OPTIMIZATION OF A COLD FIELD EMISSION ELECTRON GUN FOR A MINIATURIZED SCANNING ELECTRON MICROSCOPE. S. K. Medley[1], D. A. Gregory[1], A. R. Sampson[2], and J. A. Gaskin[3], [1]Physics Department, The University of Alabama in Huntsville, Huntsville, AL 35899 USA, Stephanie.Medley@uah.edu, [4]Advanced Research Systems, St. Charles, Il 60174, [3]NASA/ Marshall Space Flight Center, Huntsville, AL 35812

Introduction: Scanning Electron Microscopes (SEMs) permit high resolution imaging (often 10 nm or better) and quantitative chemical analysis, on a fine scale, of a given sample. Regularly used for analytical studies involving mineralogy, petrology, sedimentology and non-destructive material analyses; a miniaturized SEM, capable of *in-situ* operation on the Moon (or other planetary body), would provide a useful capability. Over the past few years, NASA Marshall Space Flight Center and colleagues from: The University of Alabama in Huntsville, The University of Tennessee in Knoxville, Case Western Reserve University, and Advanced Research Systems (d.b.a.), have been working to define appropriate science goals for such an instrument and have started fabrication and testing of proof-of-concept components for a miniaturized SEM (mSEM) [1, 2, 3, 4].

The concept of a miniaturized SEM is not new. The SEM and Particle Analyzer, developed in the late 1980's specifically for the Comet Rendezvous Asteroid Flyby satellite (since canceled), achieved ~40nm resolution, operated on a relatively low power of 22W, and weighed roughly 12kg [5, 6]. Additional efforts in this field have produced a range of results concerning the development of a miniature SEM or miniature electron focusing column [7, 8, 9 – to name a few]. Utilizing current technologies and a novel design, we are able develop an even smaller, lighter, lower-power version that is easily adaptable to a variety of missions.

SEMs work by focusing an electron beam (generated by an electron gun) and rastering that beam across a sample [10, 11]. This produces backscattered electrons, secondary electrons, and x-ray photons which are specific to the material being analyzed. This work focuses on the simulations necessary for optimizing the operation of the electron gun for the mSEM. Modeling of the electron gun and the beam it produces allows for an initial estimate of the aberrations and emission current density for a given electron optical design. These predictions will be used to improve the electron gun performance and will be compared to experimental results from testing of our current prototype electron gun [1].

Electron Gun Simulations: The mSEM gun is a tungsten cold field emitter in a Butler-like triode configuration [12]. A large potential applied between the emitter and the first anode (a.k.a. the extractor anode) causes electrons to overcome the work function of the tungsten and tunnel through to the surface. These electrons are then accelerated forward to a second, grounded anode [11]. The maximum accelerating voltage for the mSEM is 10kV.

The gun is currently being simulated using the commercially available charged particle propagation software programs CPO (Charged Particle Optics Software) and SimIon 7.0 [13, 14]. Figure 1 shows a preliminary simulation of the cold field-emission electron gun using CPO. Emitted electrons are followed through the extractor anode and grounded anode, where the current density can be calculated. Both programs calculate the electrostatic and magnetic fields and determine the particle trajectories through those fields, though they use different methods to do so. Results from these two models will be compared. Of particular importance are effects from any aberrations that may be present, and the electron current density at the sample.

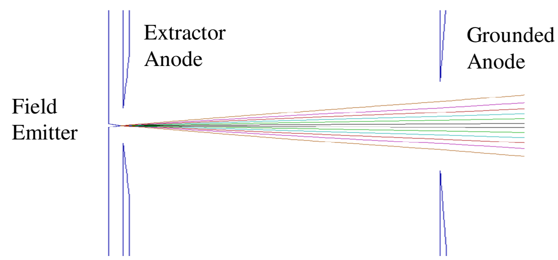

Figure 1. Preliminary simulation of the electron gun in CPO. Electrons that terminate on the extractor anode and grounded anode surface are not shown.

Aberrations of the mSEM. Aberrations in optical systems arise when an object point is not mapped to a conjugate image point. A model using SimIon/CPO as a starting point will be used to estimate the aberrations' effect on resolution that will then be compared to the mSEM requirements. Specifically, the goal is to determine the effects of chromatic and spherical aberrations that may be present, and their effects on mSEM performance.

It has been shown that miniaturizing the SEM can actually reduce aberrations [15]. However, aberrations will still be present in the mSEM due to the geometry of the electron lenses and apertures, the type of gun used, and the spread in energy in the electron beam. The energy spread for other cold field emission guns has been measured to be 0.2 to 0.3 eV [10]. A slight offset or tilt of the electron beam focusing column, the electron gun itself, or the components in the column or gun will be seen as vignetting or coma and will be included in the overall assessment, although through careful alignment, these aberrations can be significantly reduced [16].

Spherical aberration results in the smallest focused spot being a circle rather than a point, called in optics the circle of least confusion. Chromatic aberration is caused by the spread in the energies of the electrons. The chromatic and spherical aberrations are calculated using a standard equation from optics:

$$d_r = M\, C_S\, \alpha^3 - M\, C_C\, \alpha\, (d\varphi/\varphi)$$

where d_r is the value of r at the image plane for an axial object point that emits a ray at an angle α. C_s and C_c are the spherical and chromatic aberration coefficients, respectively, M is magnification of the image, and $d\varphi/\varphi$ is the fractional spread in the energy of the electrons, which, for the gun, is initially zero [17].

Current density calculations. The current density is modeled by each of the software packages but requires validation through self-coded simulations. These can then be compared to test results from the prototype electron gun. Cold field emission is characterized by the Fowler-Nordheim equation, relating the current density to the work function of the material and applied electric field [18]. For cold field emission, the work function for Tungsten is 4.5 eV [10].

Improving the mSEM electron gun: A prototype of the electron gun has been designed and fabricated and is currently being tested. Emission current from the mSEM gun is measured using a standard Faraday cup placed after the anode. Figure 2 shows a schematic of the electron gun and Figure 3 is a photograph of the finished product. The results from the tests of this prototype will be compared to those provided by the simulation software. Based on these results, the simulation will be improved, and the electron gun redesigned to fully optimize the maximum emission current density. This improved electron gun will be tested and the process repeated as necessary.

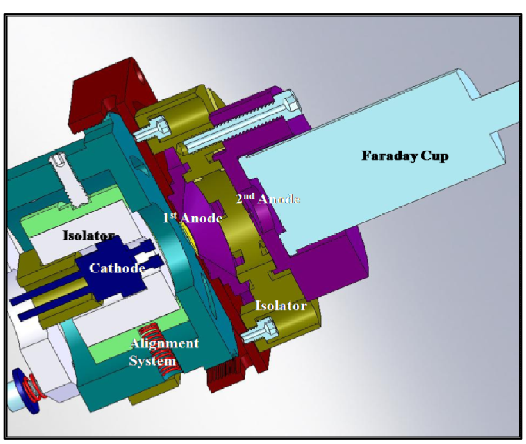

Figure 2. Schematic diagram of the mSEM electron gun, with Faraday cup attached.

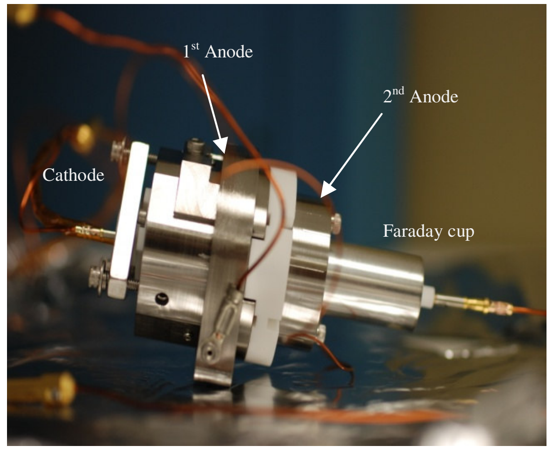

Figure 3. Image of the electron gun prototype

Future Work: In the near term, we plan on placing a phosphor screen and CCD camera just after the grounded anode, to image the resulting emission spot. From this image we will be able to determine emission spot size through the grounded anode. Following the completion of the electron gun model, we will model the remaining mSEM components and use these for optimization of the instrument as a whole.

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