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MAGNETICALLY INSULATED ION DIODE WITH A GAS-BREAKDOWN PLASMA ANODE

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14. Abstract/Notes

An active anode plasma source has been operated on the LONGSHOT annular magnetically insulated ion diode. This source uses an inductive voltage from a single turn coil to break down an annular gas puff produced by a supersonic nozzle. The resulting plasma is magnetically driven toward the radial insulating magnetic field in the diode accelerating gap and stagnates at a well-defined surface after about 300 ns to form a plasma anode layer defined by magnetic fields. An ion beam is then extracted from this plasma layer by applying typically a 150 kV, 1 μs pulse to the accelerating gap. Optimization of the timing of the gas puff, the plasma production discharge and the high voltage pulse has resulted in 1 μs duration 75-150 keV ion beam pulses with >100 A/cm² peak ion current density over an area of about 400 cm². Up to 5 J/cm² has been collected by a 4 cm² calimeter. The diode impedance history can be varied so that rising, flat, and falling voltage pulse waveforms can be produced. Streak photographs of beamlets impinging on a scintillator and time integrated targets both show beam divergence angles $\leq 3^{o}$*, but under certain operating conditions, large excursions* $(\sim 25^{o})$ *in mean aiming angle on time scales of 20-200 ns. These and other operating characteristics of the gas-breakdown diode are discussed.*

15. Remarks

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Magnetically Insulated Ion Diode With a Gas-Breakdown Plasma Anode*

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Abstract

An active anode plasma source has been operated on the LONGSHOT annular magnetically insulated ion diode. This source uses an inductive voltage from a single turn coil to break down an annular gas puff produced by a supersonic nozzle. The resulting plasma is magnetically driven toward the radial insulating magnetic field in the diode accelerating gap and stagnates at a well-defined surface after about 300 ns to form a plasma anode layer defined by magnetic fields. An ion beam is then extracted from this plasma layer by applying typically a 150kV, 1 μs pulse to the accelerating gap. Optimization of the timing of the gas puff, the plasma production discharge and the high voltage pulse has resulted in 1 μs duration 75-150 keV ion beam pulses with >100 A/cm² peak ion current density over an area of about 400 cm². Up to 5J/cm² has been collected by a 4 cm² calimeter. The diode impedance history can be varied so that rising, flat, and falling voltage pulse waveforms can be produced. Streak photographs of beamlets impinging on a scintillator and time integrated targets both show beam divergence angles ≤ 3°, but under certain operating conditions, large excursions (~25°) in mean aiming angle on time scales of 20-200 ns. These and other operating characteristics of the gas-beakdown diode are discussed.

Introduction

Magnetically insulated diodes (MID's) have proven to be very useful intense ion beam sources in applications ranging from Inertial Confinement Fusion at the $>10^{12}$W level [1] to materials science research at a power level of about 10^{10}W [2]. The ion source at the anode in these diodes has usually been a flashover plasma induced on a dielectric surface by the high voltage pulse that accelerates the ion beam [3]. Electrons which "leak" across the insulating magnetic field and impinge upon the surface are also believed to play a major role [4]. Such "surface flashover anodes" have several disadvantages, including: 1. The turn-on delay, especially for short pulses or at low voltages, can waste a substantial fraction of the power pulse delivered to the ion diode; 2. The large number of neutrals blown off the surface as part of the flashover process are believed to be responsible for the rapidly impedance characteristic of these diodes [7]; 3. Ion beams drawn from surface flashover plasmas tend to be a mixture of protons and heavier species, especially various charge states of carbon and oxygen and 4. The life of surface flashover anodes ranges from one pulse at the highest power levels [1] to perhaps a few hundred at the 10^9W/cm² level [2,7] due to the damage they sustain from electron bombardment.

There have been several attempts to provide an anode plasma ion source which does not suffer from these disadvantages, such as the plasma filled diode of Mendel [8], the plasma source used by Humphries et al [9] which is a direct ancestor of the source we describe here, and the actively driven surface flashover anodes (using an energy source independent of the main ion accelerating power pulse) of McClure [10] and Greenly [11]. Other possibilities in various stages of development are described in other papers in this conference [O-E-6, O-H-2 and 4, P-B-20, etc].

In this paper we describe a magnetically insulated diode with a gas-breakdown anode plasma ion source which improves upon almost all catagories of results obtained with a surface flashover anode when operated on the same pulsed power generator (LONGSHOT). The total ion output has been more than doubled. A variety of diode impedance histories including constant or even rising impedance can be selected by changing parameters of the source. Proton beams produced when H_2 gas is used show no impurity species, within the ± 10% ability of the foiled Faraday-cup measurement technique. Furthermore, the beam extraction can be made to begin coincident with the beginning of the voltage pulse. The diode was fired hundreds of times without damage or replacement of parts. Only the divergence angle, 3°, was not improved over surface flashover diode results.

Clear correlation is seen between various aspects of the diode performance and measured anode plasma characteristics. For example, the ion beam current density is related to the anode plasma flux and to its position as determined by the magnetic field of the plasma source and diode. These dependences, along with the ion beam chacteristics, have led to an understanding of the source gap operation which will be discussed in future publications.

Description of the Gas-Breakdown Anode Plasma Source.

The principal components of the gas-breakdown anode plasma source are shown in the LONGSHOT diode in Fig. 1. The sequence of events for the system is as follows: The "slow" field coils are energized first, producing the quasi-static magnetic field configuration shown in Fig. 2. (Note that the space just in front of the fast coil is a relatively weak field region before the fast coil is pulsed). Next the puff valve on the diode axis is suddenly opened, and an annular gas puff is delivered to the volume in front of the fast coil (at 15 cm radius) by a supersonic nozzle. The axial puff profile is sufficiently sharp that the gas pressure in front of the middle of the fast coil can be up to 100 mTorr while the pressure in the ion diode accelerating gap 4 cm away (to the right in Fig. 1) is below 0.5 mTorr. At the optimum moment relative to the time of opening of the puff valve (a function of gas species), the preionizer is energized, followed about a microsecond later by the fast coil. The latter generates a loop voltage of 17 kV (typical) which drives a current in the preionized gas cloud and rapidly breaks it down. The $\underline{J}x\underline{B}$ force on the plasma current then drives the plasma toward the ion diode accelerating gap. The plasma stagnates against the magnetic field produced by the slow coils, which field serves to magnetically insulate the accelerating gap of the LONGSHOT ion diode. The precise position of stagnation is determined by the relative sizes of the fast and slow magnetic fields and is designed to be near the axial position of the metal anode. It takes about 300 ns for the plasma to be driven to the stagnation point under typical plasma source conditions. The high voltage pulse is then delivered to the accelerating gap.

Figure 3 shows the plasma flux observed on the source side of the stagnation point, as a function of time between pulsing the preionizer and the fast coil. By selecting this time in the range of about 0.2-1.0μs, it is possible to substantially vary the amount of plasma delivered to the accelerating gap. Varying the gas puff pressure in the range 30-70 mTorr, or the loop voltage over the range 14-23kV changed the plasma flux roughly linearly. The data in Figure 3 were obtained with biased Faraday cups. Double Langmuir probe measurements as a function of axial position across the stagnation point showed a factor of ten decrease over a distance of 3mm, from a peak density of $\sim 10^{14}/\mathrm{cm}^3$.

Ion Diode Operation with the Gas-Breakdown Plasma Anode

Ion beam production by the LONGSHOT diode using the gas-breakdown plasma anode was monitored with arrays of single small-aperature biased (-200V) Farday cups, with a multiple-small-aperture 12 cm^2 biased Faraday cup, with a $4\mathrm{cm}^2$ calorimeter, with damage targets (both with and without shadowplates), and with a shadowplate-Pilot-B-Scintillator-streak camera combination to obtain time resolved beam optics information. We first consider the basic diode performance(impedance and output current density) obtained with the gas-breakdown anode plasma source, followed by results on the beam quality.

Diode Characteristics

By adjustment of the amount of plasma delivered to the diode accelerating gap, the time of arrival of the plasma relative to the application of the high voltage pulse from the LONGSHOT generator, and the magnitude of the insulating magnetic field, a variety of diode operating conditons could be achieved. Figures 4,5 and 6 show sets of data for pulses which illustrate the range of results that can be obtained. Each set contains inductively corrected diode voltage, total diode current, and two or more Faraday cup traces. They show that flat or even rising voltage waveforms can be produced by this ion beam source, in contrast to the typical falling voltage waveform obtained using a surface flashover anode plasma ion source. Ion current extraction can be made to begin coincident with the arrival of the high voltage pulse as shown in Figure 5, or delayed relative to it as in Figure 4b and 4c. Ion beam pulses of 0.6 - 1μs above 70keV can be routinely obtained. In fact, the voltage pulses shown in Figures 4b and 6 are as long as "open-circuit" shots without injected plasma. Figure 6 shows that constant diode impedance could be maintained for long times with high ion output.

Beam uniformity better than ± 35% in both radial and azimuthal directions was obtained with Faraday cups. Faraday cups 1 cm apart agreed to ± 10%. Gas-puff and preionizer uniformity were critical to the attainment of this performance.

By averaging Faraday cup traces such as those in Figure 5, integrating the average over time and multiplying by 300cm^2 (out of the total 400 cm^2 to correct for radial profile), we estimate that (1.5 ± 0.5)x 10^{17} ions with energies greater than 60 keV were produced. A 4 cm^2 calorimeter measured as much as 5J/cm^2 in the most energetic shots; this is consistent with 100 A/cm^2 for 0.5 μs, or 1 x 10^{17} 100keV ions over 300 - 400 cm^2. Since Faraday cups are likely to over-estimate the current density while the calorimeter-determined energy density is a lower limit because of surface blowoff from the high ion fluence, these numbers are consistent. It is then possible to estimate the ion current efficiency (ion current/total diode current). Without correcting for possible Faraday cup error, ion current efficiencies up to 70% for 0.5 μs or more have been obtained. A lower limit of 30% average efficiency over the whole pulse is given by the calorimeter.

Beam Optics

If plasma source conditions were set such that the extracted ion current density, j_i was < 60 A/cm^2, or if the high voltage pulse was applied to the accelerating gap before any plasma reached it, streak photographs of beamlets passing through an aperture plate and impinging upon a Pilot-B scintillator showed beam divergence of <3° agreeing with time integrated shadowbox targets, and no time dependent beam aiming error. However, if $j_i \geq 60$ A/cm^2 at some time in some part of the diode, and plasma had been driven into the accelerating gap by the time the voltage pulse arrived, substantial time-dependent beamlet aiming error occured at that location. The streaks then showed beamlet motion of 20-30° on a time scale of tens to hundreds of nanoseconds. Such aiming errors might be due to a time-varying uneven anode plasma surface. This behavior disappeared when screen mesh was attached to the anode contact forming a flat equipotential surface over the entire anode area.

Finally, we note two additional observations. Because the puff valve can, in principle, be filled with any gas, it should be possible to produce pure beams of many different ion species. In fact, we have produced more than 100 A/cm^2 beams using a nitrogen gas puff. No major diode components required replacement in over 700 shots with the gas-breakdown anode plasma source, confirming the possibility that this ion beam source is capable of reptitive pulse, long lived operation.

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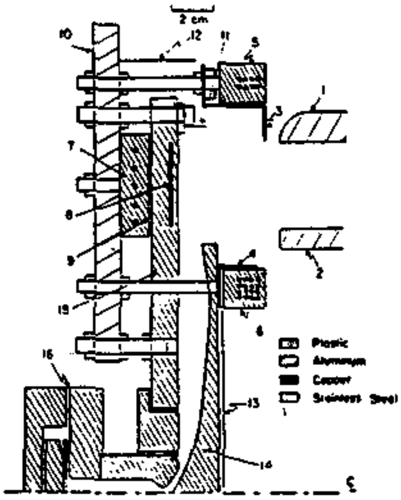

Fig. 1 Diode and plasma source components: (1) outer cathode, (2) Inner cathode, (3) Anode contact and outer field excluder for fast field, (4) Inner field excluder for fast field, (5) Outer diode insulating coil, (6) Inner diode insulating coil, (7) Back slow coil, (8) fast coil, (9) Back field excluder for fast field, (10) Diode support, (11) Preionizer support, (12) Mylar collar shield, (13) Stainless steel, (14) Front nozzle structure, (15) Fast coil insulator, (16) Puff value.

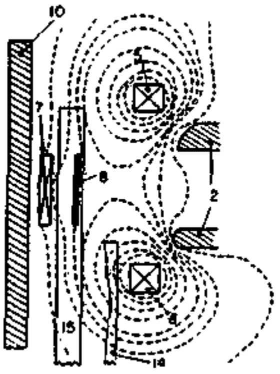

Fig. 2.

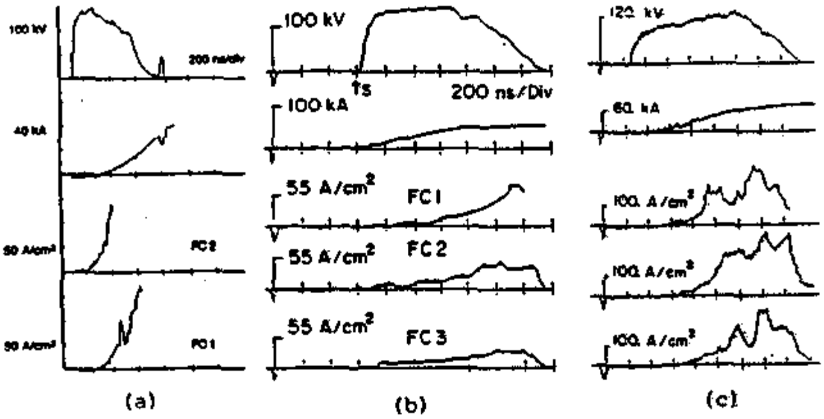

Fig. 4 (a) Diode voltage and current and Faraday cup traces for a standard flashover anode shot. (b) and (c), traces for two shots with the plasma anode, with different injection and timing conditions.

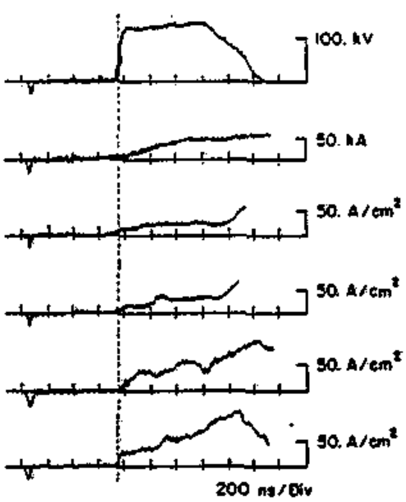

Fig. 5 Traces for a shot with plasma injection timing giving prompt ion beam turn-on.

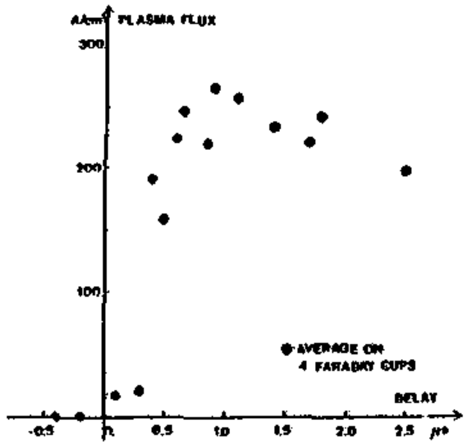

Fig. 3 Flux of plasma from fast coil as a function at delay between preionizer and fast coil firing.

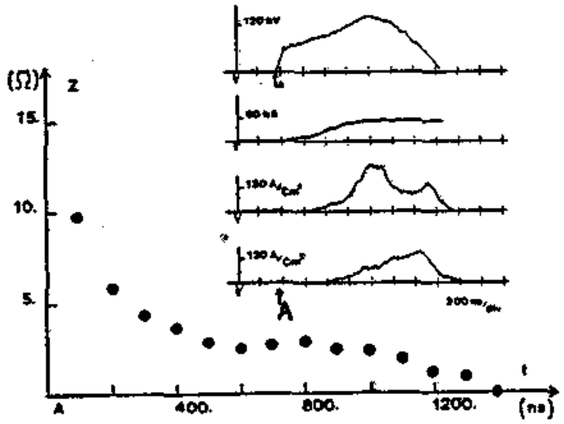

Fig. 6 Diode impedance versus time for the shot with traces shown.

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