kV and the discharge current was kept at 50 A. The results are summarized in Table I.

V. DISCUSSION

As the mica is made thinner, the thermal conductance between the cathode and the cooling flange increases, thus allowing the source to run at longer duty cycles without overheating. Reducing the mica thickness also increases the thermal conductance between the source body and the cooling flange which indirectly improves cooling of the anode.

The thermal conductance k of the mica sheet can be calculated from the equation,

$$k = KA/l,$$

where A is the interface contact area, K is the thermal conductivity of the mica, and l is the thickness of the mica sheet.

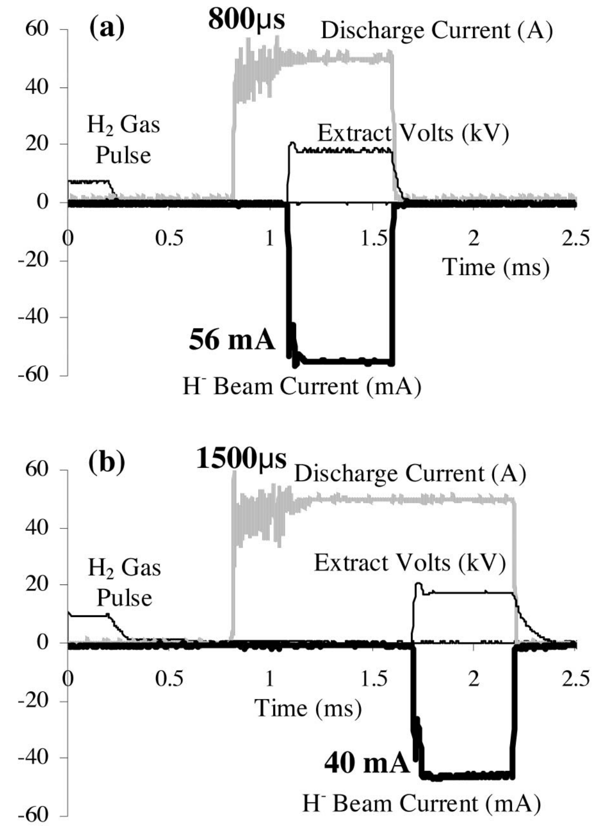

FIG. 3. The ion source hydrogen gas pulse, discharge current, extraction voltage, and beam current wave forms for (a) a 800 μs and (b) a 1.5 ms discharge.

Mica has a thermal conductivity of 0.26 W m^{-1} K^{-1}. For 0.6-mm-thick mica sheet this gives a conductance of 0.16 W K^{-1}. As the mica thickness is halved, so is its conductance.

The direct thermal conductance between the cathode and the water-cooled flange will be this value in series with the conductance of the copper spacer and the contact conductances of the interfaces. Contact conductance depends on interface contact pressure, surface roughness and material properties of the mating surfaces, interface temperature, and pressure. Thermal contact conductances have previously been calculated using measurements from a thermal test rig and finite element modeling[1] and found to range from 0.01 to 0.05 W K^{-1} in this case.

The cathode also transfers a small amount of heat by conduction through the ceramic spacer and by radiation to the source body. The overall calculation of heat transfer is

TABLE I. The experimental results.

Discharge length	Mica thickness	Cesium boiler temperature	Air coolant flow rate	H_2 flow rate	Beam current	Extractable beam length
800 μs	0.60 mm	162 °C	14 L min^{-1}	15 ml min^{-1}	56 mA	600 μs
1200 μs	0.30 mm	164 °C	18 L min^{-1}	19 ml min^{-1}	47 mA	1000 μs
1750 μs	0.15 mm	165 °C	20 L min^{-1}	22 ml min^{-1}	40 mA	1450 μs

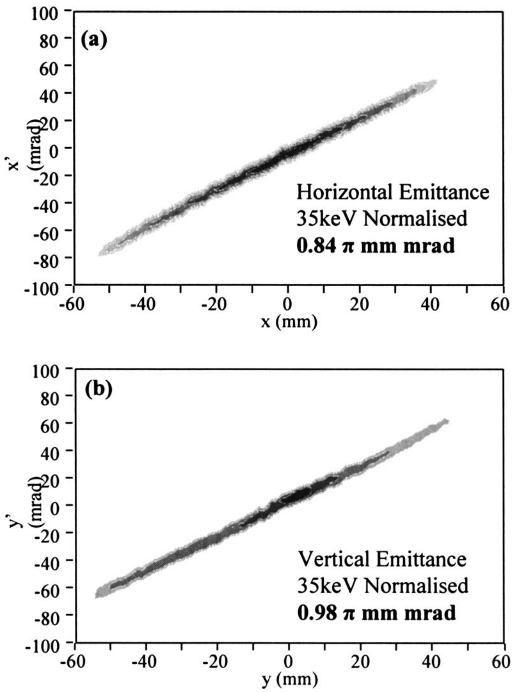

FIG. 4. The (a) horizontal and (b) vertical emittance plots as measured 600 mm downstream from the ion source.

complicated and dependent on many material properties and can only be accurately studied using three-dimensional (3D) finite element techniques.[1,2]

Table I shows the air coolant flow rate which primarily cools the anode and needs to be increased to keep the source operating in the correct temperature range. As the duty cycle is increased the source consumes more hydrogen, so the hydrogen flow rate is increased. The cesium boiler temperature which controls the amount of cesium delivered to the source also increases slightly, though this is within the range of normal settings and therefore not significant. The output beam current decreases as the duty cycle increases.

It is currently not possible to extract beam for periods longer than 500 μs due to limitations of the extraction voltage power supply. A new extraction power supply (due by the end of 2005) will allow extraction lengths of up to 2 ms. Figure 3(a) shows the source wave forms for a 800 μs discharge and Fig. 3(b) for a 1.5-ms-long discharge. There is a small amount of droop in beam current along the length of the discharge. Figure 4 shows the emittance plots taken during a 1.5-ms-long discharge. The emittance is the same along the whole length of the discharge and is not significantly different for any discharge length. This shows that there are no emittance growth problems for longer duty cycles. The measured emittances are quite large; this is because the emittance scanners are located 600 mm downstream from the ion source. Previous studies[3] have shown that there is a significant amount of emittance growth caused by space charge and hence the true source emittance is much lower.

VI. SUMMARY AND FUTURE WORK

The ISIS ion source duty cycle has successfully been increased by a factor of 3 by simply reducing the thickness of the mica insulation. Increasing the duty cycle requires higher hydrogen flow rates, but does not appear to require higher cesium boiler temperatures. Increasing the duty cycle reduces the H^- beam current. To return the beam currents to the previous levels, a higher extraction voltage or higher discharge current is required. Extraction voltages of up to 25 kV and extraction over the full extractable length of the discharge will be tested when the new extraction voltage power supply is available at the end of 2005.

ACKNOWLEDGMENT

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