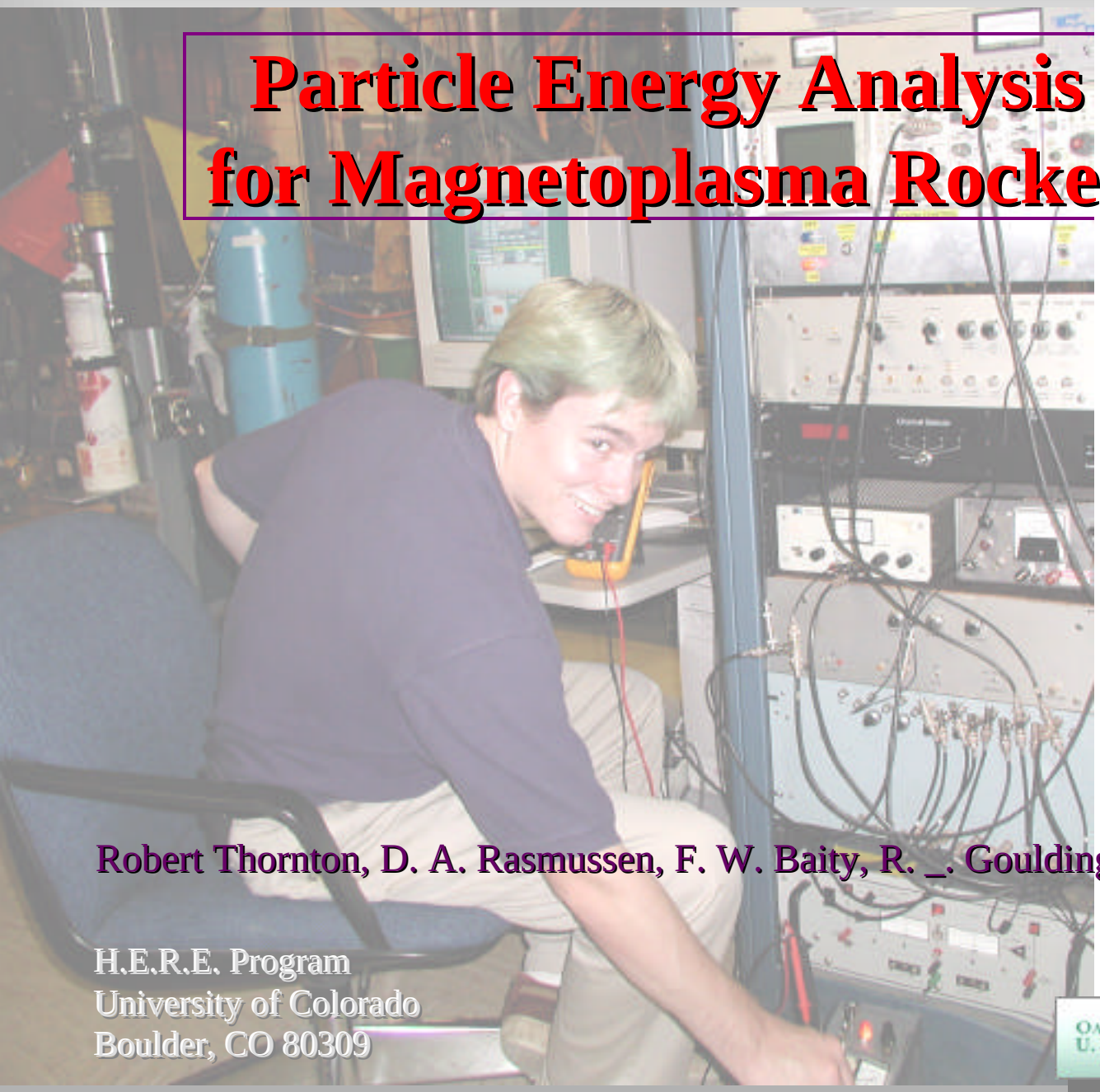
Particle Energy Analysis for Magnetoplasma Rocket



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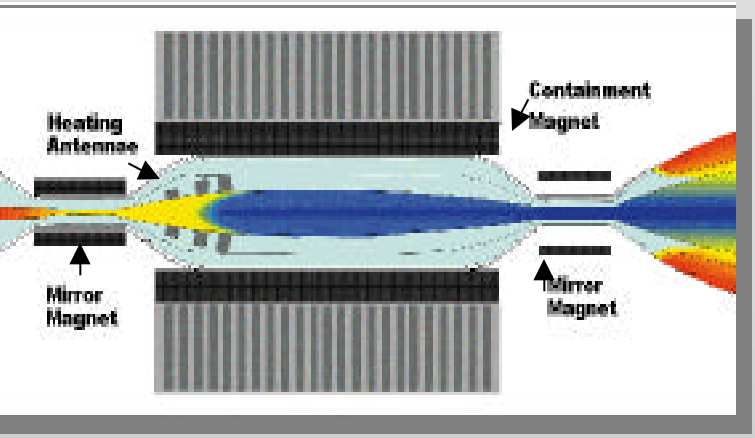
Abstract

Analysis of Particle Energies in RF-Driven Plasmas for Spacecraft Thrusters Using a Retarding Potential Energy Analyzer. R. F. Thornton (University of Colorado, Boulder, USA 80309) D. A. Rasmussen (Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831).

The two most important quantities in calculating thrust from a rocket engine are the mass flow rate of the propellant and the energy of propellant particles. For this reason, a focus of the experimentation in Mini-RFTF for the VASIMR plasma-driven rocket engine is in the energy of the plasma particles. The energy levels are measured using two types of retarding potential analyzers (RPA). An RPA is a device that consists of parallel grids and a collector plate. The plasma beam passes through the grids of various negative voltage bias and strikes the collectors. The grids repel electrons, and the current from the collector reveals the energy of the ions. Studies with the RPA have revealed information about particle temperatures and limitations of the experiment equipment. Mini-RFTF has shown plasmas with ion temperatures much higher than predicted by theory or similar experiments. Much of the work done with the RPA's in Mini-RFTF, therefore, has been in changing parameters to verify the correct operation of the analyzer. Initial measurements provide an estimate of the ion energies, but accurate quantitative results will require refinements in the analyzer hardware.

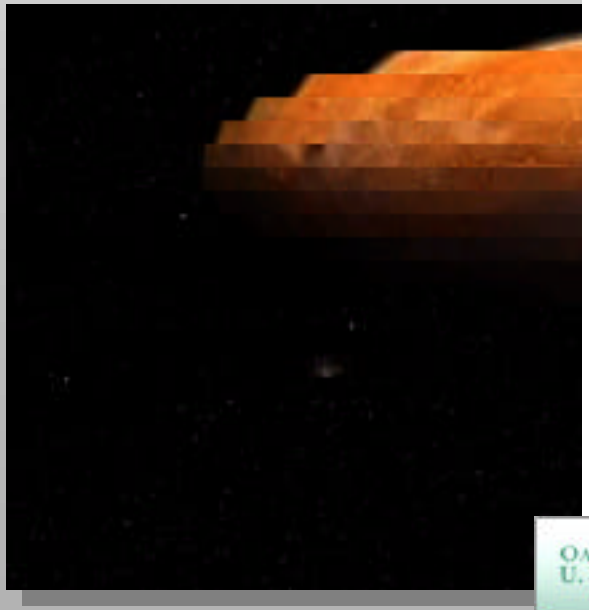
VASIMR



VASIMR stands for Variable Specific Impu
Magnetoplasma Rocket. It is a cutting ed
spacecraft engine being developed for
purpose of propelling the first humans to Ma
Thrust for this engine is provided
superheated plasma contained and controlled
magnetic fields. The diagram at the top
illustrates the basic operation of the engine.

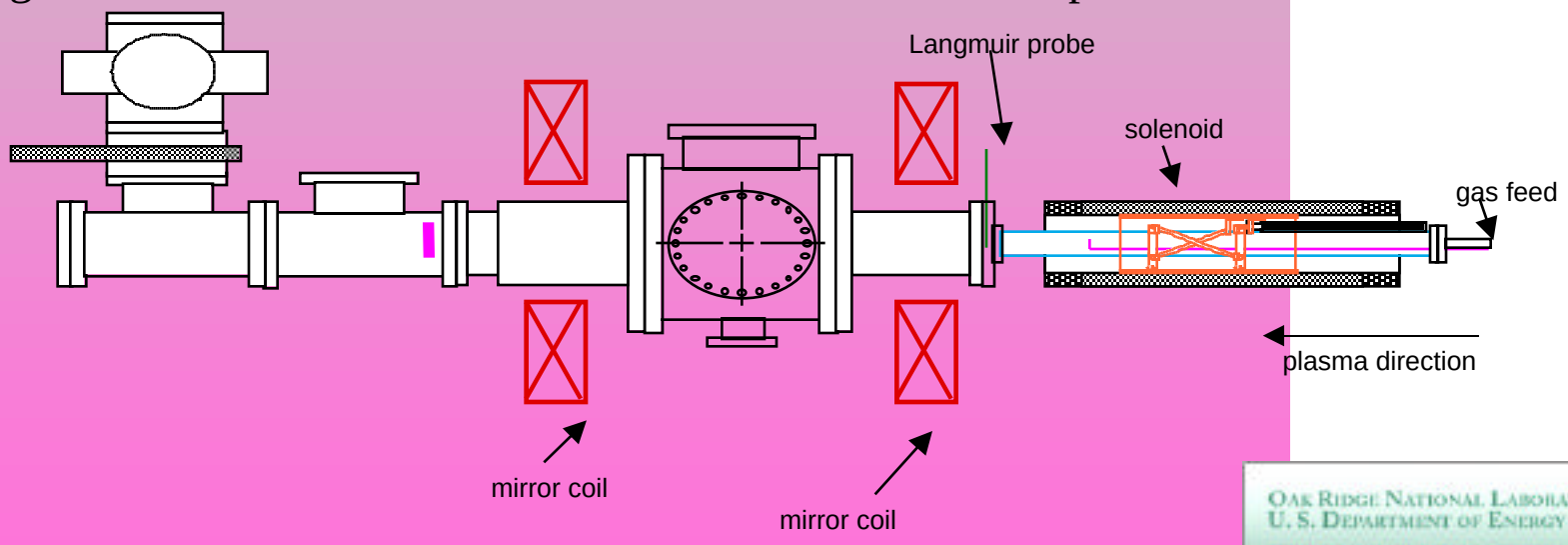
e propellant gas is pulsed into the
ening on the left. The helicon antenna
aks the gas down to plasma. Heating
ennae raise the plasma to over 10^7 °F.
ntainment magnets then guide the
sma out of the rocket bell at high
eed, which produces thrust.

the right is an image of the first
nned mars vessel, powered by
ASIMR engines.



Introduction

he equation used to calculate the thrust produced by a rocket engine depends rimarily on two factors: propellant mass flow rate, and propellant particle velocity. A najor focus of rocket development, therefore is in the energy of propellant particles. I ne Fusion division at ORNL, a device called Mini-RFTF models a portion of the VASIMR engine, and allows researches to take diagnostics to measure the dynamics o ne plasma particles. There is a variety of devices used for making measurements of lasma particle energy in Mini-RFTF, including Retarding Potential Analyzer and angmuir Probe. Below is a sketch of the Mini-RFTF setup.



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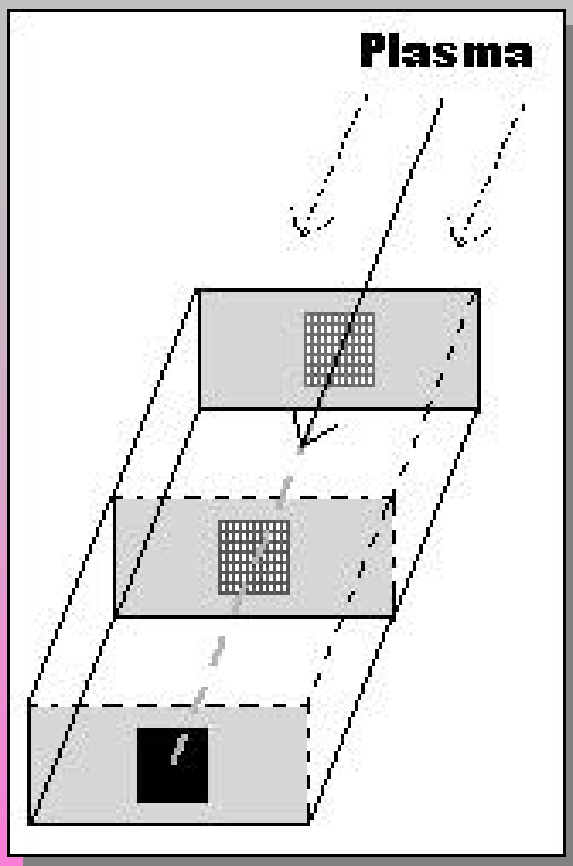
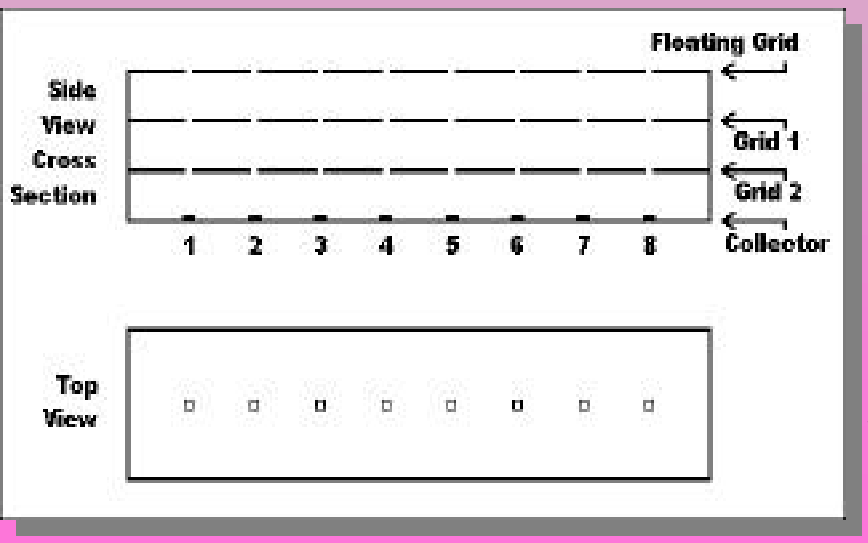
Retarding Potential Analyzer



The purpose of the retarding potential energy analyzer (RPA) is to measure the energy of ions in the plasma beam. The image to the left is a general example of an RPA with two grids through which the plasma passes, followed by a collector plate. This RPA would be configured as follows. The first grid would be floating or grounded, intended to reduce plasma density. The second grid would be biased to repel electrons and accelerate ions. Finally, the collector plate would have a positive bias to repel ions. The ion energy can be determined by the number of ions that reach the collector despite the positive repelling bias.

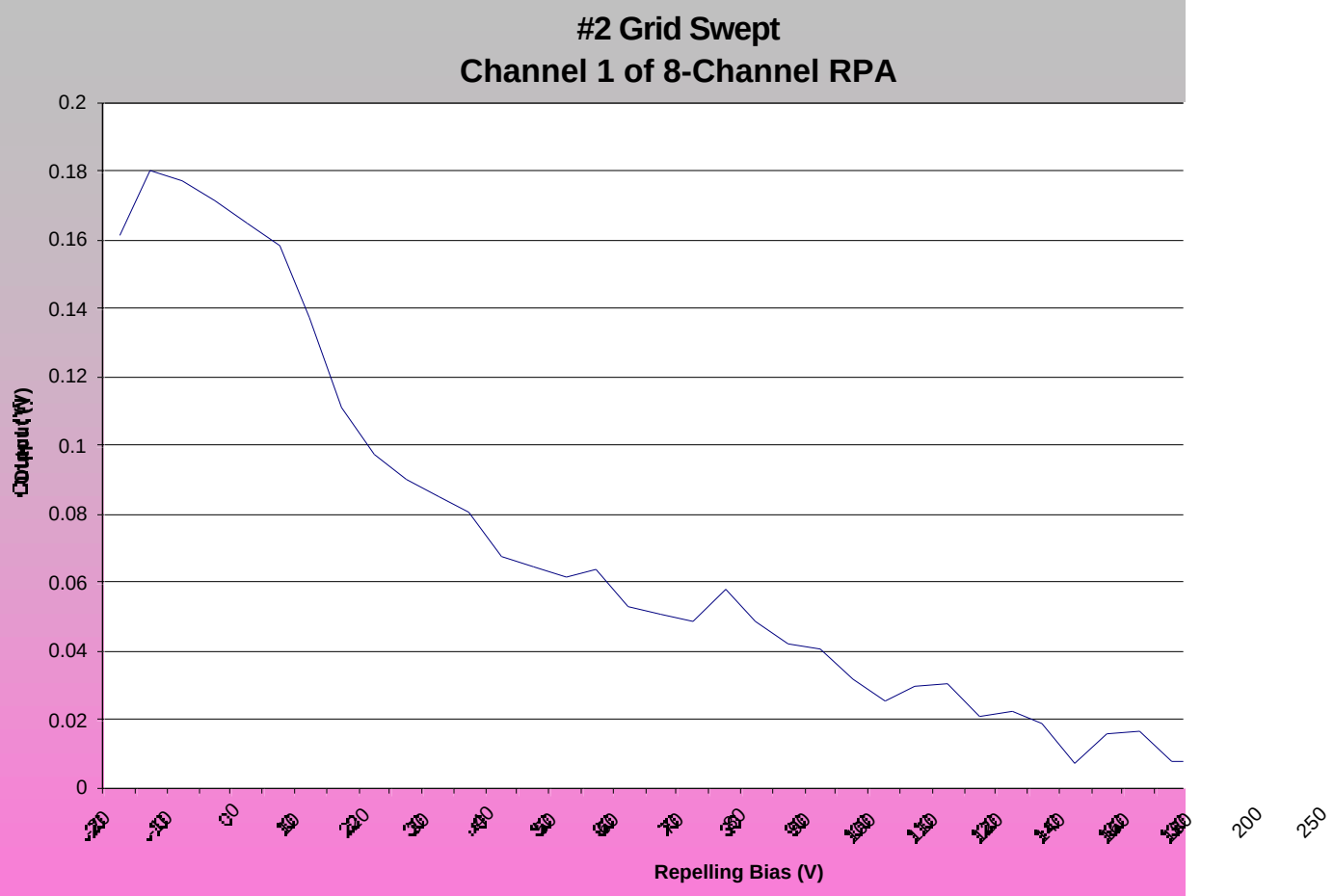
8-Channel Macroscopic RPA

This RPA, depicted below, has been in use on the Mini-RFTF device for several months. It functions basically as explained above, though in this case the first grid floats and has two screens to reduce plasma density, the second and third can have variable bias for electron and ion repulsion, and the collector grid is given a constant negative bias. The ion current is collected on eight plates and carried via coaxial cable to a computer DAQ system. In Mini-RFTF, the center of the plasma beam strikes channel 1, and the edge of the beam is near channels 5 and 6. Actual beam size depends on experimental conditions.



Problems with this type of RPA arise from a quantity called Debye length, which is a function of plasma density. It is a measure of the depth of an electric field in a plasma. This effect causes changes in particle trajectories, giving false energy measurements.

8-Channel Macroscopic RPA



Results from RPA analysis with sweep on #2 grid from -20 to 250 volts

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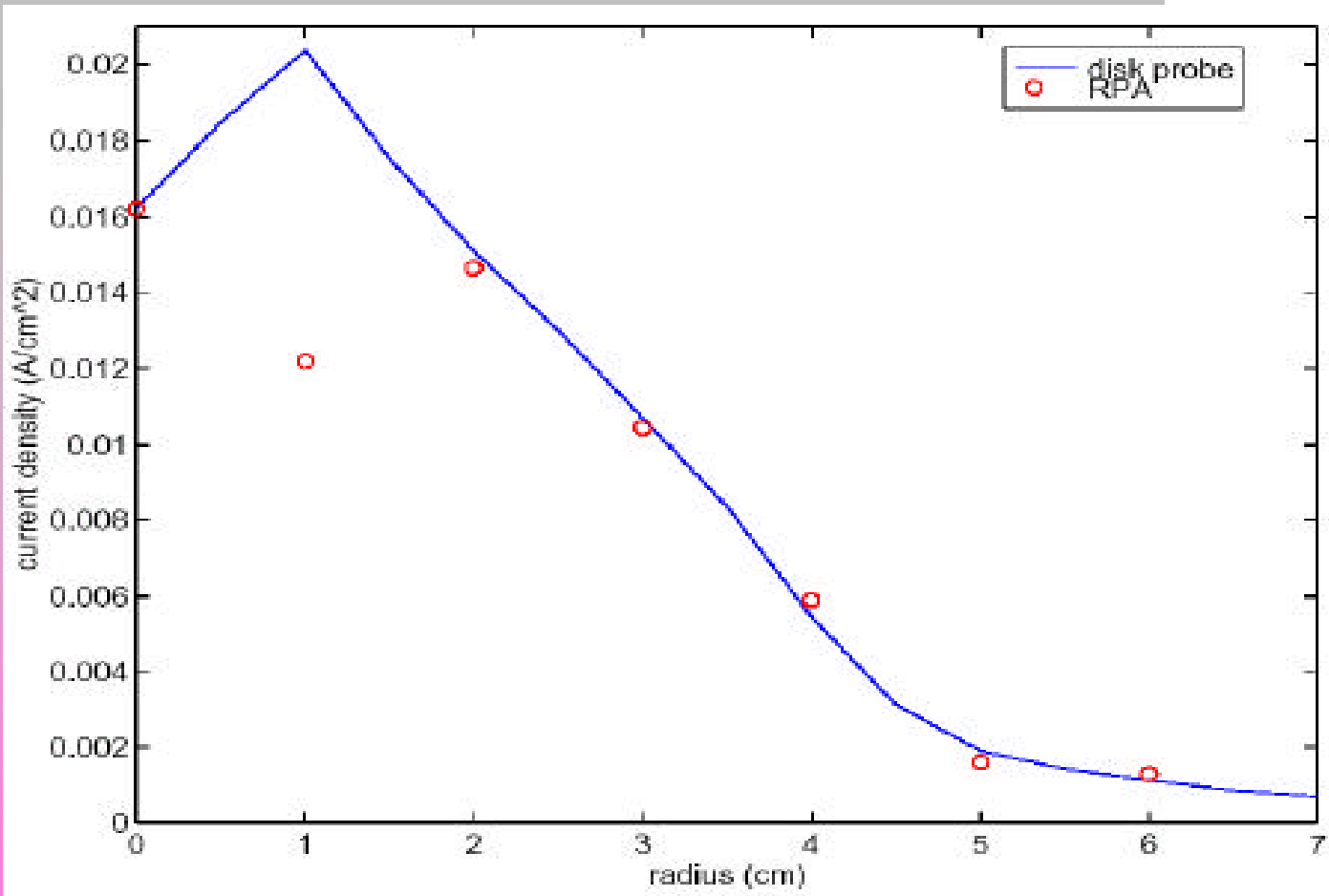
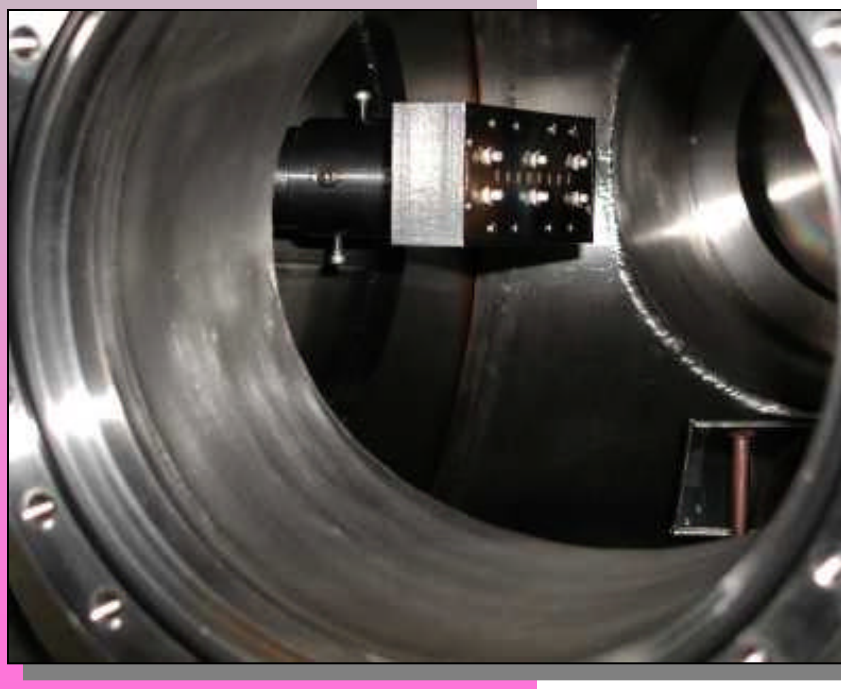
8-Channel RPA Calibration



The RPA was calibrated by comparing current density with a copper disk probe.

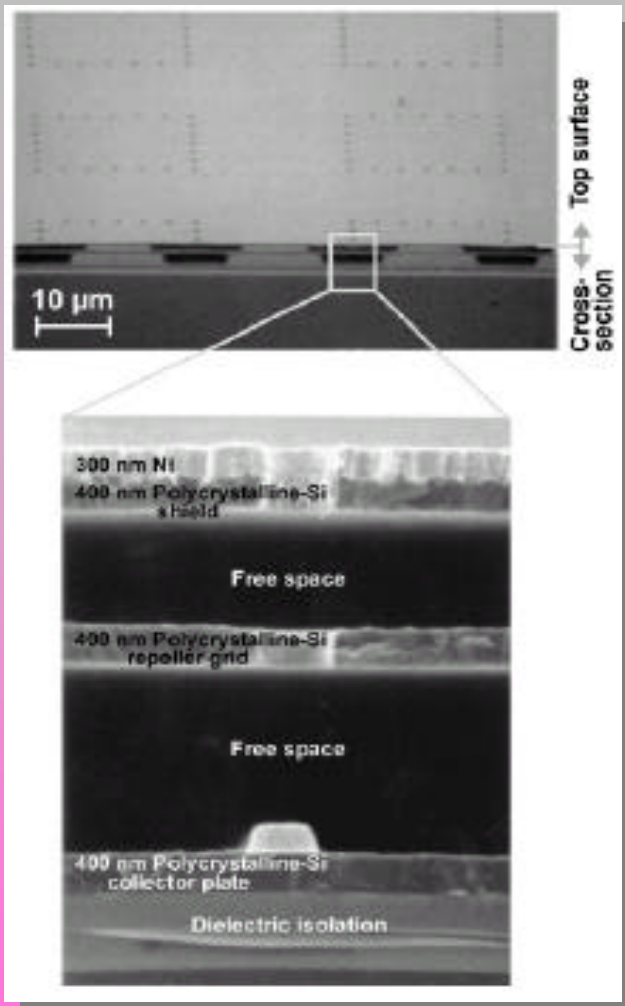
8-Channel RPA Images

This is the actual RPA



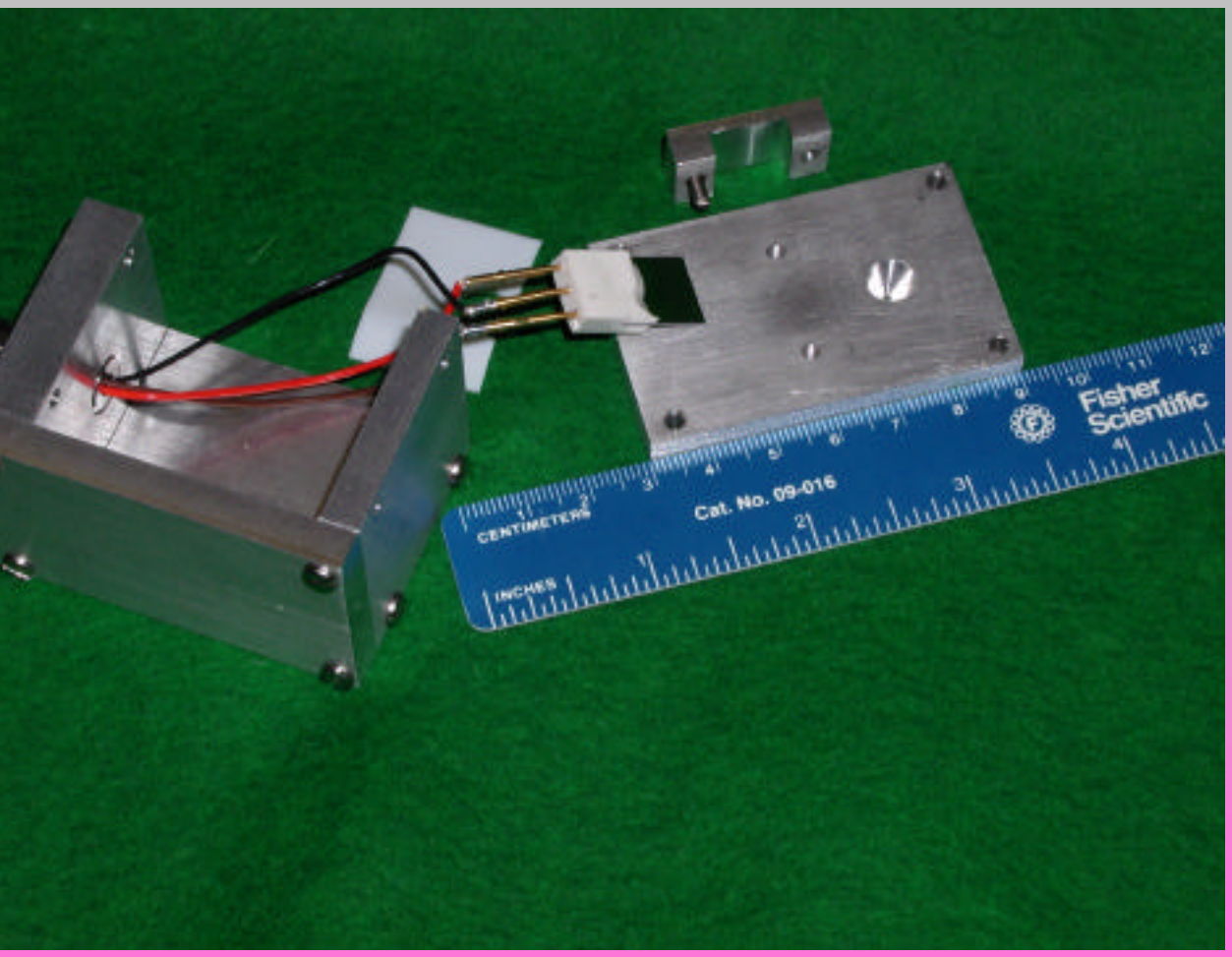
This is the RPA mounted in Mini-RFTF. It can be maneuvered axially as well as azumuthally. In the plasma path.

High-Res. Submicron RPA



The submicron RPA has grid layers etched from silicon wafers with apertures less than one micron in diameter. The first grid floats, the second grid repels electrons, and the collector grid is swept in voltage to repel ions. The immediate advantages to this RPA are that the tiny apertures eliminate any issues of Debye length, and the size improves resolution and maneuverability. There are important disadvantages as well. First, the small size means a small signal is produced. Second, with so little space between grids, very small amounts of contamination can produce a short from one to the other. A few problems need to be resolved, but this device is likely to produce excellent data in the near future.

High-Res. Submicron RPA

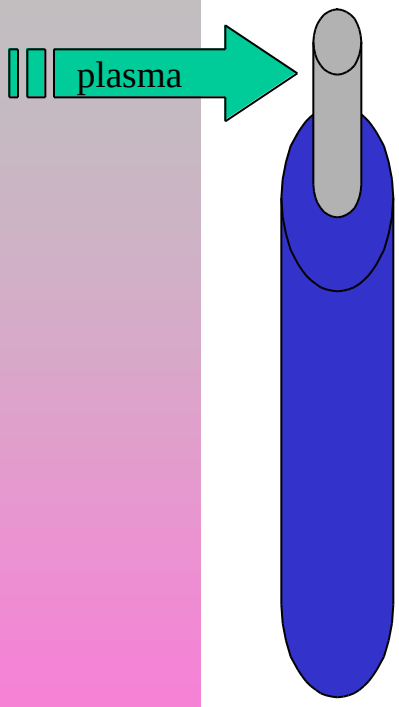


This is a picture
the RPA with t
aluminum case
which it is mount
for insertion in
plasma beam. T
aperture on the fro
plate is 0.052” a
expands 60 degree

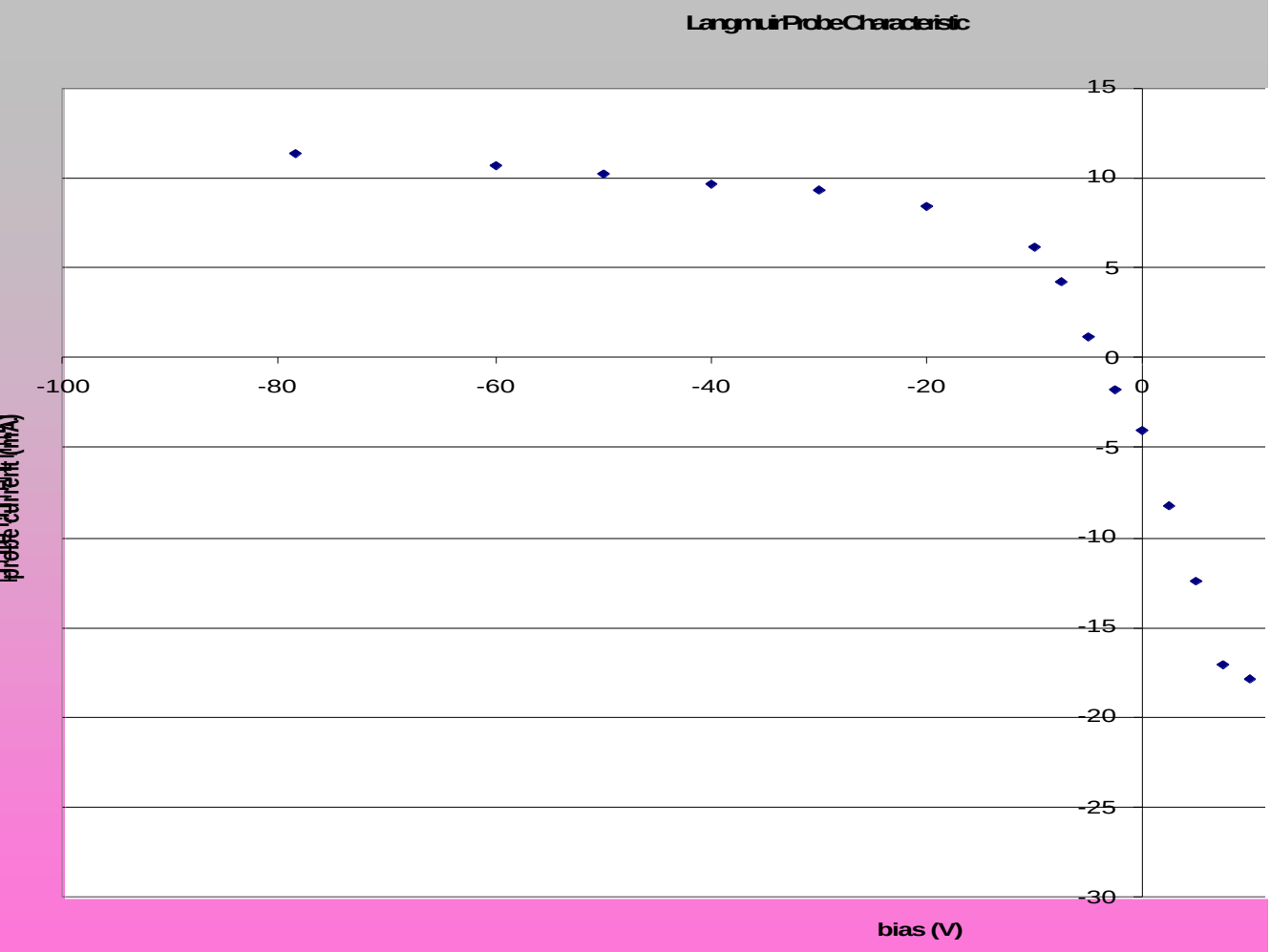
Total dimensions
the RPA a
1.26x0.47x0.19”

Langmuir Probe

Another method for determining particle energies in a plasma beam is with a Langmuir Probe. In the most basic form, a Langmuir probe is simply an exposed piece of wire inserted into the plasma beam. A bias is applied to the wire, and the current induced on the wire from the plasma is measured. A characteristic is developed by measuring the current on the wire at different biases. This characteristic reveals the electron temperature of the plasma beam. The slide to the right shows the characteristic obtained from one scan with the probe. This probe also reveals that exceptionally high plasma densities have been achieved in Mini-RFTF.



Langmuir Probe Characteristic



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