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BNL NEUTRAL-BEAM DEVELOPMENT GROUP

PROGRESS REPORT FY 1982

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Introduction

The Brookhaven Neutral Beam Development Group is developing injector systems for the next generation of experimental fusion devices, which require high energy neutral deuterium beams. The injectors are based on the acceleration and neutralization of negative deuterium ions, because their neutralization efficiency is high and nearly independent of energy in the range beyond 50 keV/nucleon.

We have mainly concentrated our efforts on the development of H^-/D^- sources capable of delivering about 1A of beam current, operating steady state at an energy of several tens of keV and having properties that would allow a scaling up to 10A and their use in a high energy neutral beam line. In the seventies we have developed negative ion sources of the plasma surface type with extracted current densities of several hundred mA/cm². Particularly successful was the development of the magnetron source, from which pulsed beam currents in excess of one ampere have been obtained and accelerated up to 120 kV. These magnetrons have become standard sources in high energy accelerator laboratories around the world and they are candidates for application in polarized H^- ion sources as well.

In FY 1981, we started the transition from pulsed high current negative ion sources to sources designed to operate steady state. We have been testing since then two types of d.c. sources; a standard magnetron source and a modified magnetron with plasma injection from a hollow cathode discharge (HCD). Both sources are now operating with steady state discharges; 0.12A of H^- has been extracted from a d.c. magnetron while about 0.5A of H^- has been extracted from the HCD type source. The HCD source operates at much lower pressures ($\sim 10^{-3}$ Torr) than the regular magnetron ($\sim 10^{-1}$ Torr) while sustaining the same high plasma density (10^{13} - 10^{14} cm⁻³).

In order to avoid costly construction of high power electrostatic equipment, we are planning the construction of two components of a neutral beam line: an HCD source and a plasma neutralizer. These two components will match the Berkeley electrostatic accelerator, presently in the design stage.

The experiments with HCD sources and HCD plasma neutralizers are the main topics in this report.

The BNL Approach

The principal elements of the neutral beam system are the ion source, the accelerator and the neutralizer. The BNL objective in source development is a steady state negative ion source with a beam density as high as it can be handled in the rest of the neutral beam line. In this way, the size of the system and the injection port in the fusion device will be minimized. High densities of negative ion beam currents can be achieved by surface conversion of particles originating from a dense plasma and bombarding a low work function surface.

Among several devices to produce a high density plasma, the most attractive is a hollow cathode. The cathode is usually a hot tantalum tube, operating steady state and producing an almost fully ionized plasma flowing along magnetic field lines. A low work function surface, molybdenum with a partial monolayer of cesium, is most widely used. Positive ions from the plasma are accelerated toward the converter. After conversion, the converter voltage accelerates negative ions back, through the plasma and out of the source. Cylindrical curvature of the converter surface helps to focus negative ions into the extraction grid. The newly constructed BNL source has to match the LBL high energy electrostatic accelerator.

The performance of plasma neutralizers for negative ions with a neutralization efficiency of more than 80% exceeds significantly the capabilities of gas neutralizers. In such a neutralizer, plasmas from multiple highly efficient hollow cathodes are guided along magnetic field lines into the neutralizer channel.

Project Goals for FY 1982

Initial tests of magnetrons with independent plasma injection from hollow cathode discharges have shown the promise of high density beams and a low background gas operation. Extensive studies of the HCD based negative ion source are planned for further evaluation, including operation at full power, selection of methods of cesium injection, density control, measurements of plasma properties and operation of the source in the steady state mode.

Studies of a plasma neutralizer based on the hollow cathodes will be initiated.

Progress in FY 1982

Highlights

1. In this fiscal year we have realized the extraction of 0.5A steady state negative hydrogen ion beams from a hollow cathode discharge source. This source, with independent plasma injection, appears to be superior to the standard magnetron.
2. The creation of low work function surfaces by diffusion of liquid or vaporized cesium through porous tungsten and molybdenum plates at "low" temperatures has been successfully explored and appears to be applicable for larger systems.
3. Transportation studies of high density plasmas from hollow cathodes guided through solenoidal magnetic fields suggest their application in plasma neutralizers as a practical alternative for laser neutralizers.

Hollow Cathode Discharge Experiments

In this fiscal year, attention was concentrated on the operation of HCD sources. Most studies were done with two hollow cathodes in parallel, with a rectangular shape in order to produce plasma sheaths as thin as possible

Figure 1 shows the dual hollow cathode source in d.c. operation. During the work substantial changes have been made in the design of cathodes, electrode shielding, electrode cooling and magnet pole shapes. With the Livermore MFE computer program and with shimming and reshaping the poles, the magnetic field was considerably improved in uniformity ($< 10\%$). These field modifications allowed the hollow cathode discharge to ignite immediately, in particular with independently controlled cathode power supplies. The operating parameters of the source are summarized in Table I.

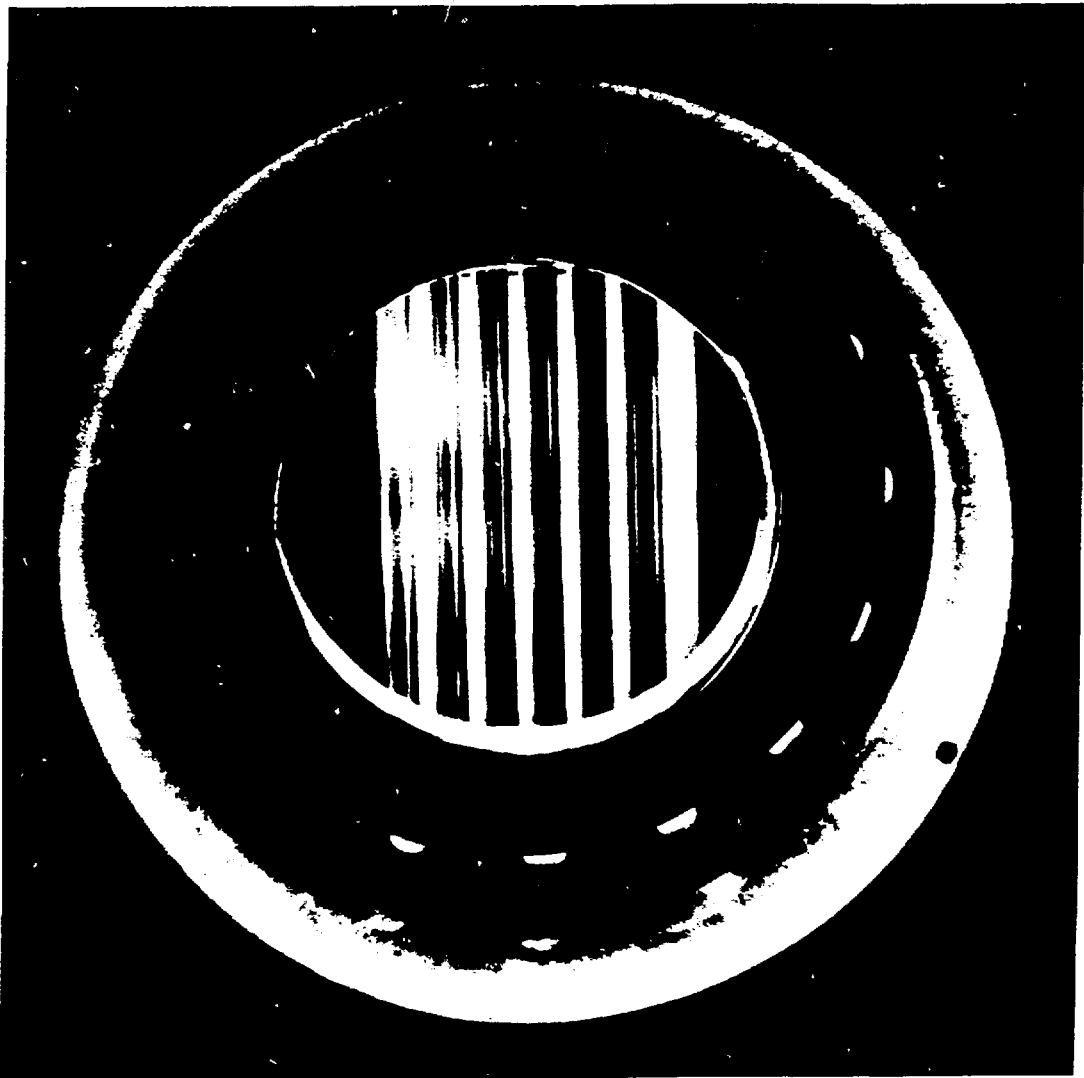


Figure 1 -- A view toward the five ion emission slits of the one-half ampere BNL hollow cathode discharge source in d.c. operation.

TABLE I
Parameters of the HCD Source

Operation of Hollow Cathodes	Steady State (> 60 hrs)
Plasma Density	10^{13} - 10^{14} cm^{-3} (10^{14} cm^{-3} required)
Magnetic Field	250 Gauss
H ⁻ Yield	0.5A (1A design value)
H ⁻ Extracted Current Density	0.1A/cm ² (0.2A/cm ² design value)
Arc Current (per cathode)	40A
Converter Current	8A
Background Pressure	8×10^{-4} Torr

The cathodes ran continuously for 60 hours. It is expected on the basis of weight loss that cathodes could last hundreds of hours of continuous operation in hydrogen. In order to extend this range, we are looking for metals or alloys in which hydrogen does not form solid solutions.

All the components of this system operate reliably except for the cesium supply, although many hours of reliable operating time were achieved at relatively low H⁻ output (150 mA). New approaches to achieve low work function converters have been actively pursued. Construction of a porous molybdenum converter, in which Cs will diffuse from the back, is completed and will be tested soon.

Cesium was successfully injected through one of the hollow cathodes. Although there was no significant increase in the H⁻ yield (as compared with cesium vapor injection near or on the converter), a spectacular improvement was observed in the operation of the hollow cathode itself: the arc current of that cathode jumped from 18 to 75 amperes, while its arc voltage dropped from about 100 to 40 volts. This mode of operation holds the potential of improving the power efficiency of an HCD based negative ion source by more than a factor of two and prolonging the cathode lifetime since the cathode temperature is much lower.

Experiments were done to examine the feasibility of controlled injection of liquid cesium (instead of vapor) through a porous molybdenum

converter. After verifying the wettability of porous moly, and the transparency of porous moly, and after comparing (with the Mk III magnetron) the H^- yield of porous and non-porous molybdenum cathodes (only slightly less yield!), we fabricated a cesium system with a porous wall. We were able to produce a low work function converter surface by forcing the liquid cesium through porous (80% dense, 4 mm thick) molybdenum. The H^- beam output of 25 mA, detected on a Faraday cup oriented 90° with respect to the converter, could be maintained for many hours even after the cesium back pressure was removed.

A new converter front surface, which incorporates a porous wall, has been designed and fabricated to be tested on the large HCD source.

Three new arc power supplies from EMI were installed including an instrumentation amplifier system for remote computer control and monitoring of the supplies. Work on the software is continuing. A large aperture (6") non-destructive high energy d.c. current beam transformer has been constructed, installed and is operating successfully.

Plasma Neutralizers

One of the very efficient types of neutralizers is the plasma neutralizer, with an efficiency exceeding 80%. We injected an HCD plasma from a T-shaped dual cathode system into a straight neutralizer section, which was a part of a closed-loop solenoidal magnetic field (see Figure 2). Electron densities well in excess of 10^{13} cm^{-3} were measured. This system, which operates steady state, simulates the plasma neutralizer needed for an optimum neutralization of 0.2-1 MeV D^- beam. The target thickness is about 75% of the theoretically optimum target. Only the small size of the vacuum system (which limited the coil length to 24 cm) and the power supply limitation (to 25 amperes arc current) prevented the achievement of the desired target thickness. A new test stand with a solenoidal field has been built and experiments are underway to determine plasma properties as a function of various parameters.

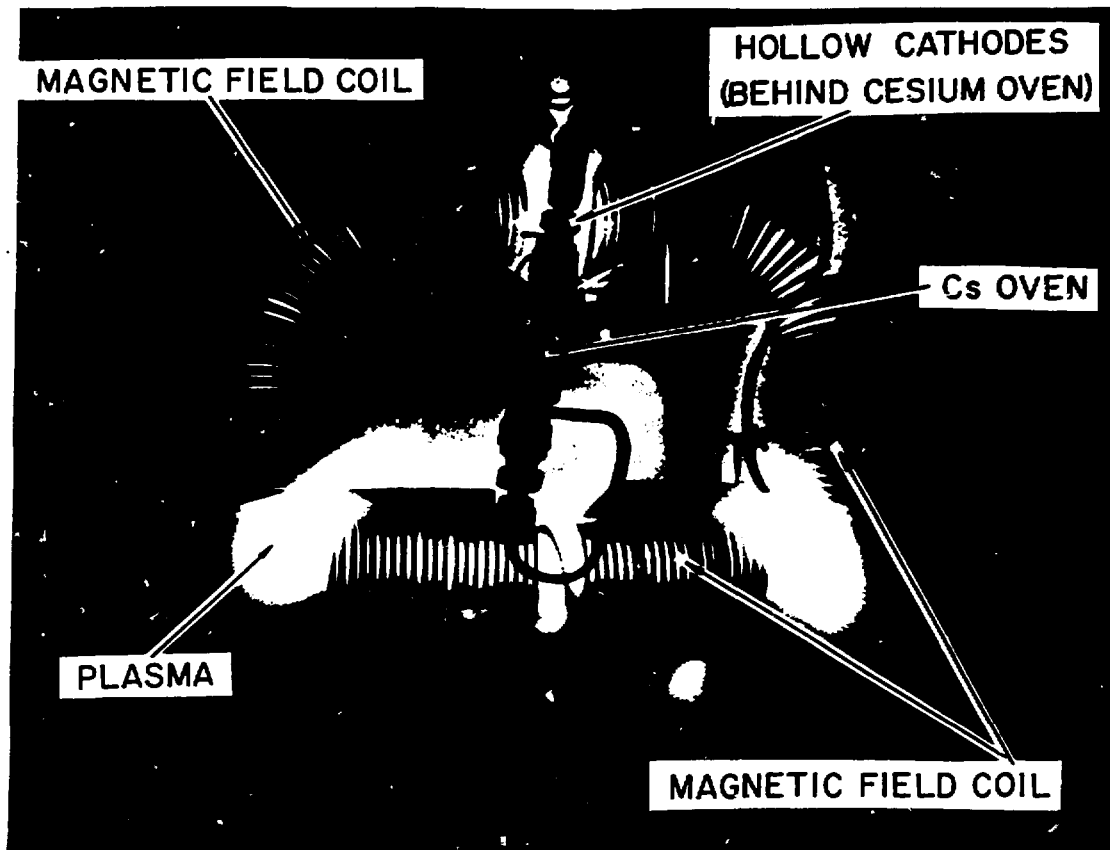


Figure 2 -- A close-looped 4 cm^2 steady state hydrogen plasma from a hollow cathode, streaming along magnetic field lines into the neutralizer.

Plans for FY 1983

Studies with hollow cathode discharges in magnetron type d.c. negative ion sources will continue with special attention to the formation of a thin ($< 1 \text{ cm}$), wide (30 cm) and uniform dense plasma sheet, produced by using several hollow cathodes, guided along special shaped magnetic field lines. Several low work function converters will be tested, including a large porous molybdenum unit with cesium fed by diffusion from the back side. A 1-2A prototype source, which has to match the Berkeley 80 kV accelerator, will be designed and fabricated. Design studies of a hydrogen plasma neutralizer based on hollow cathode discharges will be initiated. This neutralizer will also match the 80 kV prototype neutral beam injector.

Neutral Beam Development Group

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