Plasma Channels for Light Ion Beam Propagation in the Target Development Facility

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Fusion Technology Institute
University of Wisconsin
1500 Engineering Drive
Madison, WI 53706

http://fti.neep.wisc.edu

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Robert. R. Peterson, Gregory A. Moses, and John J. Watrous
Fusion Technology Institute, 1500 Johnson Drive
University of Wisconsin-Madison, Madison, WI 53706

Richard E. Olson
Sandia National Laboratory, P.O. Box 5800, Albuquerque, NM 87185

Abstract

Plasma channels provide an attractive means of propagating light ions from ion diodes to inertial fusion targets. The advantages include pulse shaping of the ion pulse while in the channel, large standoff distances between the ions and targets, and relatively high density gases in the cavity that provide first wall protection. The design and analysis of plasma channels for the light ion fusion Target Development Facility will be discussed. Specific issues currently under study are channel formation with electrical discharges, the effect on the channels of the ion beams, energy losses by the ion beams while in the channels, plasma stability of the beam-channel system, interactions between channels, and the effects of externally applied magnetic fields on the channels.

Introduction

Plasma channels are presently under consideration for the light ion fusion Target Development Facility (TDF). The TDF would be used to study the ignition and burn of high gain light ion fusion targets and could be the major light ion fusion device to follow the Particle Beam Fusion Accelerator (PBFA-II) at Sandia National Laboratory. Plasma channels could provide the pulse shaping of the ion pulse that is required for high gain targets and would allow a large distance between the target and the diodes that is required if the diodes are to survive the proposed repetition rate of 10 shots a day.

Plasma channels in the TDF target chamber will guide the eight ion beams from the diodes to the target. A gas of molecular nitrogen (N_2) will fill the target chamber at a density of 9.63×10^{17} cm^{-3} and will act as a medium for the channels. Lasers will pre-ionize the gas to the point that it will break down along preferred directions. Banks of capacitors will be discharged through the channels to drive an electron current that will heat and rarefy the channels and will create several kilogauss magnetic fields to confine the beam ions. At an optimal time in the development of the channels, the ion diodes will inject a pulse of ions into each channel. These are lithium ions, with an average energy of 30 MeV. At injection, each ion beam will have a maximum current of 1.25 MA and a main pulse width of 30 ns with a 100 ns long prepulse. This current history is shown in Fig. 1. As the beams move toward the target, they increase their instantaneous currents due to bunching induced by voltage ramping at the diode. At the target, their currents and thus their powers, have doubled. Thus, the eight channels direct a total pulse of 9 MJ into the region surrounding the target at a maximum power of 600 TW.

We have recently studied several aspects of the plasma channels. These include the formation and behavior of channels before and during the injection of the ion beams, the interaction of plasma channels with neighboring channels, and the effect of an externally applied magnetic field on the channel behavior, where

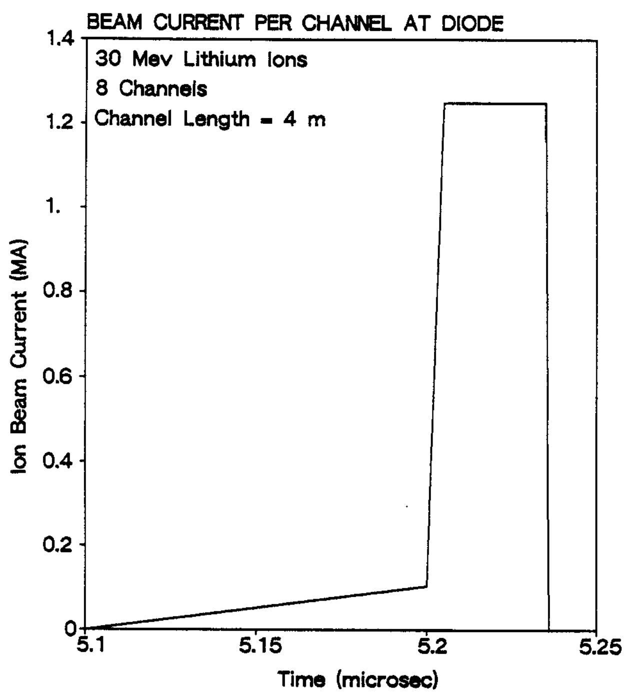


Fig. 1. TDF Ion Current in Each Channel Near the Diode Versus Time After the Start of the Discharge.

the magnetic field is meant to prevent breakdown between the channel and the TDF pressure vessel. The discussion in this paper will mainly deal with the channel formation and interaction between channels and ion beams. Some other issues will be mentioned when conclusions are made.

Channel Formation

We have studied the radial behavior of plasma channels with a one-dimensional Lagrangian magnetohydrodynamics multigroup radiative heat transfer computer code with discharge current flow, ion beam heating, and magnetic field generation and diffusion [1]. This code is called ZPINCH. The channels are to be formed in a N_2 background gas. A laser guides the channel formation by providing an increased temperature along the axis of the channel. The initial temperature profile is 0.78 eV at the center of the channel and has a full width at half maximum of 0.8 cm. The initial gas density is uniformly 9.6 x 10^{17} cm^{-3}. We have assumed that the channel is 4 meters long. We have used a discharge current profile determined by the intrinsic inductance and the breakdown requirements of plasma channels, shown in Fig. 2.

The mass density, gas temperature, and azimuthal magnetic field plotted against radial position and time are shown respectively in Figs. 3, 4 and 5. One sees that the mass density near the channel center that is reduced by a factor of 2 to 3 from the initial mass density of 2.25 x 10^{-5} g/cm^3, and the reduced density region extends out to about 1 cm. The gas temperature profiles show that there is significant heating outside the channel low density region. There is radiative heat transfer from the center of the channel, which is being ohmically heated by the discharge current. We have compared this temperature profile with one for an identical calculation for argon gas, which has generally much lower opacities. There was much less heating of the gas that lies from 1 to 2 cm from the channel center for the argon gas calculation. This comparison indicated that radiative transport is important in spreading the temperature profile. This changing temperature profile means that the region of low electrical resistivity is spreading also, which allows some of the discharge current to flow outside the low density region. The magnetic field profiles show that there are local maxima about 1 cm from the channel center and the increasing fields at large radii imply significant discharge current densities outside the channel. The local maximum fields at 1 cm from the center are between 2.5 and 3.0 kG. The next important question is how well such channels can propagate ions to the target.

Ion Propagation

Three aspects of ion propagation have been studied: the effects that are seen in the channel behavior due to the presence of the ion beam, the radial confinement of the ions by the azimuthal magnetic fields, and the limits on the ion current and thus the ion power due to plasma instabilities and energy losses to the ions. The behavior of the plasma channels is once again studied with the ZPINCH computer code. The discharge current of Fig. 2 is used and the particle current of 30 MeV lithium ions near the diode, seen in Fig. 1, is assumed. The radial mass density profile has been calculated with the result that the ion beam causes a great rarefaction of the channel center. In the case where the ion beam has a Gaussian radius of 0.5 cm, the width of the rarefied region is the same 1.3 μs after the start of the main ion pulse. This rapid outward movement causes a v x B force on the ions that is a major contributor to their energy loss in the channel. The gas temperature of the center of the channel was found as a function of time for ion beam Gaussian widths of 1 and 2 cm (Gaussian radii of 0.5 and 1 cm, respectively). For the 0.5 cm radius beam the maximum temperature is 32 eV, while it is 20 eV for the wider beam. The trajectories of 30 MeV lithium ions in the discharge channel have been calculated for the case of a focal spot Gaussian radius of 0.15 cm at the entrance to the channel and a maximum injection angle of 0.075 radians. The average radius of the beam in the channel is much larger than the focal spot. For this case 21 out of the 25 trajectories calculated were confined. The window of beam propagation in ion beam injection angle versus ion beam power space is shown in Fig. 6. This result comes from the WINDOW computer code [2] that is based on models developed at NRL [3]. The window of propagation is that region below all of the curves. The curves on the left are due to the con-

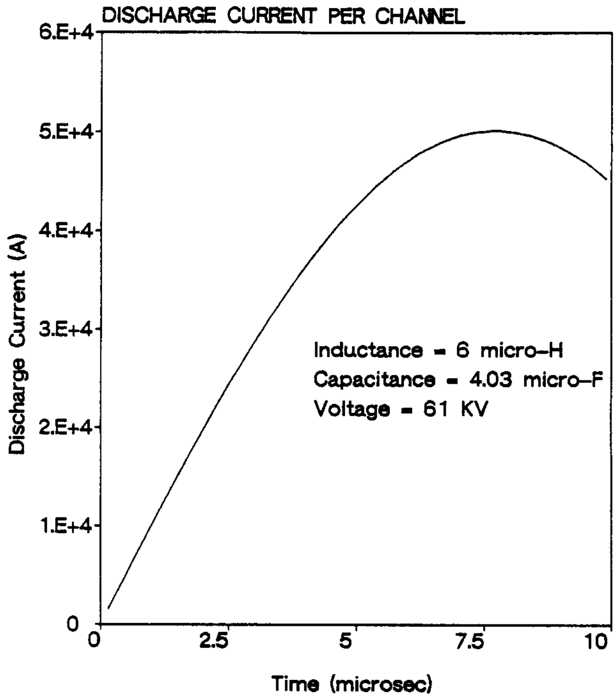


Fig. 2. Discharge Current in Each Channel.

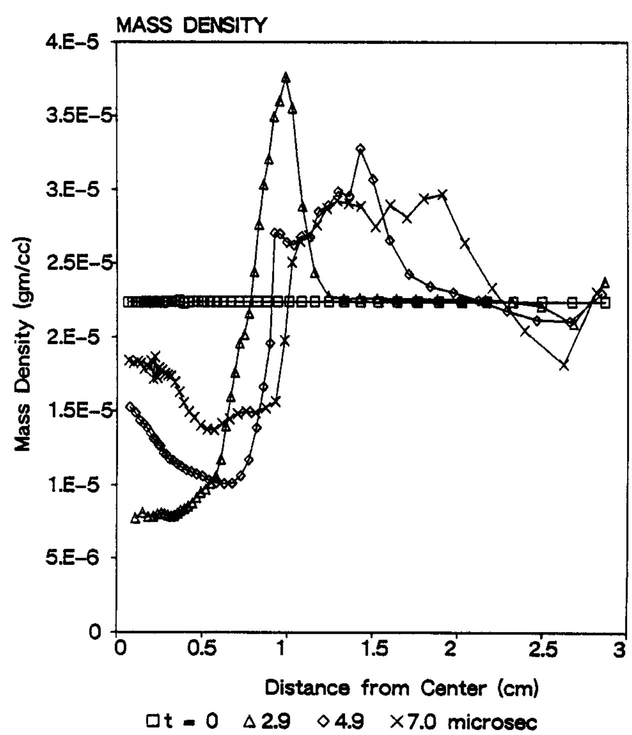


Fig. 3. Radial Mass Density Profile for Discharge in N_2.

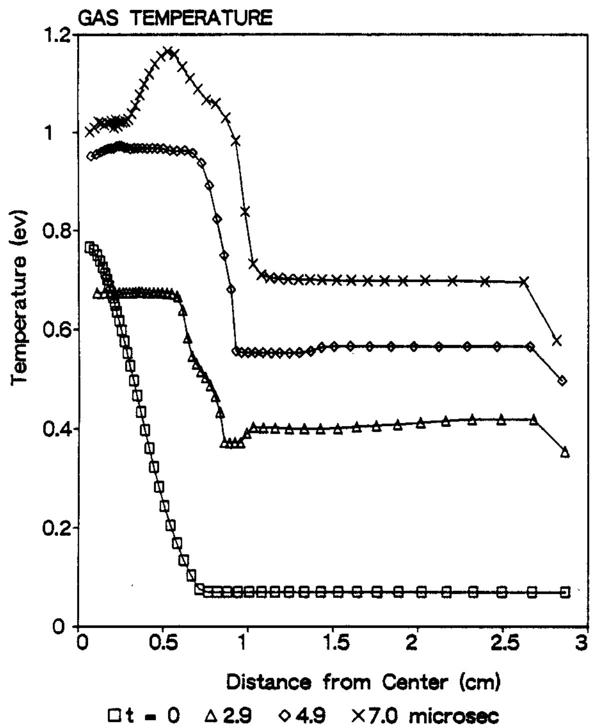


Fig. 4. Radial Temperature Profile for Discharge in N_2.

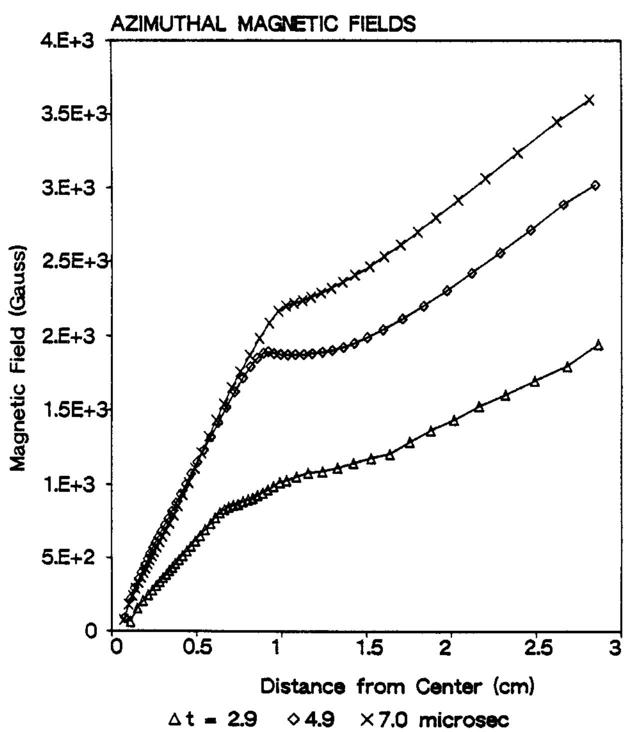
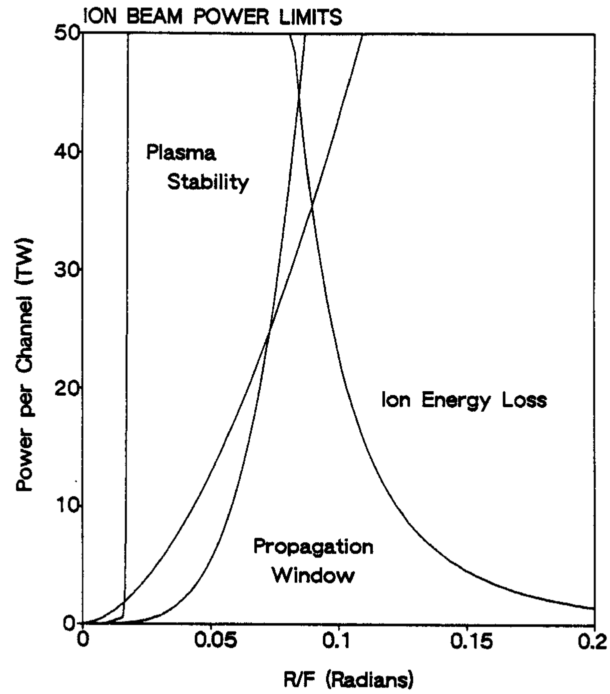


Fig. 5. Radial Profile of the Azimuthal Magnetic Field for Discharge in N_2.



Fiq. 6. Window of Propagation in Ion Injection Angle versus Ion Power Space for 30 MeV Lithium Ions in the Discharge Channel. The Channel Length is 4 Meters, the Radius is 1 cm and the Bunching Factor is 2.

straints imposed by electrostatic, beam current filamentation, and channel current filamentation instabilities, while the curve on the right is due to beam ion energy loss. This energy loss ion power limit requires that the ions lose no more than 25% of their energy during transit down a 4 meter long channel and assumes that the channel is created in a deuterium gas. The results differ from those for a N_2 gas because N_2 radiates much more strongly. Thus, N_2 will not get as hot and will have a lower outward velocity leading to smaller v x B forces. Figure 6 shows that one should be able to propagate 1 MA of 30 MeV lithium ions at an injection angle of 0.1 radians. From our ZPINCH runs, we have estimated our ion energy losses for a 1.25 MA beam to be about 6 MeV per ion or 20% [4]. All of these results seem to indicate that the TDF channel design allows 1.25 MA of 30 MeV lithium ions to be propagated per channel.

Summary and Conclusion

The formation of plasma channels with a discharge current has been discussed, as have various issues of the interaction of the plasma channels with the ion beam. In addition, we have studied the interaction between neighboring channels and the effects that an externally applied magnetic field would have on the formation of the channels. The interaction of channels that we have considered is through mutual forces of their discharge currents. We have found that if all 8 channels are properly formed mutual forces cause no problems, but if one of the channels is not formed, the others would be deflected enough for the ion beams to miss the target. An externally applied magnetic field could be used to keep the channel from breaking down to the wall of the target chamber vessel [5]. We have determined to a first approximation that the external magnetic field plays no role in the channel formation.

In conclusion, we have found that it is possible to create 1 cm radius channels to provide 9 MJ of 30 MeV lithium ions to the region around the target. There are still several unanswered questions: the loss of ions between the ends of the channels and the 1 cm diameter targets, the stability of channels during the relatively long formation times, and the effects of nonaxial components of the applied magnetic field on ion energy losses. These issues, especially the first two, need attention because they could have serious enough consequences to require redesign of the TDF channels.

Acknowledgements

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References

[1] J.J. Watrous, G.A. Moses, R.R. Peterson, "Z-PINCH - A Multifrequency Radiative Transfer Magnetohydrodynamics Computer Code," University of Wisconsin Fusion Technology Institute Report UMFDM-584 (June 1985).

[2] R.R. Peterson, "WINDOW - A Code to Compute Ion Power Constraints," Fusion Power Associates Report FPA-84-6, Dec. 1984.

[3] P.F. Ottinger, S A. Goldstein, D. Mosher, "Constraints on Transportable Ion Beam Power," Naval Research Laboratory Memorandum Report 4948, Nov. 1982.

[4] R.R. Peterson, J.J. Watrous, G.A. Moses, "Numerical Simulation of Plasma Discharge Channels for Ion Beam Propagation in the Light Ion Target Development Facility," Bull. of the Amer. Phys. Soc., Vol. 30, p. 1504, 1985.

[5] R.E. Olson, "Magnetic Insulation of Plasma Channels," Bull. Am. Phys. Soc., Vol. 29, p. 1389, 1984, 8R11.