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Faraday Cup Designs for High Efficiency Determination of Energy- and Angular-Resolved Charged Particle Fluxes

Kent D. Hartley
Utah State University

Undergraduate Research and Creative Opportunities

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Kent Hartley

Mechanical Engineering, Utah State University

Mentor

JR Dennison

Physics Department, Utah State University

Project Abstract

Faraday cups provide a simple and efficient apparatus to measure the absolute magnitude of charge particle fluxes, and with the addition of a retarding field analyzer and defining apertures the capability to determine the energy and angular distributions of the fluxes. Through careful design of the electron optics, a Faraday cup can be tailored to meet specific requirements for detector size, minimum detectable flux, collection efficiency, absolute accuracy, energy discrimination, and angular resolution. This project explores optimal design concepts through electric field and charged particle trajectory simulations, theoretical analysis, and evaluation of experimental prototypes to develop compact, high efficiency Faraday cups capable of a range of energy and angular resolutions. The designs rely on high capture-efficiency Faraday cups, coupled with grid-free Einzel lens energy analyzers for nearly energy-independent determination of absolute fluxes. The project will also develop specific designs for applications of these Faraday cup detectors to electron emission and transport studies, spacecraft charging applications, and electron beam characterization measurements done in conjunction with various projects conducted by the Materials Physics Group.

Introduction

Dr. JR Dennison's Materials Physics Group (MPG) conducts research in the field of surface and materials science. Specifically, we examine the interactions that occur when a spacecraft material is irradiated with charged particle fluxes analogous to those found in the space environment. Frequently we use a Faraday cup, located inside an ultrahigh vacuum (UHV) chamber, to characterize the charge particle magnitude, spatial distribution and beam divergence that a sample of material is irradiated with. The data collected with the Faraday cup are critical not only in the characterization of the charged particle fluxes, but also in understanding the physical phenomena that occurs when these particles interact with the spacecraft material. Thus, we would like to design Faraday cups that meet specific requirements such as size, accuracy, efficiency, energy discrimination, and angular resolution.

Background

A Faraday cup is a simple detecting apparatus that is shaped like a cup. The Faraday cup detects when charged particles (usually electrons) strike the inner surface of the cup. Secondary electrons (SE) and backscattered electrons (BSE) are produced when this occurs and, if they are allowed to escape, can affect the instrument's accuracy and collection efficiency. In order to prevent the escape of SE's and BSE's, the depth of a Faraday cup should typically be at least five times its diameter. [1] Another approach that can be taken to prevent the escape of these electrons is to bias the Faraday cup. [1] A similar bias may also be used for energy discrimination, in order to further characterize the incident beam. A history of recent Faraday cup detectors used by the Materials Physics Group can be found in Robert Davies'[2] thesis and Jason Kite's[3] dissertation. Figure 1 shows electric field maps and electron beam trajectories from simulations using

SIMION™ [4] a sequence of increasingly sophisticated designs of charge particle detectors developed for a feasibility study of this project.[5,6]

Research Objectives

This project will build upon the knowledge gained from these previous works with Faraday cup detectors and my initial feasibility study, [5,6] with a goal of producing a set of optimal design criteria for specific Faraday cup requirements. A summary of the research objective to be completed in chronological order are:

- Employ SIMION simulations and analytic calculations to evaluate the effect on Faraday Cup performance of:
    - Faraday cup material electron emission curves, as measured previously by the Materials Physics Group[7]
    - Faraday cup depth and geometry
    - Angular emission spectra of SE and BSE[3]
    - Faraday cup material surface finish (roughness)
- Design Faraday cups tailored to meet specific requirements (*e.g*. desired energy and angular resolution, desired accuracy, desired sensitivity)
- Build Faraday cup prototypes
- Test prototypes in UHV chamber to determine capture efficiency, energy discrimination and range, and angular resolution
- Analyze prototype data through a comparison with preliminary theoretical expectations and SIMION simulations
- Implement any design modifications based on analysis

Research Methods

In order to accomplish these objectives I will use SIMION to perform electric field and charged particle trajectory simulations. This software package makes use of the finite-difference method to compute charged particle trajectories within a user defined potential field. Figure 1 demonstrates the power of this tool. It shows the design progression of a charge particle sensor from a simple circular plate to the preliminary Faraday cup design. These simulations give instant results which I can then evaluate and adjust in order to achieve the desired performance of the Faraday cup. This saves valuable production time and cost, since we can instantly see if the design performs to our specification.

Once the design is optimized through simulation and other related analytic calculations, prototypes will then be manufactured, tested in the UHV chamber (Fig 2), and compared to the preliminary simulations. Testing of the prototypes will include measuring the Faraday Cup efficiency as a function of incident energy, lens voltage, and Faraday Cup bias voltage using highly focused electron beams of various energies (20 eV to 25 eV). Beam profiles as functions of incident electron energy and electron gun focusing settings will also be collected.

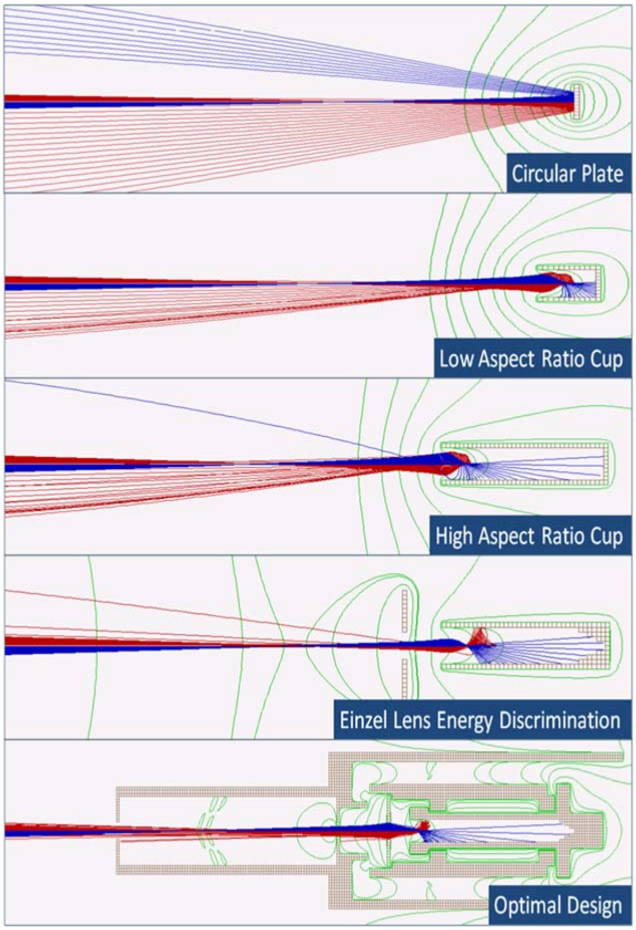

Fig. 1 - Cross-sectional views of design progression with two consistent incident electron beams to determine energy resolution. The red beam energy is 99.9 eV and the blue is 100.1 eV, with 0.1% resolution. Each design is set to detect only electrons with energies greater than or equal to 100 eV. The green contour curves represent the electric field potentials.

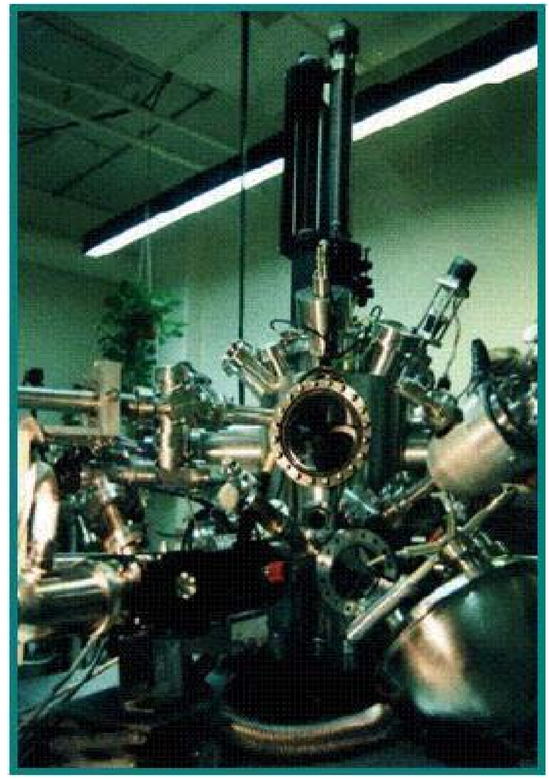

Fig. 2. USU electron emission test chamber where Faraday cup testing will be conducted.

Outcomes

The nature of this project will allow me to gain valuable engineering experience by taking an idea through a full design cycle, from concept to working prototype. Critical design elements of the Faraday cup will be identified. The critical features identified will then be cataloged, with the idea being that it may be used as a guide for building Faraday cups that meet specific requirements. Finally, the Faraday cups produced will be used in future experiments conducted by the Materials Physics Group.

Presentation of Results

Preliminary design work and SIMION simulations for the feasibility were presented at the 2013 Undergraduate Research on Capitol Hill event. The next presentation of the project will be at the Utah Council for Undergraduate Research. I will present the results of this project at the American Physical Society Regional Meeting on October 18-19, 2013 and the Student Showcase in 2014. Additionally, we will write an article for the peer reviewed journal *Reviews of Scientific Instruments*. Below is a list of the presentation events.

- Undergraduate Research on Capitol Hill, Salt Lake City UT, Jan. 31, 2013, (Completed)
- Utah Council for Undergraduate Research, Utah State University, Logan UT, Feb. 22, 2013
- American Physical Society Four Corners Regional Meeting, University of Denver, Denver CO, October 18-19, 2013
- Utah State University Student Showcase, Utah State University, Logan UT, April 2014

Funding

I have a total budget of $1515 and request $500 from the undergraduate research office. The major expense is to upgrade the current version of SIMION (*circa* 2000) to the latest version, which will allow better interfacing with 3D CAD design software such as SolidWorks. Funds are also requested for materials and machining costs to build the prototype Faraday cups. Matching funding beyond the $500 contribution from URCO will come from the Materials Physics Group overhead return reserves.

Table I. URCO Project Budget

URCO BUDGET SUMMARY	
EXPENSES:	**AMOUNT:**
Upgrade from SIMION 7.0 to SIMION 8.1 Ion and Electron Optics Simulation Software (Scientific Instrument Services)	$ 850
Machine shop time (6 hrs@50/hr) (SDL Machine Shop)	$ 300
Metal stock (McMaster-Carr)	$ 225
eV Parts (4 packages @$35/pack) (Kimball Physics)	$ 140
TOTAL BUDGET:	$ 1515

References

1 John H. Moore, Christopher C. Davis, Michael A Coplan. 1983. "Building Scientific Apparatus." Addison-Wesley Publishing Company. London. Pg. 320.

2 Robert E. Davies. 1996. "An Instrument for Experimental Secondary Electron Emission Investigations, With Application to the Spacecraft Charging Problem." MS Thesis, Utah State University, Logan, UT. Pg. 87-94

3 Jason T. Kite. 2007. "Secondary Electron Production and Transport Mechanisms By Measurement of Angle-Energy Resolved Cross Sections of Secondary and Backscattered Electron Emission From Gold." PhD Dissertation, Utah State University, Logan, UT. Pg. 30-33

4 SIMION™ Version 8.1. Scientific Instrument Services, Inc. Ringoes, NJ. http://simion.com/.

5 Kent Hartley and JR Dennison, "Faraday Cup Designs for High Efficiency Determination of Energy- and Angular-Resolved Charged Particle Fluxes," Utah Undergraduate Research on Capitol Hill Salt Lake City, UT, January 31, 2013.

6 Kent Hartley and JR Dennison, "Faraday Cup Designs for High Efficiency Determination of Energy- and Angular-Resolved Charged Particle Fluxes," Utah Council on Undergraduate Research, Logan City, UT, February 22, 2013.

7 JR Dennison, Jason Kite, C.D. Thomson, Jodie Corbridge, Robert Berry, and Carl Ellsworth, *Final Report Part IV: Additional Materials Reports*, NASA Space Environments and Effects Program Grant, "Electronic Properties of Materials with Application to Spacecraft Charging," May 2003. Published by NASA electronically at http://see.msfc.nasa.gov/ee/db_chargecollector.htm, the work is comprised of 6 individual *Materials Reports* with a combined length of ~250 pages.