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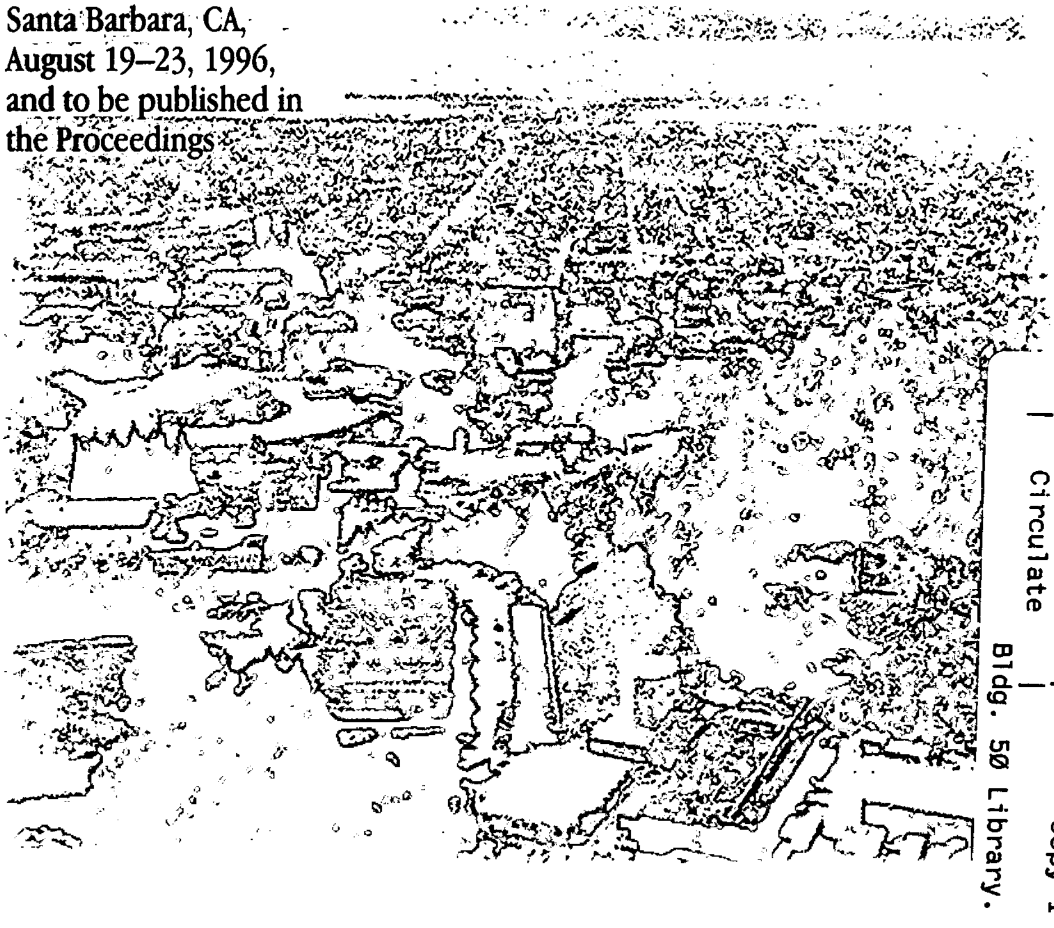

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High Current Short Pulse Ion Sources*

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Abstract

High current short pulse ion beams can be generated by using a multicusp source. This is accomplished by switching the arc or the RF induction discharge on and off. An alternative approach is to maintain a continuous plasma discharge and extraction voltage but control the plasma flow into the extraction aperture by a combination of magnetic and electric fields. Short beam pulses can be obtained by using a fast electronic switch and a dc bias power supply. It is also demonstrated that very short beam pulses (~10 μs) with high repetition rate can be formed by a laser-driven LaB_6 or barium photo-cathode.

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1. INTRODUCTION

High current short pulse ion beams are required in many accelerator facilities, such as Fermi Laboratory, LANSCE at Los Alamos, KEK in Japan, DESY at Hamburg, the SSC and the Proton Therapy Machine at Loma Linda Hospital. Future Spallation Neutron Sources (the NSNS, the ESS and the LANSCE upgrade) as well as compact neutron tubes will be operating with even higher current intensities and duty factor. In order to meet these future requirements, new ion sources or source operating schemes are being developed in some of the accelerator laboratories.

Ion beams can be conveniently extracted from a plasma generator. Short beam pulses are normally formed by modulating the arc discharge with an electronic switch. Figure 1 shows the experimental setup when a multicusp ion source is employed. The multicusp generator is capable of generating large volumes of uniform, high density and quiescent plasmas. It was originally developed to produce multi-amperes of deuterium ions with pulse length as long as 30 sec for neutral beam heating of tokamak fusion plasmas.

During the last decade, the multicusp source has been modified to produce high current, short-pulse ion beams for particle accelerator applications. In particular, the filament cathode in the source chamber is now replaced by an antenna coil and the plasma is produced by a 2 MHz RF induction discharge. It has been demonstrated that the RF driven multicusp source can be operated in pulse mode to provide high intensities of either positive or negative ion beams.

Ion beams formed by RF discharge are typically limited to pulse lengths greater than 20 μs. Several new schemes are now being tested to generate ion beams with shorter pulses. This paper describes two techniques for short pulse ion beam formation. The first scheme employs a fast electronic switch together with a relatively low bias voltage on the plasma electrode. The second approach utilizes a laser-driven photocathode as a source of primary ionizing electrons.

2. EXPERIMENTAL SETUP

Generation of a RF discharge by placing the induction coil (or antenna) inside a multicusp source chamber was tested at Berkeley and Garching for neutral beam applications.[1] In 1991, a new RF driven H^- source was developed at the Lawrence Berkeley National Laboratory (LBNL) for use in the injector unit of the SSC.[2] The source chamber is a thin walled (4-mm-thick) copper cylinder (10-cm-diam by 10-cm-long) surrounded by 20 columns of samarium-cobalt magnets which form a longitudinal line-cusp configuration for plasma confinement. The magnets in turn are enclosed by an anodized aluminum cylinder, with the cooling water circulating around the source between the magnets and the inner housing wall.

A pair of permanent magnet filter rods can be installed near the first or plasma electrode to enhance the production of atomic H^+ or N^+ ions and volume-produced H^- ions. The back flange has four rows of magnets cooled by drilled water passages and contains all the required feedthroughs and ports, including a gas inlet, antenna feedthrough, and a 1-cm-diam opening for a quartz rod serving as a light pipe or window.

The source plasma is generated inductively by a two turn porcelain-coated copper coil antenna. The porcelain coating can survive months of operation without any significant deterioration. This two-turn induction coil is connected in series to a matching network as shown in Fig. 2. The 2 MHz RF signal, generated by a digital synthesizer is sent to a preamplifier, and then to the main power amplifier. The RF power output of the main amplifier can be controlled by changing the amplitude and frequency of the synthesizer signal. Maximum efficiency is achieved when the output voltage and current of the main RF amplifier are in phase and operating at a 50 Ω impedance. The RF power travels through a 50 Ω coaxial cable to the isolation transformer and matching network, and antenna. The matching network matches the impedance of the antenna coil immersed in the plasma to the 50 Ω impedance of the amplifier.

When the source is operated in pulsed mode, a small tungsten filament can be used to generate some electrons to aid in plasma ignition. However, the filament has a limited lifetime and contributes tungsten impurities to the plasma. It has been demonstrated that the ultraviolet light from a nitrogen laser impinging upon a magnesium target can provide enough photo emission electrons to ignite the plasma[3]. Recently, it is shown that the more expensive laser could be abandoned in favor of an inexpensive xenon flash lamp[4]. The timing of the flash with respect to the RF pulse affects the plasma starting. In normal operation, the RF amplifier and the flash lamp are triggered at the same time. This will enable the plasma to be formed at the very beginning of the pulse and thus avoid the porcelain coating to be damaged by high RF antenna voltages.

3. EXPERIMENTAL RESULTS

(a) Pulsed H^- Ion Beam Operation

A multicusp source has been operated with a RF induction discharge to generate volume-produced H^- ions. The SSC RF-driven source routinely provided 35 kV, >35 mA H^- beams with a normalized rms emittance less than 0.1 π-mm-mrad. The source was typically operated with 100 μs beam pulse width at a 10 Hz repetition rate. The H^- output current of a RF-driven multicusp ion source can be increased by introducing a trace amount of cesium into the collar region. Most recently, the SSC RF-driven H$^-$ source was modified to enhance the H$^-$ output for testing a high current LINAC. A collar with eight cesium dispensers was installed at the exit aperture. A plasma grid heater element controls the temperature of the cesiated surfaces and the rate of cesium dispensation. With this arrangement, beam current in excess of 100 mA and e/H$^-$ ratios close to one have been observed (Fig. 3)[5].

The extraction of H$^-$ ions is accompanied by a large amount of electrons, which must be removed from the beam before further acceleration. The remaining H$^-$ ion beam must be focused properly to match the acceptance of the next element of the accelerator system, e.g., a radio-frequency-quadrupole (RFQ). Recently, a permanent-magnet insert structure for the removal of electrons from pulsed, extracted negative ion beams has been developed at LBNL[6]. The simulated output of Fig. 4 shows that the electrons are removed from the H$^-$ beam and made to impinge on the second electrode[7]. The trajectories of the H$^-$ ions are not noticeably perturbed.

(b) Source Operation with Inert and Diatomic Gases

The RF multicusp source has been tested with inert gas plasmas such as He, Ne, Ar, Kr, and Xe. Figure 5 shows the extractable positive ion current density as a function of RF power. The optimum source pressure is typically below 1 mTorr. It can be seen that the output currents increase linearly with RF input power. In most cases, the extractable ion current density can be as high as 1 A/cm^2 at approximately 50 kW of RF input power.

The hydrogen ion species composition in the RF driven source has also been investigated. With a magnetic filter in place, the H^+ ion concentration is greater than 97% for an RF input power of 30 kW. The highest current density achieved is about 1.5 A/cm^2.

For a nitrogen discharge, the atomic N^+ ion concentration also increases with the RF input power. A nearly pure (>98%) N^+ ion beam with current densities in excess of 500 mA/cm^2 has been obtained when the magnetic filter is employed. Similar results are obtained when other diatomic gases (such as oxygen) are used for the discharge.

(c) Compact High Intensity Neutron Generator

A 25-mm-diameter RF-driven ion source has been developed for a high output, compact neutron generator[8]. This generator is designed to provide a 14 MeV neutron flux of 10^9 n/s, utilizing the D-T fusion reaction. Due to thermal and power constraints, the ion source is operated in pulse mode. This source is operated at 10-20 μs pulse width (Fig. 6) and repetition rate of 100 Hz. It is capable of producing the necessary extractable hydrogen current density of 800 mA/cm^2 with a monatomic species yield over 94% at a source pressure as low as 5 mTorr[9]. Thus, the new ion source demonstrates a substantial improvement over the Penning ion source used in the conventional sealed-tube neutron generators.

(d) Pulsed Beams for Induction Linacs

In order to minimize the required volt-seconds, induction linacs are operated with short beam pulses of about 3 μs in width. Switching on ion beams by pulsing the discharge is too slow due to plasma formation time. An alternative approach is to keep the discharge and the extraction voltage at steady state while the plasma flow into the extraction aperture is controlled by a combination of magnetic and electric fields. Short beam pulses with high repetition rate can be generated with a combined arrangement of fast electronic switches and a dc bias power supply.

The dc power supply and the electronic switch are installed between the plasma electrode and the source chamber wall. In normal operation, the plasma electrode is connected to the anode walls. If a positive voltage (~100 V) is suddenly applied to the plasma electrode, the plasma in front of the exit aperture is pushed away by the electrostatic field and the positive ion current disappears (Fig. 7). The time response of the beam intensity follows closely the applied voltage. A voltage modulator with rise/fall time less than 100 ns is now being developed at LBNL to reduce the beam pulse width.

(e) Formation of Short Beam Pulses by Laser Driven Photocathodes

The feasibility of laser induced photo-electron emission as a driving mechanism for short plasma pulse production has recently been investigated at LBNL with an excimer laser[10]. The exciting laser pulse energy ranged from 300 mJ to 500 mJ with a photon energy of 5 eV and a pulse width of approximately 40 ns. Two low work function materials, LaB_6 and barium, were used as cathode materials. A significant increase in the photo-emitted electron current was obtained when a low density plasma was present; the highest observed photo-emission current exceeded 140 A. Preliminary results (Fig. 8) showed that very short ion current pulses (~10 μs) can be formed by this laser-driven photo-emission scheme.

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FIGURE CAPTIONS

Fig. 1	Pulsed mode operation for the multicusp ion source.
Fig. 2	Schematic diagram of the complete RF power system.
Fig. 3	Oscilloscope traces showing a H^- current of 100 mA.
Fig. 4	Planar calculation showing the effect on the extracted electrons due to a pair of permanent magnets located inside the first electrode.
Fig. 5	Extracted beam current and density as a function of RF power for various inert gas plasmas.
Fig. 6	Beam pulse shape obtained from a subcompact RF driven ion source.
Fig. 7	Micro beam pulses obtained by pulsed biasing the plasma electrode. Each beam pulse is about 40 μs in width.
Fig. 8	Langmuir probe signal of a pulsed plasma generated by a laser-driven photocathode.

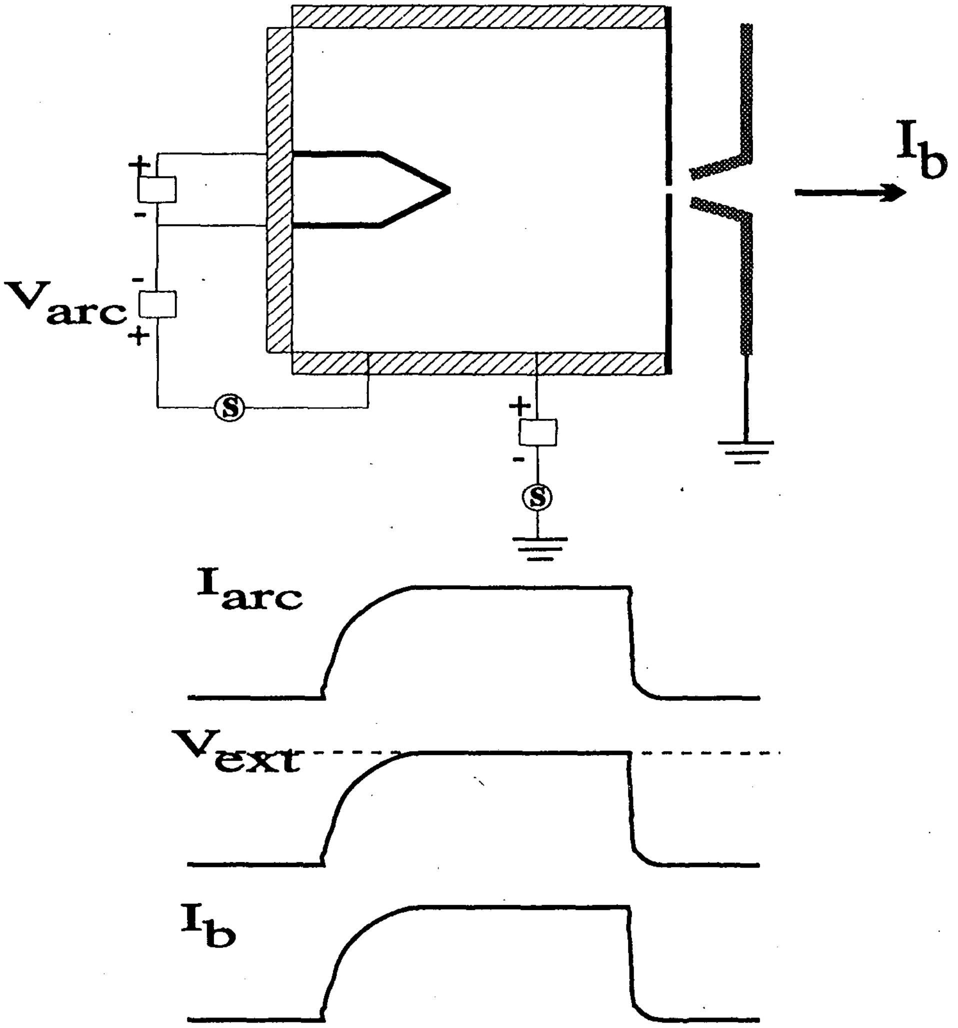

Fig. 1

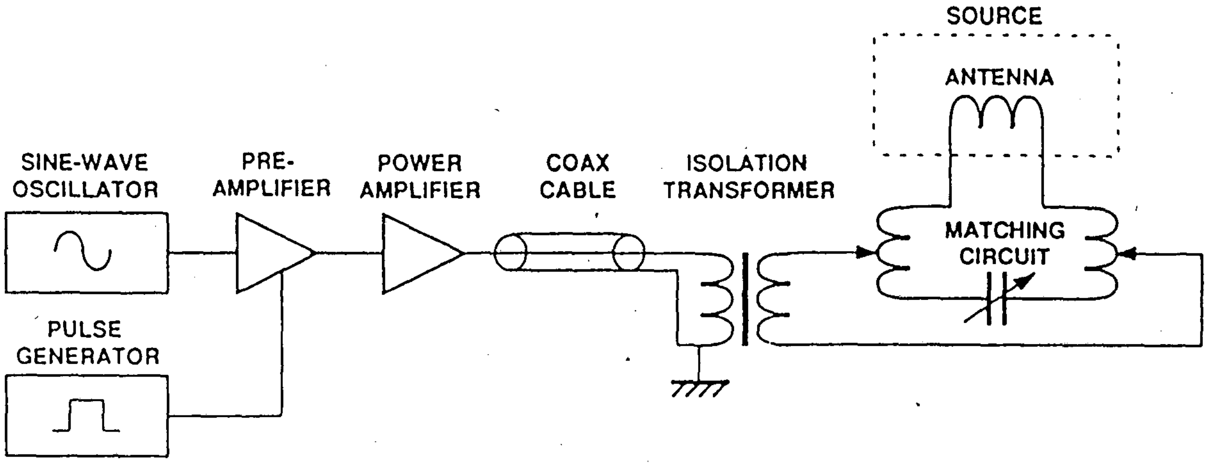

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Fig.2 Schematic diagram of the complete rf power system.

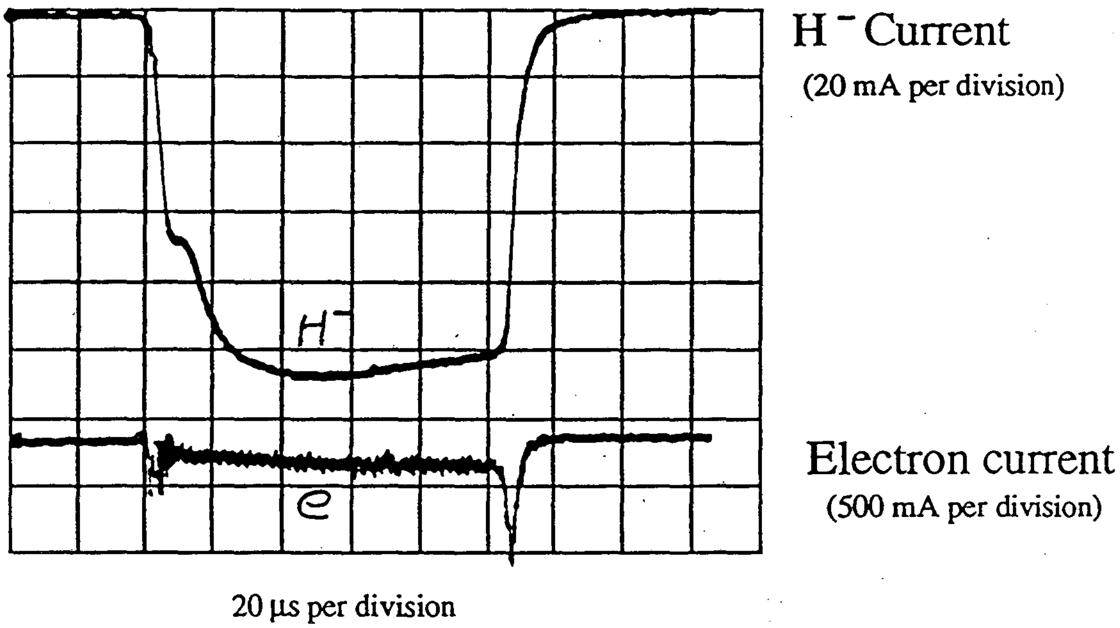


Fig.3 Oscilloscope trace showing a H^- current of 100 mA.

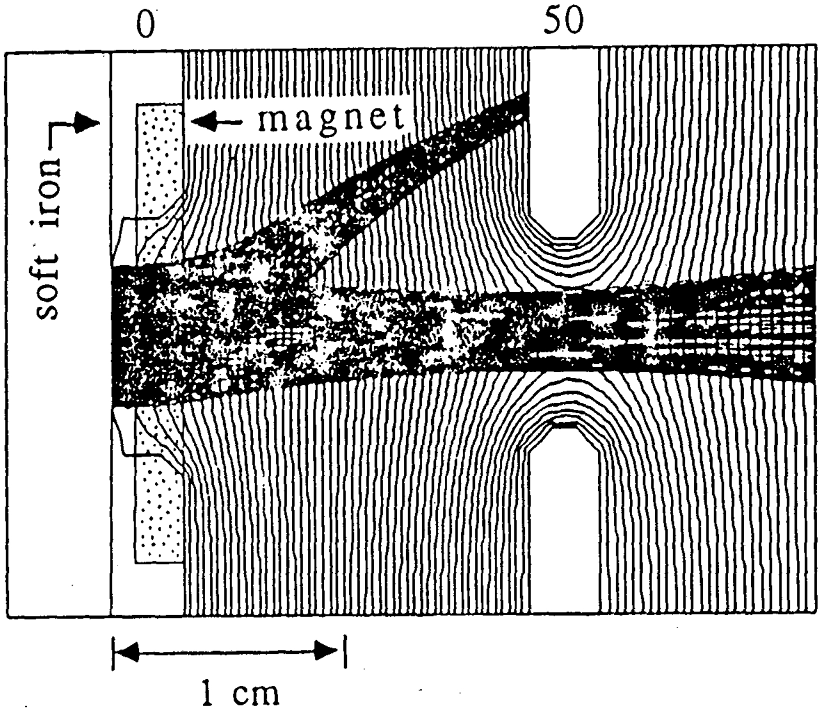


Fig. 4

Planar Calculation Showing the Effect on the Extracted Electrons due to a Pair of Magnets Located Inside the 1st Electrodes

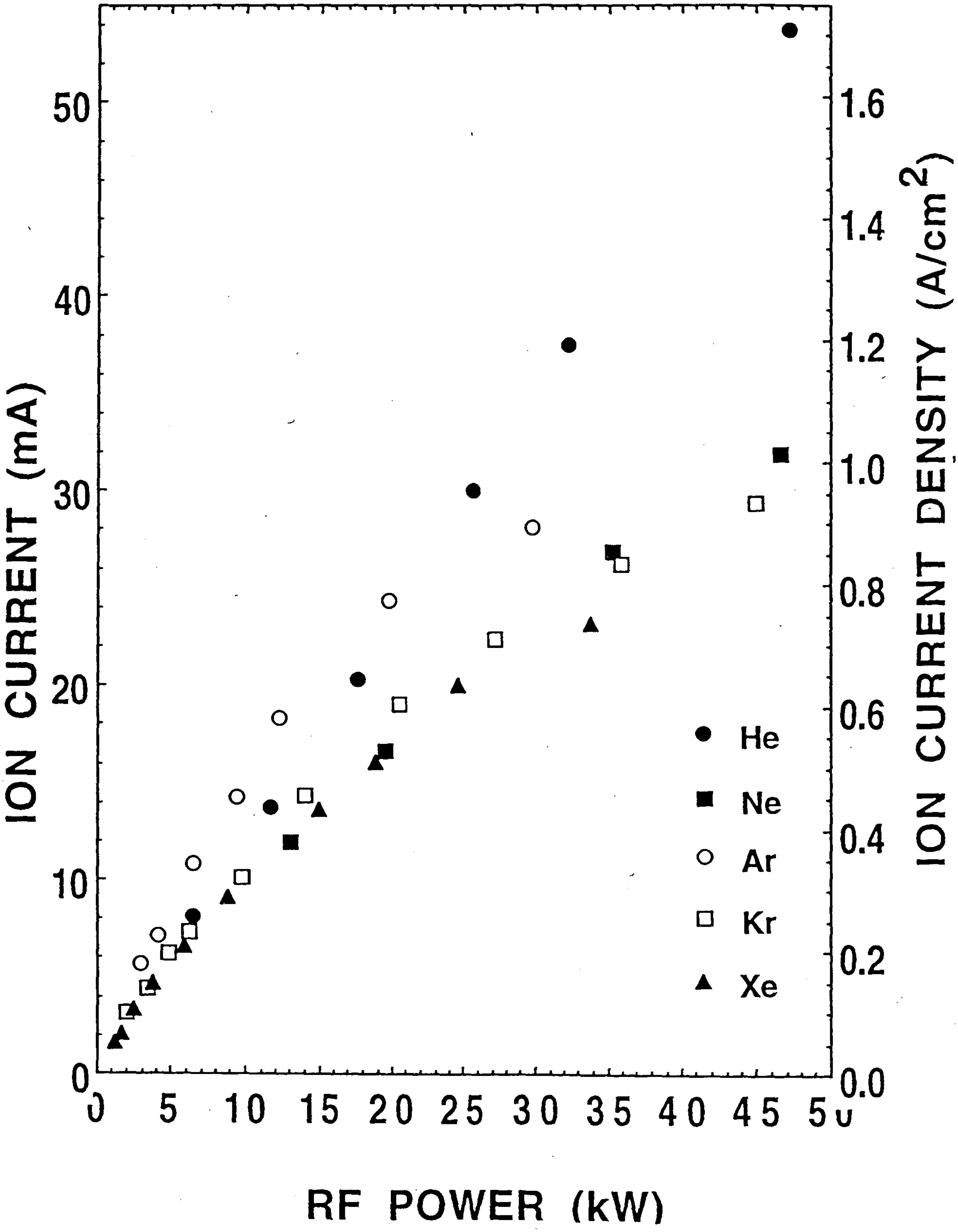
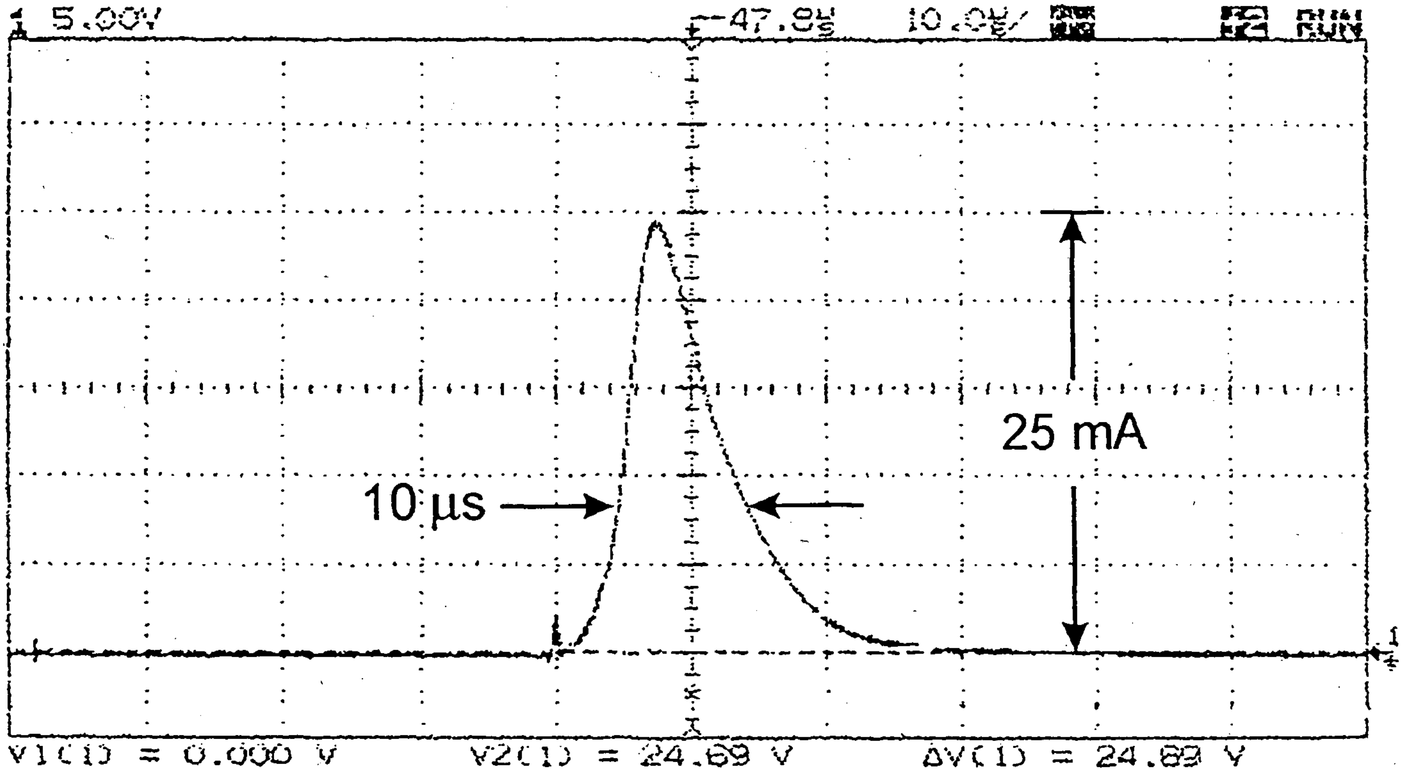

ION CURRENT (mA)
ION CURRENT DENSITY (A/cm²)
RF POWER (kW)
0
10
20
30
40
50
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
0
5
10
15
20
25
30
35
40
45
50
● He
■ Ne
○ Ar
□ Kr
▲ Xe

Fig. 5

SATURATION HYDROGEN ION BEAM CURRENT EXTRACTED FROM 2 mm DIAMETER APERTURE



58 kW - 5.6 mTorr
[No cusp and no filter magnets]

Fig. 6

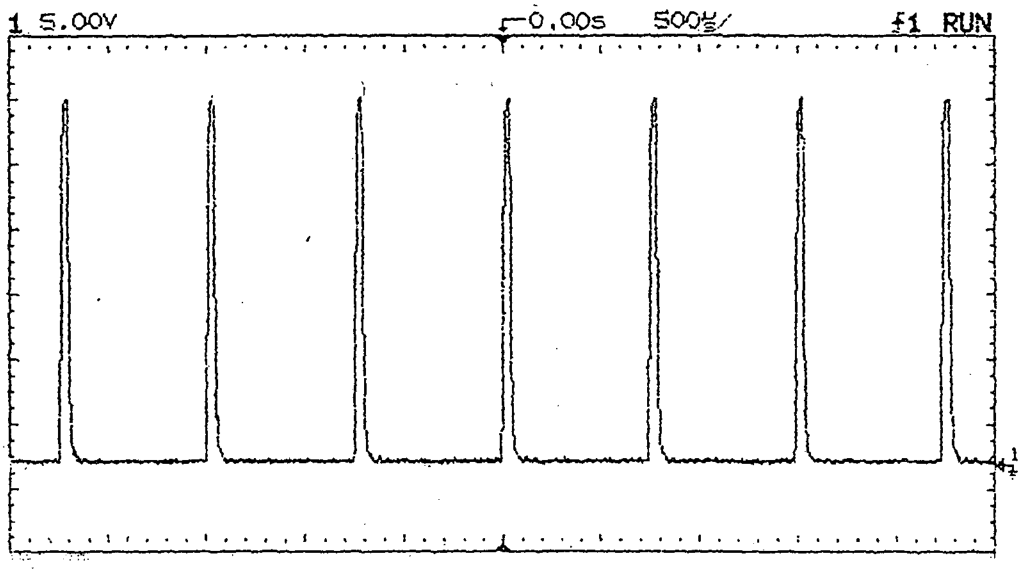


Fig. 7

Micro beam pulses generated by pulsed biasing the plasma electrode

Langmuire Probe Signal

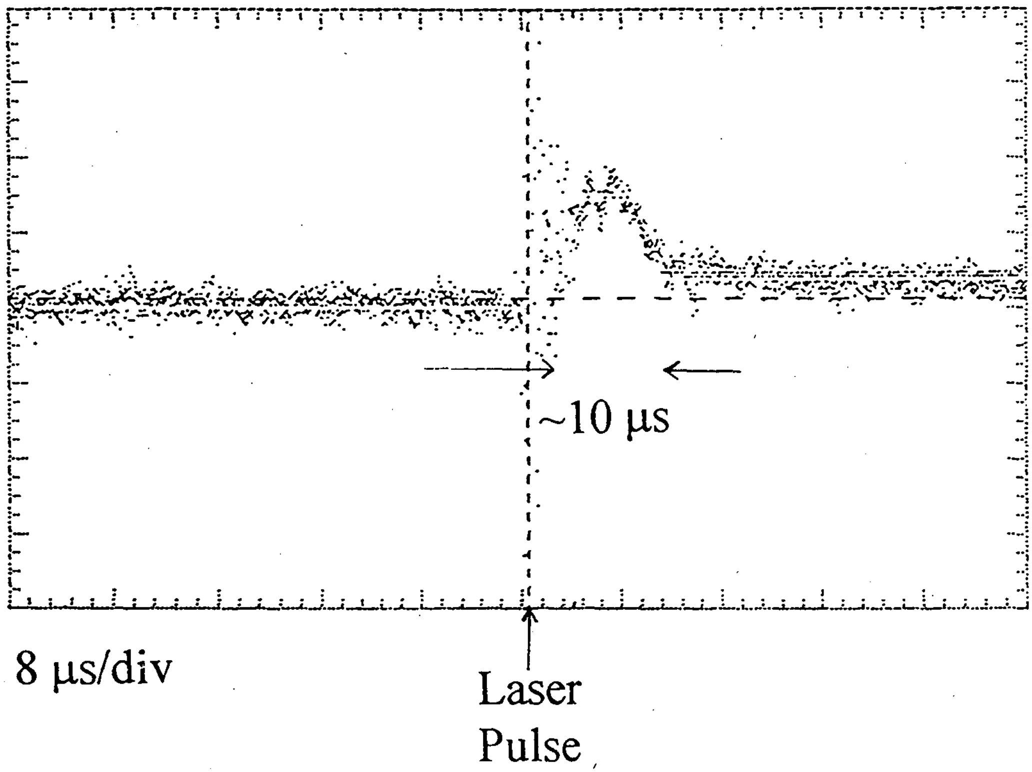


Fig. 8

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