Experimental Evaluation of Resistive Glass Ion Optics

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Objective

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- Recently a promising new type of material has been developed that can be used to dramatically simplify the construction of some critical components in mass and ion mobility spectrometers.

- The objective of this project is to directly measure the properties of resistive glass and to compare the performance of the Time of Flight Mass Spectrometer Reflectron lens fabricated using proprietary BURLE Resistive glass material to that of a conventional metal ring lens assembly.

Introduction

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- Resistive glass products are geometric glass structures with resistive properties that can be used to create uniform electric fields in order to guide or direct charged particles.
- Resistive glass products are fabricated from reduced lead-silicate glasses.
- These proprietary lead glasses are produced from high purity raw materials. They are formed into tubes or flat plates and then heat-treated to produce a semiconductive layer on the surface of the glass.

Using Resistive Glass to Make Ion Optics

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Resistive glass has unique properties that affect the way it can be used to create ion optics.

- Resistive glass is easily formed in a variety of shapes
- Thin film metal electrodes enable complicated equipotential lines to be patterned on the surface
- Non-conducting paths can be made by removing a surface layer, allowing multiple resistive networks on a single piece
- Object surfaces can be electrically isolated from each other. For example, the inner surface could be ion optic and outer surface could function as a separate voltage divider

Typical Resistive Glass Structures

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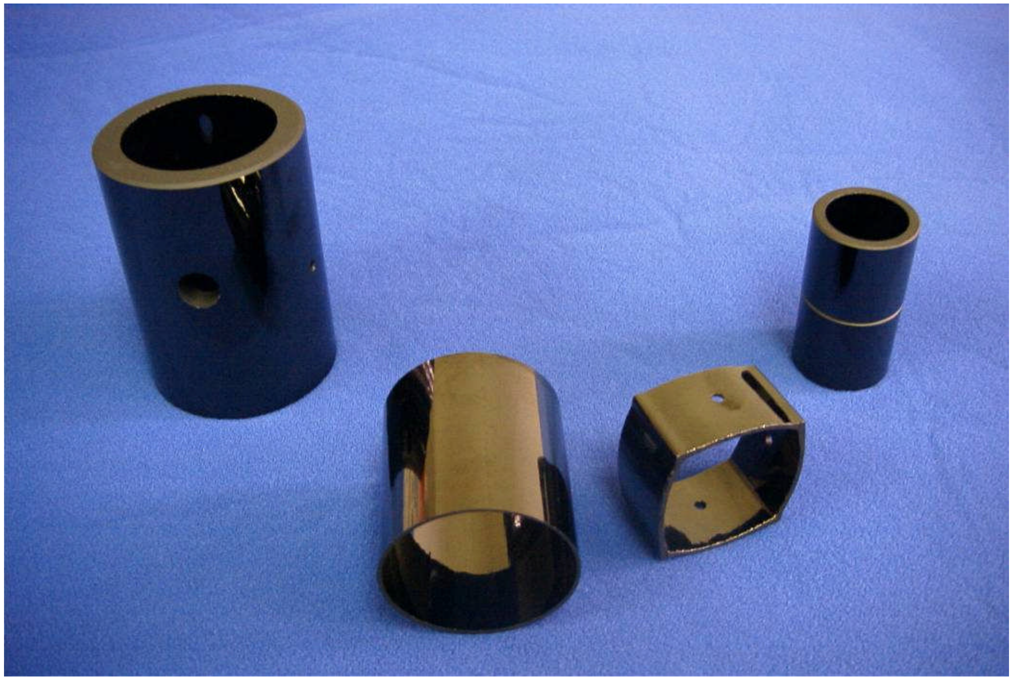

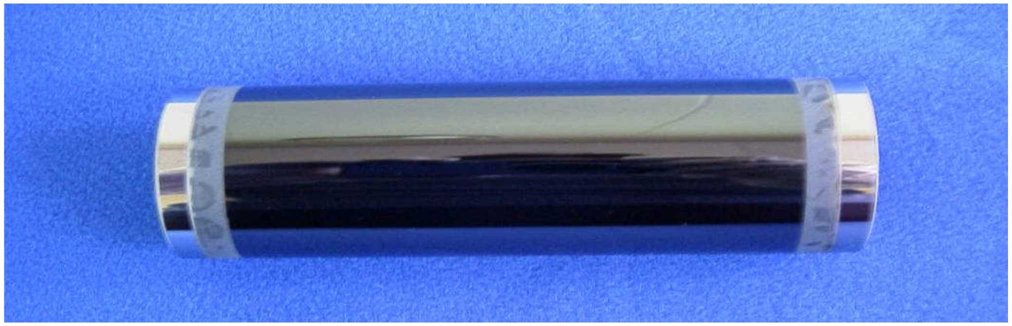

Resistive Glass Uniformity Analysis

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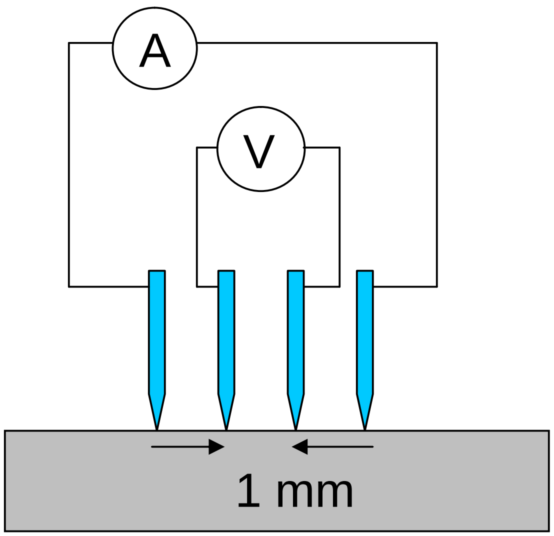
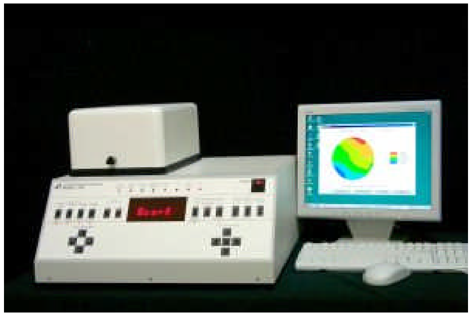
- A first step in evaluating resistive glass for use in ion optics is to determine the uniformity of the fields created by the resistive glass. Since the resistive properties of the glass are often relied on to create those fields, a detailed knowledge of the resistance variation across the sample is essential. While simulations can be used to check electric field uniformity, we chose to directly measure the glass to confirm its behavior.

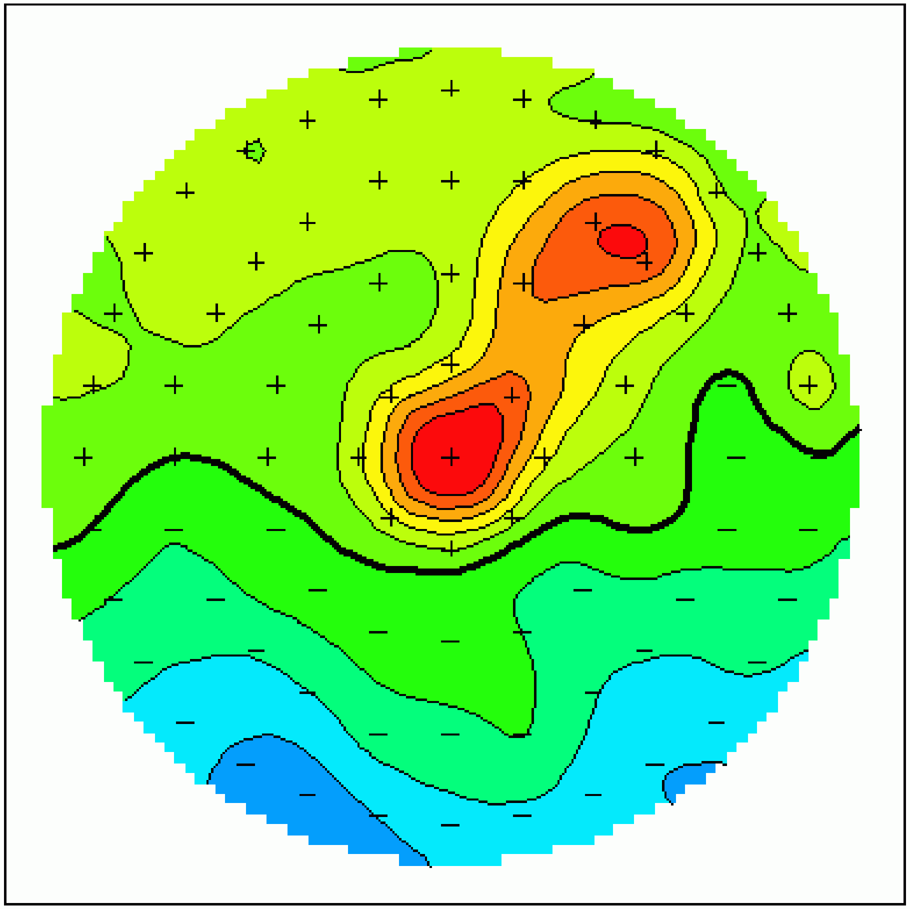
Four Point Probe Analysis



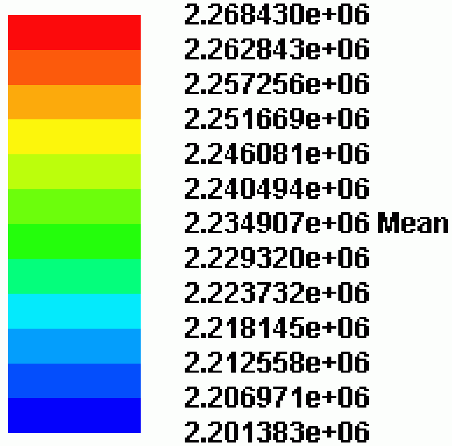


The four point probe technique is a sensitive method for measuring the resistivity of materials and the most common technique for measuring the resistivity of semiconductors. It uses four equally spaced metal probes, which contact the surface with a known pressure. The two outside probes are used to pass a fixed current through the sample, while the two inner probes are used to measure the resulting voltage drop, which is proportional to the resistivity of the material. Since the probes are typically tightly spaced (~1 mm), it is possible to measure the resistivity of a small section of the sample, allowing for easy mapping of resistance uniformity.

Typical Resistance Uniformity



Resistance is uniform to within 1.5 % across the sample



49-point map of a 75mm dia. sample measured with a 4-point probe

Kelvin Probe Analysis

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- A Kelvin Probe uses a vibrating capacitor tip to make extremely sensitive measurements of the potential difference between the probe and the sample surface. For an unbiased sample, the probe measures the work function difference or surface potential between the probe and the tip, which is a very sensitive indicator of surface charging, contamination, or local anomalies in the surface. For samples with a bias across them, the Kelvin probe allows us to measure the electric field a fixed distance above the sample, giving us a picture of the field and of the distribution of voltage across the sample.

Resistive Glass Acts Like a Good Conductor

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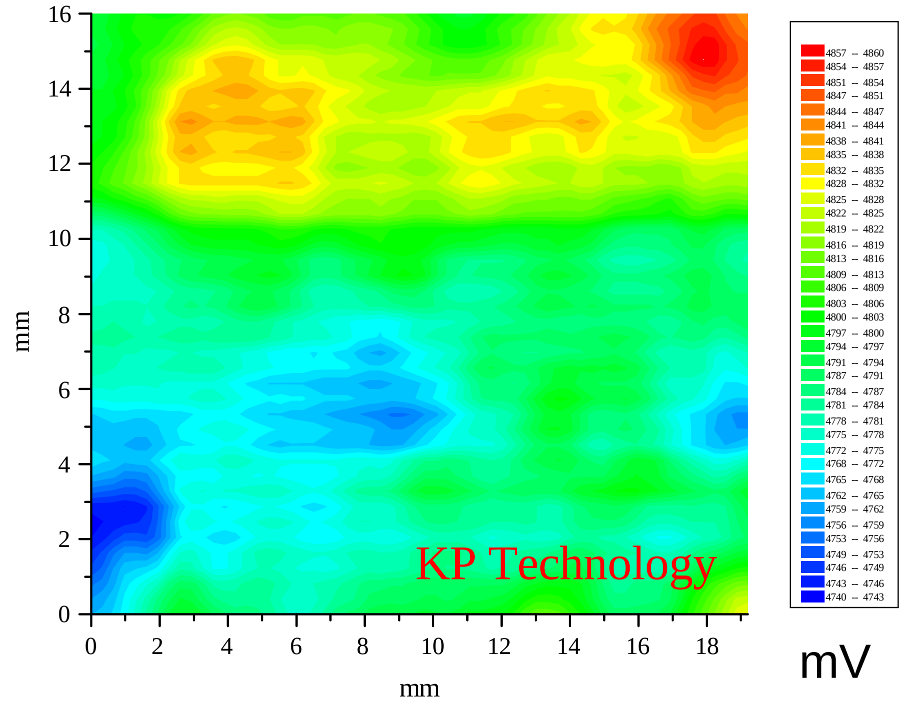
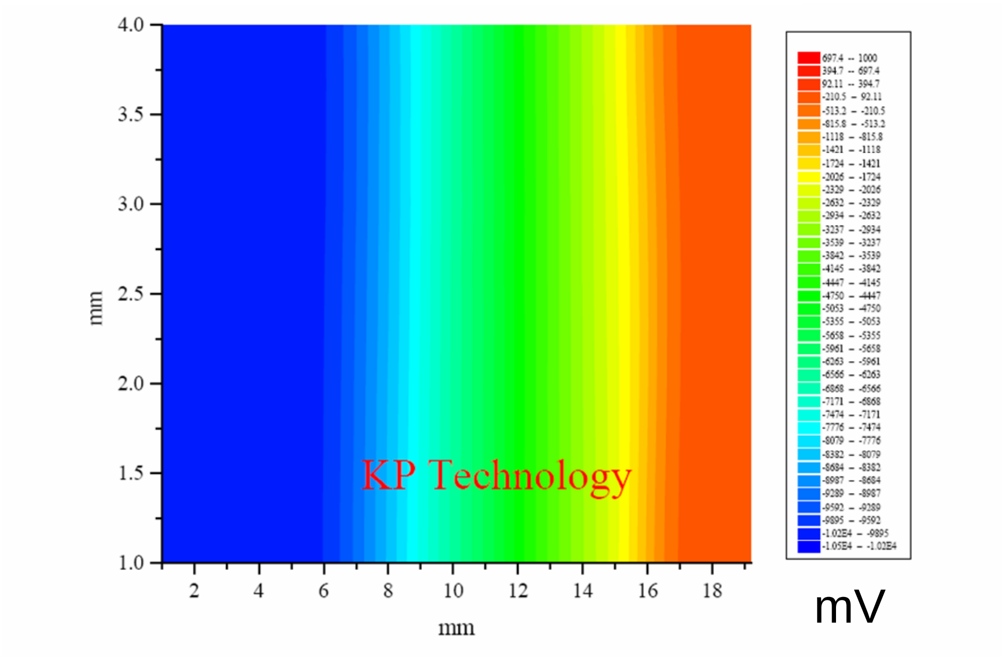
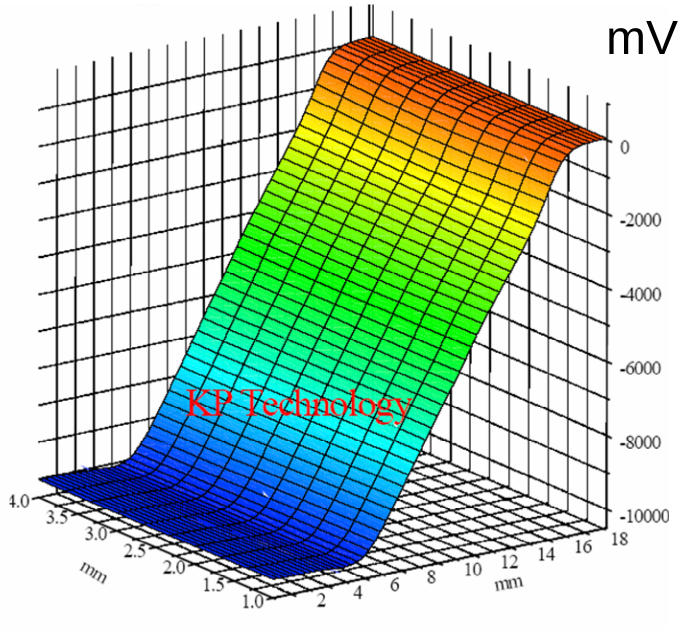


- This measurement of an unbiased resistive glass sample shows a very uniform (±0.024 eV) work function. This kind of uniformity is similar to that measured for a metal electrode, indicating that the resistive glass is a good dissipater of charge with a well-defined Fermi surface.

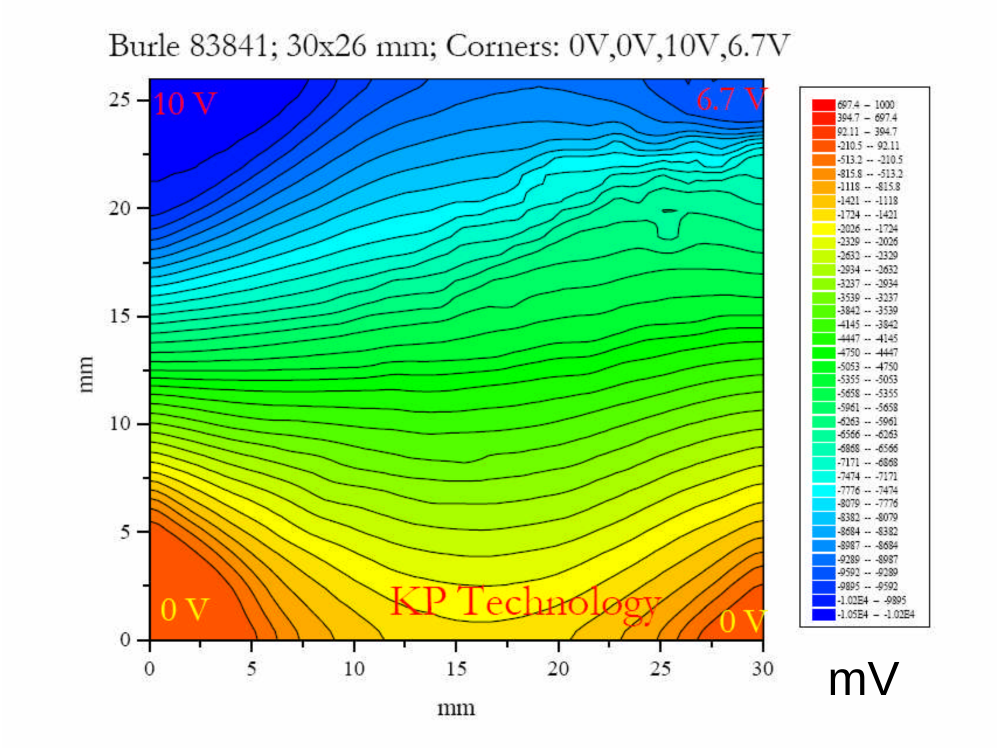
Direct Measure of Electric Field Linearity

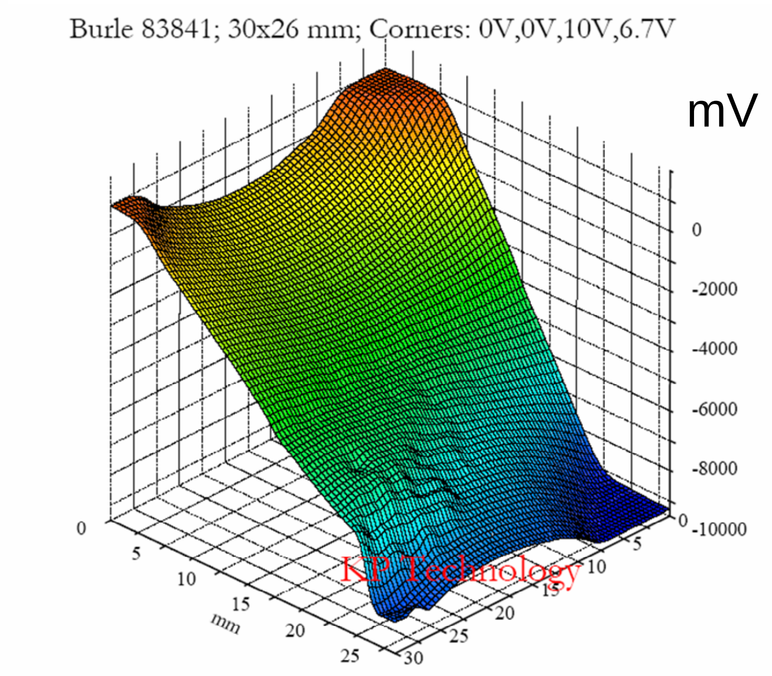




The Kelvin probe was used to measure the voltage distribution developed across a square flat plate of resistive glass when the two ends were held at constant voltage. As expected, the resistive glass provides a uniform gradient with no significant anomalies. The smooth gradient indicates extremely uniform resistivity in the surface of the resistive glass.

Measurement of Complicated Electric Field Patterns Produced on a Resistive Glass Surface

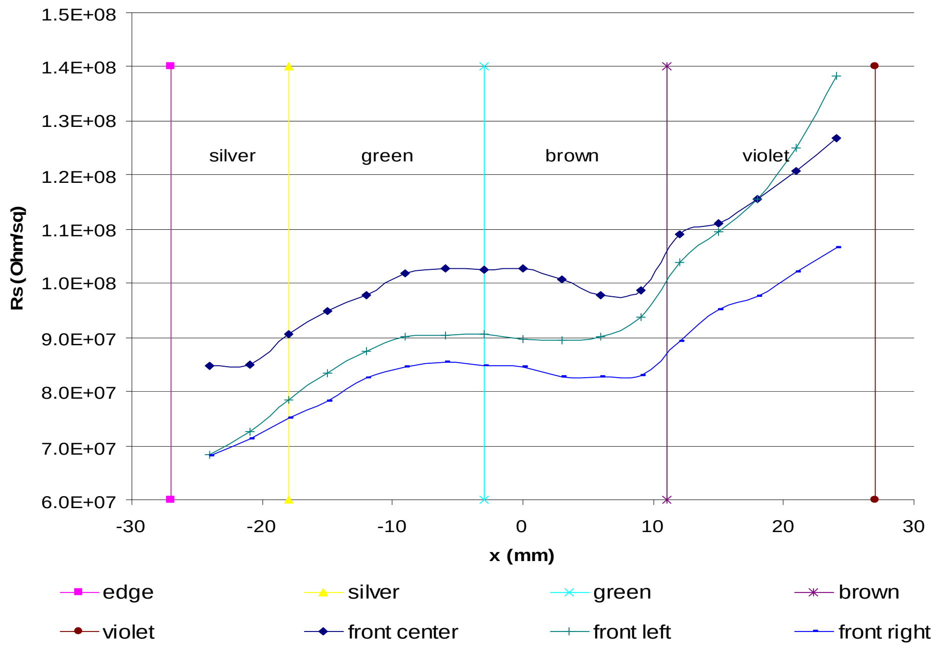


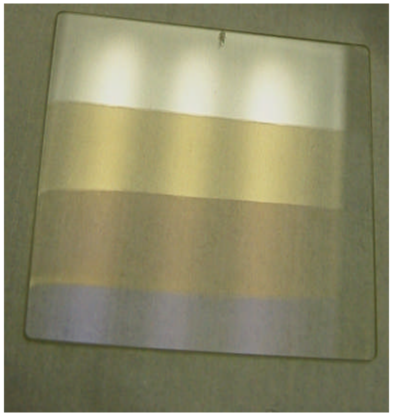


- Electrode patterns can be used produce complicated electric fields.
- Kelvin probe analysis can be used to reveal small field anomalies (like the one near the 6.7 V contact in this example.)

Future Work: Different Resistivities on the Same Sample

- A proprietary technique has been developed to produce flat plate samples with distinct regions of varying resistance.
- Four point probe data of a 2″ x 2″ plate prepared with four different resistance regions indicates this technique is viable for producing plates of varying resistance.
- This technique should produce tubes and plates with a constantly varying resistance from one end of the sample to the other.
  - This could be used to create non-linear fields for guiding ions.





Resistive Glass Ion Optic Example: A Reflectron Lens

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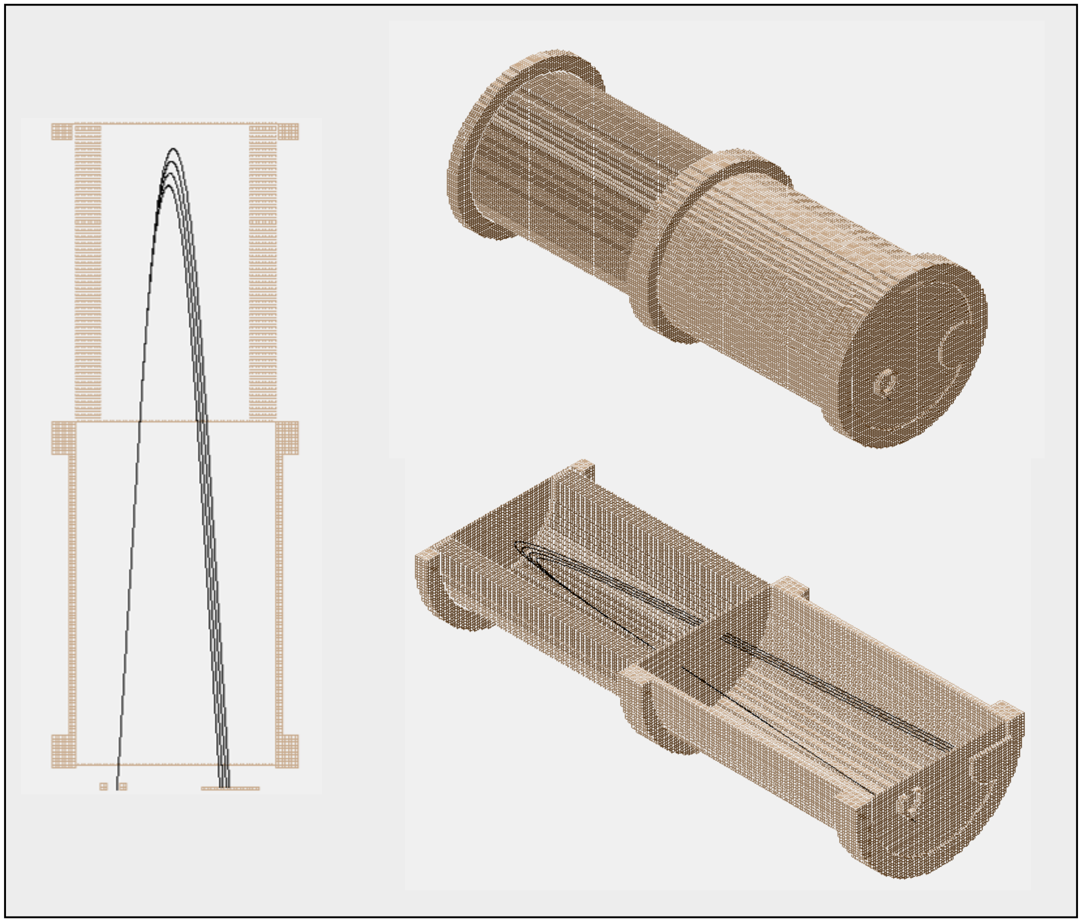

- A reflectron uses a static electric field to reverse the direction of energetic ions, increasing their flight times and improving the resolution of a mass spectrometer by helping ions with different initial kinetic energies reach the detector at the same time.

A Resistive Glass Reflectron

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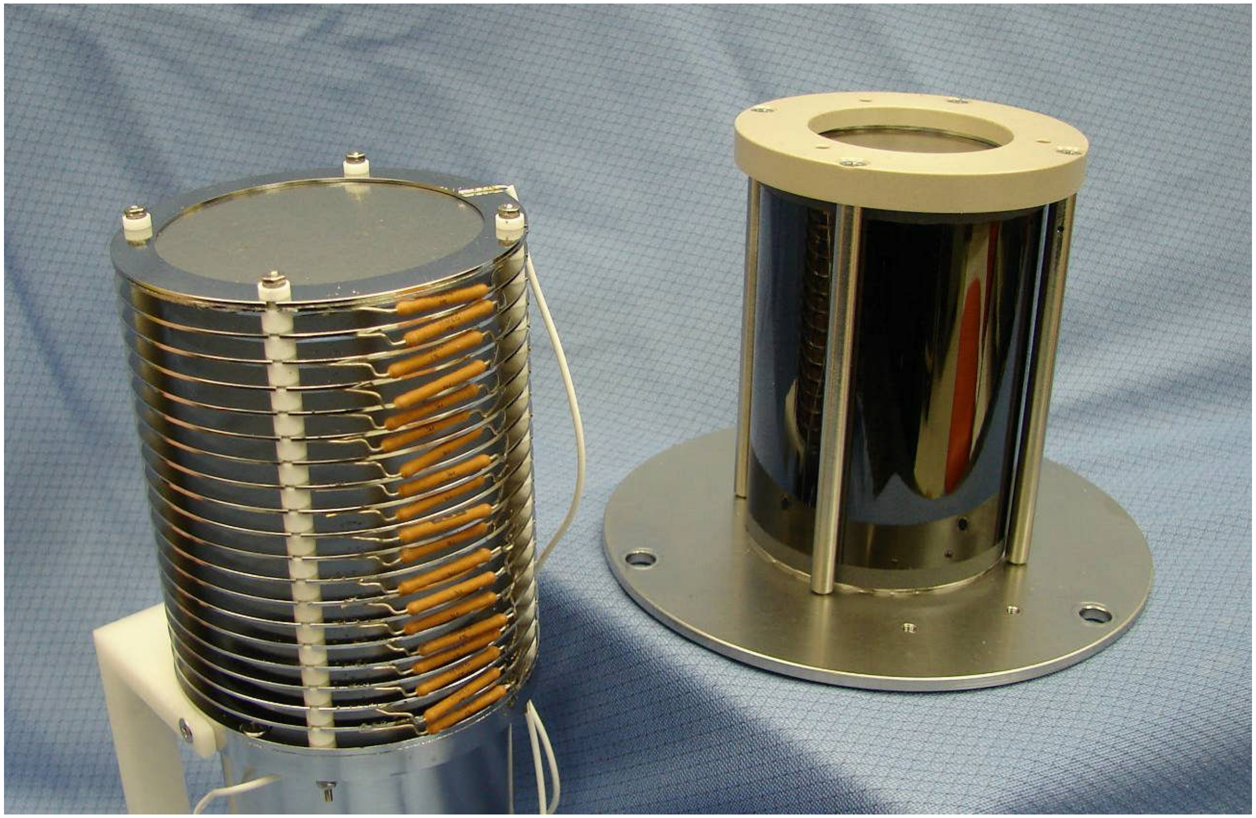
20 plates
80 insulators
19 resistors
4 rods
1 grid
8 fasteners

132 parts



1 end cap
1 contact
1 glass tube
4 rods
1 grid
4 fasteners

12 parts

The resistive glass reflectron is extremely simple when compared to the stacked metal electrode version

Simple Orthogonal TOF Experiment with Resistive Glass Reflectron Lens

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- Source gas (Argon) is bled into the vacuum chamber through a leak valve.
- A hot filament electron-impact ionization source passes a beam of electrons through the ion source body parallel to the face of the ion pusher-plate, ionizing the source gas. A phosphor is used to monitor the focused electron spot as it exits the other side.
- A pulsed pusher-plate ejects the ions out of the source towards the reflectron.
- The ions travel to the resistive glass reflectron, where they can be detected by the linear ion detector or reflected back to the reflected ion detector.
- The peak shapes from the detectors can be analyzed on an oscilloscope that has been triggered using the pusher pulse.

Orthogonal TOF Experiment

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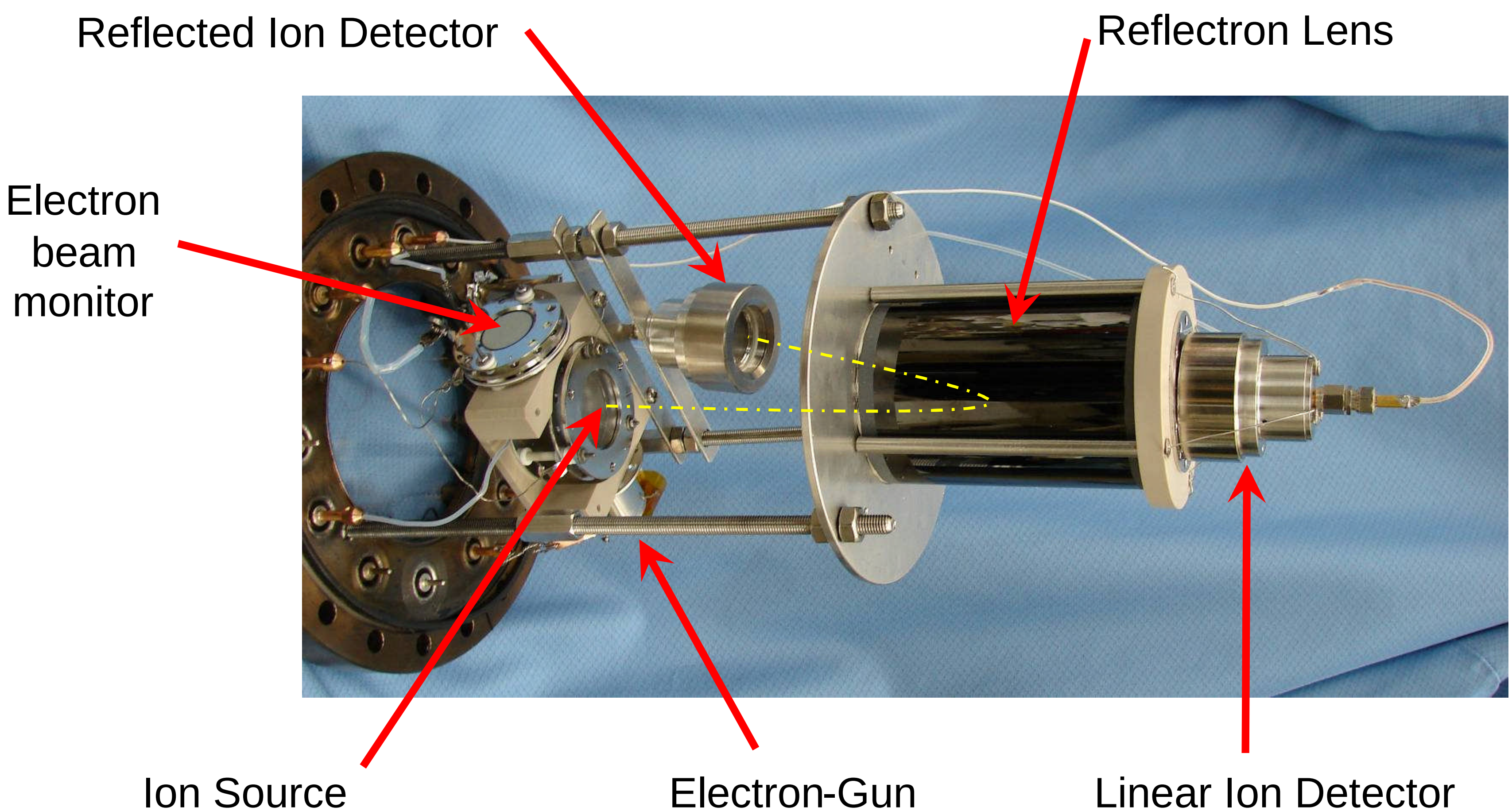

Glass Reflectron Energy Focusing

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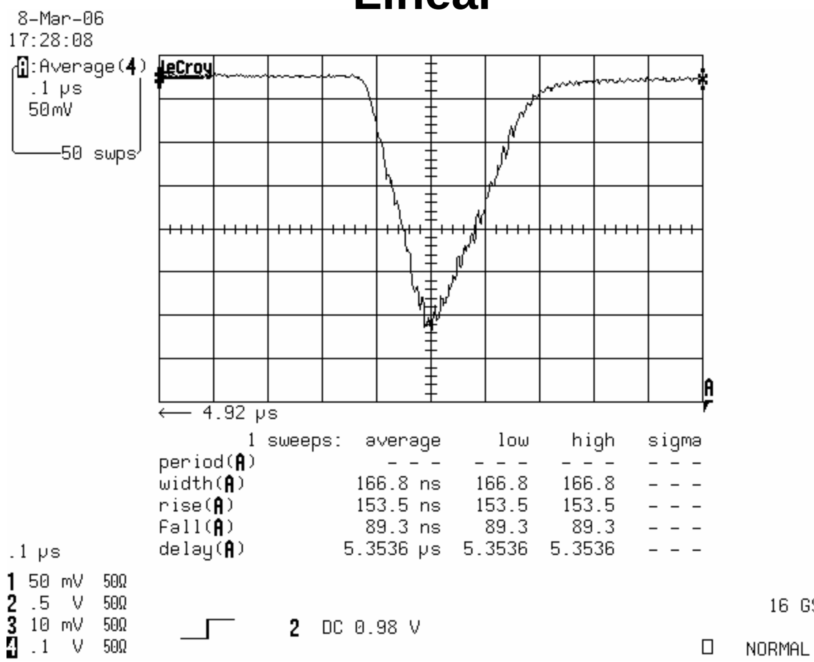
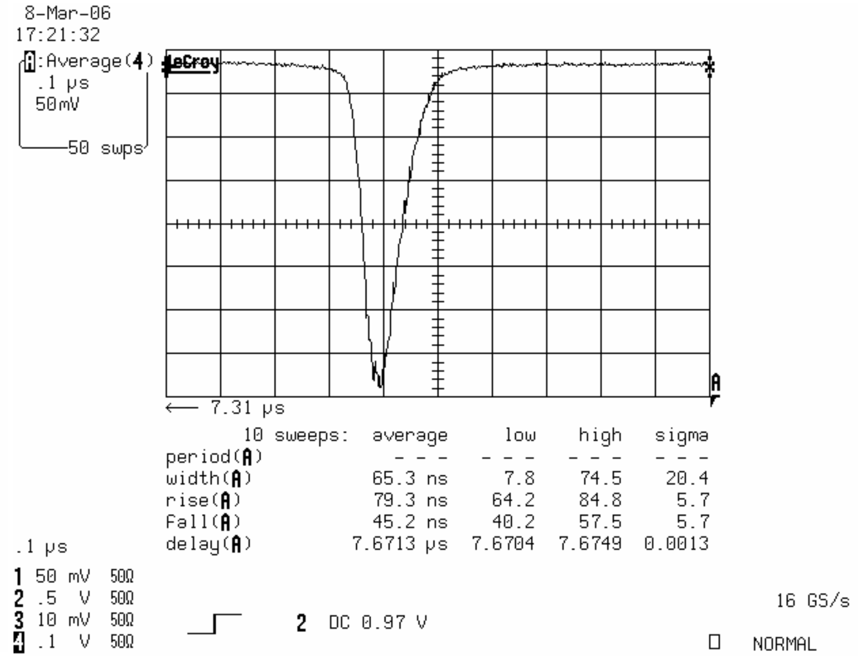
Linear



Reflected



These are oscilloscope traces of APTOF detector signals due to linear and reflected 650 eV Ar^+ ions measured using the experimental apparatus shown on the previous slide. The reflected peak is significantly narrower than the linear peak, demonstrating the energy focusing behavior of the resistive glass reflectron lens.

Resistive Glass Reflectron Data

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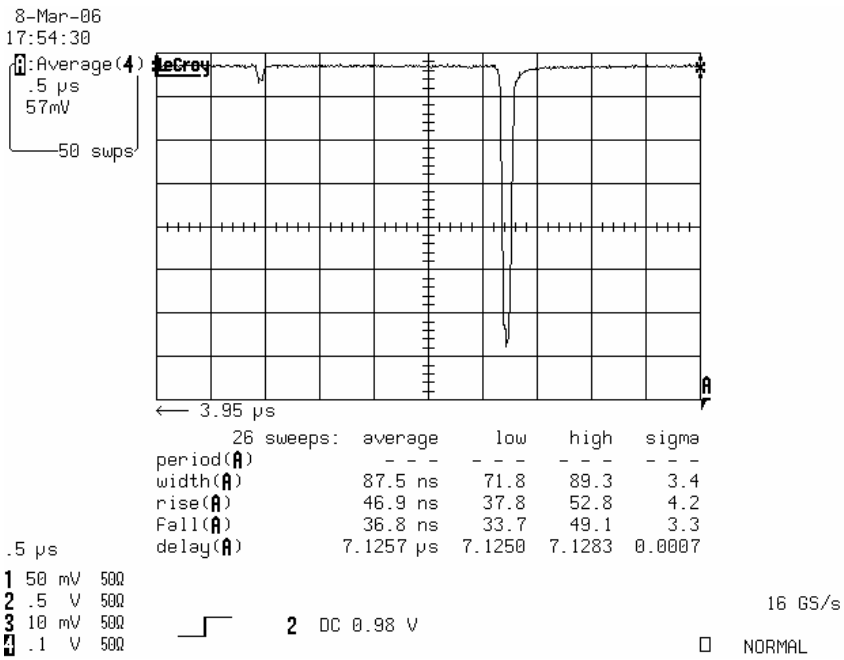
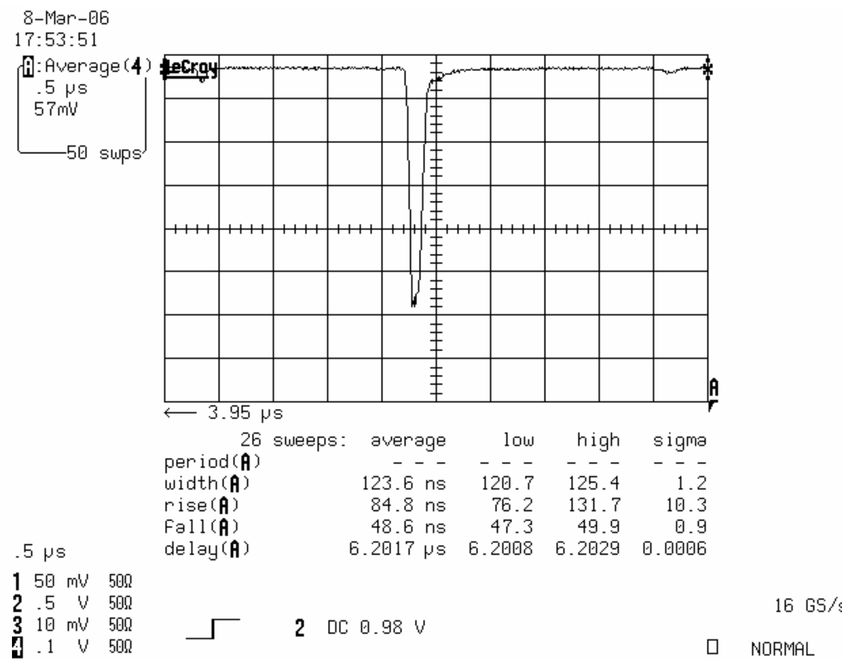
Reflectron = 1800 V

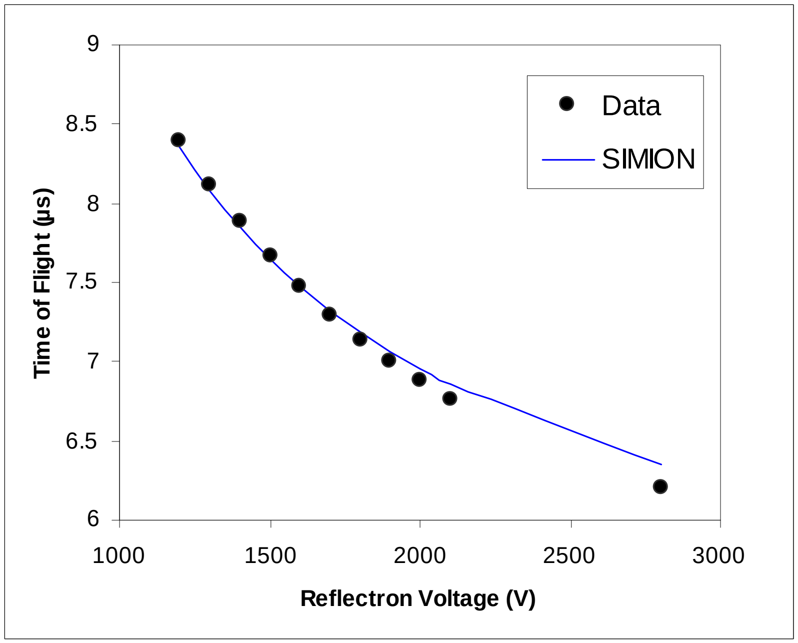


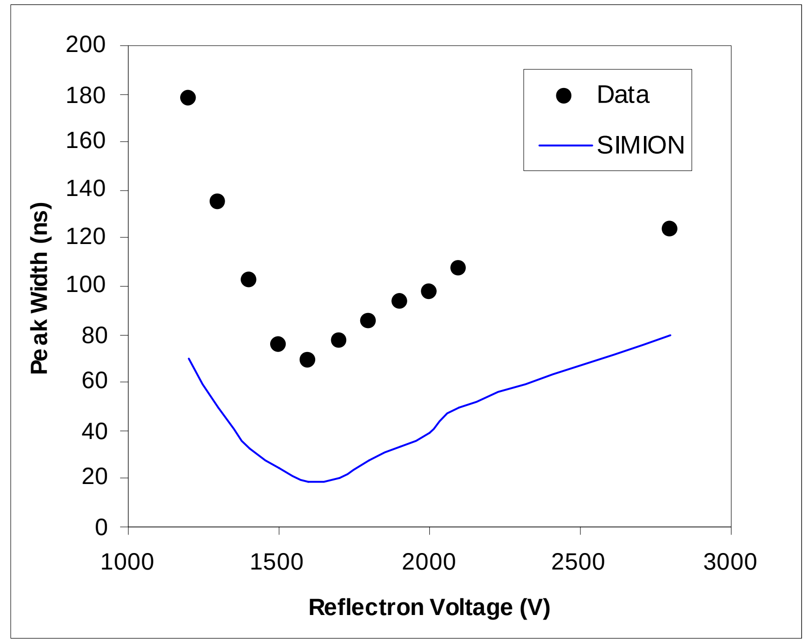
Reflectron = 2800 V



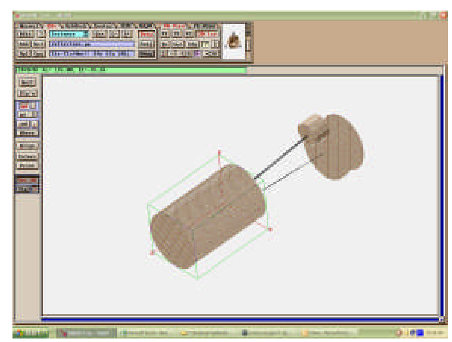
These traces show the shift in peak position due to a change in the reflectron voltage for reflected argon ions. As the reflectron voltage is increased, it shifts the peak to the left indicating shorter flight times, and changes the width of the peak, indicating a change in the energy focusing behavior.

Resistive Glass Reflectron Data





Here measured time of flight (TOF) and peak width data for reflected 650 eV Ar^{+} ions are compared with a SIMION simulation. The shape of the peak width curve again demonstrates the energy focusing behavior of the lens. The lower values of the SIMION peak width curve are largely due to the simplicity of the simulation.



Preliminary Comparison:
Resistive Glass vs. Stacked Electrode Reflectron

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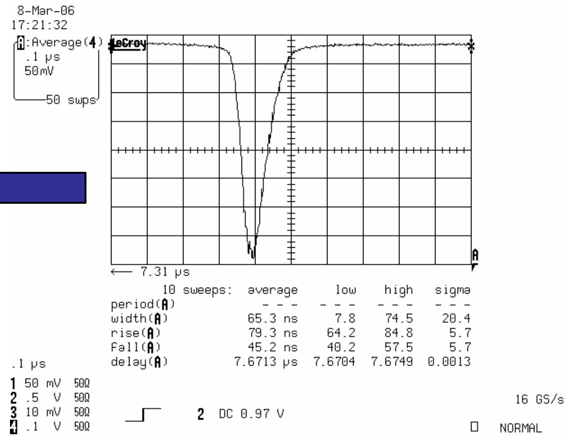

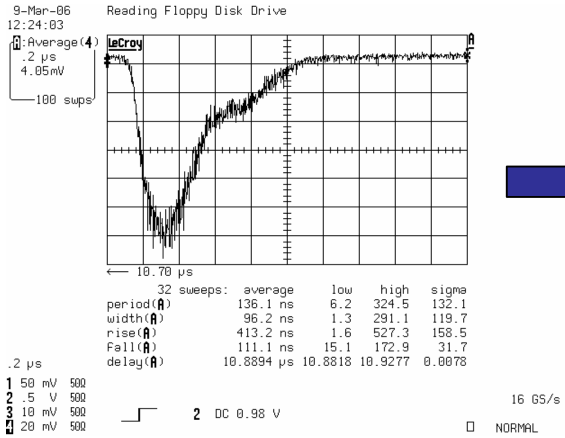

These preliminary results indicate that resistive glass makes a very good reflectron when compared to a stacked electrode reflectron of roughly the same size.

Some Advantages of Resistive Glass Ion Optics

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- One piece design
- Integral electrodes and resistive divider
- Reduced cost
- Minimal assembly labor
- Ultra-high vacuum compatibility
- Smooth electric fields
- Custom sizes
- Integral grids are easily added
- Good stability in vacuum
- High breakdown voltage

Conclusions

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- Resistive glass has good resistance uniformity and behaves as a good conductor.
- Experimental evaluation of resistive glass confirms it is well suited for making ion optics components.
- Resistive glass can be used to simplify the construction of ion optic components
- A simple one-piece glass reflectron lens built of resistive glass demonstrated excellent energy-focusing behavior.

Future Work

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- A direct comparison of a stacked metal electrode reflectron and a resistive glass reflectron where all of the geometric factors are preserved.
- Direct measurement of glass reflectron properties for different mass ranges.
- Work continues on developing glass samples with controlled variable resistance.
- Kelvin probe analysis of samples with variable resistance.

Acknowledgements

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- Four point probe data appears courtesy of Dr. Nikos Jaeger of 4 Dimensions Inc., Hayward, CA.
  4 Dimensions makes Four Point Probes and Mercury Probes capable of measuring high resistances like those of the resistive glass components used in these experiments.

- Kelvin Probe analysis was performed by Dr. Iain Baikie at Kelvin Probe Technologies, Wick UK.

- We would like to thank Dr. Matt Evans of Syagen, Inc. and Dr. Eugene Moskovets of the Barnett Institute for their help with development of the reflectron lens experiment.