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DEVELOPMENT OF MULTIAMPERE NEGATIVE ION SOURCES*

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Abstract

The Neutral Beam Development Group at BNL is developing H^-/D^- surface plasma sources as part of a high energy neutral beam injector. Uncooled Penning and magnetron sources have operated at a maximum beam current of 1 A (10 ms pulses, Mk III) and a maximum pulse length of 200 ms (0.3 A, Mk IV). A magnetron source with focusing grooves on the cathode and an asymmetric anode-cathode geometry operates at a power efficiency of 8 kW/A and a 6% gas efficiency. As the next step, a water cooled magnetron, designed to give a steady state beam of 1-2 A, has been constructed. In initial tests in the hydrogen mode, we have obtained a steady state discharge current of 8 A at 500 V. In addition, experiments are in progress to test a modification of the magnetron which may significantly improve its performance. By injecting a sheet of plasma, produced by a highly gas efficient hollow cathode discharge, into a magnetron type anode-cathode geometry, we anticipate a reduction of the source operating pressure by at least three orders of magnitude. Initial experiments have given indications of H^- production. The next plasma injection experiment is designed to give a steady state beam of ≃ 1 A.

Introduction

Multiampere negative hydrogen and deuterium sources are required for efficient high energy neutral beam injectors to be used for plasma heating in future fusion devices and possibly for current driving in Tokamaks. The present objective is to develop a 10 A source module with pulse lengths ranging from several seconds duration up to a steady state operation.

There are three actively pursued methods for negative ion production: production of negative ions in the volume of a plasma discharge, conversion of a positive ion beam by double charge exchange in a gas or vapor jet, and surface plasma production. Sources developed at BNL belong to the last category. In these sources a glow discharge is established in a magnetic field. Positive ions from the plasma are accelerated into the cesium coated cathode and converted there into negative ions. Early models of sources were not cooled and beam currents of 0.5 to 1 A were obtained in pulses from a few ms to 0.2 s. Presently the BNL group is engaged in the development of long pulsed (5-30 s), water cooled magnetrons to deliver 1-2 A beams of H^-/D^- with an energy of several tens of keV.

While both the magnetron and Penning are promising negative ion sources for multiampere beams, they have the disadvantage that a relatively high pressure (≃ 0.1 torr) is required in the source to maintain the discharge. A new approach is now under investigation where a plasma sheet, created via the highly gas efficient hollow cathode discharge, is injected into a magnetron-type anode-cathode configuration. The plasma can be sustained in the magnetron region at very low pressures (≃ 10^{-4} torr). With this new arrangement a significant simplification is anticipated in the extraction and acceleration of high current dc beams.

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In the following sections we will describe in some detail recent BNL progress in the development of high current negative ion sources.

Asymmetric Magnetrons with Geometrical Focusing

In regular magnetron ion sources a plasma is established in a narrow racetrack discharge chamber having perpendicular electric and magnetic fields. Late in 1979 there was a breakthrough in the development when it was shown that one can focus H^- ions from a curved cathode into the narrow anode emission slit.[1] Figures 1a and 1b show the anode-cathode configuration with and without a focusing groove in the cathode. The efficient use of ions produced on the cathode resulted in a significant reduction of the required arc current density and source gas pressure. With a 5 cm long groove, having a radius of curvature of 3.75 mm and a width of 4.5 mm, a beam of 270 mA was extracted from an emission slit of 0.5 x 45 mm^2, corresponding to a current density of 1 A/cm^2 in the slit, while the cathode current density was only 2 A/cm^2 or 25 A total. The extraction voltage was typically

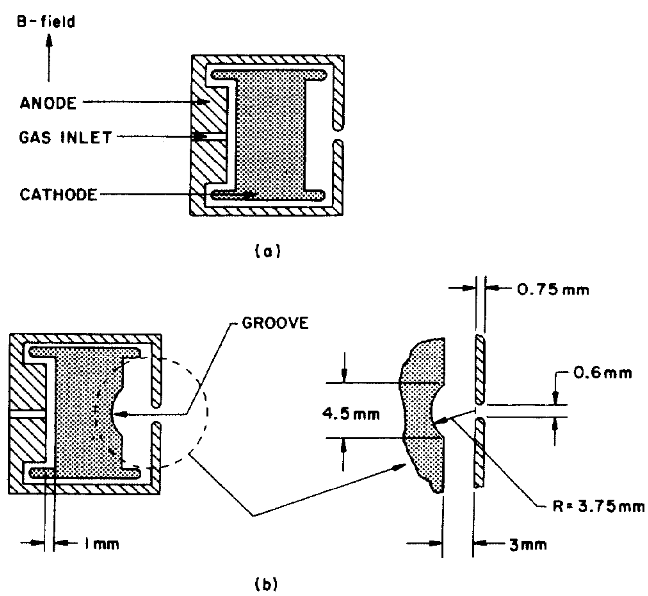

Fig. 1 Magnetron configurations and dimensions with and without a groove in the cathode.

12 kV with an average gradient of 80 kV/cm and the pulse length was 10 to 25 ms. The H^- output and corresponding emission current density vs arc current are shown in Fig. 2 for the ion source with and without the focusing groove. In an attempt to further enhance source performance, an asymmetric magnetron was tested. Such a source has a wide gap in the back of the cathode, so that the discharge may ignite at a lower pressure.[2] Figure 3 represents the asymmetric magnetron configuration with a groove. The output currents vs arc current are shown in Fig. 2. Indeed the H^- output is increased by 70% over that with the normal grooved magnetron. The normalized emittance of a 300 mA negative deuterium beam is only 0.078 π cm-mrad. The net result of the grooves and the asymmetric configuration was that the power efficiency,

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defined as the power required to produce 1 A negative ions, improved by a factor of four, to 8 kW/A. The lower operating arc current reduced the required pressure and the gas efficiency improved from 2 to 6%. When we changed the gas from hydrogen to deuterium, no isotope effect was observed in this arc current range.

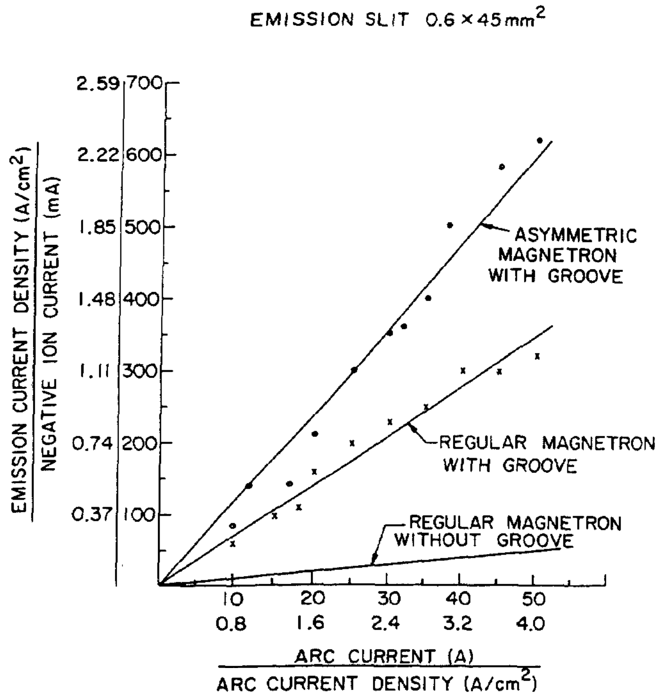

Fig. 2. Negative ion output as a function of arc current and arc current density for regular magnetron with and without groove and for a grooved, asymmetric magnetron.

The output of negative ions was quite sensitive to the source pressure and Cs coverage. The maximum output was always obtained with the lowest possible pressure. With an energy analyser it was demonstrated that at these low pressures most negative ions originated from the cathode converter and that with an increased source pressure, the ratio of fast ions to slow ions formed by charge exchange decreased accordingly.[3]

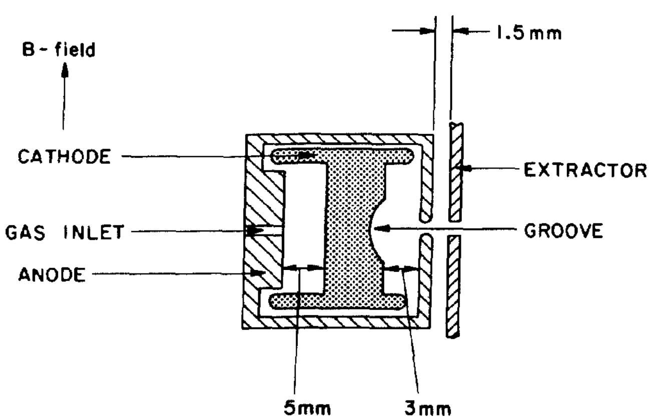

Fig. 3. *An asymmetric magnetron with single groove.*

Status of the Multiampere Cooled Magnetron

Until recently the BNL negative ion sources were not cooled, and therefore had to operate in the pulsed mode. Beam currents did not exceed the 1 A level (Mark III, 10 ms) and beam pulses were not longer than 200 ms (Mark IV, 0.3 A). However, the need for steady state neutral beams has led the BNL group to begin the development of a new generation of negative ion sources, with cooled electrodes. Until a year or two ago the development of steady state sources was limited due to a very high cathode power density (1-2 kW/cm²) required for an extracted H^- current density of several hundred mA/cm².[4] Nucleated boiling techniques had to be used to remove the heat from electrodes. The development of the grooved, asymmetric magnetron improved the power efficiency, and also reduced the electrode heat load by an order of magnitude, so that a simple water flow is now sufficient as the method for heat removal. Table I shows essential design parameters of the first cooled magnetron (Mark V) and Fig. 4 is a cross section of the source.

The whole cathode structure has been fabricated of molybdenum, while the rest of the source is made of stainless steel. In order to prevent the diffusion of electrons from the discharge region, the side shields are shaped such as to obtain always an electric field component parallel to the magnetic field.[5]

Table I. Mark V Magnetron

Features:	Cathode with 5 Grooves
	Asymmetric Chamber
	Water Cooling
Design Parameters:	
Beam Current (H^-/D^-)	1 A
Emission Current Density	0.5 A/cm²
Extraction Voltage	10-15 kV
Mode of Operation	5 s to steady state
Power Efficiency	9 kW/A
Gas Efficiency (Atomic)	> 5%

Initial tests with the source have started. In the hydrogen mode steady state (several hours) have been obtained with currents up to 8 A and at voltages around 500 V. It was observed that in such a large magnetron source (60 cm² cathode area) the uniformity of the magnetic field over the full area of the cathode is essential for a uniform discharge distribution.

Magnetron Sources with Plasma Injection

Recently we began to investigate a modification of the magnetron which may significantly improve some of its characteristics. In the standard source, the plasma is sustained between the anode and cathode at relatively high gas pressures (≃ 0.1 Torr). The cathode also serves as the main negative ion converter. This dual function does not allow an easy optimization of source parameters.

An attractive alternative is to separate the plasma production from the conversion by using a hollow cathode discharge as the plasma source. Hollow cathode discharges have almost ideal characteristics for this purpose: a steady state operation, a very high ionization efficiency (> 90%) and high plasma densities (10^{13}-10^{14} cm^{-3}), while the plasma can be sustained at very low background pressures (≃ 10^{-4} Torr). The position and the bias voltage of the converter, for maximum H^- yield, can in such a system be optimized independent of the plasma parameters. The low gas pressure results in a reduction of H^- losses inside and outside the source and improves the voltage hold-off of the accelerator electrodes. Figure 5 shows the idea schematically.

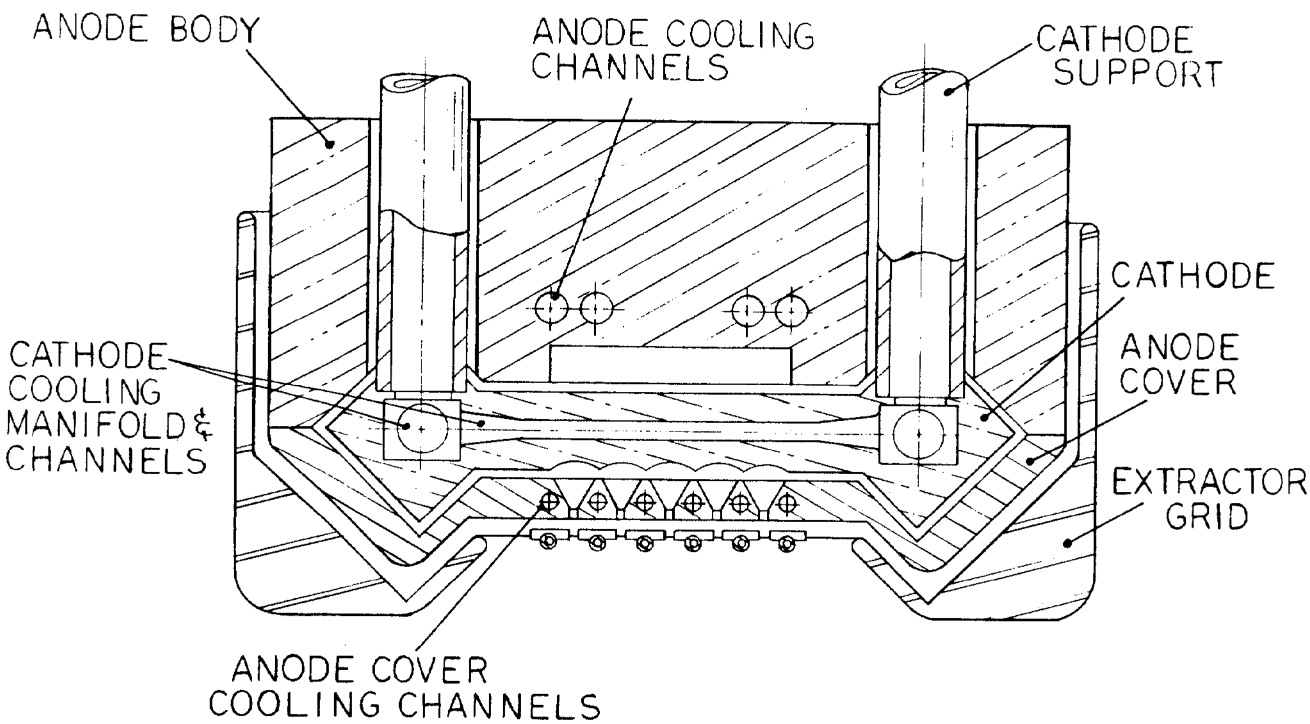

Fig. 4. A cross section of the Mark V water cooled magnetron for steady state operation.

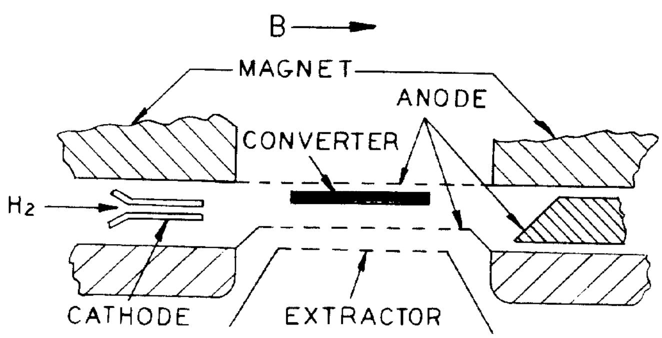

Fig. 5. Schematic of the magnetron with independent plasma injection from a hollow cathode discharge.

Several experiments were performed at MIT on an existing hollow cathode discharge test stand.[6] By inserting a cesium coated converter there was a strong evidence for a substantial H^- production, with densities comparable to those obtained with the standard magnetron (several hundred mA/cm^2), but at background pressures of only 3×10^{-4} Torr.

In subsequent experiments at BNL, rectangular shaped hollow cathode plasmas (required for large area converters) were successfully tested with single and multiple models.[7]

An experiment is now prepared that will simulate a magnetron with independent plasma production from three hollow cathodes. The parameters are chosen such as to extract a 1 A steady state beam.

In more complex designs, hollow cathode discharges with background pressures of 10^{-5} Torr can be obtained. A magnetron source with injection of this type of hollow cathode plasmas might be used to produce T^- and $^3He^-$ beams due to the very low background pressure.

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