Development of Novel Monolithic, Resistive Glass Tube with Multi-Stage Capability for Use as Reflectrons, Ion Guides and Collision Cells

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Introduction:

Resistive Glass can be used to create uniform electric fields in analytical instruments to control ion paths. Resistive Glass is an alkali doped silica glass which can be formed in an infinite number of useful geometries to produce unique electric fields. This material has been operated stably in high vacuum for decades and does not contribute to the chemical background in mass spectrometers. The characterization of Resistive Glass has been previously described by Laprade, Mrotek, Dunn and Ritzau[1].

Resistive Glass devices replace dozens of ring electrodes, ceramic spacers and resistor dividers in such devices as ion guides, reflectron lenses and drift tubes.

Resistive Glass Tubes are used in Ion Mobility Spectrometers for both the ionization chamber and the drift tube. The combination of the uniform electric field and the turbulence free counter flow gas produces resolving powers of over 100. Resistive Glass Inlet Tubes enhances ion flow up to 1000X from the electro-spray source into the mass spectrometer.[2]

A new technology has been developed which enables single piece structures to produce multiple linear stages. This advancement enables low cost one piece reflectrons, collisions and ion guides to be produced.

Background:

Resistivity Stability

One important performance parameter for resistive devices is the long term resistance stability. Recent advancements in passivation technology have demonstrated only a 4% increase over a three year period when stored in air. The same process demonstrated enhanced stability at elevated temperature (Figure 1).

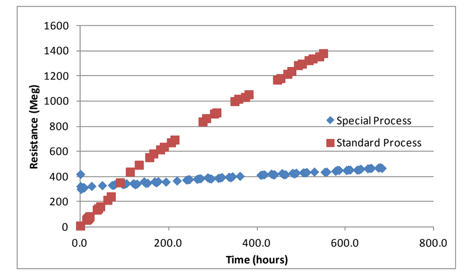

Figure 1: Resistance Stability at Elevated Temperatures.

Resistance Uniformity

The uniformity of the electric field within such structures will depend on the uniformity of the resistive wall. Resistance uniformity tests were performed along a 8-inch length structure with good results (Figure 2).

Linearity Measurement Results

A saturated solution of sodium chloride was slowly poured into the cylinder. The level of the fluid was measured with a ruler and data was taken for every 0.5". For each measurement the test voltage was reduced to maintain the test current at 30nA and the voltage and current was recorded and used to calculate the resistance of the cylinder above the fluid.

The results indicate a uniformity of better than 1%.

Height of fluid (in)	Measured Resistance (Gig)	Calculated from best-fit linear equation Resistance (Gig)	Error
0.0	17.571	17.677	0.604%
0.5	16.720	16.786	0.396%
1.0	15.849	15.895	0.294%
1.5	15.010	15.004	-0.038%
2.0	14.124	14.113	-0.076%
2.5	13.248	13.222	-0.193%
3.0	12.385	12.331	-0.439%
3.5	11.509	11.440	-0.607%
4.0	10.599	10.549	-0.477%
4.5	9.723	9.658	-0.675%
5.0	8.827	8.767	-0.690%
5.5	7.923	7.876	-0.595%
6.0	7.002	6.985	-0.245%
6.5	6.093	6.094	0.008%
7.0	5.192	5.203	0.212%
7.5	4.291	4.312	0.481%
8.0	3.389	3.421	0.929%

Figure 2: Linearity Measurement Results for Uniformity.

Background (Continued):

Reflectron Lenses:

A reflectron lens (Figure 3) 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.

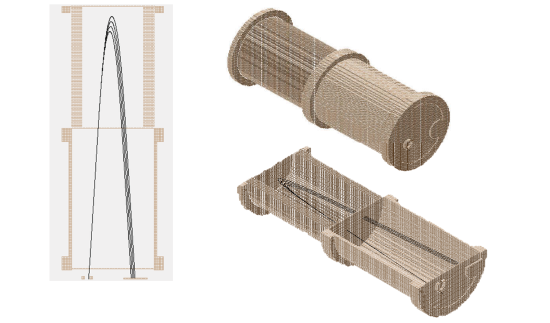

Figure 3: A Diagram of a Reflectron Lens.

Ritzau, Laprade, Mrotek and Leffingwell[3] previously showed single stage reflectron performance was comparable to the stacked ring approach. Figure 4 shows the stacked ring reflectron and Resistive Glass reflectron used for their tests. The stacked ring electrode lens consists of 127 parts that must be assembled. The Resistive Glass reflectron is a single piece.

Figure 4: A Stacked Ring Reflectron and a Resistive Glass Reflectron side-by-side.

Figure 5 (below) shows time of flight as a function of reflectron electric field measured at two masses showing good agreement between the two reflectron lenses. The solid lines are from a SIMION simulation.

Comparative spectra for the Resistive Glass and stacked ring reflectrons at near-optimal mass resolution are shown in Figure 6 (below). Overall, performance is nearly identical though the glass reflectron (inset) produces narrower peaks.

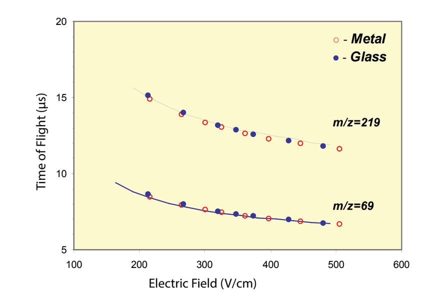

Figure 5: Time of Flight Values.

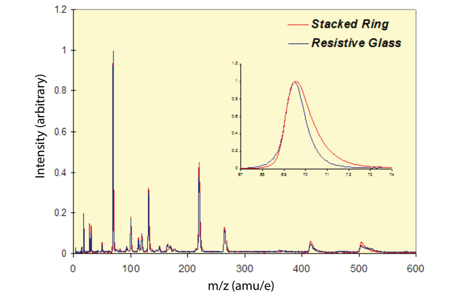

Figure 6: Comparative Spectra of Metal vs. Glass Reflectron Lenses.

Method:

A single stage reflectron lens fabricated with Resistive Glass is somewhat limited in performance. If a multi stage device could be fabricated, higher performance could be achieved.

A new technology has been developed which enables a single Resistive Glass tube to be divided into segments. The locations and dimensions of these segments are variable by design.

A method has been developed which enables small vias to be produced at any desired location. These vias are used to apply potentials from outside the Resistive Glass tube.

Results:

A series of metallic inks composed of gold or silver have been developed which are then applied in a printing fashion within the inside diameter of the tube. The location of the metallic printed features can be precisely controlled. These conductive pathways are then electrically connected to the vias. Applying potentials to the locations can then precisely control the resultant electric field.

Figure 7 illustrates the concept of a Segmented Resistive Glass Tube while Figure 8 shows a fully manufactured tube. The manufactured tube has an inner diameter of 60mm, a length of 177mm and has pin locations at 22mm, 42mm, 71mm and 111mm.

In air, a voltage was applied across the tube and the voltage subsequently measured at each pin location. Note the good correlation between the pin position and the measured voltage (Figure 9).

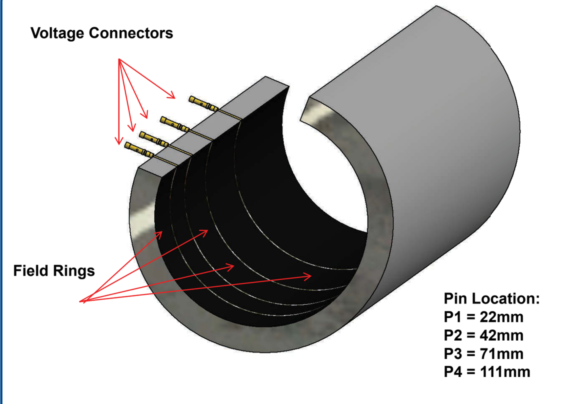

Figure 7: Cutaway diagram of a Segmented Resistive Glass Tube.

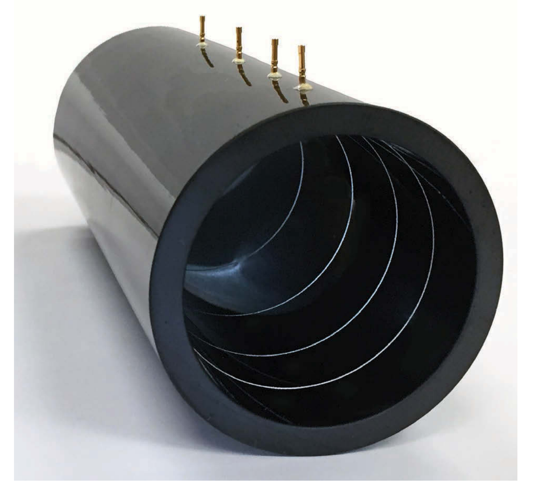

Figure 8: Photograph of a manufactured Segmented Resistive Glass Tube with the circular rings clearly visible.

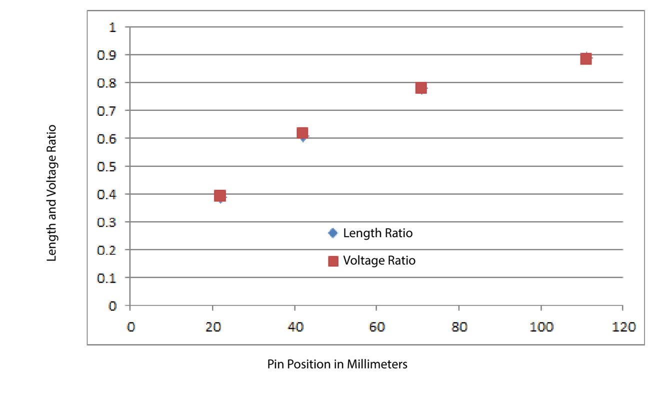

Figure 9: The graph indicates pin position in millimeters, and shows a good correlation between the position of the pins and the measured voltage.

Another useful embodiment of this technology is to produce collision cells or ion guides.

In Figure 10, a cylindrical tube is shown in cross section. A dielectric coating can be applied between the Resistive Glass surface and the silver electrode.

In operation, an RF signal may be applied to two opposite electrodes while a DC potential applied to the tube drives the ions to the exit lens. Collision gas can be introduced through machined inlets in the tube body.

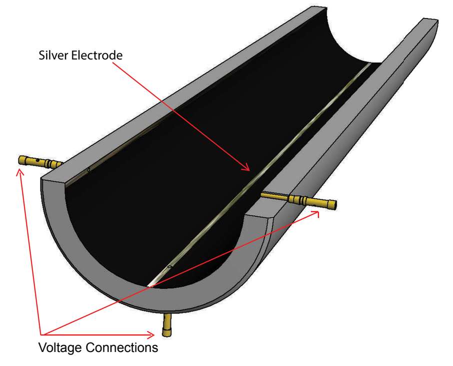

Figure 10: Cross section of a Resistive Glass Tube configured as a collision cell or ion guide.

Results (continued):

Figure 11 shows a photograph of silver electrodes applied to the inside diameter of the ion guide. Silver electrodes are electrically isolated from the Resistive Glass surface by a thin dielectric coating.

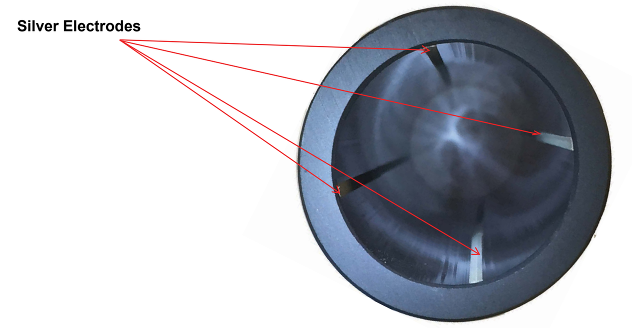

Figure 11: Photograph of a manufactured ion guide with silver electrodes applied.

Conclusions:

- A method has been developed which enables segmentation of Resistive Glass structures.
- The method consists of printing high vacuum compatible metal electrodes on the surface of Resistive Glass structures.
- In the case of tubular structures these electrodes are accessed by through-wall connectors.
- This new technology enables simple one piece multi-stage reflectrons, ion guides and collision cells to be fabricated at lower cost and provide higher performance compared to the stacked ring approach.
- Resistance uniformity has been demonstrated to be better than 1%.
- Resistance stability has been improved significantly through the application of a passivation process.

Future Work:

- Now that tube segments can be accessed, investigate the feasibility of adding ion gates to the structure. This would enable one piece IMS and IMS-MS instruments to be manufactured.
- Investigate the use of such structures as an integral part of the instrument vacuum containment system.

References:

1 Laprade, B., Mrotek, S., Dunn, W., and Ritzau, S. *The Development of Novel Resistive Glass Technology to Simplify and Improve Designs in Analytical Instruments.* Burle Electro-Optics. Presented at ASMS 2005, Poster 268.

2 Holmes, P., and Laprade, B., *Development of Resistive Glass Multi-Capillary Inlet Tubes for Enhanced Ion Transport.* PHOTONIS USA. Presented at Pittcon 2011.

3 Ritzau, S., Laprade, B., Mrotek, S., and Leffingwell, R. *Direct Comparison of a Resistive Glass and Stacked Ring Reflectron.* Burle Electro-Optics. Presented at ASMS 2006.