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A univoltage ion gun design

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Abstract

A broad beam ion gun has been designed and tested that requires only a single high voltage supply. It creates 1–2-mm-diameter 2–10 kV beams that are visually uniform in spatial intensity with a sharp edge cutoff using a Perrhenate solid state ion source. The gun's electrode geometry is designed to make beam diameter independent of acceleration voltage. Moreover, the source is imaged at the focal length of the acceleration optics to obtain a beam with visually uniform spatial intensity. With this approach, all points on the source's emission surface contribute equally to the brightness of each point in the beam. The univoltage ion gun design has demonstrated its utility in broad beam static secondary ionization mass spectrometry (SIMS) instruments and is being adopted as the ion gun of choice for many of our group's instruments. (Int J Mass Spectrom 189 (1999) 39–46) © 1999 Elsevier Science B.V.

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1. Introduction

Our group's static secondary ion mass spectrometry (SIMS) instruments require broad primary ion beams of 1–2 mm in diameter [1]. Over the years a variety of ion gun designs have been used to create broad primary ion beams with varying degrees of success and satisfaction. This experience served to identify desirable characteristics for a broad beam primary ion gun: (1) The beam intensity should be as spatially homogeneous as possible with a sharp edge cutoff. The resulting uniform sample illumination helps simplify instrument tuning and improves the consistency of the measured secondary ion spectra; (2) the kinetic energy of the primary beam should be easily varied without affecting beam diameter or requiring retuning of the primary gun. Variable kinetic energy primary beams can significantly assist in sample charge compensation strategies [2]; (3) the primary gun that requires only a single high voltage supply is very desirable, greatly simplifying power supply and beam tuning requirements. A design study initiated with these desirable characteristics in mind resulted in the univoltage ion gun design discussed below.

2. Discussion and description

The primary design goal was to limit the gun to a single high voltage supply (all gun electrodes must be either at the high voltage or at ground potential). A second goal was to obtain a design with focusing

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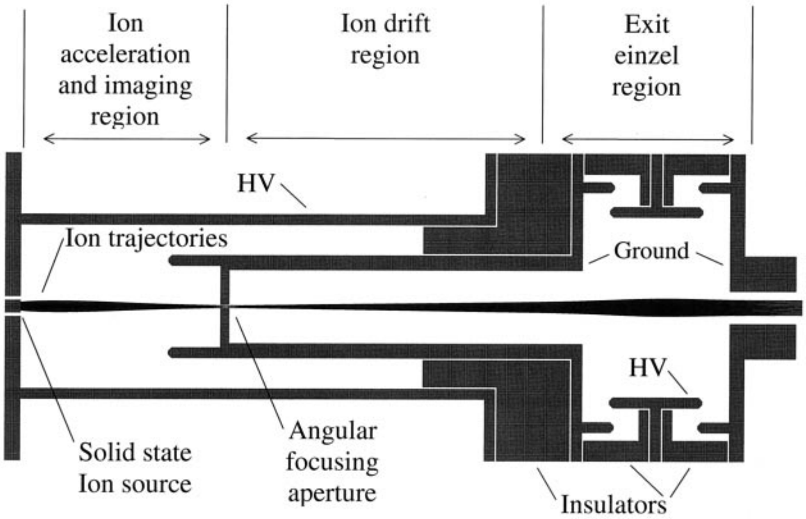

Fig. 1. SIMION model of the univoltage ion gun and a set of trajectories for ions emitted at ±89° from the ion source and focused to a 1.4-mm-beam at 26 cm from the exit of the einzel lens.

characteristics that were controlled only by electrode geometry, so that changes in the high voltage potential would have a minimal impact on beam focusing characteristics. Further, it was intended that the gun make use of solid state ion sources like our Perrhenate (ReO_4^-) negative ion source [3]. Although these sources are mechanically simple (a small rhenium tube filled with compressed ceramic emitter material) their ion emission is typically not uniform across the surface of the source. This precludes obtaining a homogeneous intensity beam by simply spatially imaging the source's emission surface.

These constraints and some insights gained from the development of a primary beam gun for an imaging SIMS instrument led to the univoltage gun design shown in Fig. 1. The gun is of a concentric cylinder geometry that has proven useful for other ion optics assemblies in our instruments. The concentric cylinder approach facilitates the alignment of the electrodes as well as creating closed electrode boundaries around all electrostatic field regions within the gun. Note also that insulators that might encounter ion flux are located sufficiently far from the ion focusing field regions that any charging of the insulator has negligible impact on the focusing fields. All modeling was performed with the SIMION ion optics modeling program [4]. The appendix contains a SIMION 6.0 compatible geometry file of the model used for the univoltage gun design.

The gun design can be divided into three functional regions: The ion acceleration and imaging region (on the left), an ion drift region for field isolation and image magnification control (center), and an einzel lens region that provides the exit beam focusing (on the right). The gun's electrostatic fields are illustrated in the potential energy surface view shown in Fig. 2.

The ion acceleration and imaging region's electrodes have been sized and shaped so that the electrostatic focal length of this region is exactly the distance between the ion source surface and the image aperture plate (angular imaging aperture, Fig. 1). Great care was taken to shape the electrodes so that the focal length remains virtually constant for acceleration voltages between 2 kV and 10 kV to insure that the first stage focusing characteristics remain independent of the acceleration voltage. Moreover, by designing the electrostatic focal length of the ion acceleration region to be the exact distance between the source plane and the aperture plate, an image very uniform in intensity can be created at the aperture plane. Unlike a spatial image of the source itself at the aperture, each point of the focal length image contains

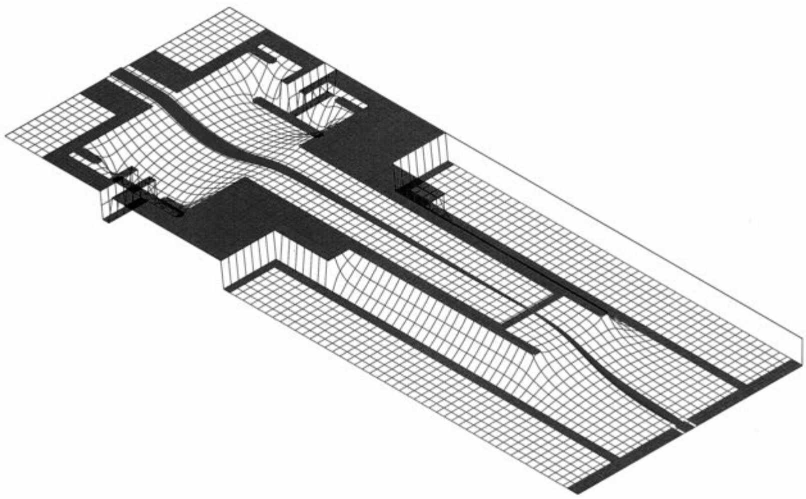

Fig. 2. Potential energy surface of the ion gun at −5 kV, and the trajectories of the ions emitted at ±89°.

ions that left the source at some fixed elevation angle (an angular focus). Thus ions emitted from everywhere on the source's surface contribute to the brightness of each point of the focal length image, as illustrated in Fig. 3. The result is an image with a uniform spatial intensity that is independent of the spatial emission characteristics of the solid state ion source itself (the ion emission inhomogeneities are

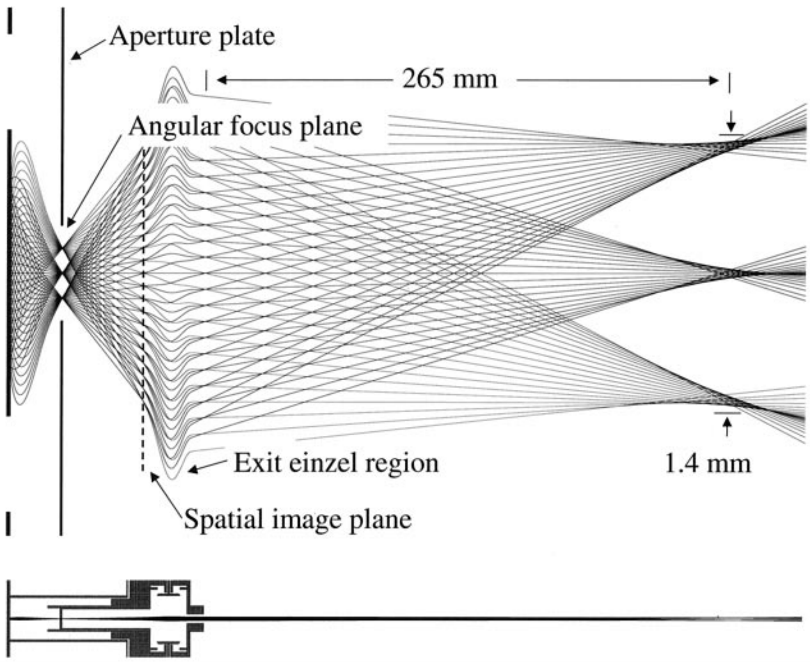

Fig. 3. Expanded *Y* scale view of the ion trajectories; note that the scaling is asymmetric in the upper view. The lower view is scaled 1:1 in *X* and *Y* for reference. The dashed vertical line at the spatial image focus plane is a reference line, not a physical part of the lens. The lens was designed to focus at 26.5 cm from the exit of the einzel lens.

averaged out at each focus point). The angular focus image shown in Fig. 3 shows three image points for groups of ions emitted across the source face at the angles 0°, +89°, and −89° from a line normal to the face of the source at 5 kV acceleration voltage. The focal plane of these points of focus does not shift perceptibly for ion emission energies below 1eV—well within the ion emission energy range of thermal ion sources, minimizing chromatic aberrations. The model makes the assumption that the ions are emitted from a flat plane, the ion source face, centered in the source plate and aligned flat with the front surface. Although the ion source mounting hardware makes it possible to carefully mechanically align the ion source, thermal expansion can move the source, which will shift the angular image out of the plane of the aperture and degrade the focusing. This can be corrected by applying a small bias voltage (0–10 V) between the ion source and the main high voltage potential. The bias voltage can also be used to completely shut down ion emission from the source—a convenient means for producing a pulsed beam.

As the acceleration voltage increases the angular focus image diameter at the image aperture decreases. In the 5 kV example shown in Fig. 3, the entire angular focus image is less than the 0.5-mm-diameter aperture (virtually all emitted ions pass through the aperture), and, as the acceleration voltage is increased the angular focus image will be compressed, resulting in a smaller diameter beam. In order to produce a beam that maintains a constant diameter over a range of acceleration voltages, the aperture must be sized to the angular focus image diameter at the highest acceleration voltage. Then, as acceleration voltage is reduced, the beam diameter is maintained (constrained by the aperture), but the beam intensity falls off (not all of the ions make it through the aperture). The design allows for either option, constant diameter or constant intensity, dependent upon the aperture size.

The image aperture is located at the left edge of a field free ion drift region (Fig. 1). The tube extension to the left of the aperture serves to reduce the field gradients near the aperture to minimize unwanted aperture focusing effects. The drift tube to the right of the aperture serves to isolate the gun's acceleration region from the exit einzel focusing region. The length of the drift tube can be adjusted (during the design phase) to control the magnification of the aperture's image at the downstream image focus point.

The einzel lens focuses an image of the aperture at the desired location beyond the gun (Fig. 3). Because the voltage of the einzel lens is the same as the source voltage, the choice of the inner diameter of the einzel ring electrode (Fig. 1) determines the image focusing distance (Fig. 3). For example, reducing the inner diameter of the einzel ring electrode shortens the focal length of the einzel lens assembly. The appropriate inner diameter for the einzel ring can be determined by trajectory simulations. Of course, there is always the option of driving the einzel lens element with a separate power supply to allow variable beam focusing.

A second image plane is evident in Fig. 3, noted as the spatial image plane. Fortuitously, this lens can also project a magnified image of this spatial image plane, and thus the ion emission surface, simply by adjusting the potential applied to the einzel lens (shown later). This particular feature is being used in studies designed to understand the chemistry controlling thermal ion emission from a variety of ceramic–metal systems.

3. Results and conclusions

A photograph of the as-built univoltage gun is shown in Fig. 4. The ion source assembly is a Re metal tube filled with a rare earth oxide blended with barium perrhenate [3], spot-welded to a Re heater ribbon supported off two electrically insulated pins. The source assembly is clamped into an adjustment gimbal used to center and axially position the Re tube within the source plate aperture (Fig. 1). Fig. 5 shows the partially disassembled components of the gun. The design allows the gun to be configured either with the einzel lens electrically connected to the source assembly, or electrically isolated for operation at a separate voltage. All metal components are fabricated

Fig. 4. As-built univoltage ion gun. Ion source gimbal assembly is at the left.

from 304 stainless steel (with the exception of the magnet and poles pieces in the ion source), and the insulators are made of vespel (Dupont). The angular imaging aperture plate is pressed into the drift tube; the remainder of the components are nested and compressed with #6-32 screws seated in either the

Fig. 5. Partially disassembled components of the univoltage gun.

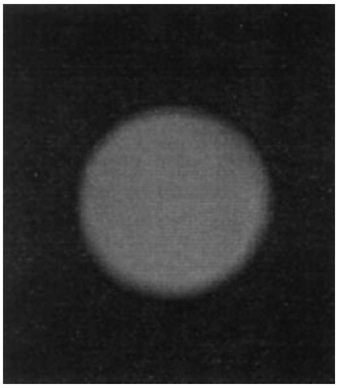

Fig. 6. Photograph of the image of the angular focused ReO_4^- beam on the MCP image intensifier. Beam diameter is 3 mm.

vespel or the metal ground plate. Engineering drawings are available upon request. A set of *XY* deflectors are typically attached to the exit plate [5].

Fig. 6 shows an image of the angular focus beam projected onto an imaging multichannel plate (MCP) detector. The beam has a visually uniform spatial intensity with a sharp edge. Intensities up to 20 nA in a 3-mm-diameter beam have been measured using our solid state Perrhenate (ReO_4^-) negative ion source (typical beam intensities used in our static SIMS are from 150–300 pA). Beam intensity was constant for tens of hours after initial warm up and conditioning of the ion source, and the beam position remained constant for days.

The focusing characteristics of the as-built gun agree quite well with the SIMION design simulations. However, the focusing is not totally acceleration voltage independent. The beam diameter changes by 10% as beam energy is increased from 2 keV to 5 keV. This change results in part from the large aperture size (0.5 mm) and also indicates, based on the SIMION model, that the source face is not perfectly aligned with the source plate and/or that the as-built dimensions are slightly different than specified in the model. Small changes (a few volts) in the source bias voltage can be applied to maintain beam diameter when acceleration voltages are changed. The beam intensity is also mildly dependent on the acceleration voltage because a stronger field draws more ions through the first aperture. Over the range 2–5 keV the beam intensity increases by 25%.

Fig. 7 shows a magnified spatial image of the ion source, generated by setting the einzel lens potential so that the spatial image plane, rather than the angular focus image plane, is projected onto the MCP (voltages were 3.8 kV on the source, 5.0 kV on the einzel lens). In this image the inhomogeneous nature of the emission surface is readily apparent. Comparing this

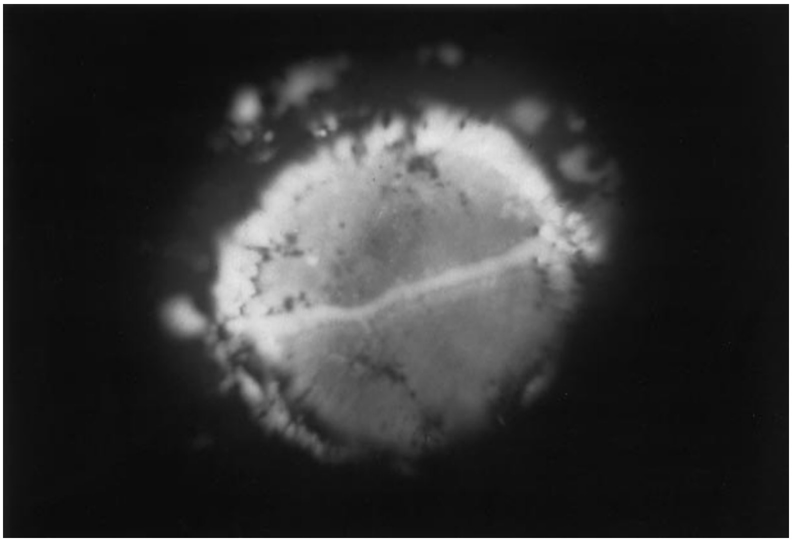

Fig. 7. Photograph of the image of the spatially focused emission surface of the ReO_4^- beam on the MCP image intensifier. Actual source is 1.5 mm diameter. The near-horizontal line is a scratch intentionally placed on the emission surface as a reference point.

with Fig. 6 demonstrates the utility of the angular focusing approach for producing a homogeneous beam from an inhomogeneous source.

Univoltage guns have been successfully employed in several of our ion trap and quadrupole broad beam static SIMS instruments. The improvement in primary beam stability and ease of tuning has been significant enough that univoltage guns have been adopted as the

4. Appendix: Geometry definition file, SIMION 6.0 compatible format

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;Univoltage gun geometry file
pa_define(771,151,1,c)        ;2D potential array definition

;a cylindrical source design
;use 0.01 inch/grid unit or 0.254 mm/grid unit
;for instance scaling

locate(0,0,0,1)          ;normal size
{
e(1)                 ;electrode 1 → source
  {
  fill{
     within {box(0,0,15,6)}
    }
  }
e(2)                 ;electrode 2 → source housing
  {
  fill {
     within {box(0,10,15,150)} ;left end
     within {box(0,80,467,90)} ;tube
     within {box(467,80,477,150)} ;flange
    }
  }
e(3)                 ;electrode 3 → aperture and housing
  {
  fill {
     within {circle(164,45,5)} ;rounded end of leading tube
     within {box(164,40,215,50)} ;leading tube
     within {box(210,2,218,50)} ;aperture
     within {box(215,36,562,50)} ;main tube
     within {box(552,36,562,150)} ;flange
     within {box(552,112,588,122)} ;einzel tube
     within {circle(588,117,5)} ;rounded end of einzel tube
    }
  }
```

```
e(4)                ;electrode 4 → einzel ring
   {
   fill {
       within {circle(594,93,5)} ;rounded left end of einzel ring
       within {circle(674,93,5)} ;rounded right end of einzel ring
       within {box(594,88,674,98)} ;einzel ring
       within {box(629,98,639,150)} ;einzel flange
      }
   }
e(5)                ;electrode 4 → insulators
   {
   fill {
       within {box(407,52,550,78)} ;acceleration insulating ring
       within {box(479,78,550,150)}
       within {box(564,130,627,150)} ;left einzel ring
       within {box(618,100,627,150)}
       within {box (650,130,704,150) ;right einzel ring
       within {box(641,100,650,150)}
      }
   }
e(0)                ;exit plate
   {
   fill {
       within {circle(680,117,5)} ;rounded end of einzel tube
       within {box(680,112,706,112)} ;einzel tube
       within {box(706,16,770,50)} ;exit plate center tube
       within {box(706,50,720,150)} ;exit plate flange
      }
   }
}
```

standard broad beam ion gun for general use in our group's current and future instruments.

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